Power Systems Introduction

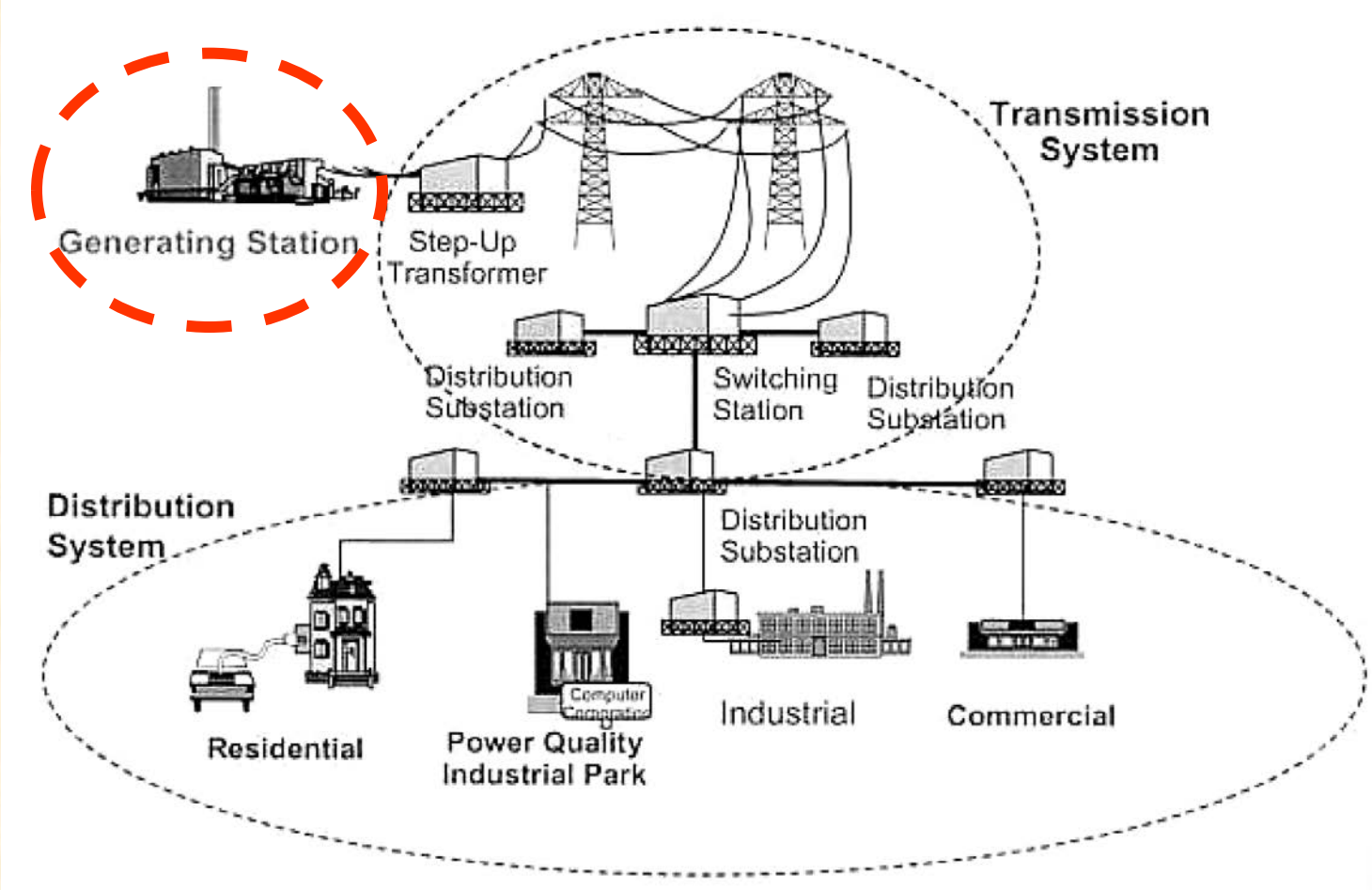
Overview of Power system

The nature of electric power

- A type of energy obtained by the movement of electrons in conductors
- Electrons are confined to conductors by the use of insulators
- The delivery of electric power requires a conductive path from source to consumer
- In the case of alternating current (AC) power, electro-magnetic fields also play a part in conduction of the power from source to user

Overview of Power system

Generation, Transmission and Distribution



Components of a power system

Nuclear Power and wind power

Components of a power system

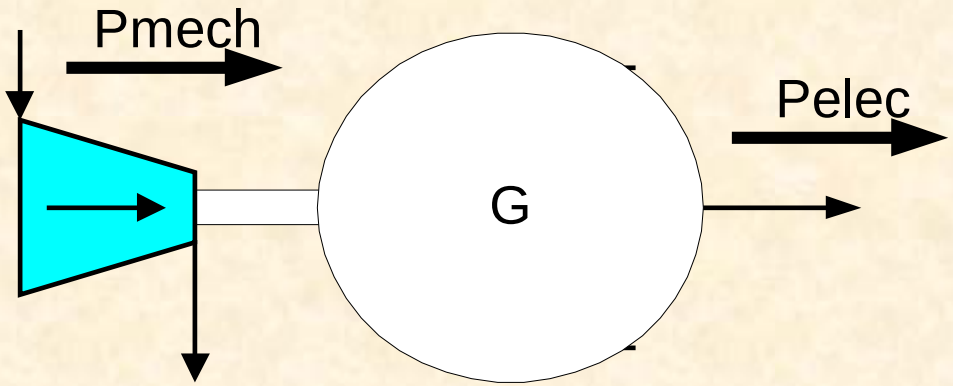
Components of a power system

Components of a power system

An Old Powerhouse

Components of a power system

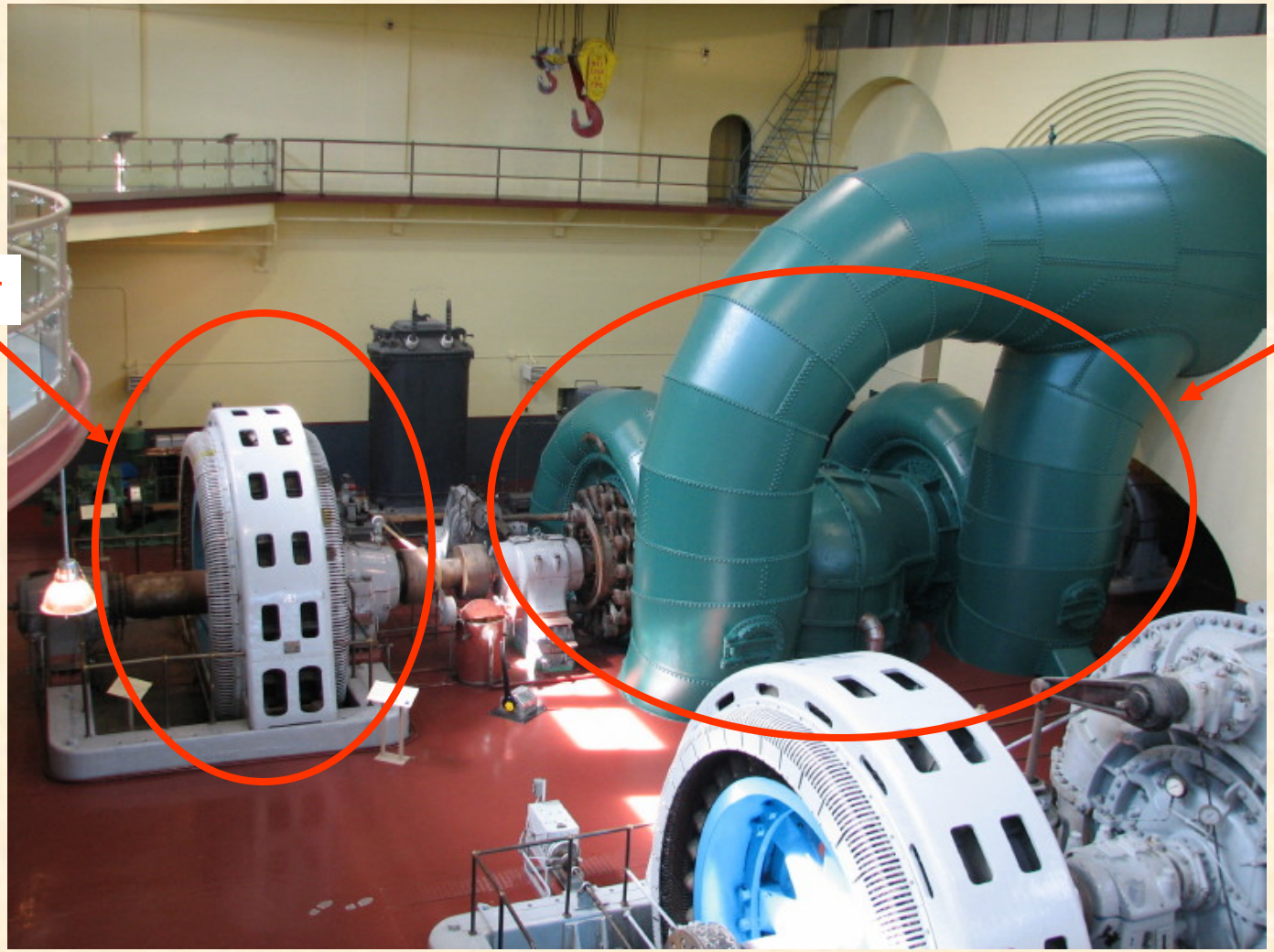
Turbine Generator



Converts mechanical power to electrical

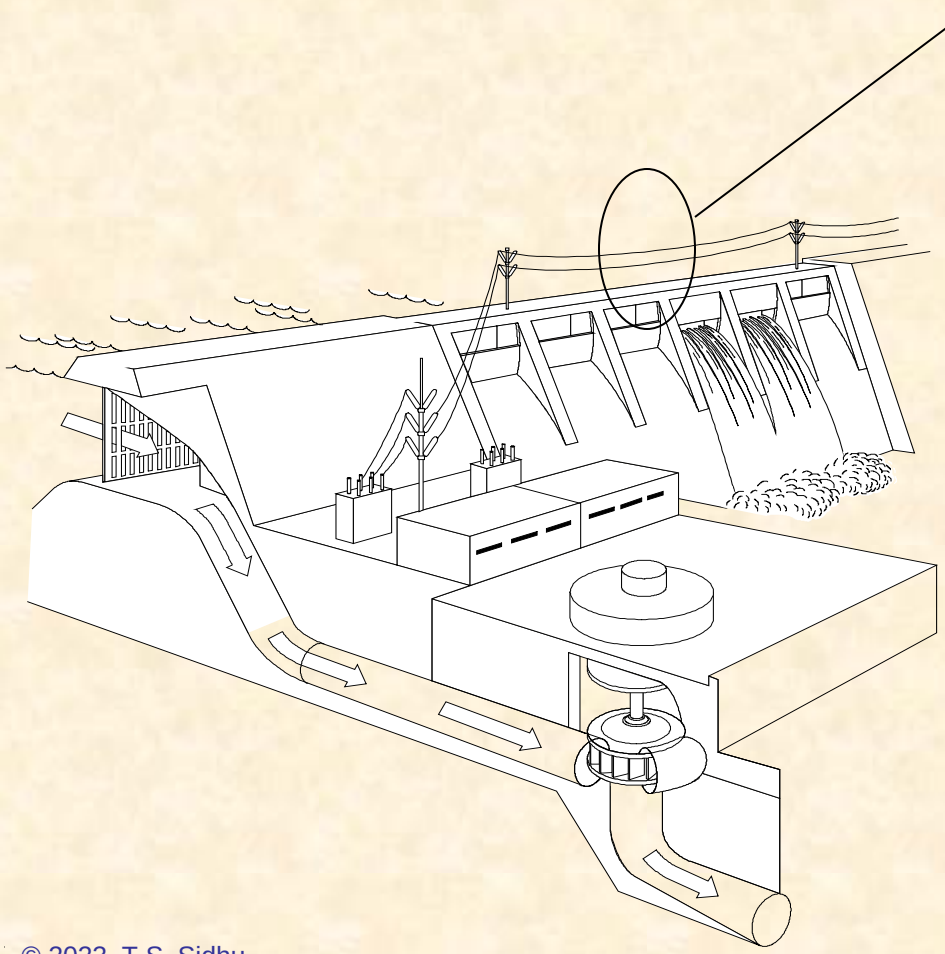
Components of a power system

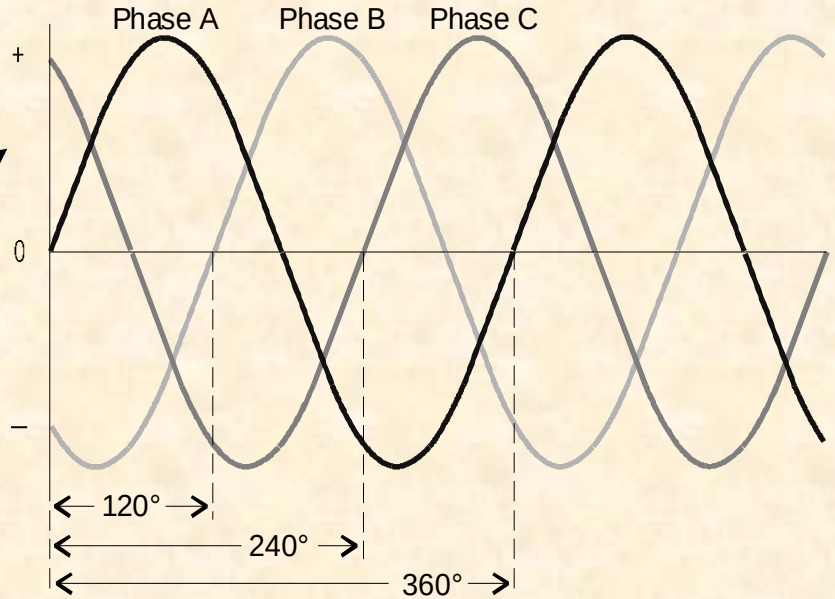
Turbine Generator Unit



Components of a power system

Generating power

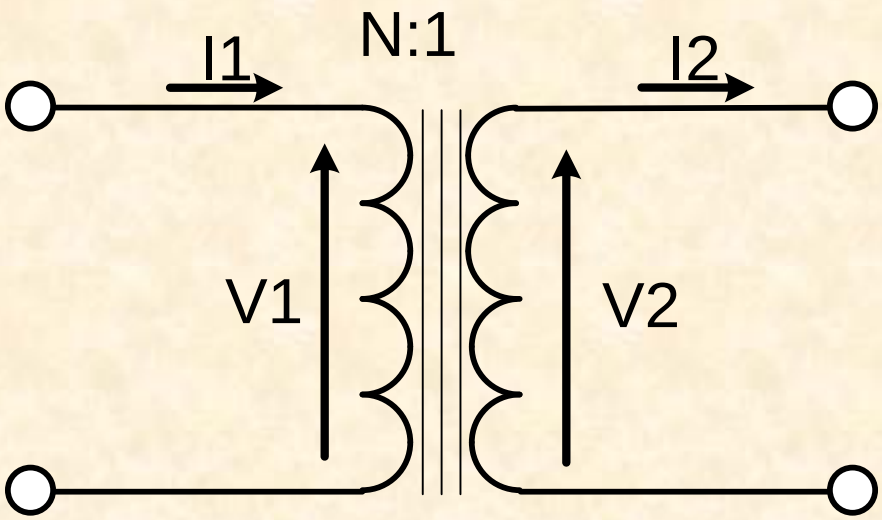




Overview of Power system

Power Transformation

- Alternating current has the beneficial property of being easily transformed from one voltage level to another.

