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 22
Voltage Control

Fall 2009

Mondays & Wednesdays 5:45-7:00

August 24 – December 18

Test 216

Topics

- Why Voltage Control?
- Voltage and Power Transfer
  - Thermal limit
  - Surge Impedance Loading (SIL)
- Automatic Voltage Regulators
  - Generator Capability Curve
- Operator Actions
  - Identifying problem conditions.
  - Using voltage control equipment.
  - Operating “smart”

Why Voltage Control?

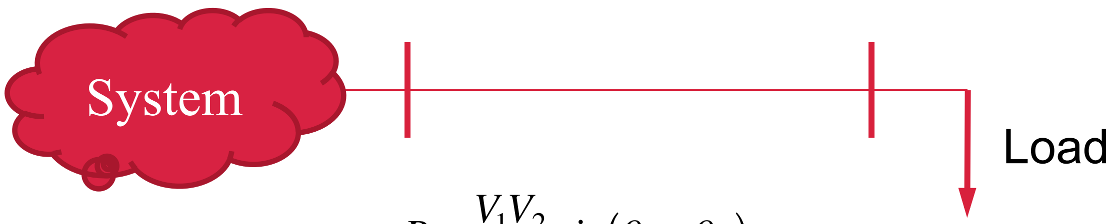
- Transmission and Distribution
  - Support power transfer
  - Maintain stability
  - Equipment protection
- End Use
  - Equipment Protection
  - Maintain reliable functions of end-use devices
    - Motor stalling issues
    - Ballasts for fluorescent lamps

Voltage requirements:
✓ Transmission: ± 10%
✓ Distribution: ± 5% (± 8% emergency)

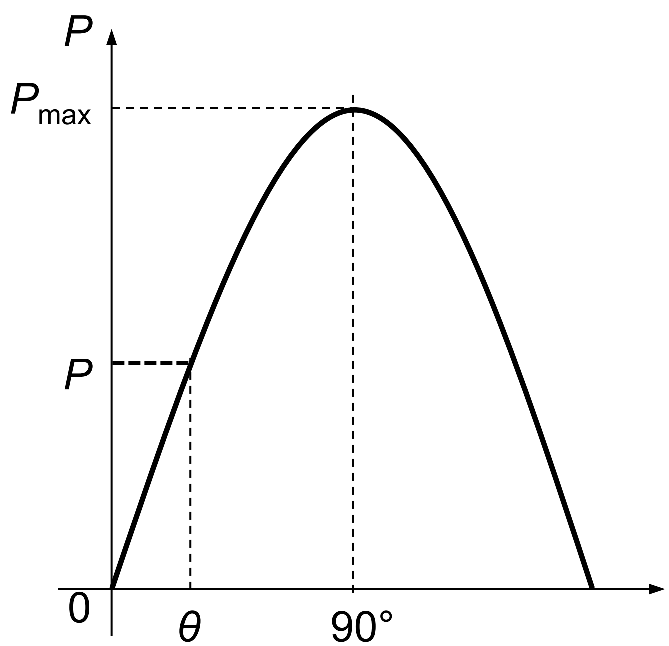
Voltage Problems

- Over-voltage
  - Causes:
    - Short-term Overvoltage: Lightning, Switching, Load Loss
    - Long-term Overvoltage: Light loading, Disturbances, Ferranti voltage rise
  - Problems:
    - Generator self-excitation
    - Insulation breakdown
    - Flashover
    - Customer equipment damage
    - Excessive heating of overexcited transformers
- Under-voltage
  - Causes:
    - Heavy line loading, Disturbances, High customer demand
  - Problems:
    - Induction motor heating/stalling, Dim lights → more lights, Less heat → more heaters, Voltage collapse

