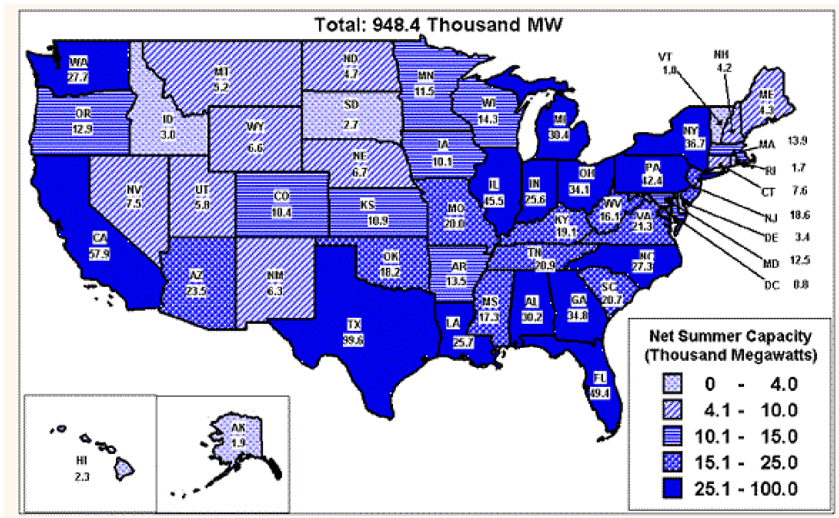
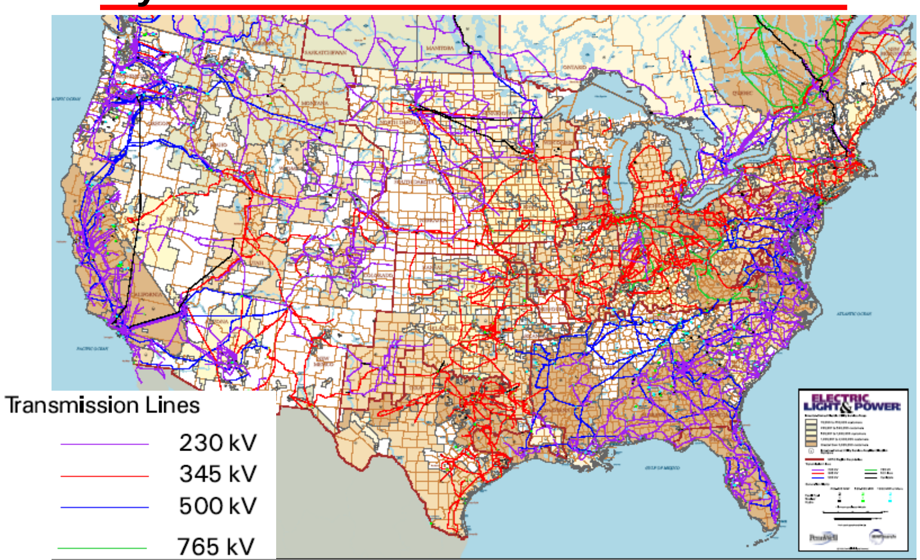
# U.S. Electric Power Industry Existing Net Summer Capacity by State, 2003




**Source:** Energy Information Administration, Form EIA-860, "Annual Electric Generator Report."



# U.S. Electric Power Transmission System in 2000



## Power Systems Components

- **Primary power sources**
  - Coal, Petroleum, Natural gas, Hydro, Nuclear, Waste products, Wind, Solar, Oceanic waves, Geothermal,…
- **Generation and power conversion**
  - Generators, Fuel Cells, Solar Cells,…
- **Transmission and distribution**
  - Step up/down transformers, transmission lines & cables, switchgear, power factor correction,…
- **Storage**
  - Flywheels, batteries, capacitors, compressed air,…
- **Load side power conversion**
  - Motors, lighting equipment, heaters,…
- **Power sinks (end use)**
  - Air ventilation, transportation, illumination, pumping, manufacturing…



