WASHINGTON STATE UNIVERSITY
TRI-CITIES
World Class. Face to Face.

Instructor: Zhenyu (Henry) Huang
(509) 438-7235, h_zyu@yahoo.com

EE 521: Analysis of Power Systems

Lecture 20
Voltage Stability 2

Fall 2009

Mondays & Wednesdays 5:45-7:00

August 24 – December 18

Test 216

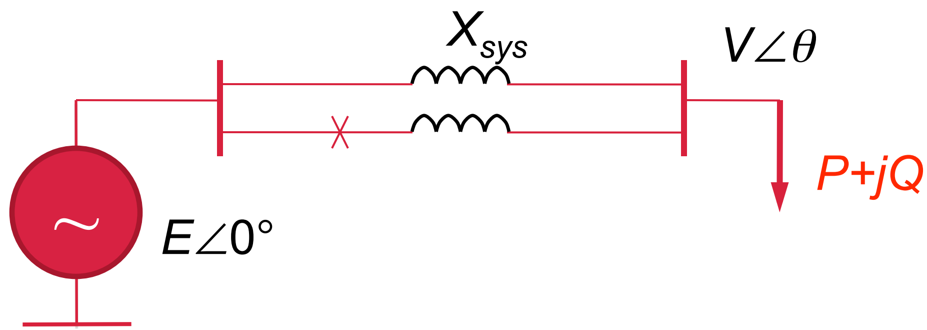
Topics

- Factors Affecting Voltage Stability
- Ways to Improve Voltage Stability
  - Reactive Compensation/Voltage Support
- Load Characteristics
- Voltage Collapse
- Prevention of Voltage Collapse

Factors Affecting Voltage Stability

- Small Operating Margins
- Contingencies
  - “N-1” stable
- Generator Reactive Power Limit
- Over-compensation of Reactive Power
- Fast Load Dynamics
- Unfavorable Load Characteristics

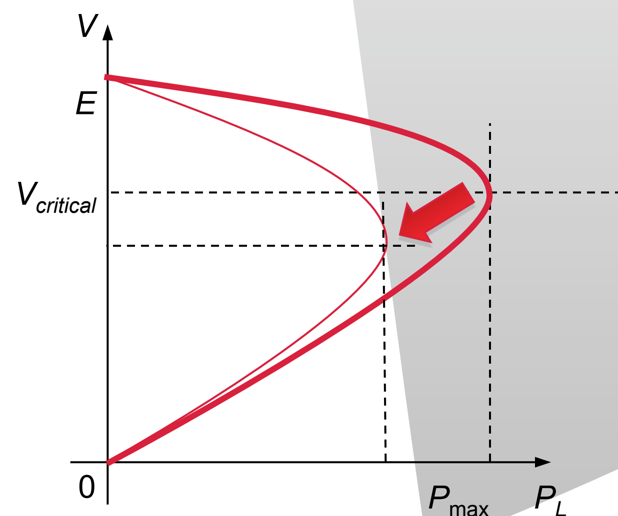
Contingencies



$$P_{\max} = \frac{E^2}{2X_{sys}}\left(-k + \sqrt{\left(1+k^2\right)}\right)$$

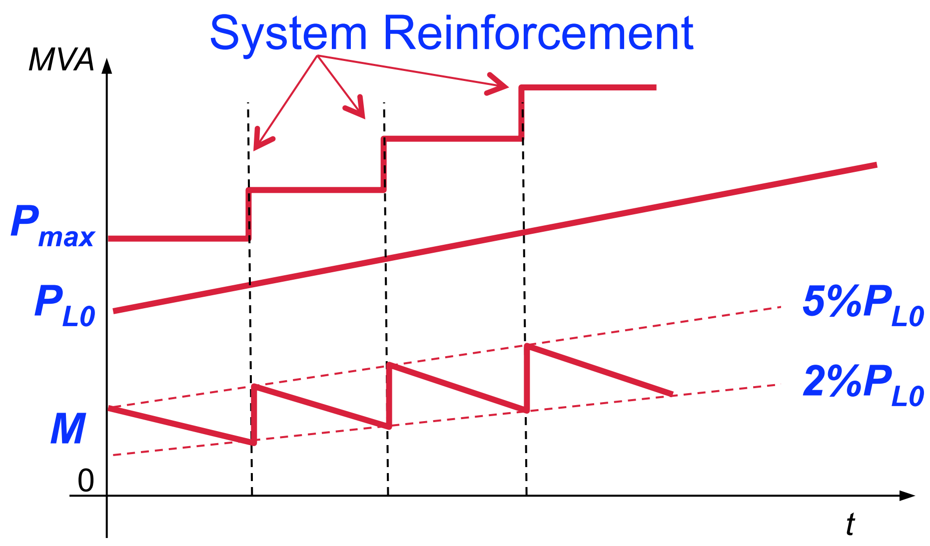
$$V_{critical} = \frac{E}{\sqrt{2}}\sqrt{1+k^2 - k\sqrt{\left(1+k^2\right)}}$$

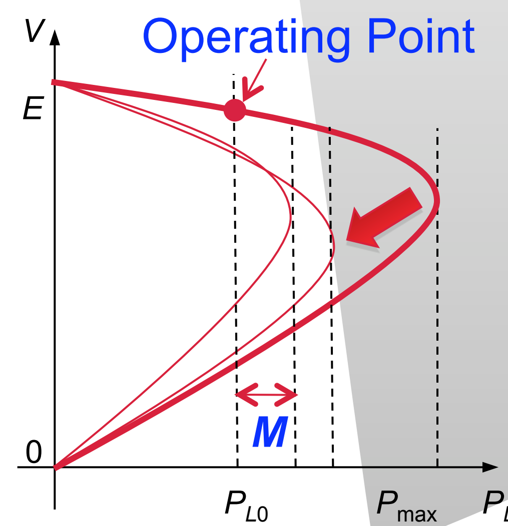
1. P_{max} decreases.
2. Contingencies “shrink” the PV curve.
3. Requirement: “N-1” stable, i.e. enough margin should be maintained with failure of any one component.



