Distribution Systems 101

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Distribution Systems and Planning Training for Southeast Region
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What are we covering today?

- Part 1) Power System Fundamentals – the foundation
- Part 2) Power System and Distribution Equipment – know what components are what
- Part 3) Communications and Sensors – what can we see & how do we see it
- Part 4) Industrial Control System Cybersecurity – an introduction to best practices

Goal: Set the foundation for the rest of the day, know the basics, terms, and present state of our distribution system

Power System Fundamentals

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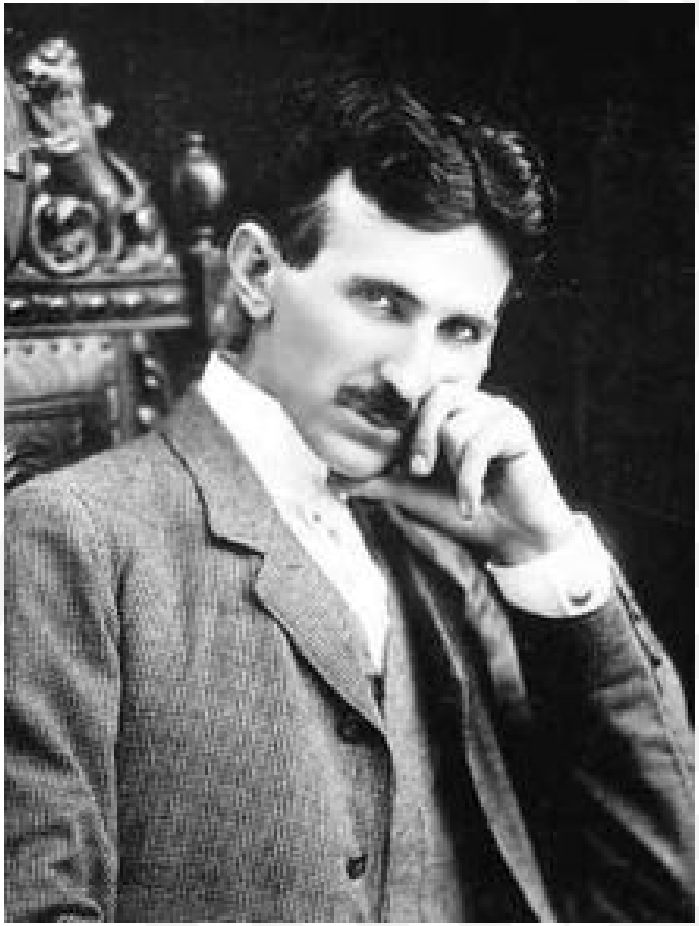
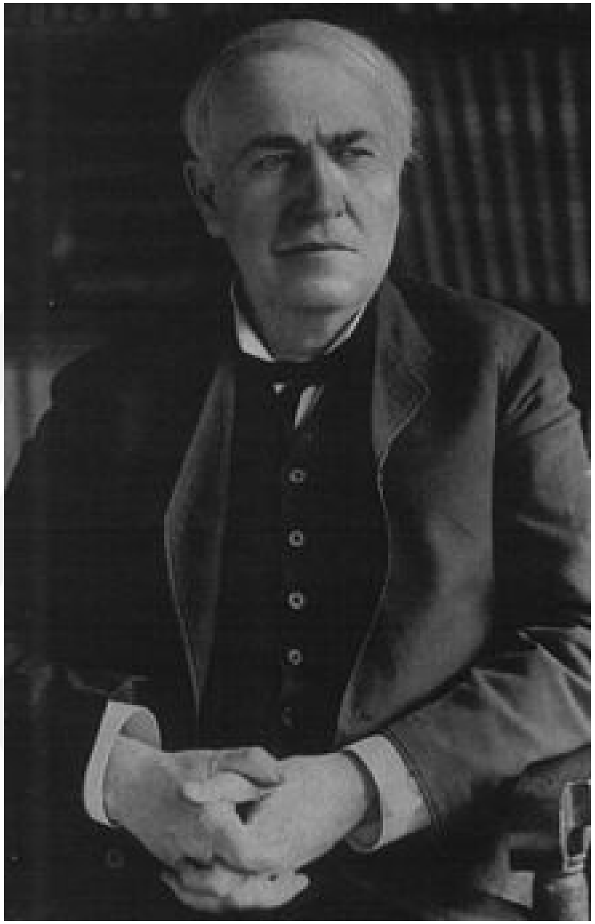
GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Power System Fundamentals

- Part 1: Fundamentals of Electricity
- Part 2: Characteristics of Modern Electrical Systems

Part 1: Fundamentals of Electricity



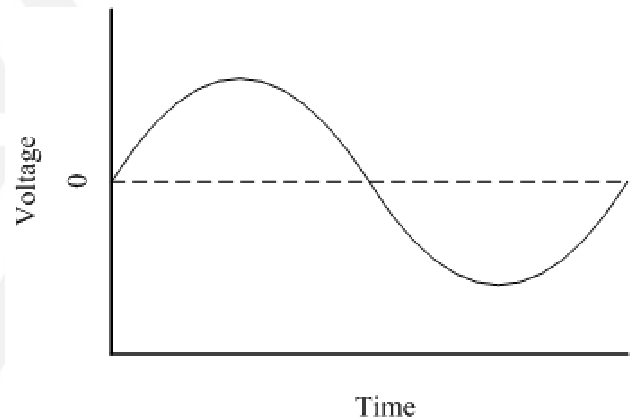


Direct vs. Alternating Current

Direct Current (DC)

- The voltage supplied is relatively constant over time, with minor variations due to transients.
- Power electronics are necessary to effectively change the voltage.
- Batteries and Solar PV produce DC.