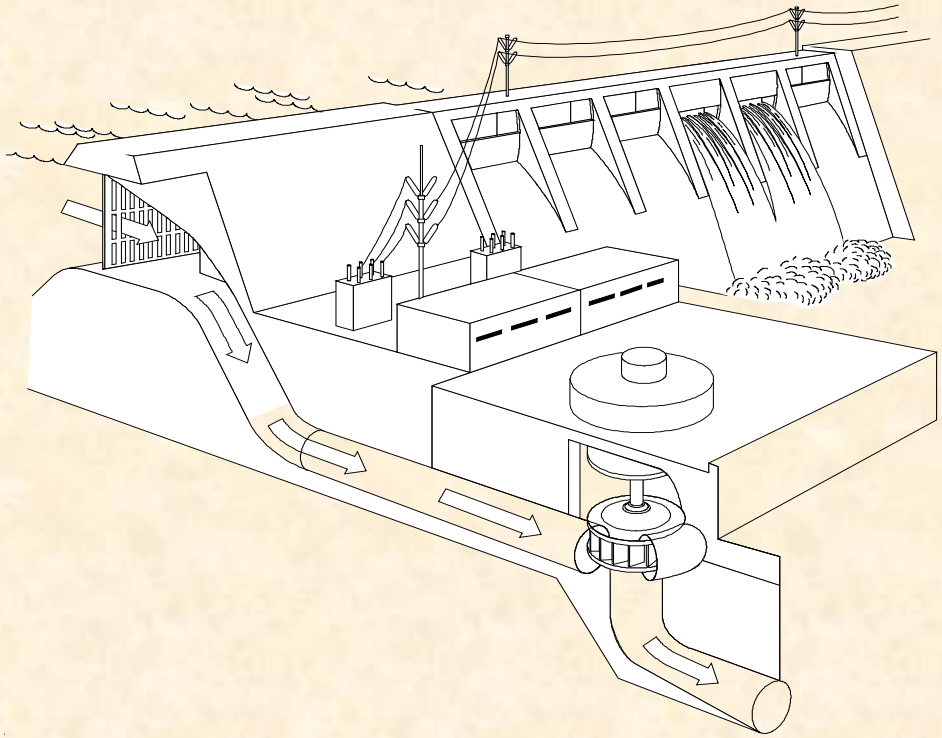


For an ideal Transformer,

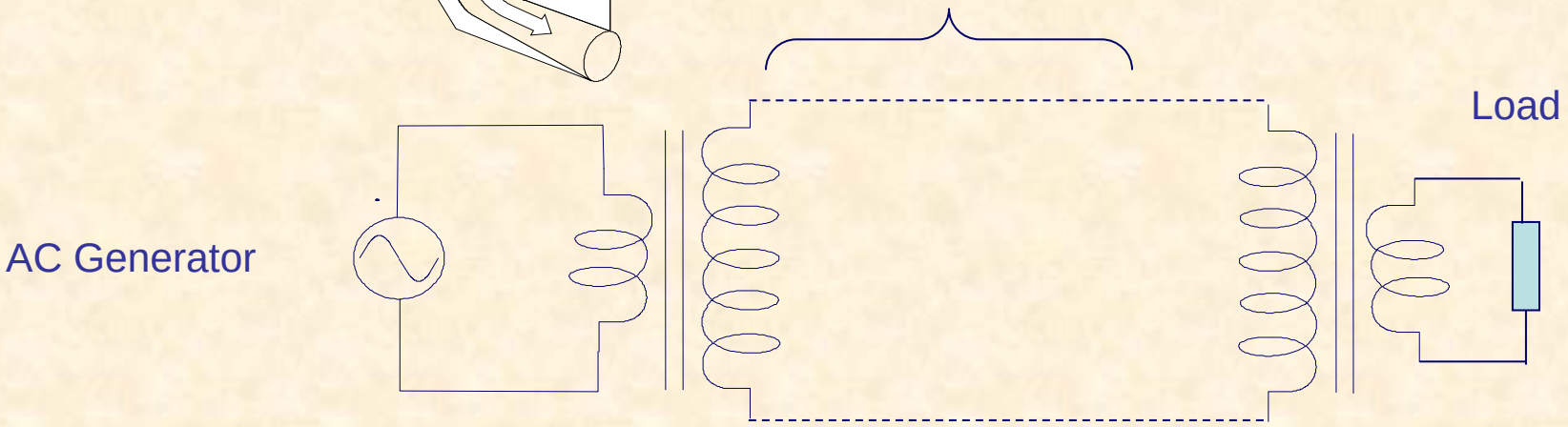
$V1/V2 = N$

$I1/I2 = 1/N$

Components of a power system

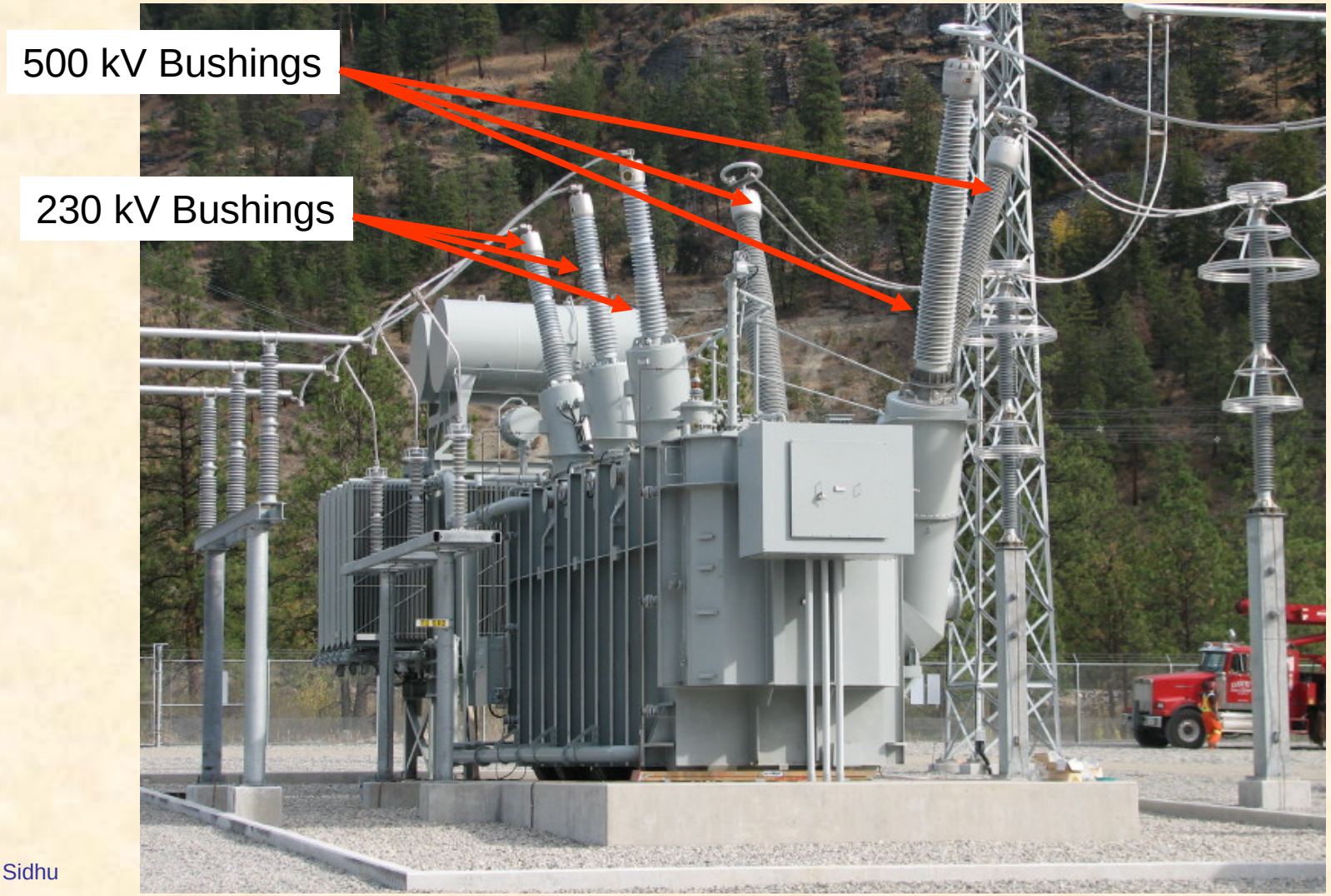


Exporting power



Components of a power system

A three phase 500 – 230 kV system transformer

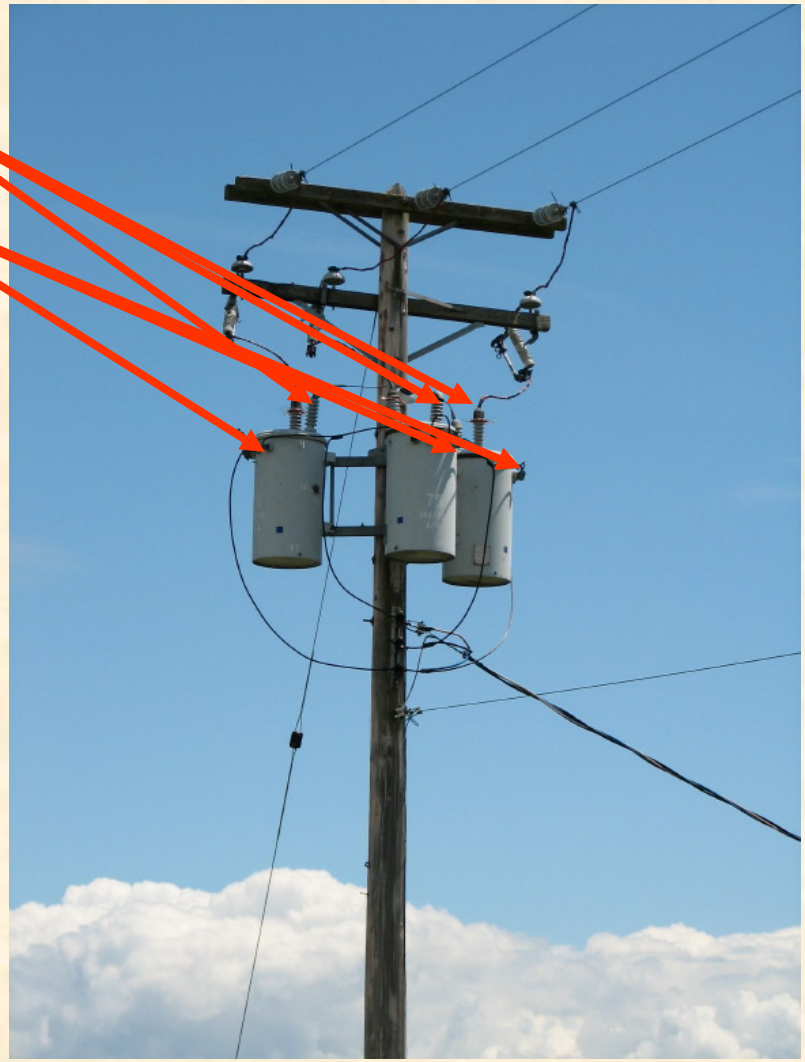


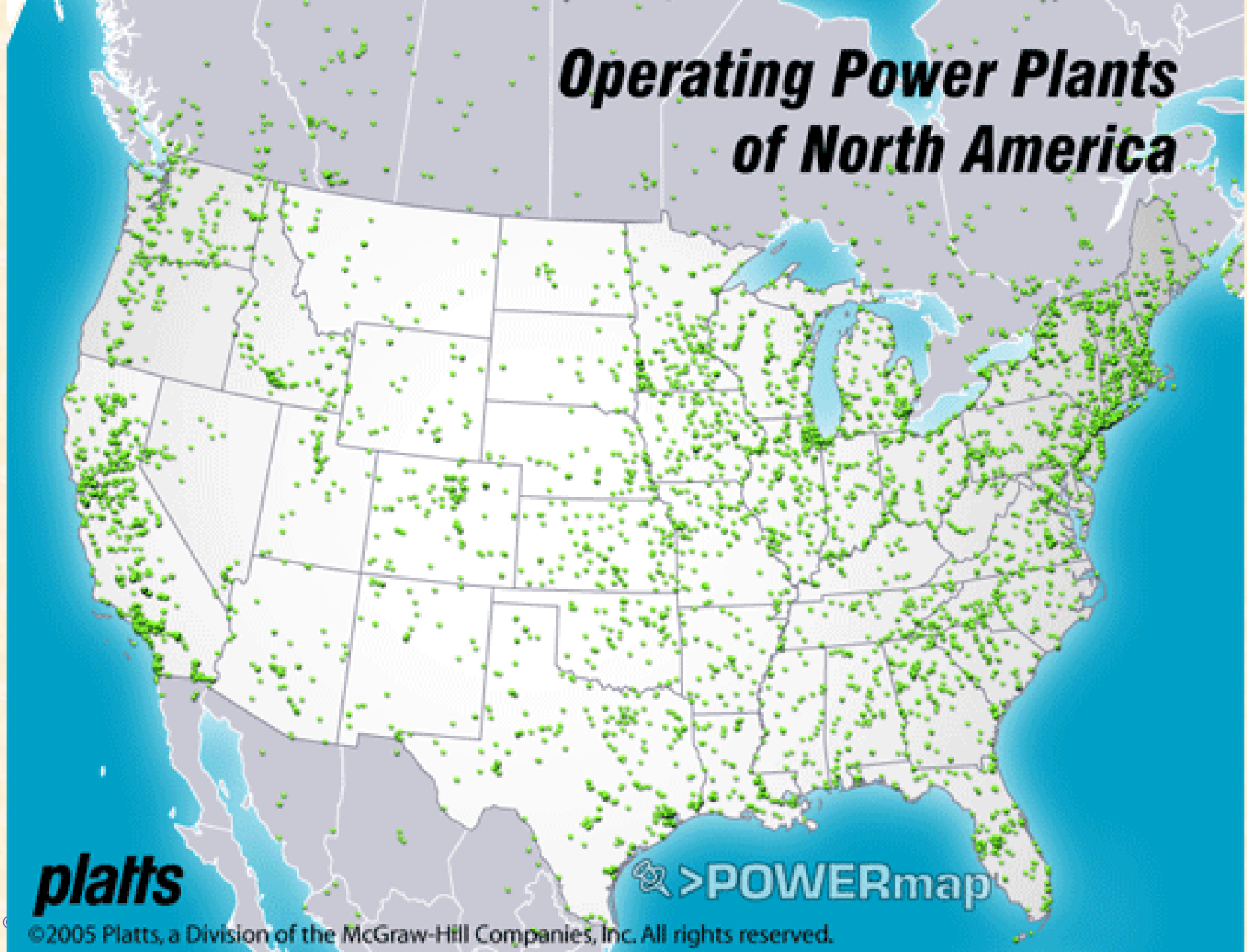
Components of a power system

A three phase 25 kV to 416V distribution transformer

25 kV Bushings

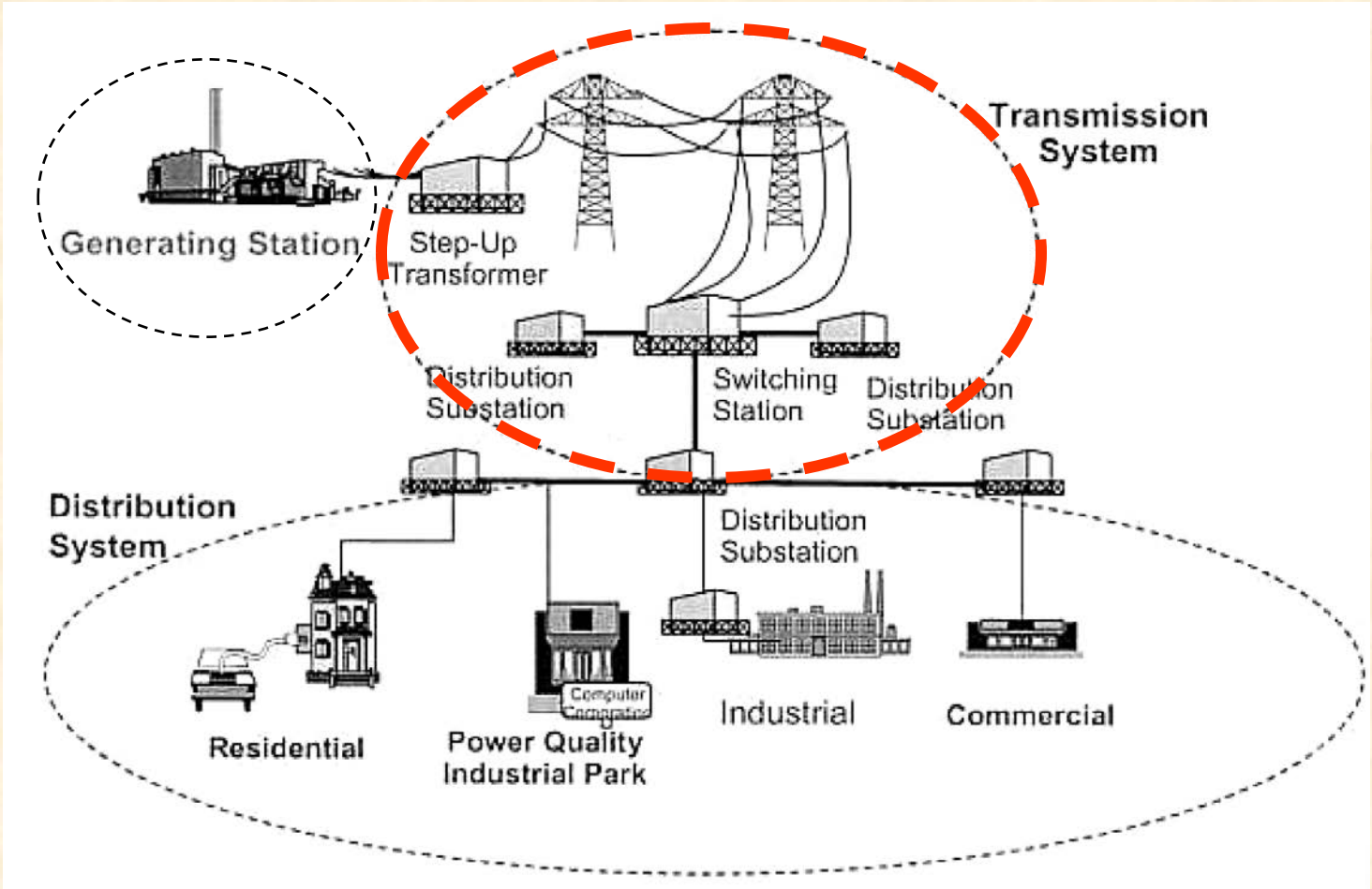
416 V Bushings





Overview of Power system

Generation, Transmission and Distribution



Overview of Power system

Power Transmission

- The higher the voltage, the easier to transmit power over long distances.
- The voltage is stepped up at major generating stations for transmission
- Then may be changed again at switching stations for transmission over greater or lesser distances
- Then stepped down at substations near the load for distribution.

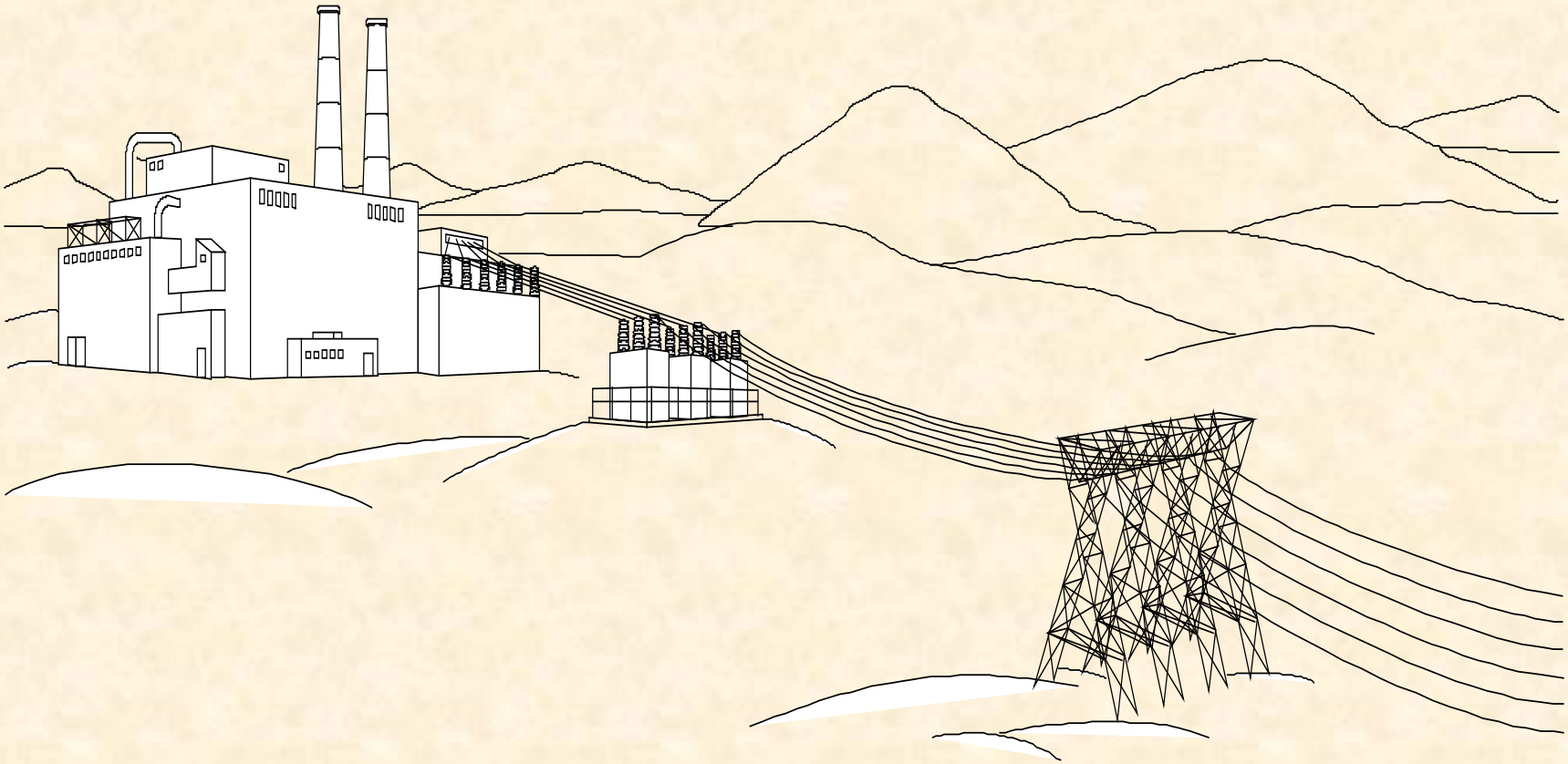
Overview of Power system

Power Transmission