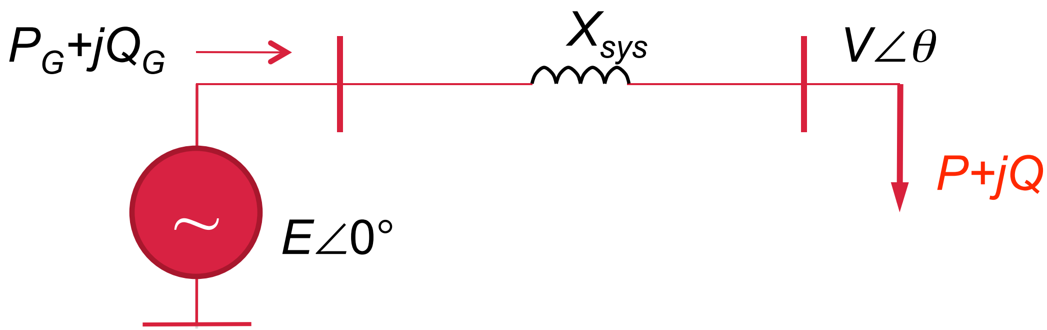
Planning and Operating Criterion

- "N-1" Stable
- Typical Criterion: $$\frac{M}{P_{L0}} = 2\% \sim 5\%$$
- For economic reasons, excessive margins are not desirable.





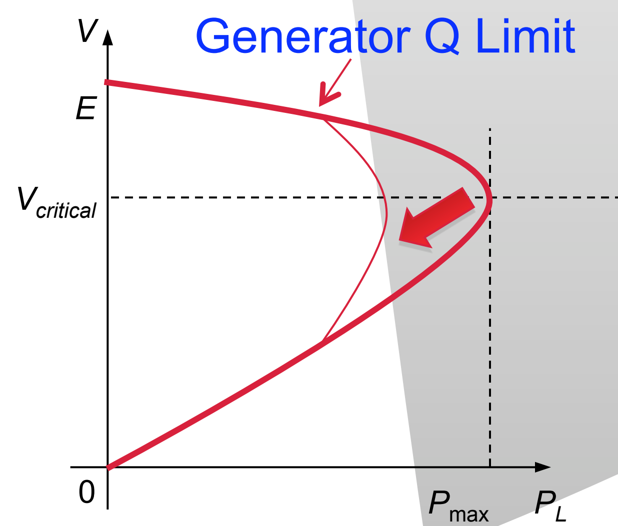
Generator Reactive Power Limit



$$P_{\max} = \frac{E^2}{2X_{sys}}\left(-k + \sqrt{\left(1+k^2\right)}\right)$$

$$V_{critical} = \frac{E}{\sqrt{2}}\sqrt{1+k^2 - k\sqrt{\left(1+k^2\right)}}$$

1. To support the source voltage, the reactive output of the generator has to increase when load demand increases.
2. However, Generator reactive output is limited by its capability curve (stator heating and rotor heating).
3. Once Q_G hits its limit, it cuts the PV curve short, reducing the PV margin.