Power Transfer Capability



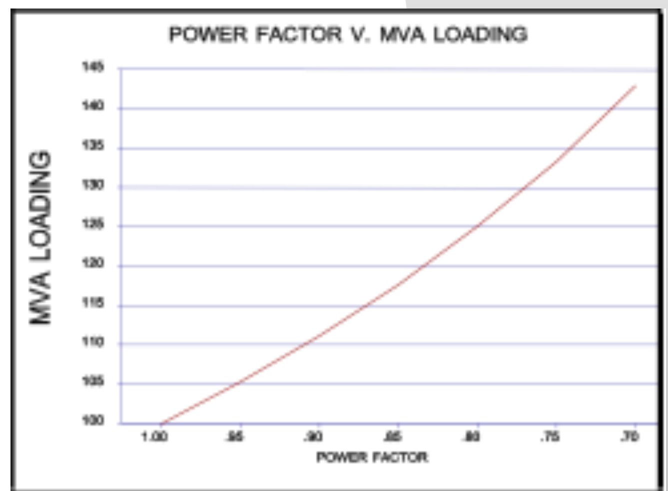
$$P = \frac{V_1 V_2}{X} \sin(\theta_1 - \theta_2)$$



Transmission Line Thermal Limit

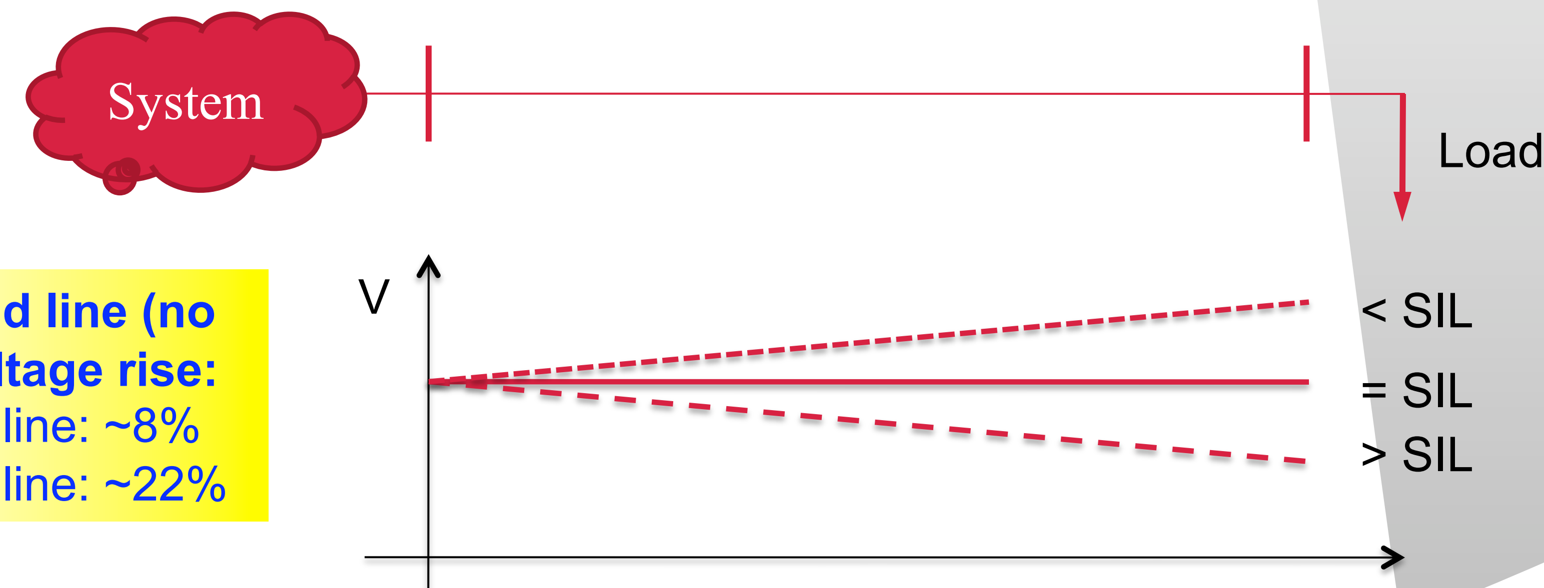
- All transmission lines have a thermal limit: I_{max}
  - E.g. I_{max} = 1650 A, 525 kV ➔ 1500 MW, if PF = 1.
    500 kV ➔ 1429 MW
- Effect of power factor
  - Lower power factor requires more reactive power support

PF	MW	MVA	**MVAr**
1.000	100	100	**0**
0.900	100	111	**49**
0.800	100	125	**75**
0.700	100	143	**102**



How many VARs do we need to transfer power?