- In North America, transmission voltages range from 60kV – 765 kV.
- Typical transmission voltage (kV) levels include
- 60, 64, 66, 69, 115, 138, 161, 220, 230, 240, 287, 345, 400, 500, 735, 765. In Russia, 1000 kV transmission is in service.
- DC transmission is also used in some special circumstances, but will not be discussed in this course

Components of a power system

Transmission System



Components of a power system

A 500 kV transmission Line

Components of a power system

A 230 kV transmission line

Components of a power system

Double Circuit Transmission Lines

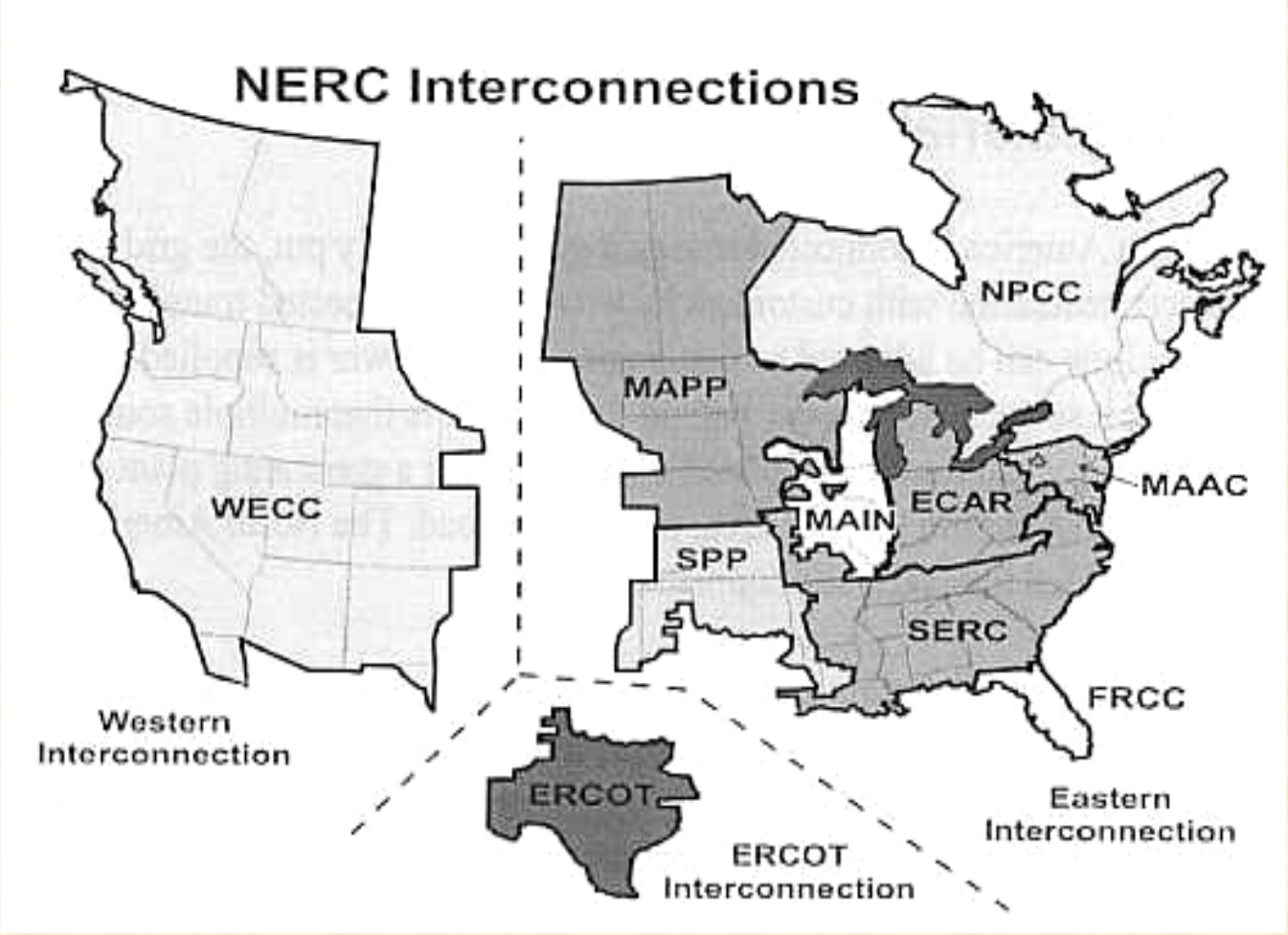
Components of a power system

Transmission networks

- The transmission system is for transporting bulk power over long distances
  - It is networked in a looped or meshed system for reliability.
  - Loss of one component will not be catastrophic
- Transmission interconnections between neighboring companies
  - Reinforce each other for reliability
  - Enable the trading of bulk power
- Bulk power users (e.g. industrial) may connect at transmission voltage levels