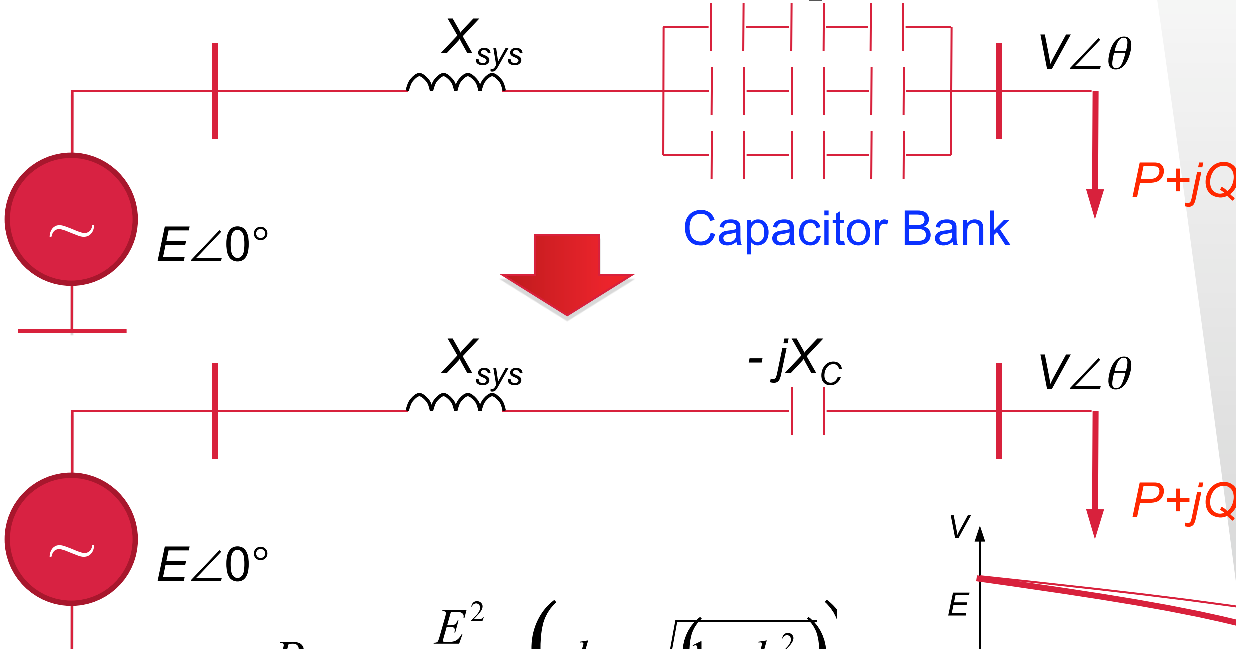
Ways to Improve Voltage Stability

Reactive Compensation

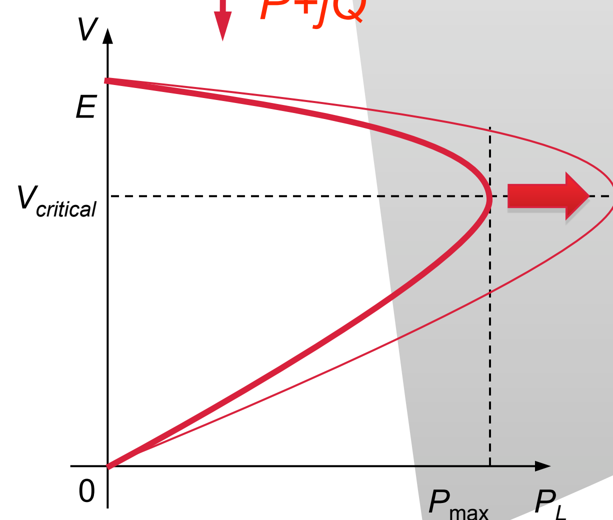
- Serial Compensation
  - Fixed Series Capacitors
  - Variable Capacitors: Thyristor-Switched Capacitor, Thyristor-Controlled Capacitor.
- Shunt Compensation
  - Fixed or Switched Shunt Capacitors
  - Synchronous Condenser
  - Static Var Compensation (SVC)
  - FACTS Devices: STATCOM

FACTS: Flexible AC Transmission Systems

Fixed Series Capacitors



$$P_{\max} = \frac{E^2}{2X_{sys}}\left(-k + \sqrt{\left(1+k^2\right)}\right)$$

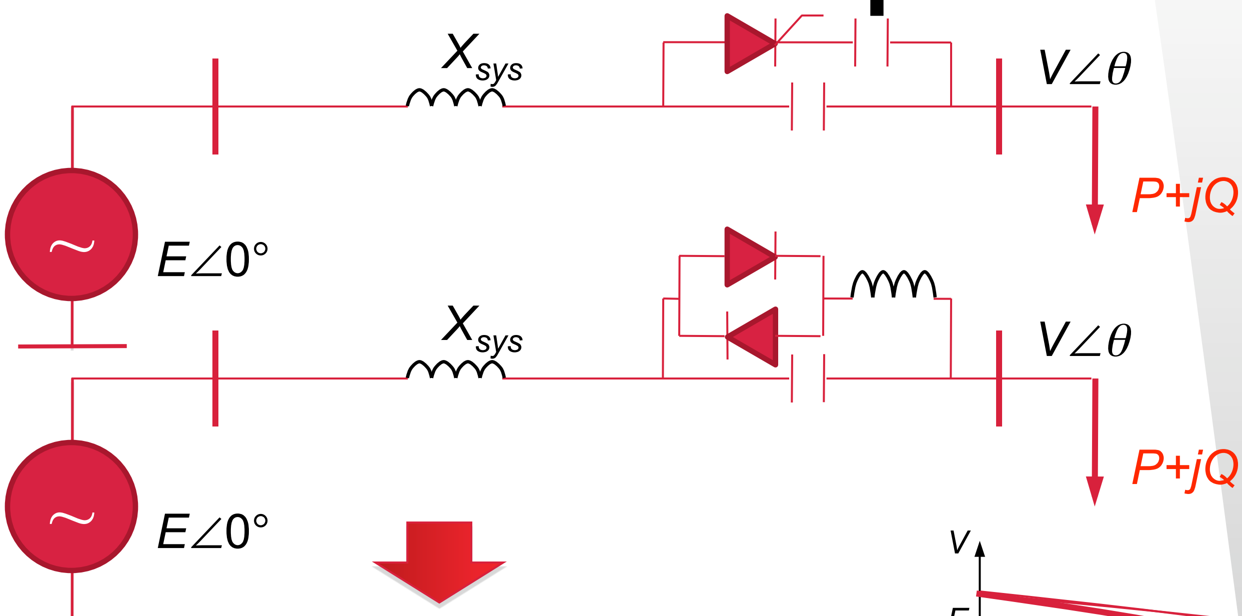


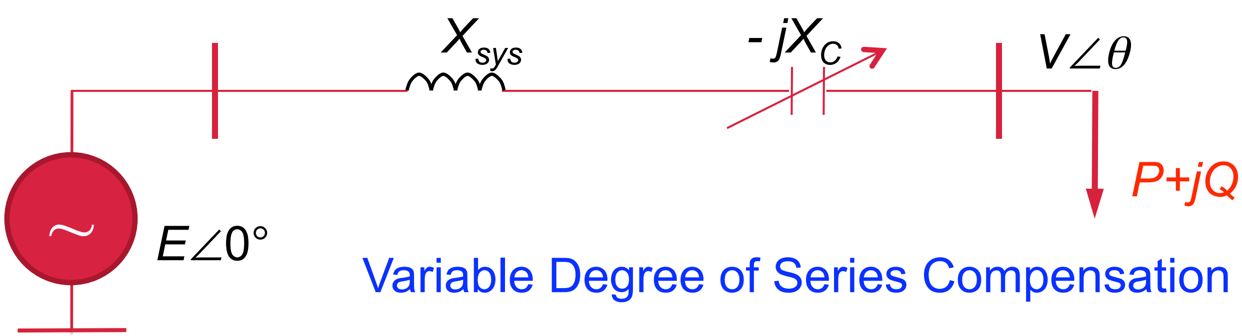
1. Capacitor Bank: increase V and I ratings.
2. Degree of Series Compensation:
   $K_{se} = X_C/X_{sys} * 100\%$.
   It is equivalent to line length reduction.