## Energy and Power

- **Energy is a measurement of work**
  - example: moving a weight along a flat surface for a fixed distance by applying a force

    $$W = F \cdot d$$

- **Power is the time rate of work**

$$P = \frac{dW}{dt}, \quad W = \int P dt$$

- **Electrical power and mechanical power are equivalent measurements of different quantities**

$$P = V \cdot I \qquad P = F \cdot v = T \cdot \omega$$

## Common Units of Measurement

- **SI – International System of Units**
  - http://physics.nist.gov/cuu/Units/
- **Power**
  - **watt (W), 1 W = 1 J/s**
  - horsepower (hp) = 746 W
- **Energy**
  - **joules (J) = 1 Ws**
  - **kilowatt hour (kWh) = 3,600,000 J**
  - **megawatt hour (MWh) = 1000 kWh**
  - British thermal unit (BTU) = 1055 J



## Efficiency

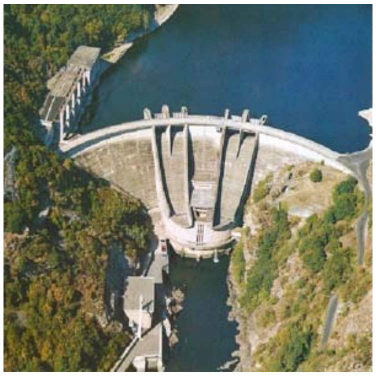
- **all machines and systems have power losses**
  - power out is always less than power in

    $$P_{in} = P_{out} + P_{loss}$$
  - conservation of power
- **the measurement of performance is efficiency**

$$\eta = \frac{P_{out}}{P_{in}}$$

$$= \frac{P_{in} - P_{loss}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{loss}}$$

## Example: Hydroelectric Power



- reservoir contains 50 million cubic meters
- the dam produces a 50 meter head
- turbine-generator efficiency is 80%
- how much energy can be produced?
- what is the power rating of all generators to provide that energy within 12 h



## Hydroelectric Power

$$h_{head} = 50\ m$$

$$v_{water} = 50 \times 10^6\ m^3$$

$$d_{water} = 933\ kg / m^3$$

$$m_{water} = d_{water} v_{water} = \left(933\ \tfrac{kg}{m^3}\right)\left(50 \times 10^6\ m^3\right) = 46.65 \times 10^9\ kg$$

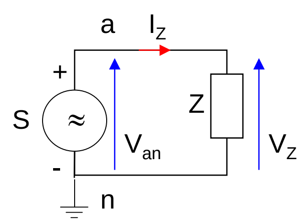
$$PE = mgh = \left(46.65 \times 10^9\ kg\right)\left(9.8\ \tfrac{m}{s^2}\right)\left(50\ m\right) = 22.85 \times 10^{12}\ J$$

$$W_{out} = W_{in} \cdot \eta = \left(22.85 \times 10^{12}\ J\right)(\mathbf{80\%}) = \boxed{\mathbf{18.28 \times 10^{12}\ J}}$$

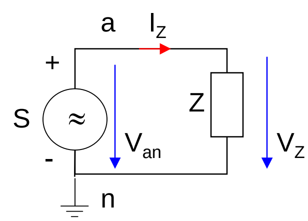
$$P_{out} = \frac{W_{out}}{\Delta t} = \frac{\mathbf{18.28 \times 10^{12}\ J}}{12 \times 60 \times 60\ s} = \mathbf{4.23} \times 10^8\ W = \boxed{\mathbf{423\ MW}}$$

# Phasor Orientation Conventions

| Source S: „source convention“ | Load Z: „source convention“ | Source S: „load convention“ | Load Z: „load convention“ |
| --- | --- | --- | --- |




Used in book




Often used in practice

- **In AC systems**
  - **„+“ and „-“ signs are meaningless**
  - **Arrows determine the phasors**