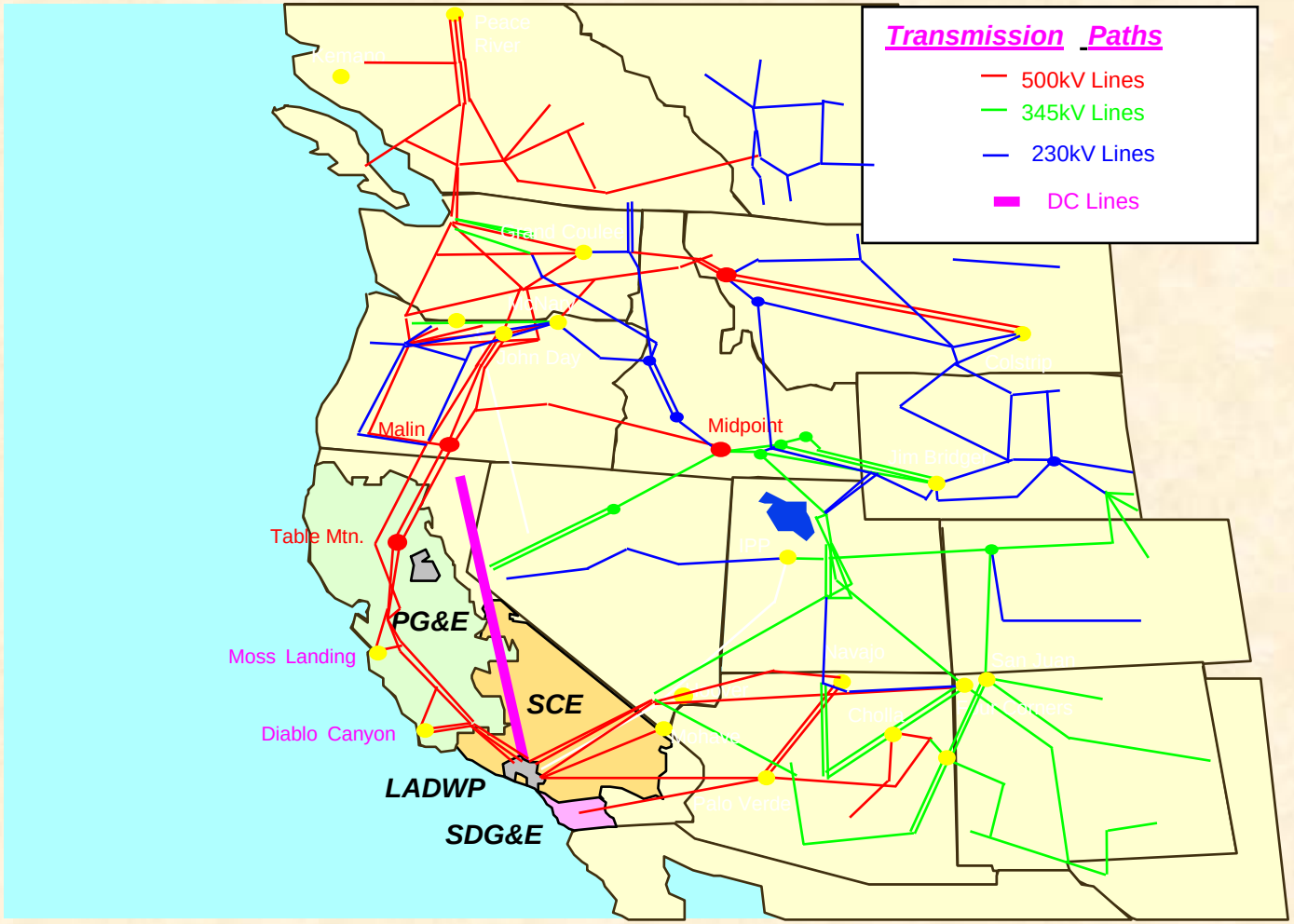
Components of a power system

Interconnected Systems



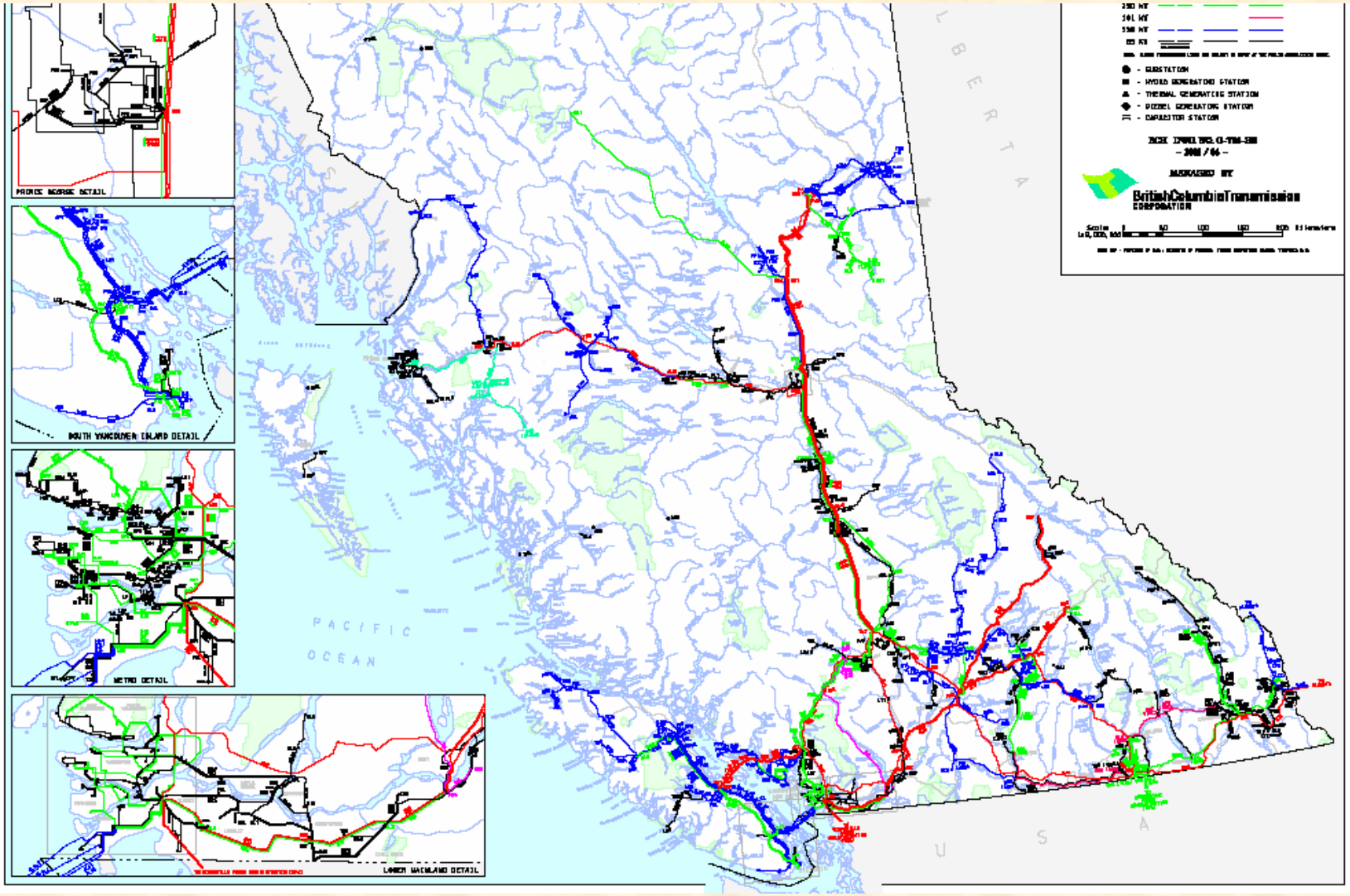
Components of a power system

WECC System



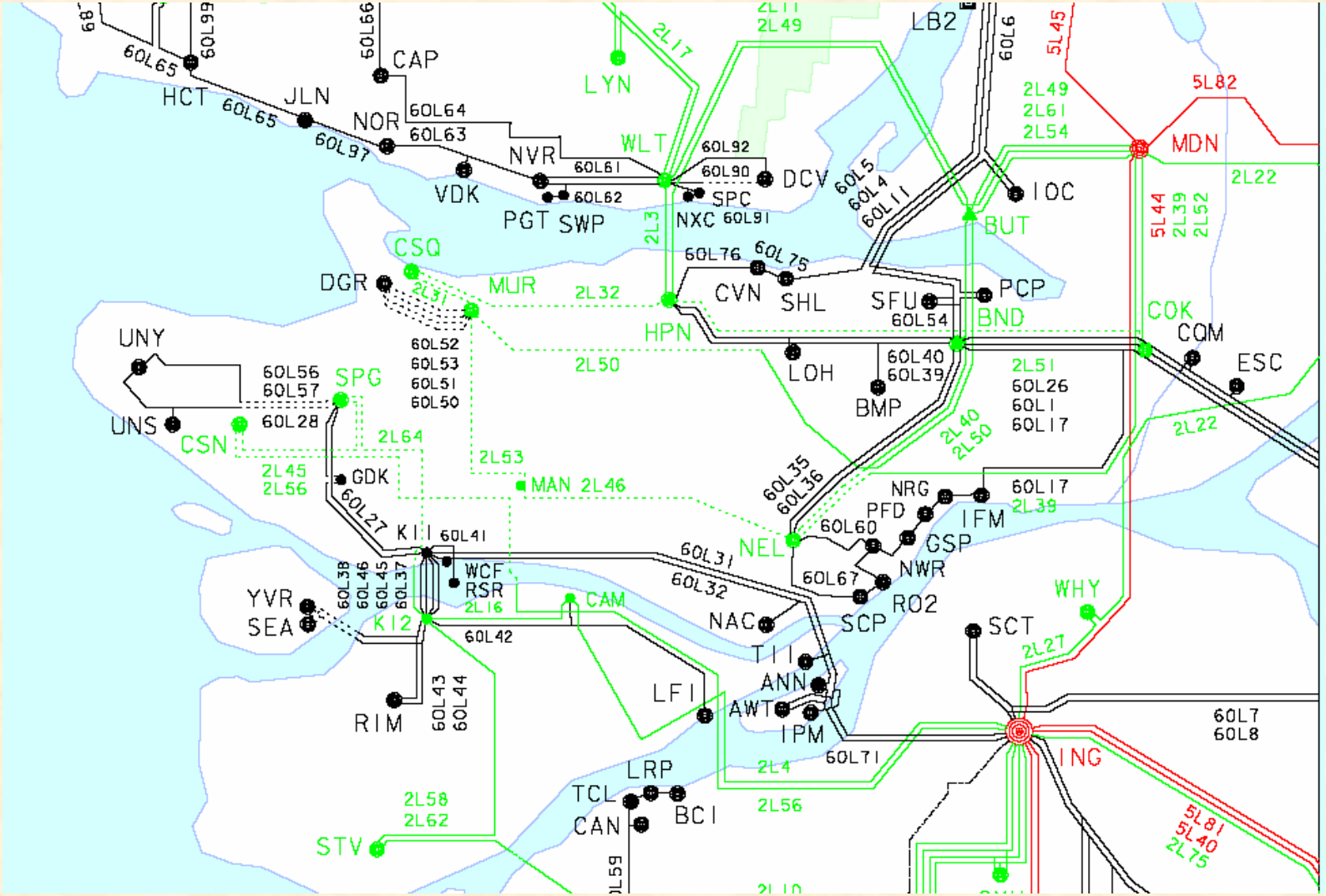
Components of a power system

Transmission System Physical Layout



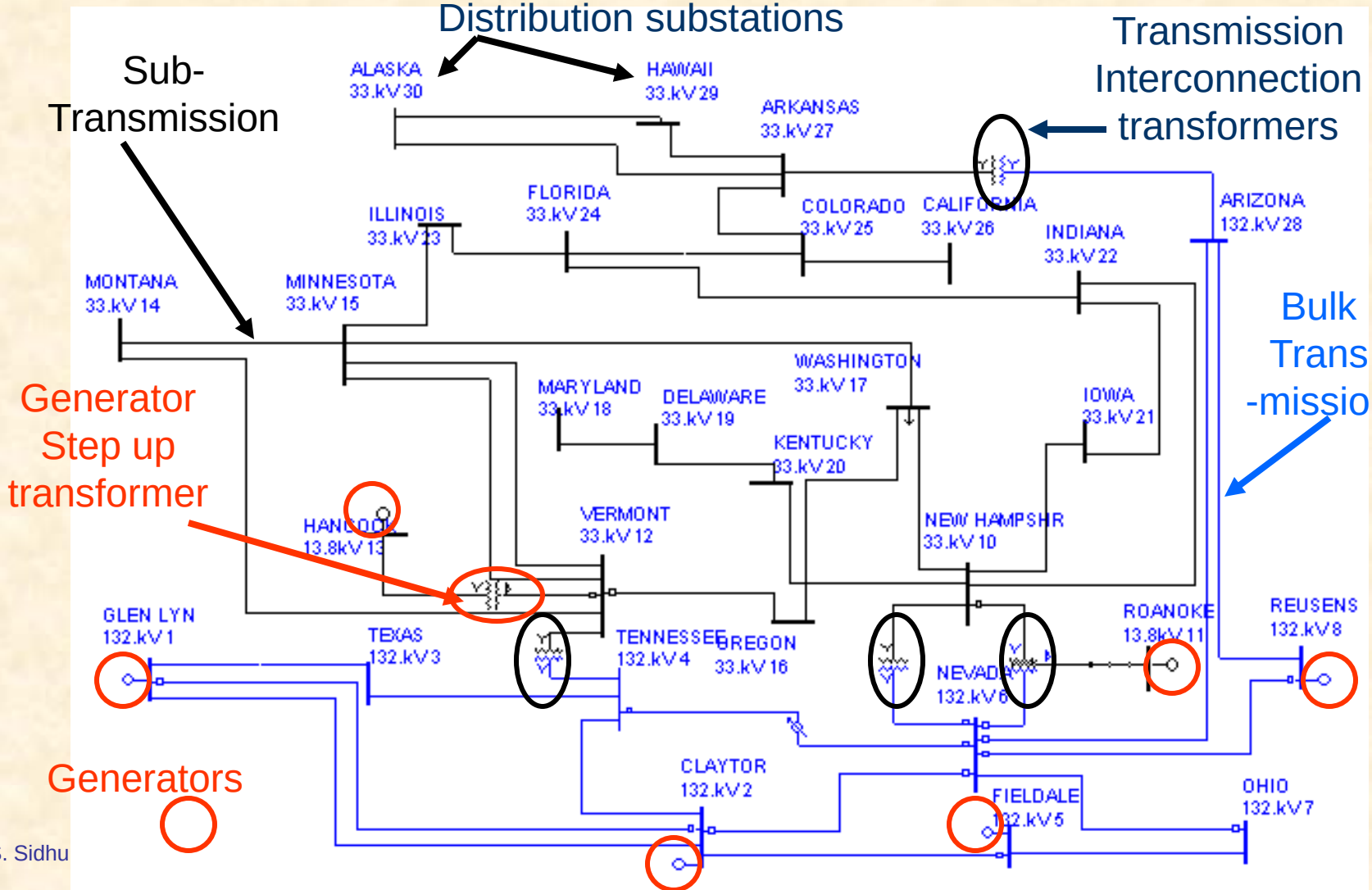
Components of a power system

Urban transmission system