Variable Series Capacitors

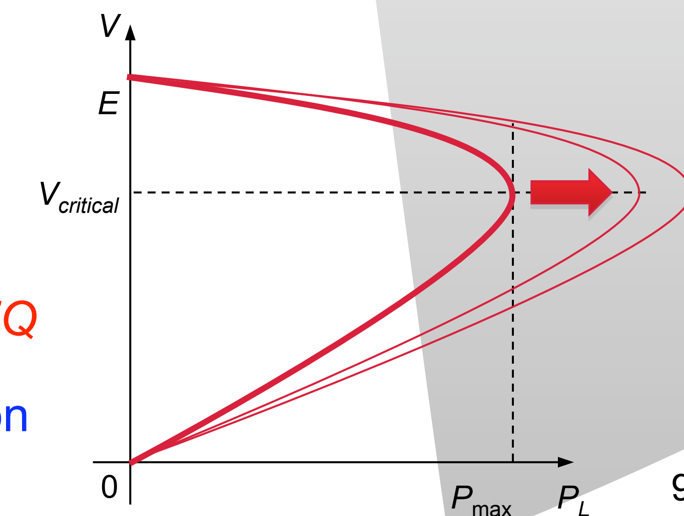
Thyristor-Switched Capacitor

Thyristor-Controlled Capacitor



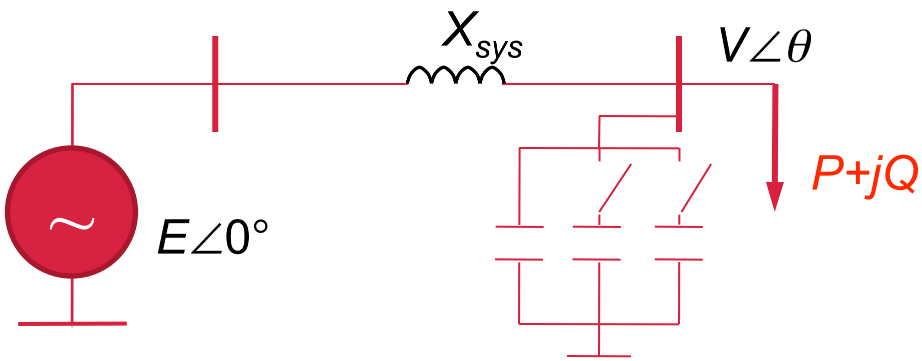


Variable Degree of Series Compensation

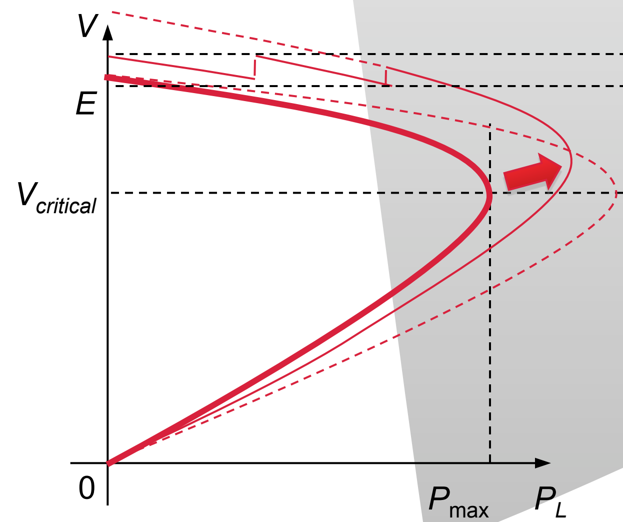


WASHINGTON STATE UNIVERSITY TRI-CITIES
World Class. Face to Face.

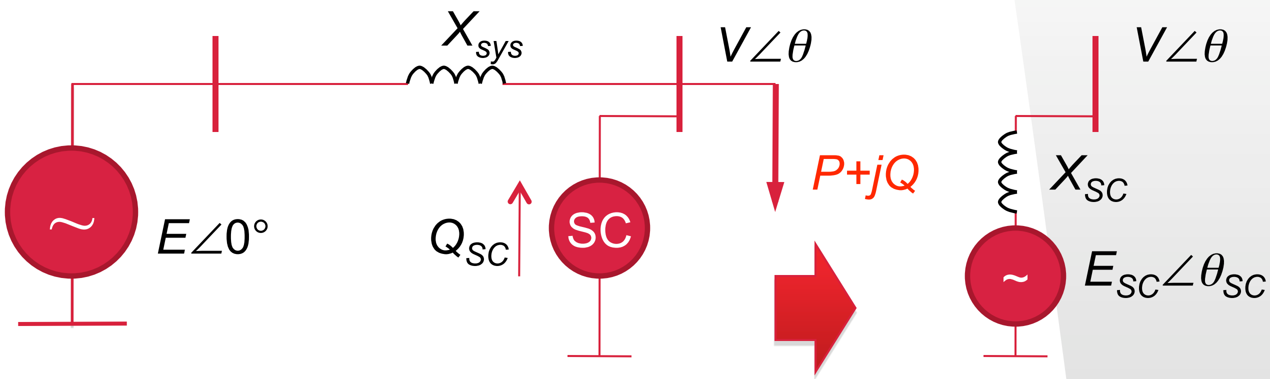
Fixed or Switched Shunt Capacitors



1. Fixed shunt capacitors are commonly used as a low cost method of shunt compensation.
2. Shunt compensation provides voltage support to the system.
3. Compared with series compensation, shunt capacitors raise the PV curve, resulting in over-voltage at light load conditions. (solution: switch off some capacitors)
4. Shunt capacitors also raise the nose point, resulting in a higher critical voltage – a undesirable effect.