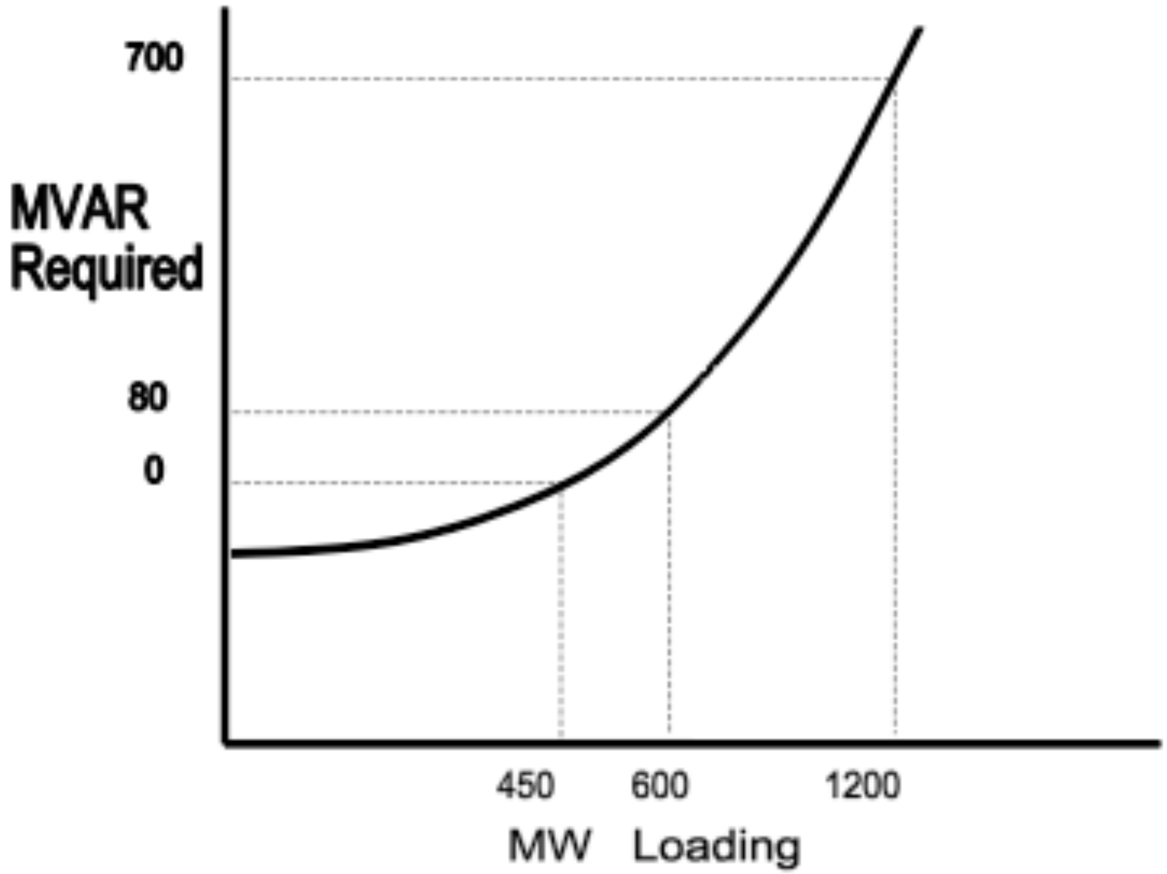
- SIL: Surge Impedance Loading
  - The capacitive VARs generated by the line capacitance = the inductive VARs created by the line loading
  - i.e. No VARs are needed to transfer power