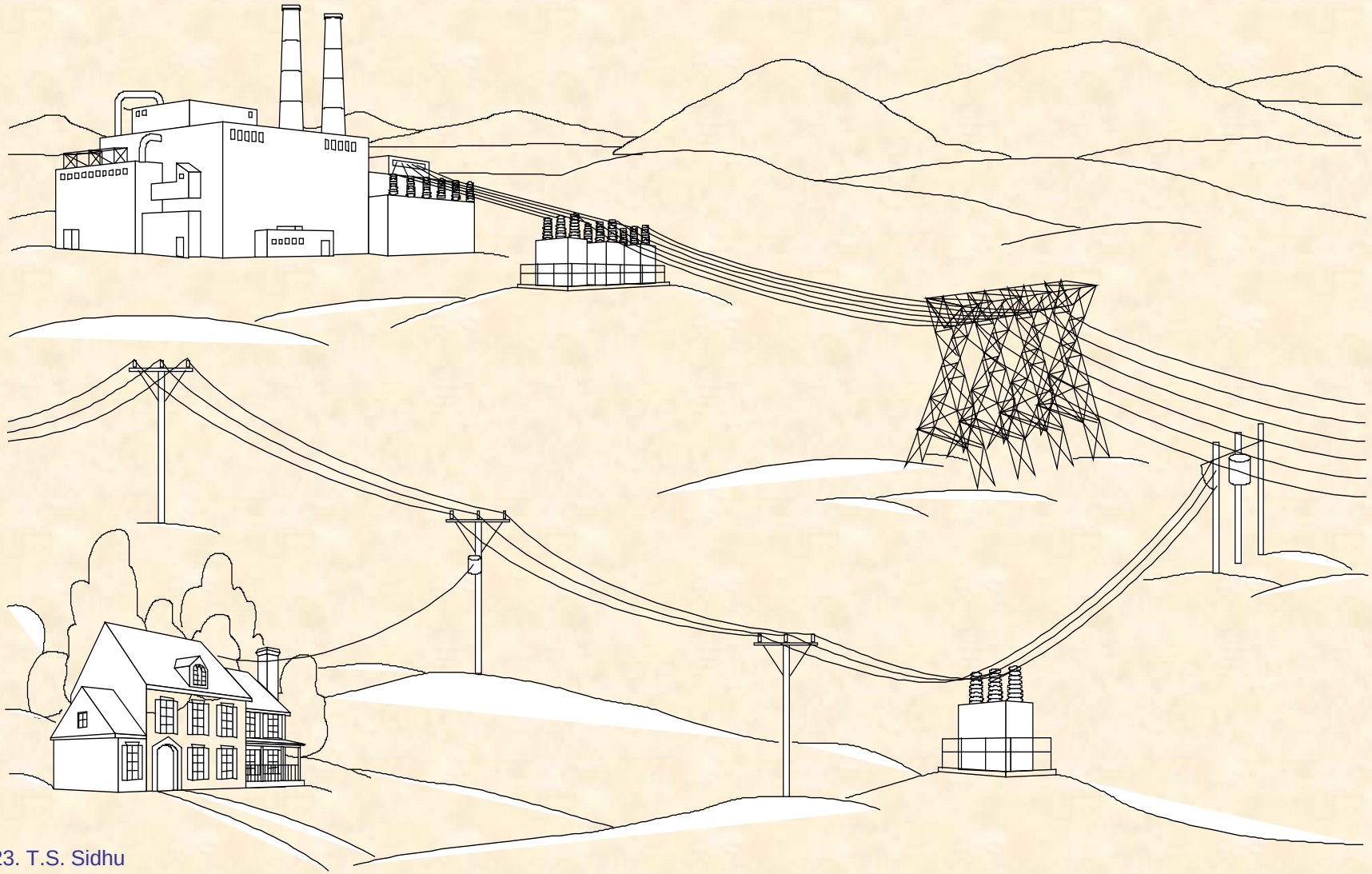
Components of a power system

Example Transmission System One Line



Overview of Power system

Transmission & Distribution

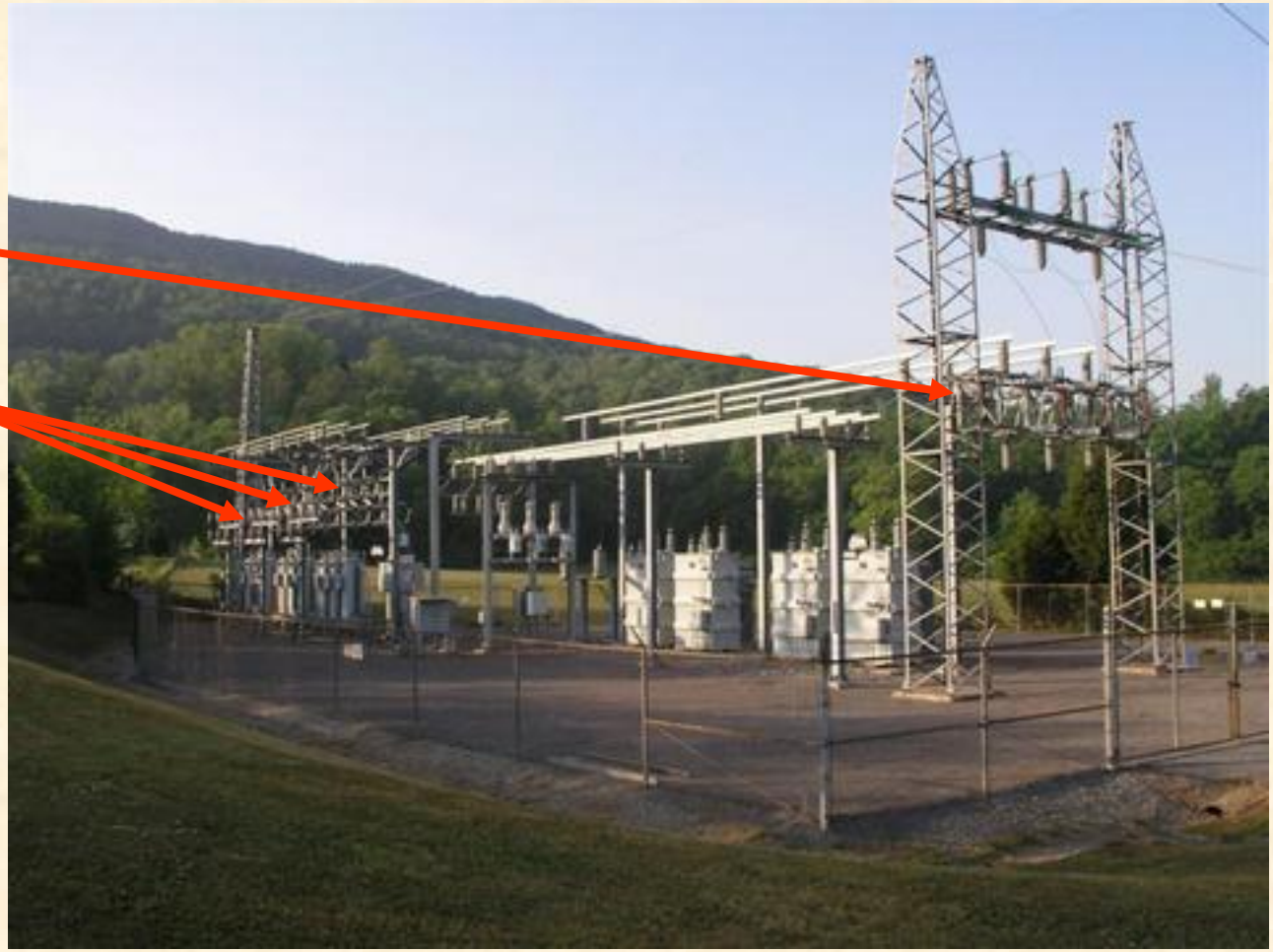


Components of a power system

Stepping down to the distribution

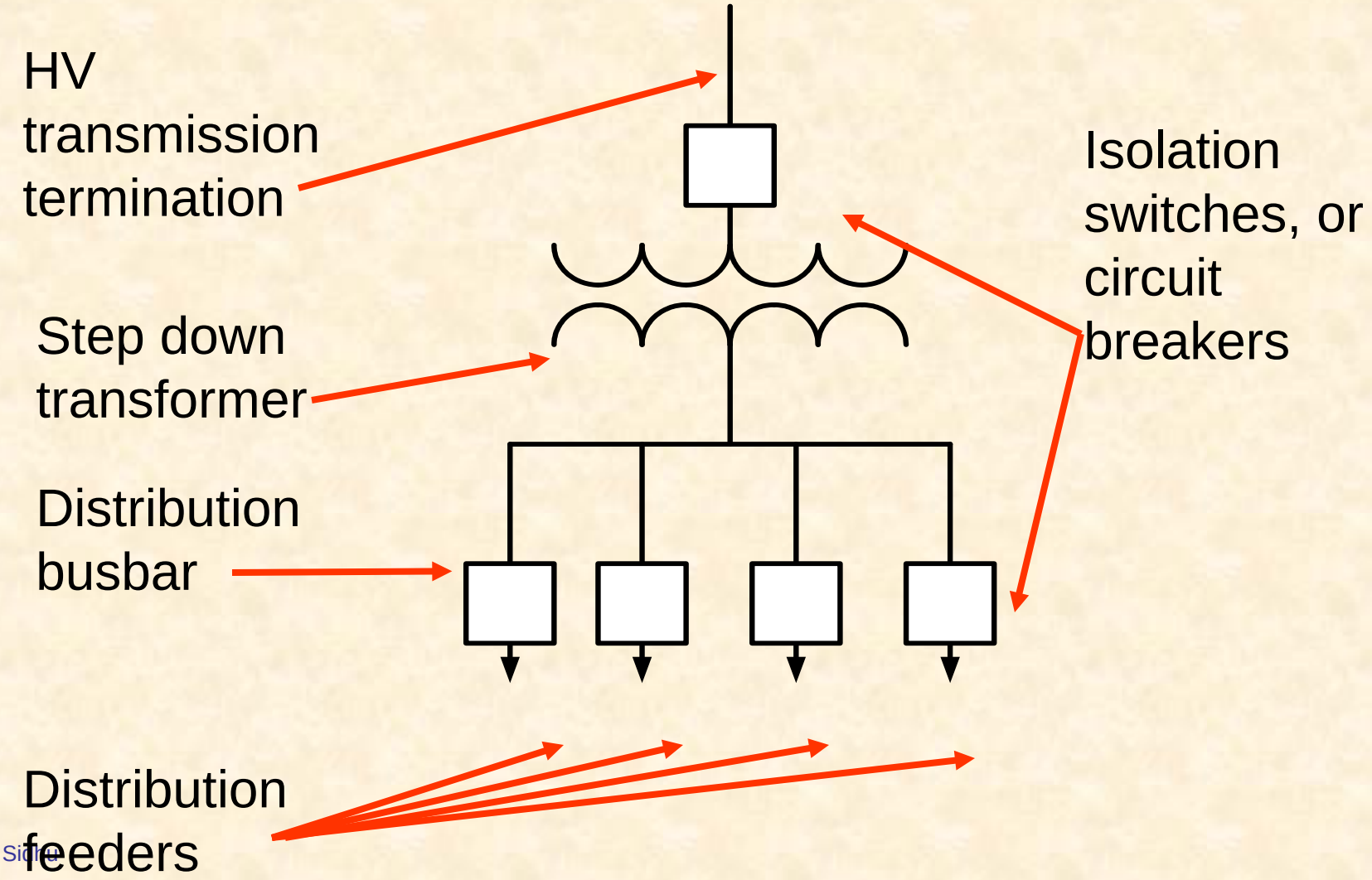
69 kV in

13.8 kV out on several distribution feeders.