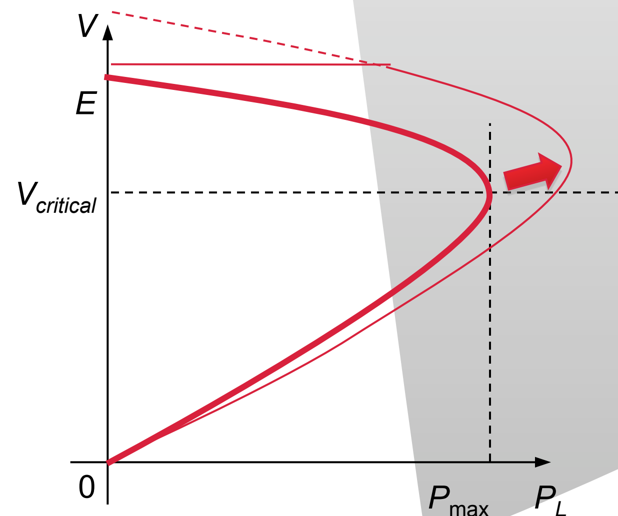


Synchronous Condenser



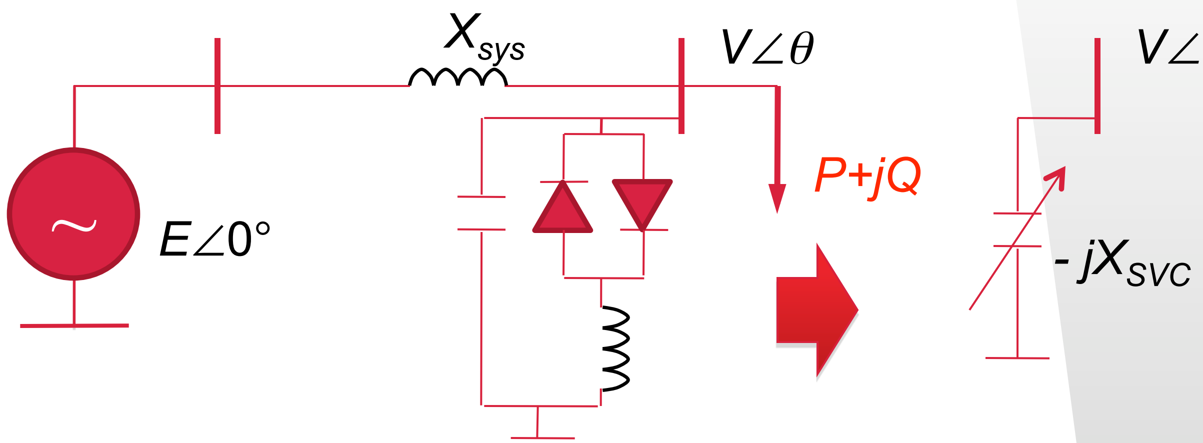
$$Q_{SC} = \frac{E_{SC}V - V^2}{X_{SC}}$$

1. Synchronous Condenser = Synchronous Generator with $P_G = 0$.
2. Synchronous Condenser provides variable reactive injection to the system, resulting in adjustable voltage support.

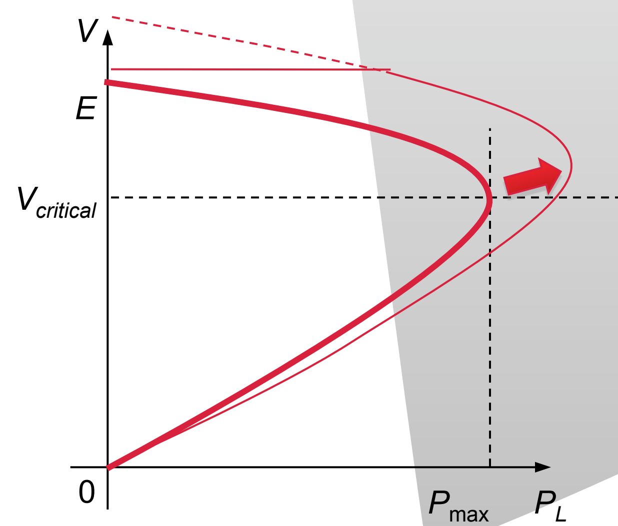


Static Var Compensation (SVC)

Thyristor-Controlled Reactor (TCR) in parallel with a fixed or switched capacitor

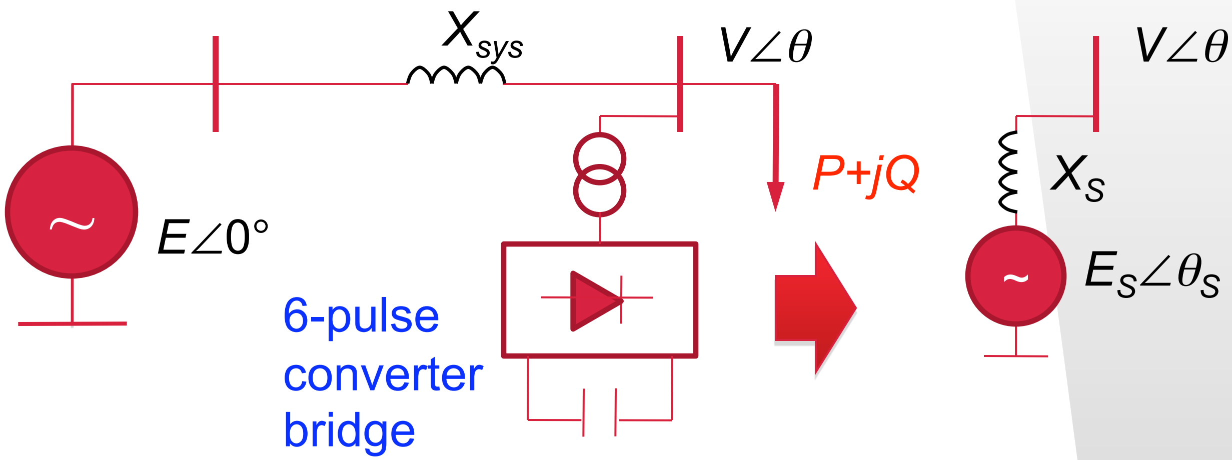


1. SVC provides variable reactive injection to the system, resulting in adjustable voltage support.
2. SVC has replaced many Synchronous Condensers as it has similar characteristics as Synchronous Condensers.