Open-end line (no load) voltage rise:
200 mile line: ~8%
300 mile line: ~22%

How many VARs do we need to transfer power? *cont'd*

- Example: 100 mile, 345 kV line, SIL = 450 MW

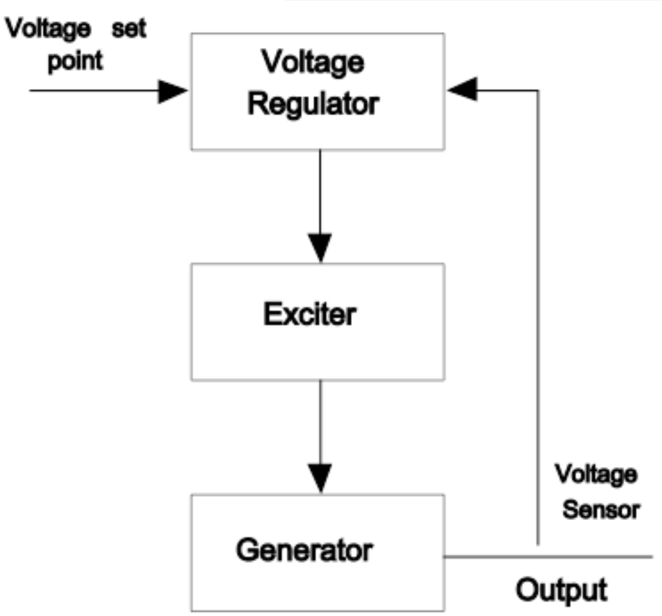


VAR Producers

- Capacitive VAR Producers
  - Overexcited generators and synchronous condensers, capacitors, lightly loaded lines, and underground cables.
- Inductive VAR Producers (VAR Consumers)
  - Underexcited generators and synchronous condensers, reactors, power transformers, induction motors and generators, and heavily loaded lines
- VARs usually flow from relatively high voltage to relatively low voltage.
- VAR flow causes I^2R loss ➔ supply VAR locally.

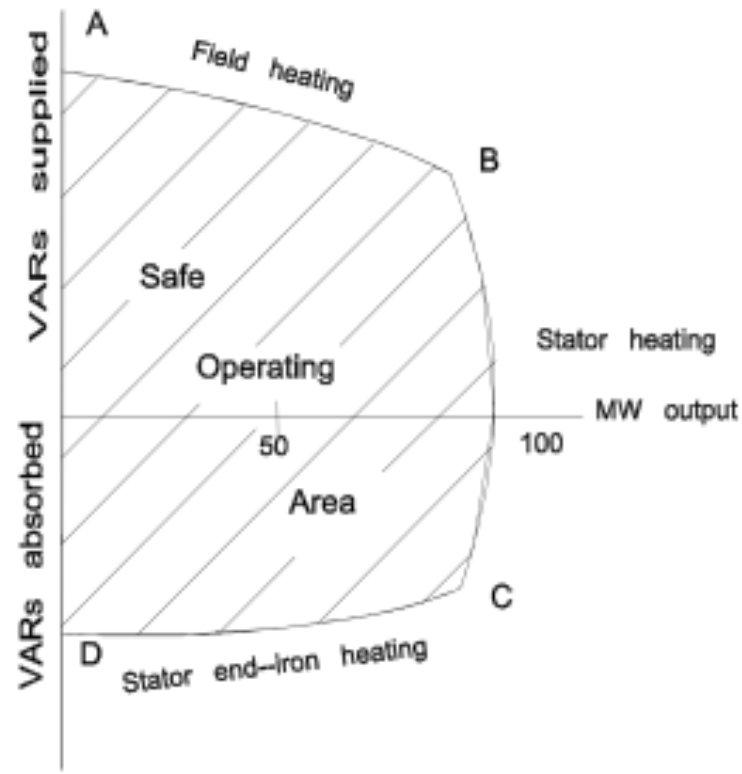
Automatic Voltage Regulator (AVR)

- V > Vset ➔ decrease generator excitation ➔ decrease field current.
- V < Vset ➔ increase generator excitation ➔ increase field current.
- *Vset – the voltage set point can be changed by operator.*



AVR Limit

- Generator Capability Curve
  - Field winding overheating limit
    - Short-term boost capability
    - 135-150% (some 300-400%)
  - Rotor winding overheating limit
  - Stator end-iron overheating limit



What an operator can do to mitigate voltage problems?