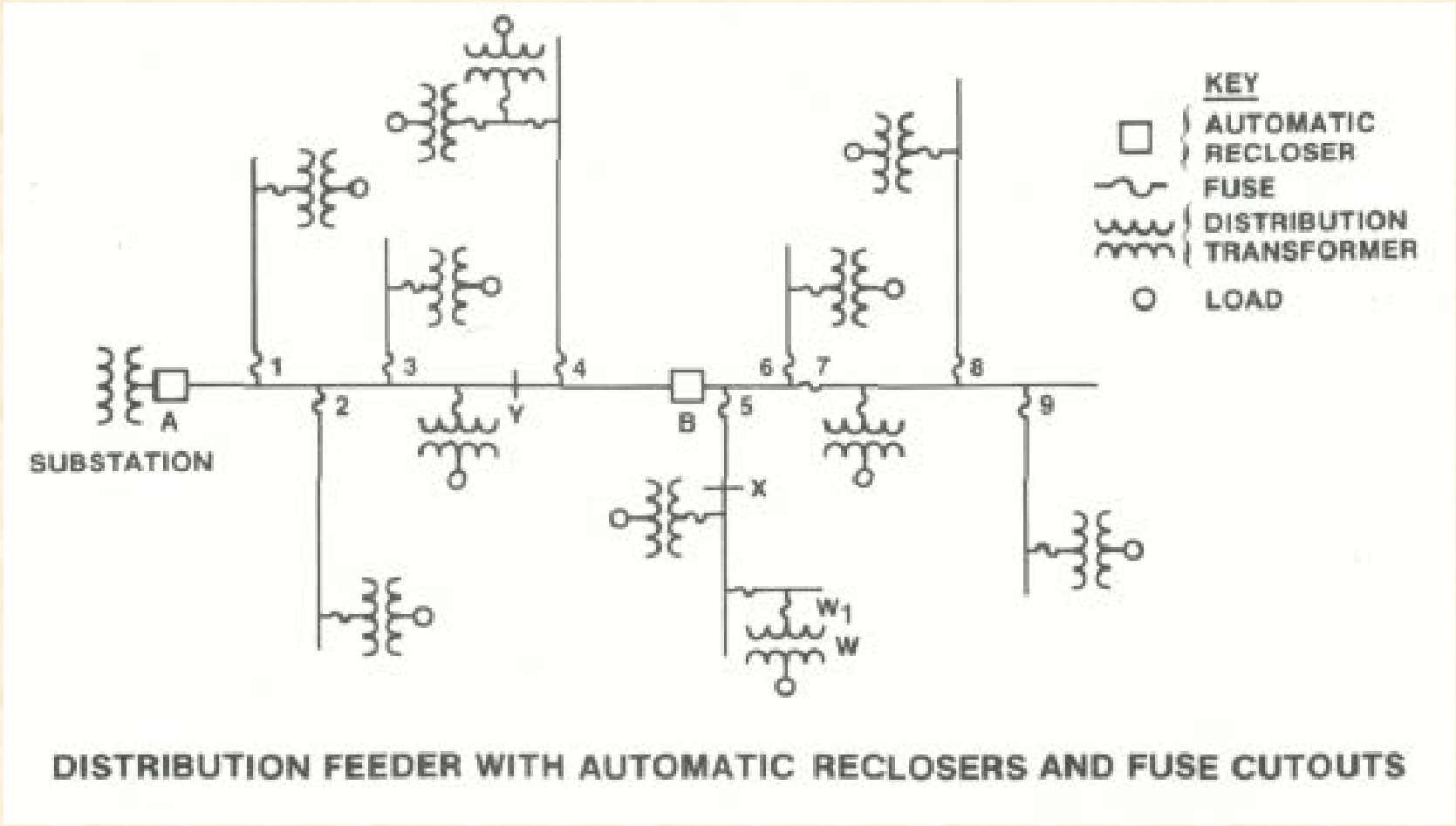
Components of a power system

Distribution Substation single line diagram



Components of a power system

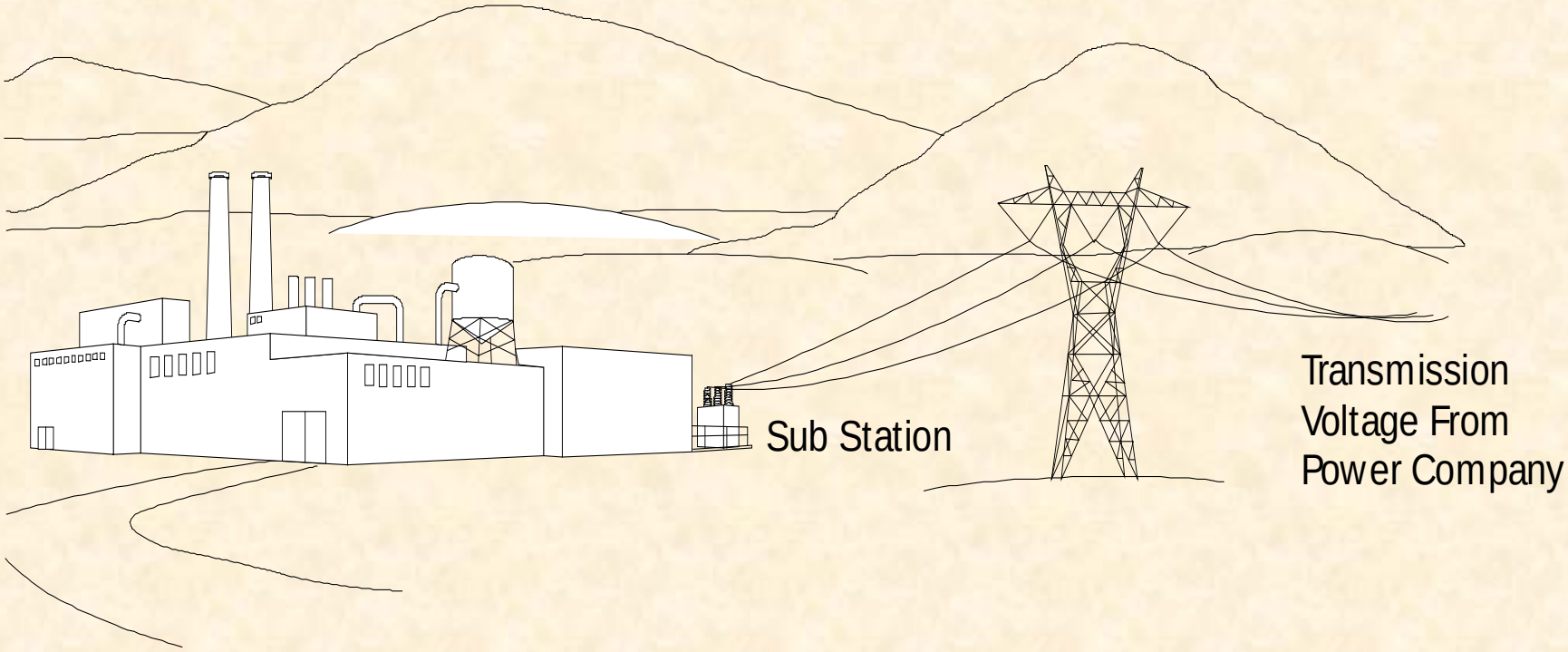
Distribution system One Line Example



DISTRIBUTION FEEDER WITH AUTOMATIC RECLOSERS AND FUSE CUTOUTS

Components of a power system

Load



Components of a power system

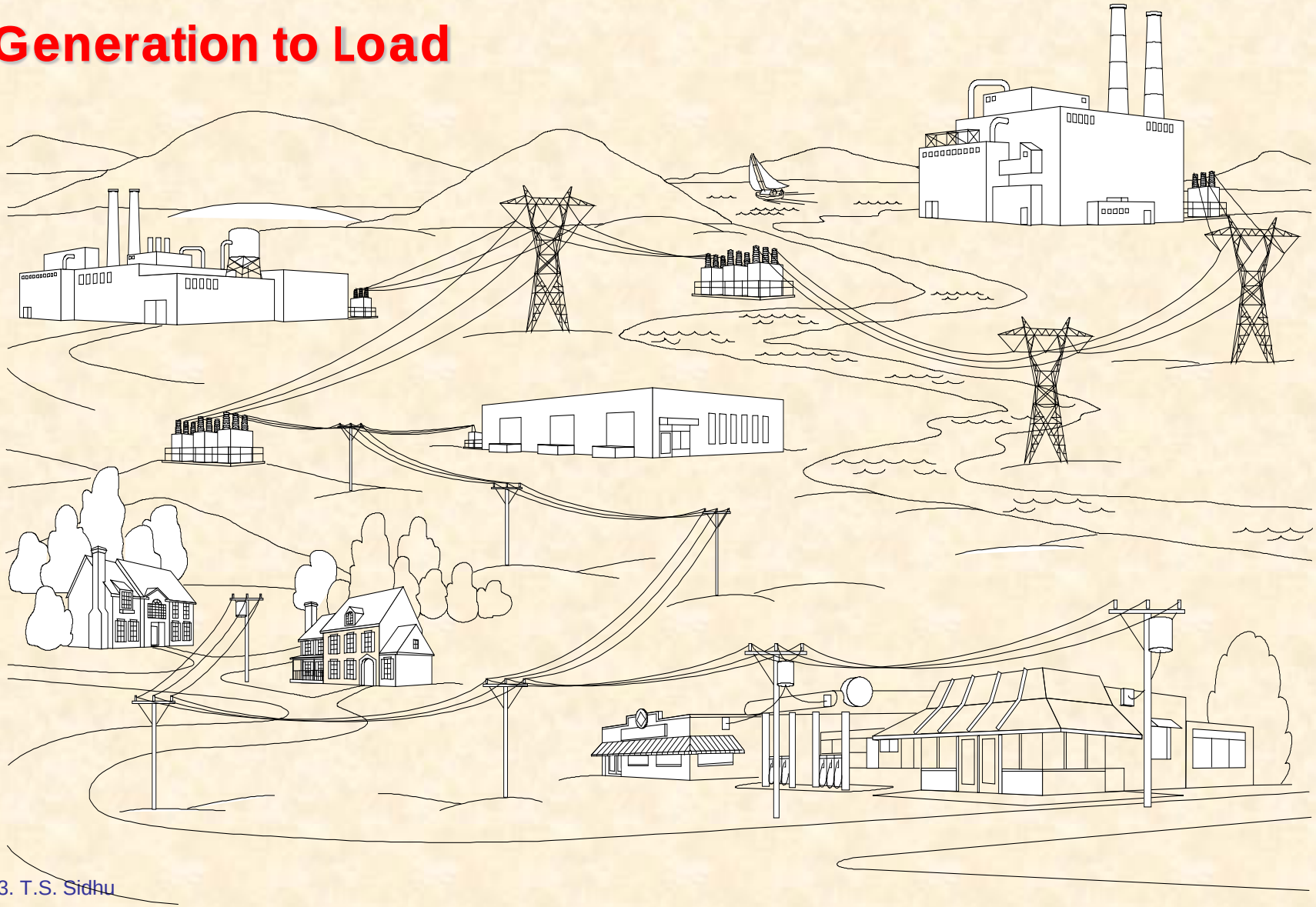
The End User

14.4 kV in

240/120V out to several residential customers

Components of a power system

Generation to Load



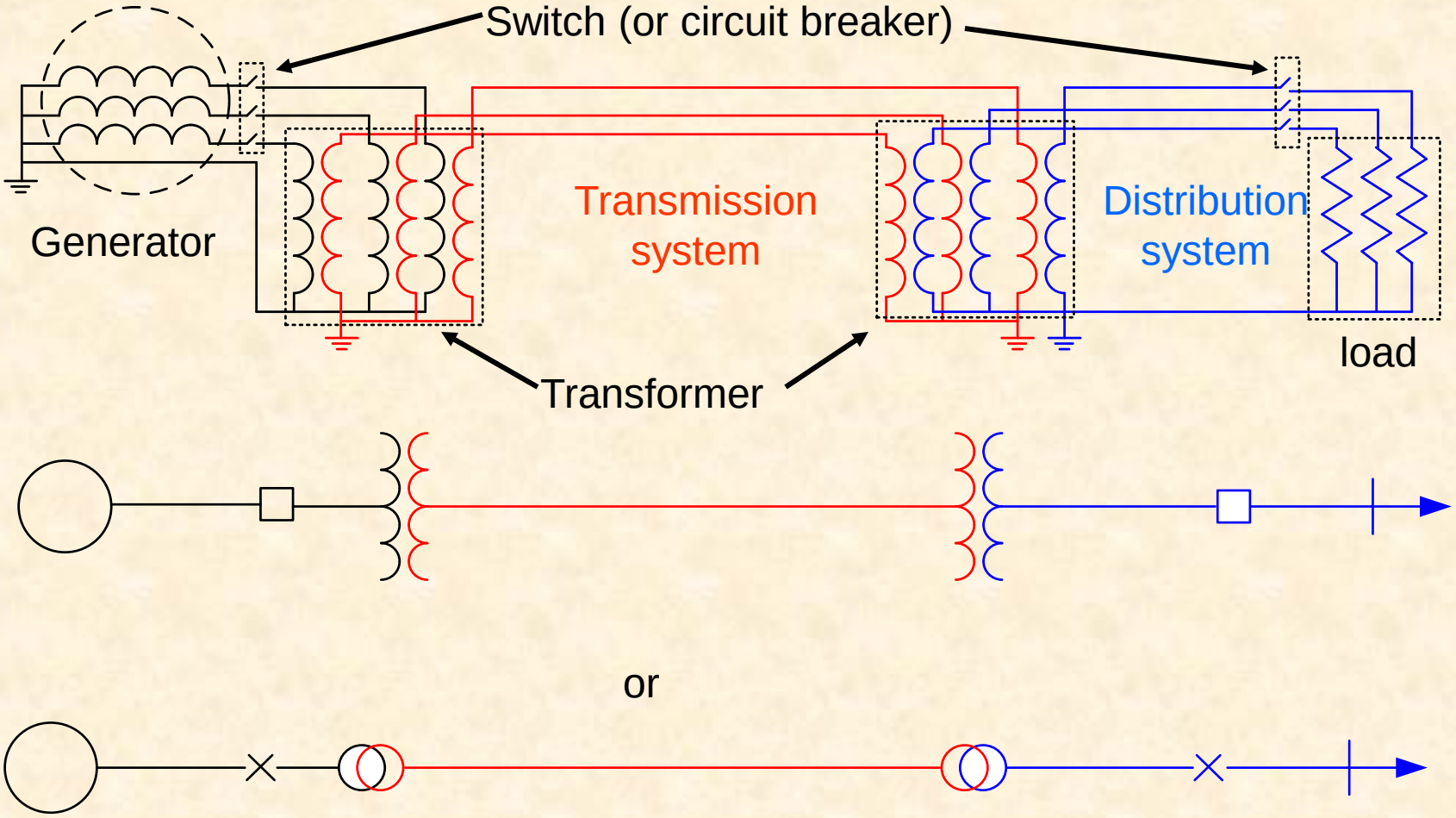
Overview of Power system

Single Line Representation

- Note the sets of conductors indicate a three phase power system.
- Under normal conditions the three phase voltages and currents are identical to each other, but displaced by 120 degrees.
- By representing just one phase we can convey complete information about all three.