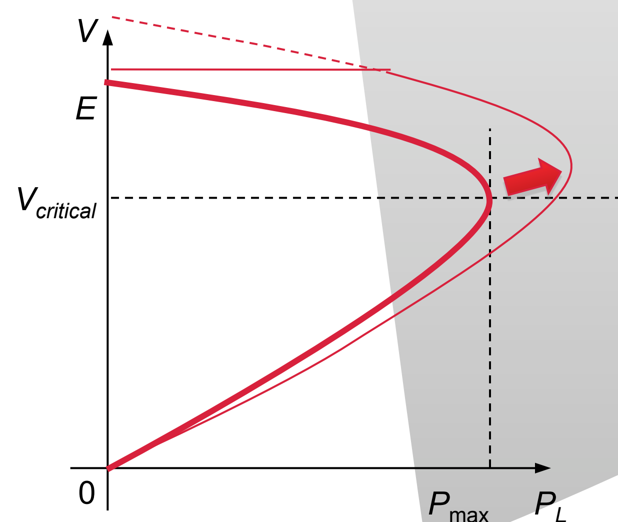


Washington State University Tri-Cities
World Class. Face to Face.

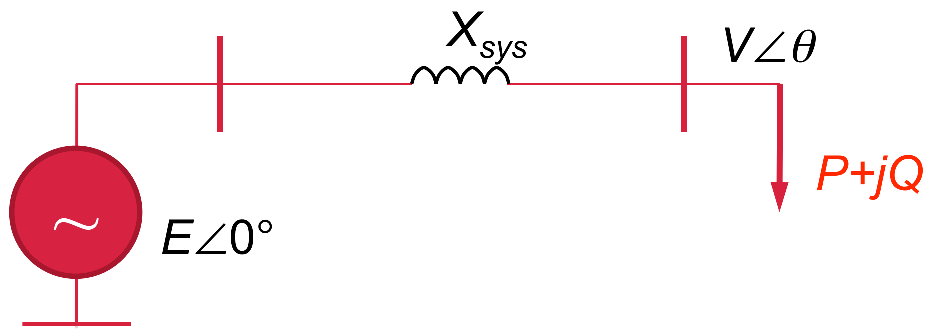
STATCOM



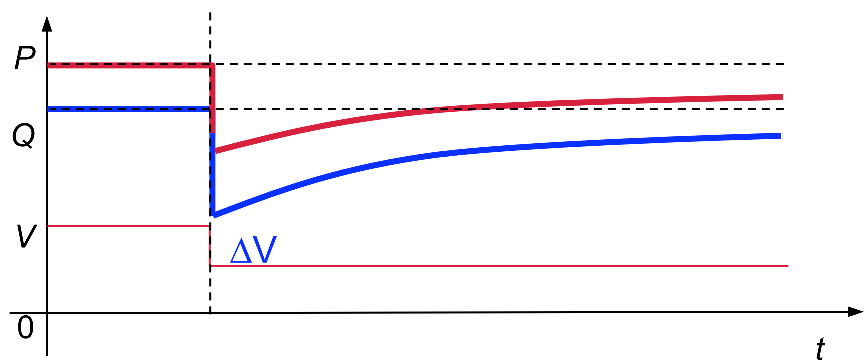
1. STATCOM provides variable reactive injection to the system, resulting in adjustable voltage support.
2. Compared with SVC, STATCOM has less components and takes less space.
3. STATCOM's characteristics are almost identical to that of Synchronous Condensers.



Dynamics of Load Response



1. A sudden drop in V will result in sudden drop in load.
2. Then load will slowly recover.
3. When the system reaches a new steady state, load will recover to a new level. The new level depends on load characteristics.



Characteristics of Load Response

Transient characteristics (for sudden V change):

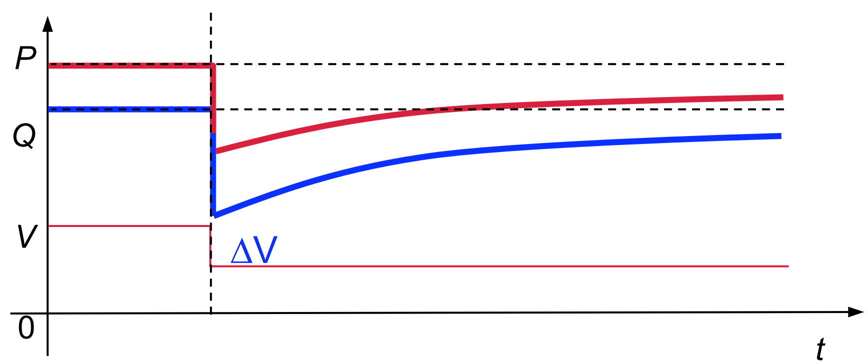
$$P = P_0\left(\frac{V}{V_0}\right)^{\alpha} \qquad Q = Q_0\left(\frac{V}{V_0}\right)^{\beta}$$

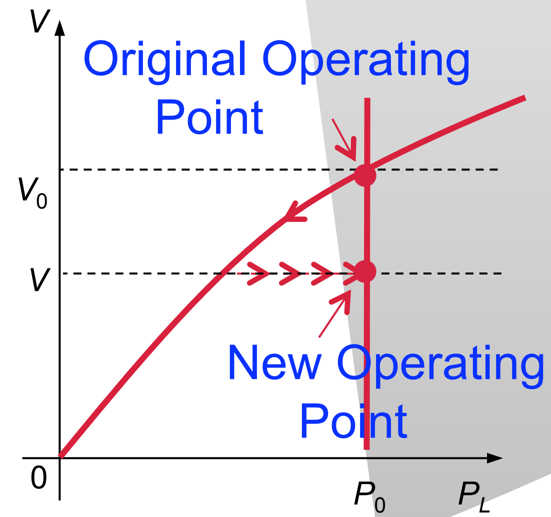
Steady-state characteristics (for steady-state V change):

$$P = P_0\left(\frac{V}{V_0}\right)^{a} \qquad Q = Q_0\left(\frac{V}{V_0}\right)^{b}$$

Parameters and their typical values:

$$\alpha = 1.0, \beta = 4.0, a = 0, b = 0.5$$





Example: Load Response

Problem: Given $\alpha = 1.0, \beta = 4.0, a = 0, b = 0.5$. A fault in the system results the load voltage suddenly drops 10%. And the voltage stays at this level after the system recovers. Determine the instant and steady-state load change.