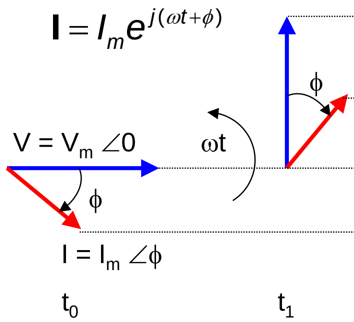


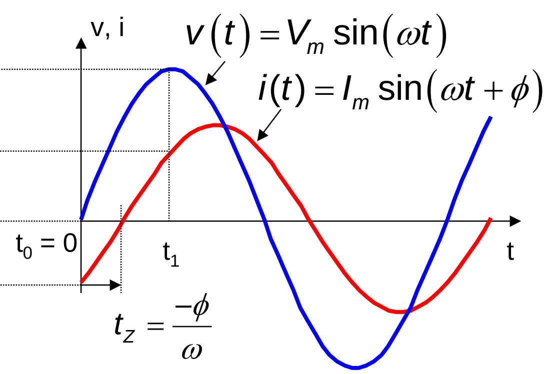
# Phasor Notation and Diagram

| Complex phasor domain | Time domain |
| --- | --- |

$$\mathbf{V} = V_m e^{j\omega t}$$

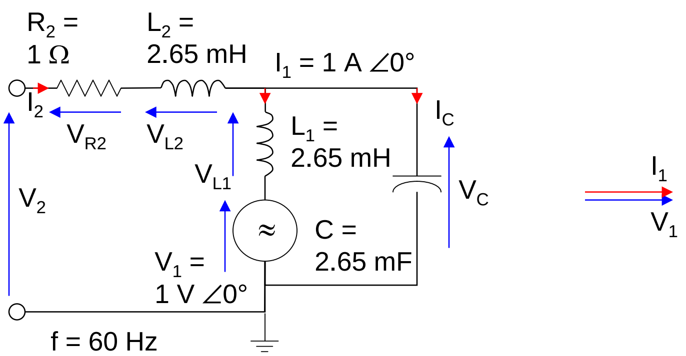
$$\mathbf{I} = I_m e^{j(\omega t+\phi)}$$




Only applicable for single frequency problems

## Example: Building a Phasor Diagram




**Build the complete phasor diagram of all voltages and currents in the circuit**



## Example: Building a Phasor Diagram

$$X_{L1} = j\omega L_1 = j2\pi 60 \cdot 2.65 \cdot 10^{-3} = 1\Omega\angle 90° = X_{L2}$$

$$X_C = \frac{1}{j\omega C} = \frac{-j}{2\pi 60 \cdot 2.65 \cdot 10^{-3}} = 1\Omega\angle -90°$$

$$V_{L1} = I_1 X_{L1} = 1A\angle 0° \cdot 1\Omega\angle 90° = \boxed{1V\angle 90°}$$

$$V_C = V_1 + V_{L1} = 1V\angle 0° + 1V\angle 90° = \boxed{1.41V\angle 45°}$$

$$I_C = \frac{V_C}{X_C} = \frac{1.41V\angle 45°}{1\Omega\angle -90°} = \boxed{1.41A\angle 135°}$$

$$I_2 = I_1 + I_C = 1A\angle 0° + 1.41A\angle 135° = \boxed{1A\angle 90°}$$

$$V_{L2} = I_2 \cdot X_{L2} = 1A\angle 90° \cdot 1\Omega\angle 90° = \boxed{1V\angle 180°}$$

$$V_{R2} = I_2 \cdot R_2 = 1A\angle 90° \cdot 1\Omega\angle 0° = \boxed{1V\angle 90°}$$

$$V_2 = V_{R2} + V_{L2} + V_C = 1V\angle 180° + 1V\angle 90° + 1.41V\angle 45° = \boxed{2V\angle 90°}$$

## Example: Building a Phasor Diagram