Overview of Power system

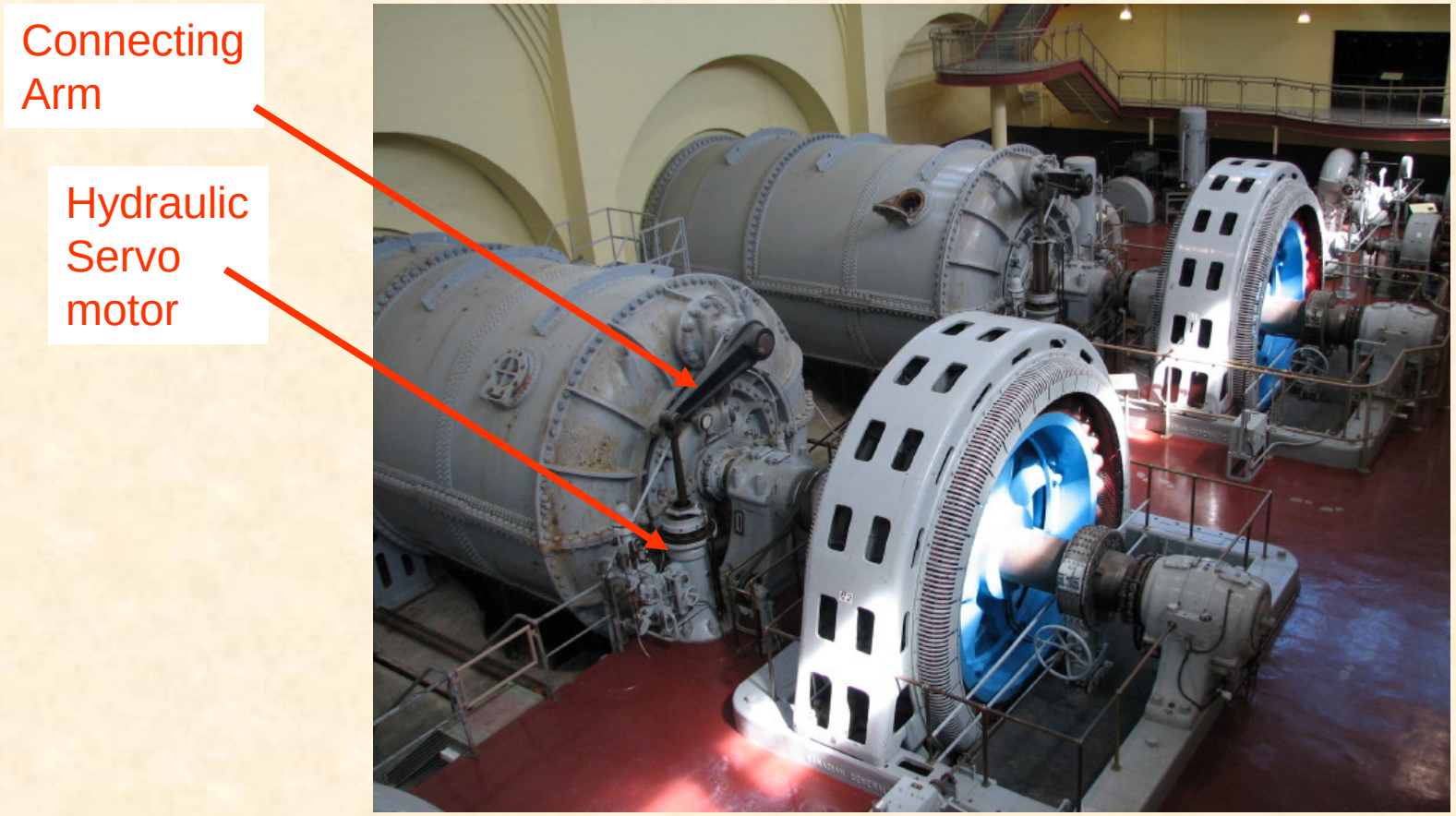
Three lines (plus neutral) simplified to one



Contents

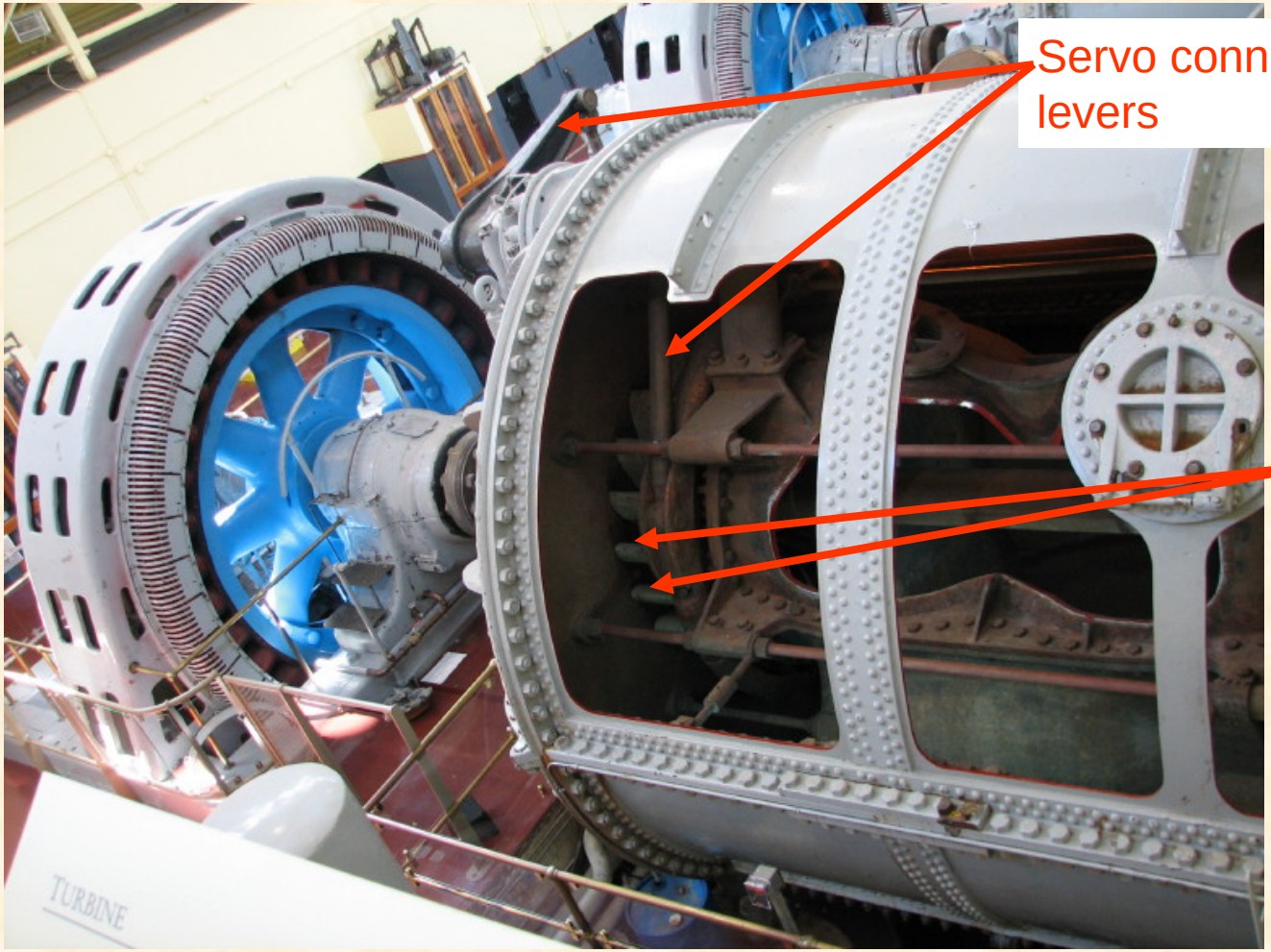
Power system operation

Wicket gate operating mechanism



Power system operation

Water intake gates inside turbine



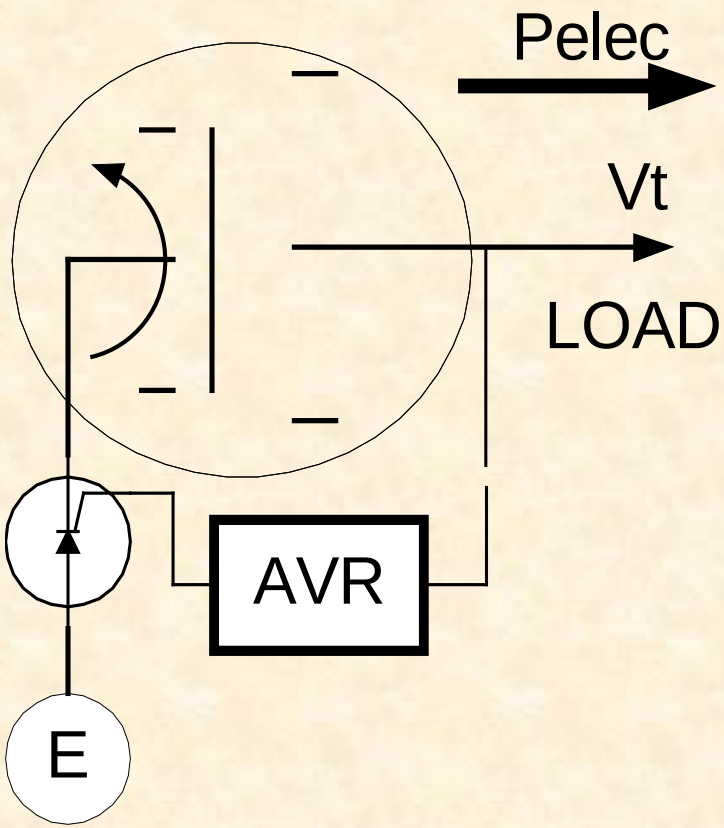
Power system operation

The reactive load – generation balance

- Reactive power controls the voltage on the system
- Voltage is allowed to vary slightly with narrow limits
- Imbalance in reactive power affects voltage level, but not without limit.
  - Sensitivity of reactive loads to voltage is much larger than sensitivity of real loads to frequency

Power system operation

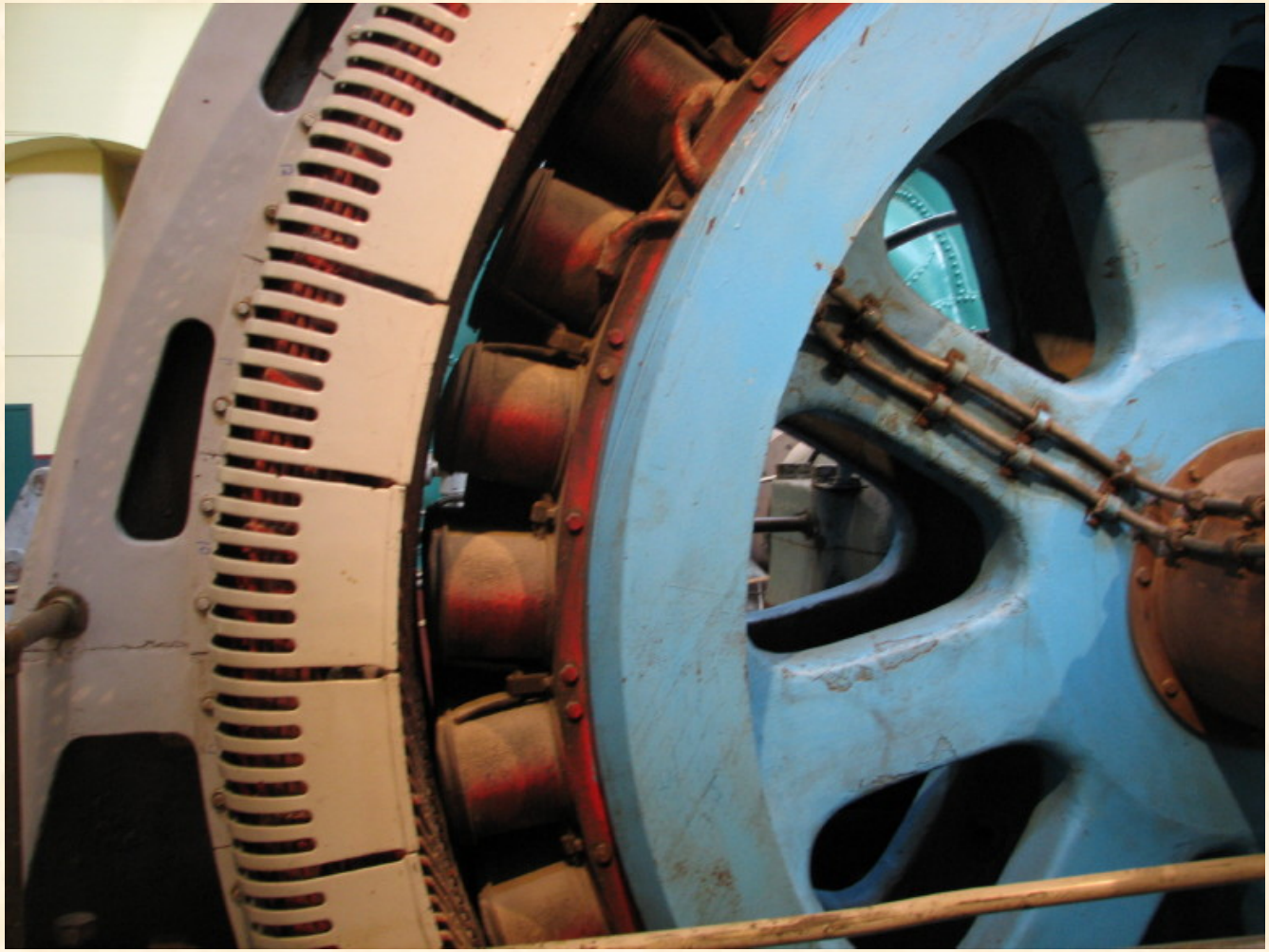
AVR Controls Generator



- Automatic voltage regulator (AVR) tries to maintain set voltage
- If voltage is fixed, increasing set voltage increases reactive power output

Power system operation

Generator field windings

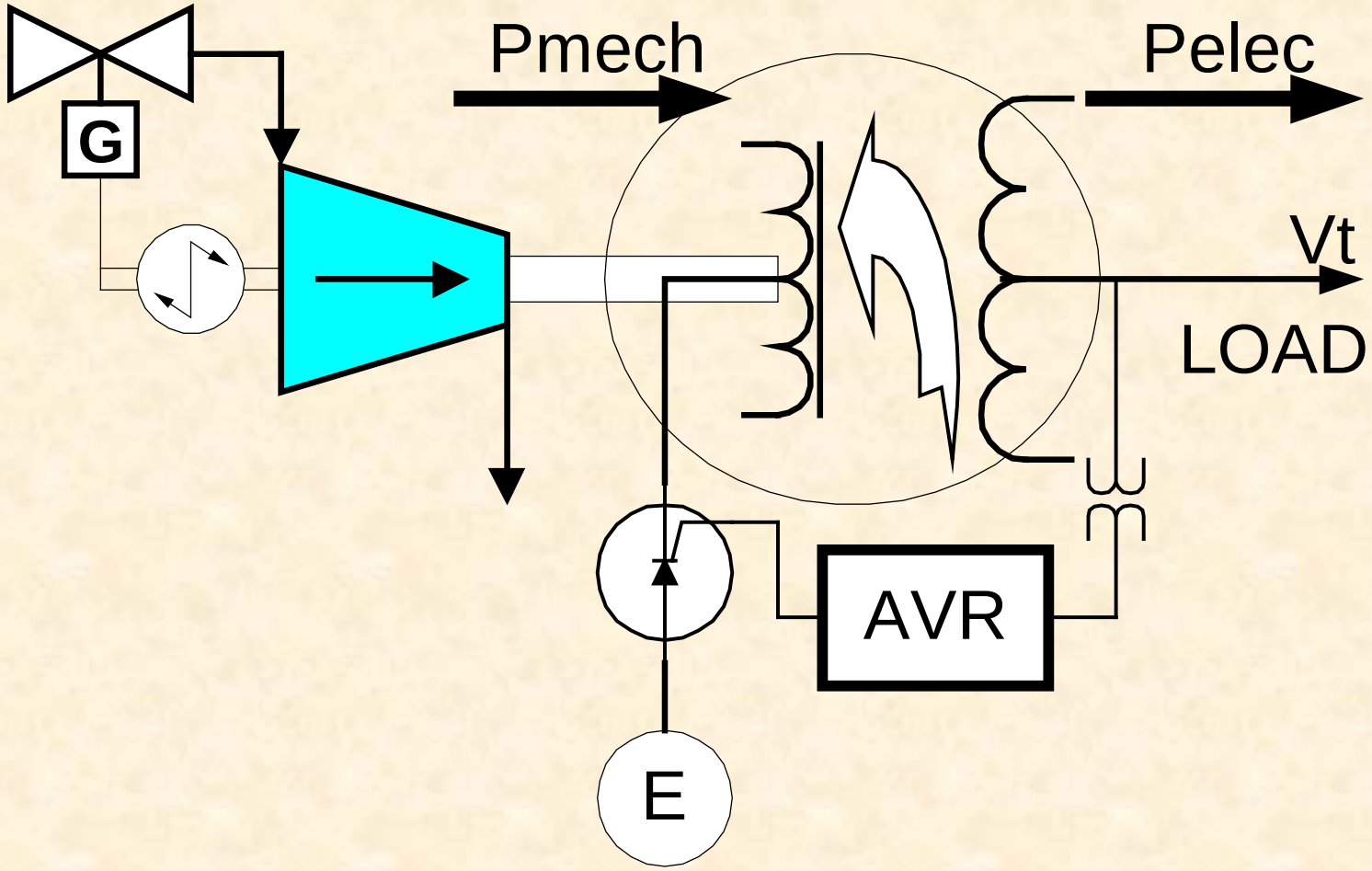


Power system operation

Exciters (small dc generators)