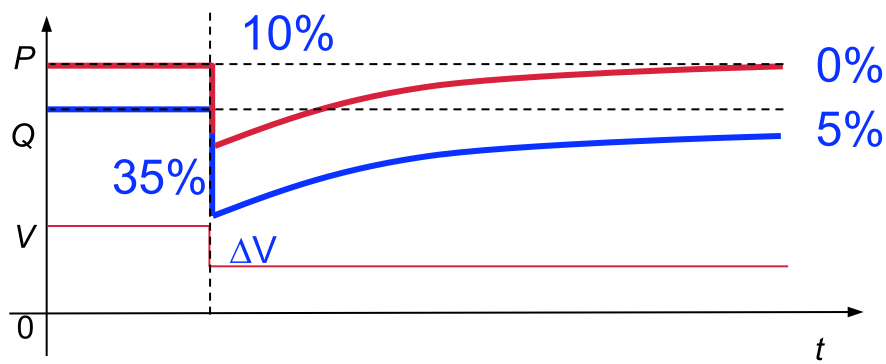
Solution:

Instant load change:

$$P = P_0\left(\frac{V}{V_0}\right)^{\alpha} = P_0\left(\frac{0.9}{1.0}\right)^{1.0} = 90\% P_0 \qquad Q = Q_0\left(\frac{V}{V_0}\right)^{\beta} = Q_0\left(\frac{0.9}{1.0}\right)^{4.0} = 65\% Q_0$$

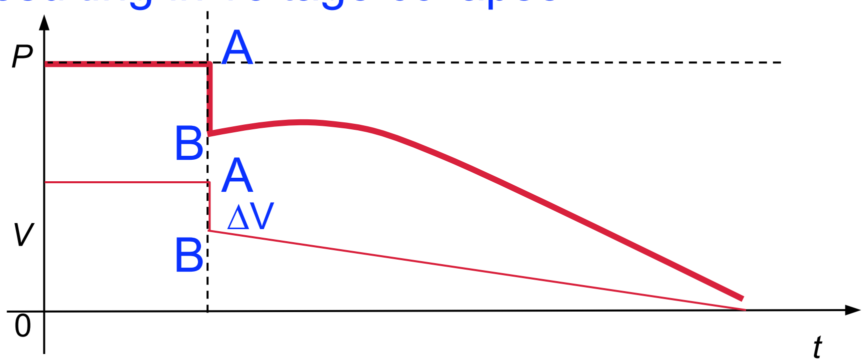
Steady-state load change:

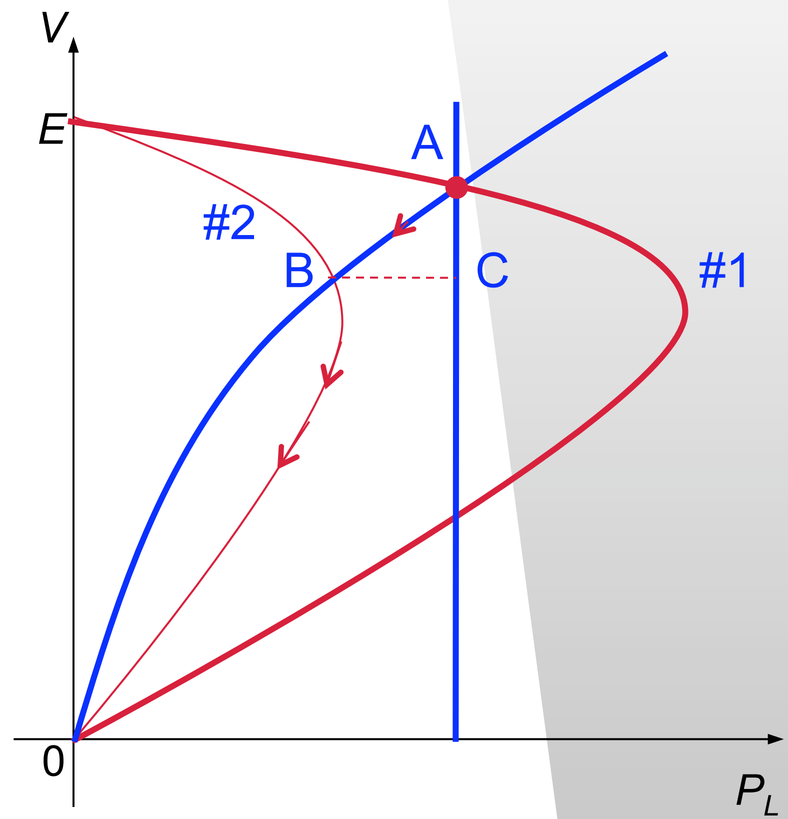
$$P = P_0\left(\frac{V}{V_0}\right)^{a} = P_0\left(\frac{0.9}{1.0}\right)^{0} = 100\% P_0 \qquad Q = Q_0\left(\frac{V}{V_0}\right)^{b} = Q_0\left(\frac{0.9}{1.0}\right)^{0.5} = 95\% Q_0$$



Voltage Collapse

1. A contingency shrinks the PV curve from #1 (pre-contingency) to #2 (post-contingency)
2. Load responds with its transient characteristics. The operating point jumps from A to B.
3. Load attempts to recover to its steady-state characteristics (point C).
4. However, the voltage follows the PV curve and continues decreasing, resulting in voltage collapse.