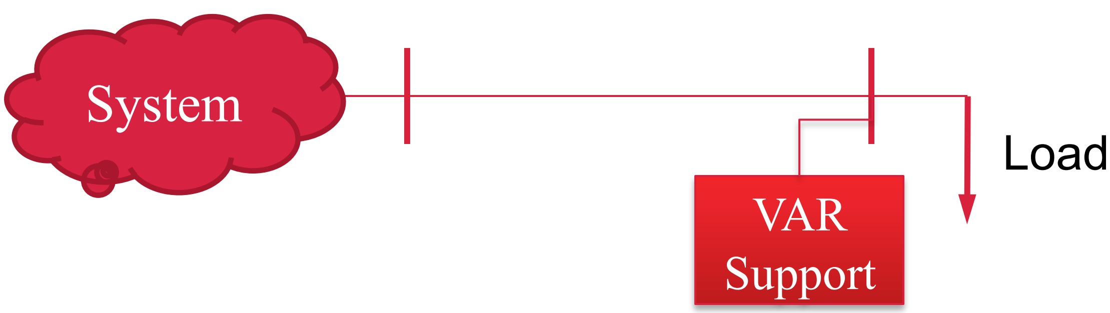
- Three Categories of Operator Actions:
  - Identifying problem conditions.
  - Using voltage control equipment.
  - Operating “smart”
- Long-term voltage problems can be mitigated.
- Short-term voltage problems can be prevented by operating the system within established thermal, stability, loading, and voltage guidelines (the system itself is more resistant to short-term voltage problems).

Identifying Problem Conditions

- From Control Center Meters/Displays (experience)
  - Voltage oscillations at high load levels.
  - Abnormally high or low voltage on key buses.
  - Voltage drifting up and down.
  - Higher than normal reactive (VAR) flow.
  - VAR flow in an abnormal direction.
  - LTCs on a more extreme higher or lower tap than normal.
  - Generator, synchronous condenser, or SVC reactive loadings rising or higher than usual.

Identifying Problem Conditions
cont'd

- Voltage Problem Scenarios
  - The radial load problem.
    - Long distance, heavy load transfer (think about PV curves)
  - The reactive shortage problem.
    - Loss of local VAR support.
    - A special case: HVDC transmission.
  - The loss of synchronism problem.
    - Combination of voltage difficulties with instability



Identifying Problem Conditions
cont'd

- Triggering Events
  - A line or cable outage.
  - Loss of a generator.
  - A capacitor bank trip.
  - SVC or synchronous condenser outage.
  - Heavy power transfers.
  - Heavy line loading due to loop or parallel flows.
  - Rapid load buildup.
  - Unusually high customer demand.
  - Motor load instability.

Using Voltage Control Equipment

- For Under-voltage Problems
  - Remove switched shunt reactors.
  - Insert switched shunt capacitors.
  - Energize open lines.
  - Raise LTC set points.
  - Raise automatic voltage regulator set points on generators, synchronous condensers, and SVCs.
  - Use the generators' temporary reactive overload capability.
  - Request reactive support from neighboring systems.
  - Curtail interruptible loads.
  - Shed firm loads.

✓ Using local resources first.
✓ Maintain reserves on VAR sources ➔ Allow rapid response to voltage deviations.

Using Voltage Control Equipment *cont'd*

- For Over-voltage Problems
  - Remove switched shunt capacitors.
  - Insert switched shunt reactors.
  - Lower voltage set points on SVCs, LTCs, and synchronous condensers.
  - Operate generators in underexcitation mode.
  - Close open-ended lines to reduce capacitance, or;
  - Take transmission lines out of service to remove their capacitance and to load up parallel lines.

Operating “Smart”

- Get under the voltage
- Use proper switching sequences
- Re-dispatch generation
- Get help from neighbors
- Request voluntary load reductions
- Manually shed load

What we have just talked about

- Some theory
- Lots of guidelines
- Real-time operation requires lots of experience

Questions?