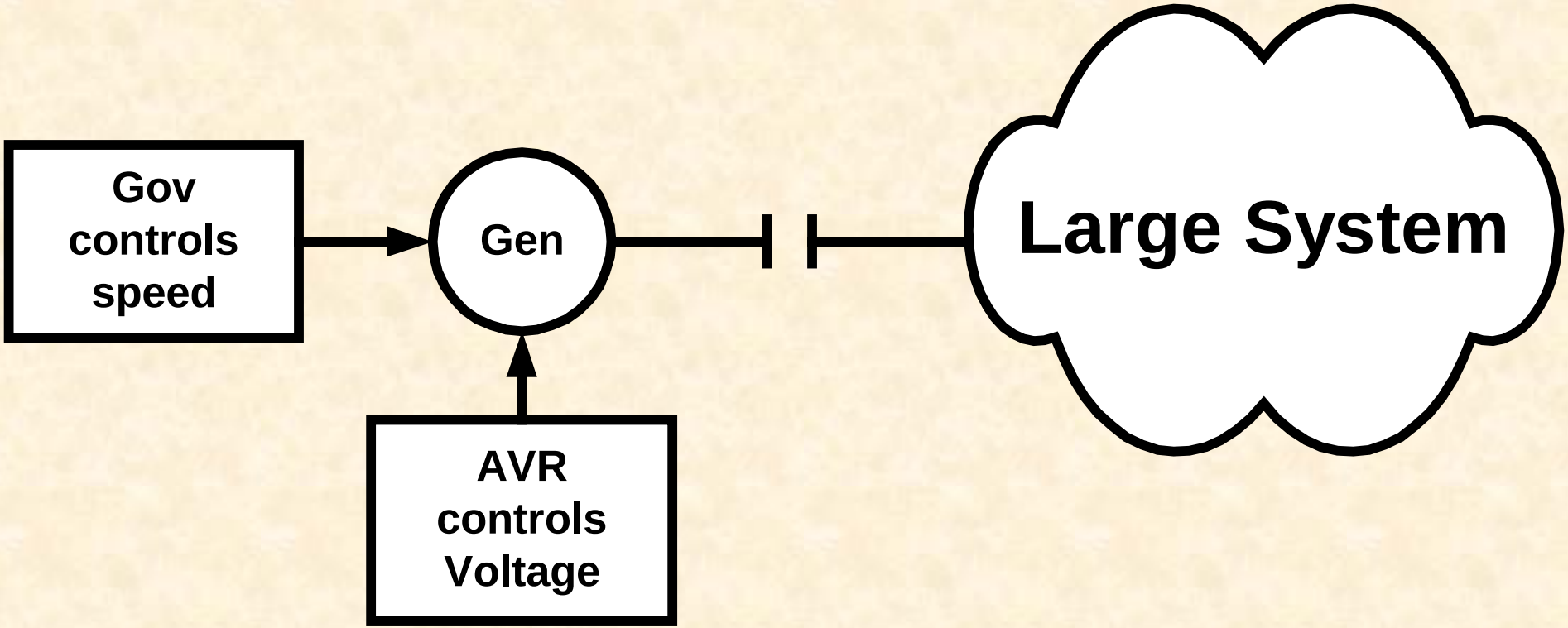
Power system operation

Turbine Generator with controls



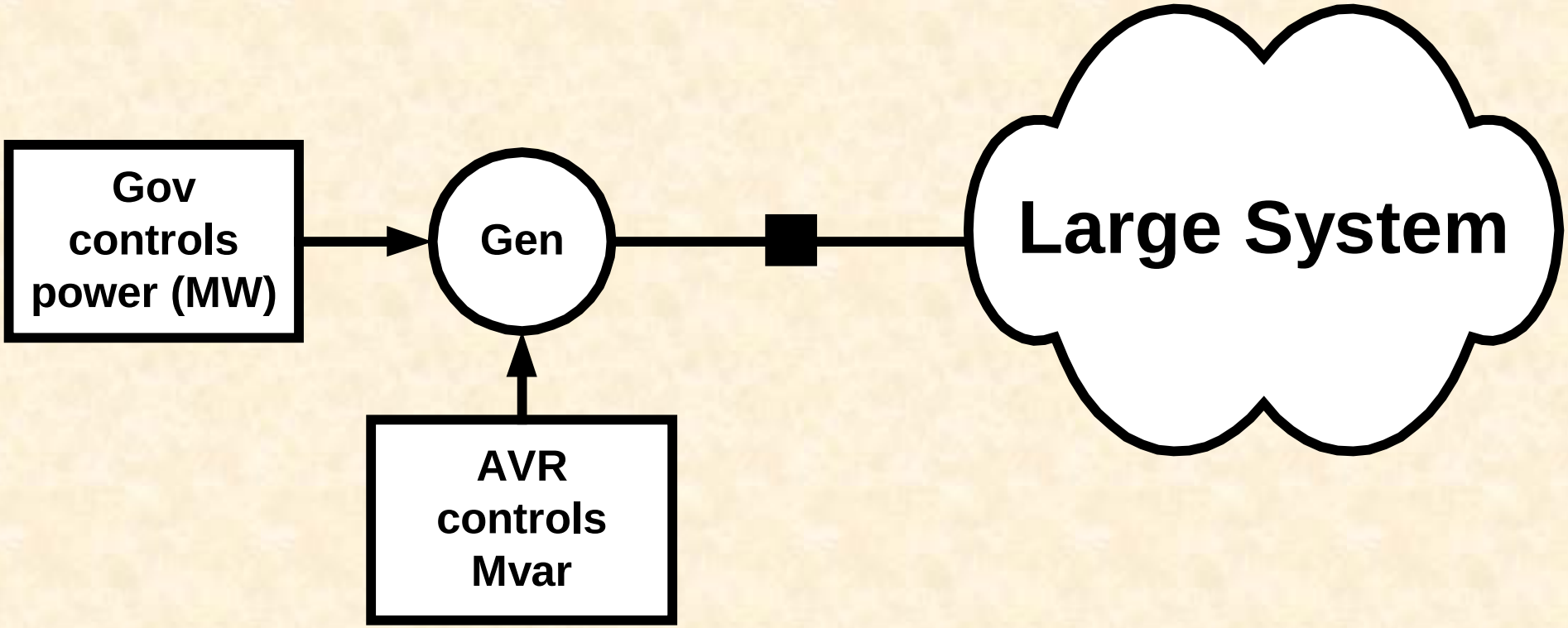
Power system operation

Unit CB open



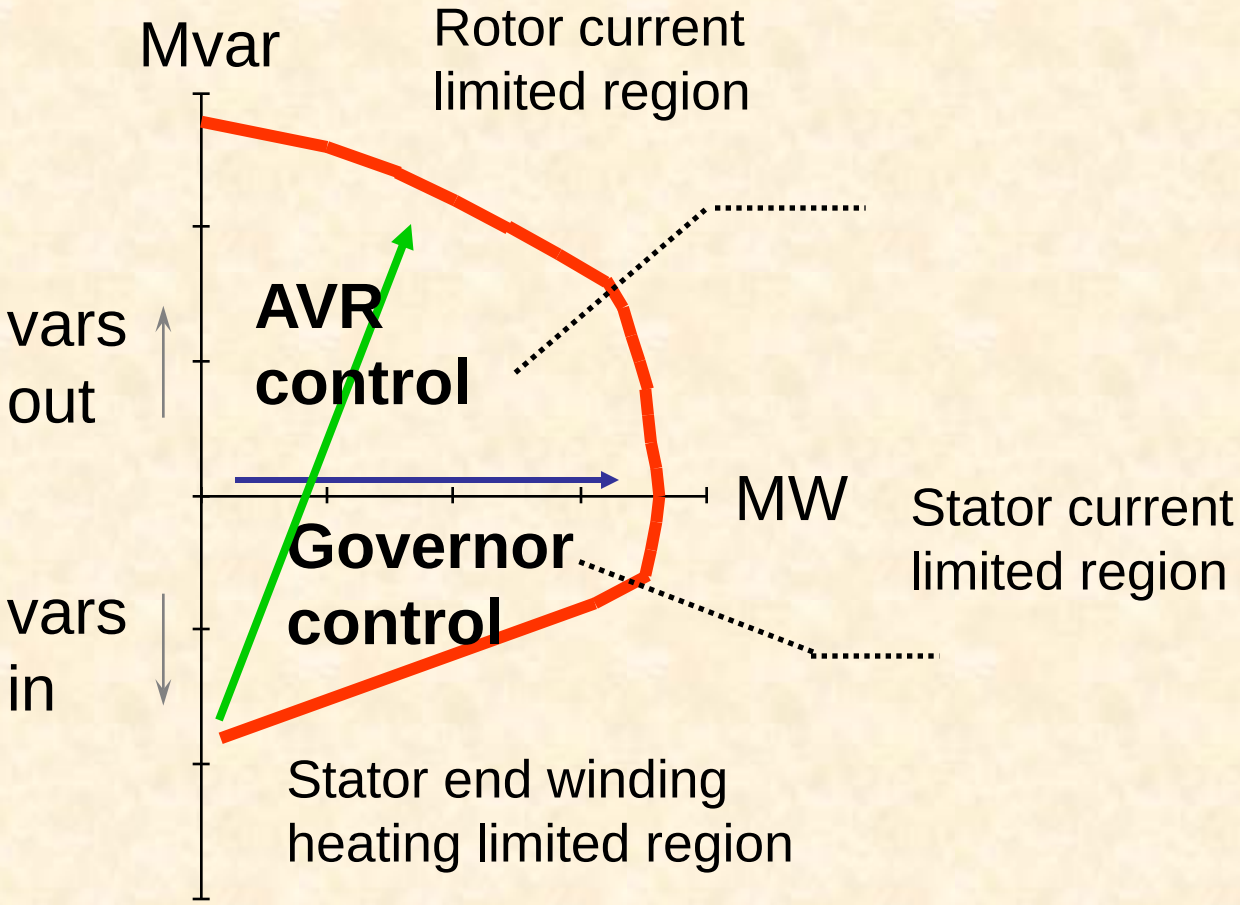
Power system operation

Unit CB Closed



Power system operation

Generator Capability Diagram



Power system operation

Real power balance affects frequency

- Consumers of real power
  - Loads
  - Losses in generation, transmission and distribution
- Producers of real power
  - Generators
- Balance achieved by
  - Monitoring daily and seasonal load fluctuations
  - Taking generators on and off line (manual coarse)
  - Adjusting set points of generator governors (manual and automatic fine)
  - Providing droop control on generator governors (automatic)

Power system operation

Reactive power balance affects voltage

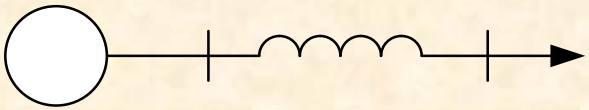
- Consumers of reactive power
  - Transformers
  - Transmission lines
  - Distribution lines
  - Inductive component of loads
  - Reactors (shunt and series)
  - Power electronics (HVDC)
- Producers of reactive power
  - Generators, synchronous condensers and motors
  - Capacitors (shunt and series)
  - Cables, lightly loaded transmission systems
  - Power electronics (SVC, Statcon, FACTS)

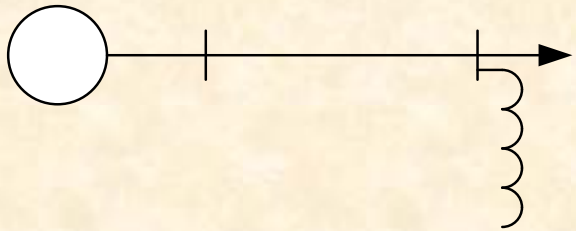
Power system operation

Reactive power consumption

- Series reactance
  - T&D lines
  - Transformers
  - Series reactors
- Mvar = I^2X_L

- Shunt reactance
  - Inductive component of loads
  - Shunt reactors
- Mvar = V^2/X_R



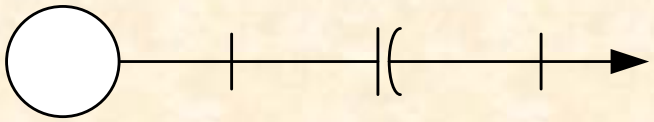


- Generators, synchronous motors, power electronics
  - Mvar depends on controls

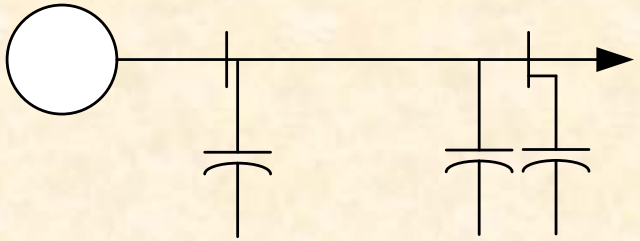
Power system operation

Reactive power generation

- Series capacitors
- Mvar = I^2X_C



- Shunt capacitance
  - Lightly loaded T&D
  - Shunt reactors
- Mvar = V^2/X_C



- Generators, synchronous motors, power electronics
  - Mvar depends on controls
- Pay attention to the sign of reactive power
- Absorbed is – ve, generated is + ve