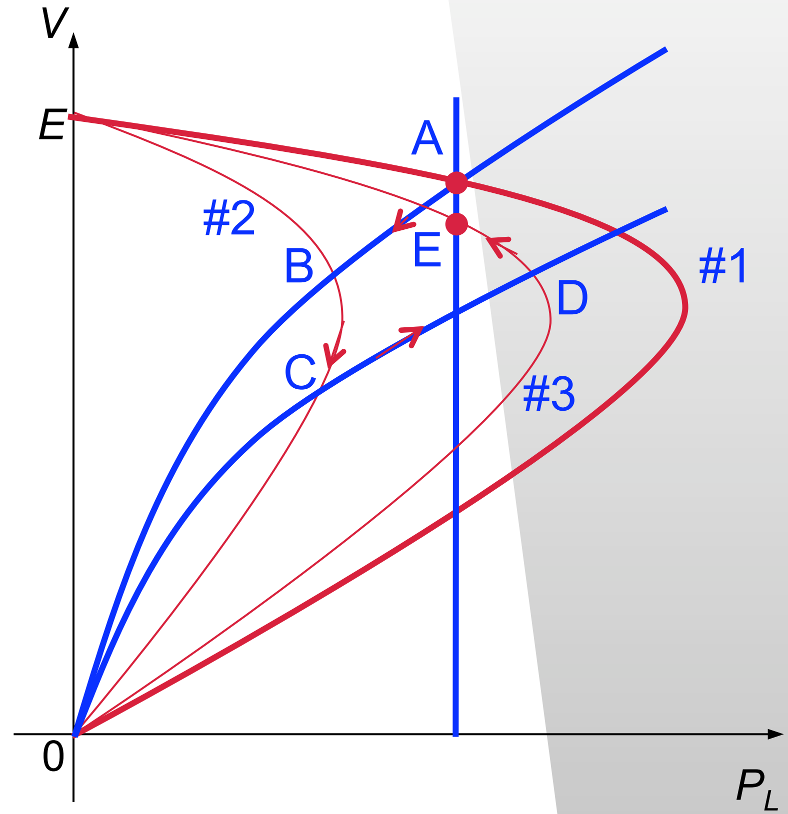




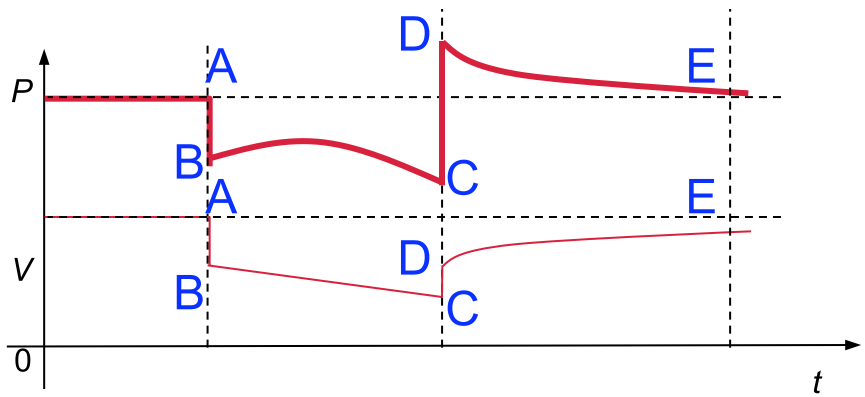
Prevention of Voltage Collapse

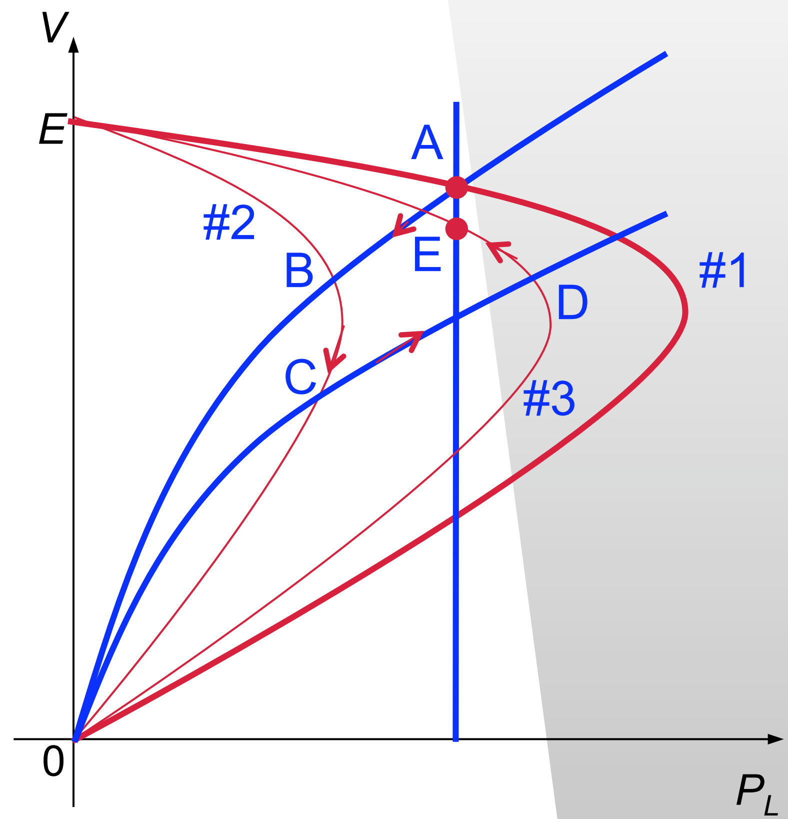
The issue: PV curve and steady-state load curve do not intersect! ➔ System reinforcement (e.g. capacitor switching) is needed.

1. Reinforcement is activated at point C, and this PV curve is changed as #3.
2. Load responds with its new transient curve, and then operating point jumps to D.
3. Voltage follows curve #3 and increases until the final operating point E is reached. The system is stabilized.



Prevention of Voltage Collapse





Questions?

WASHINGTON STATE UNIVERSITY
TRI-CITIES
World Class. Face to Face.