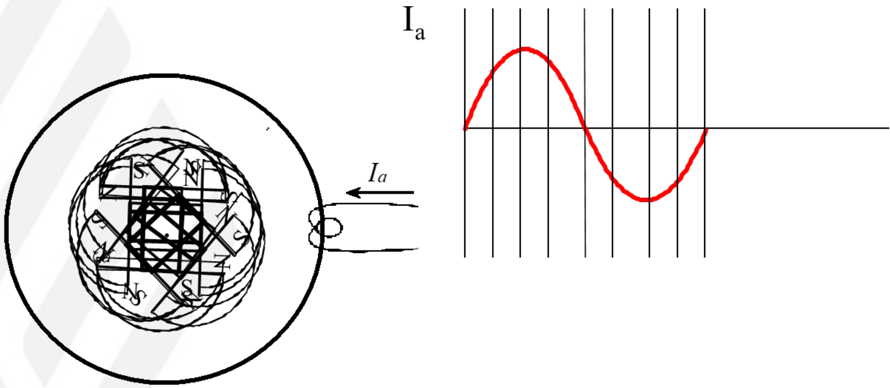
Alternating Current (AC)



- The voltage alternates at the system frequency and passes though the zero value multiple times per second.
- Transformers enable the effective change of voltage between levels.
- Most generators produce AC.

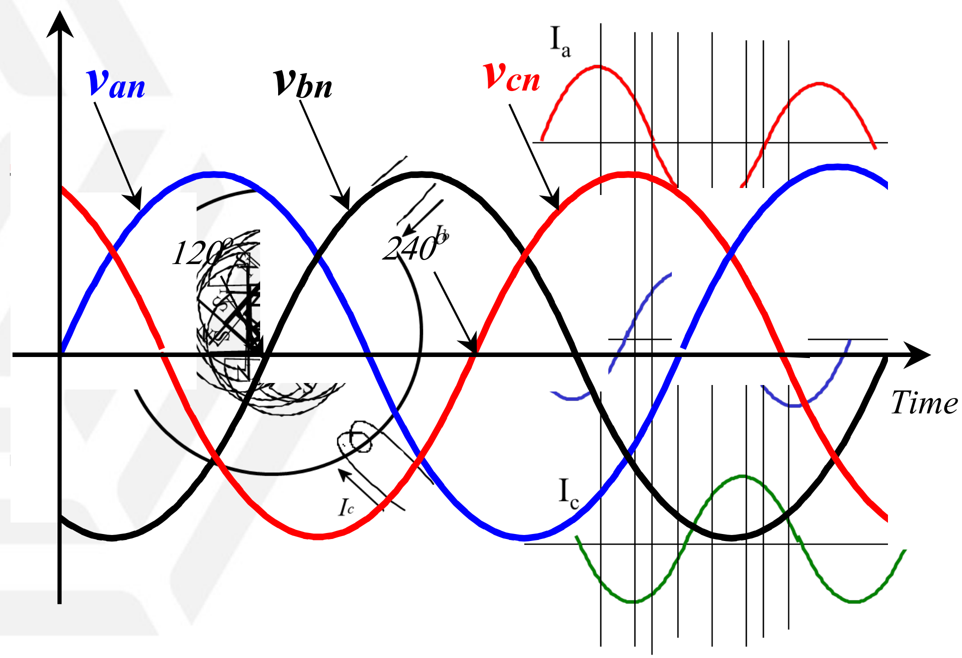
Alternating Current

- Alternating current can be formed when a magnet, or coil, is rotated by a prime mover. This is the "rotor".
- By placing coils adjacent to the rotor, voltages are induced in the coils.
- The induced voltages cause current to flow in the adjacent coils. In this case there is a single "phase".
- The current flows in an alternating manner, as the north and south poles of the rotor pass the stationary coils.
- Alternating current can also be produced by solid state inverters, but the process is more complicated.



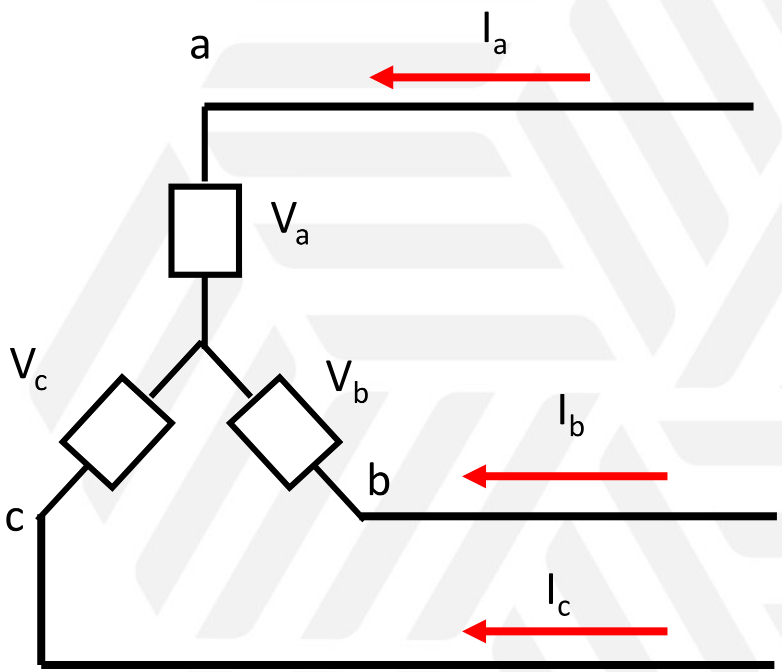
Three Phase Power

- Single phase generation is inefficient and oversized.
- Modern generators, and hence the rest of the system, use a three-phase system.
- The basis of the three-phase system is Nicolas Tesla's patent on poly-phase systems.
- Three phase has been found to be more efficient for machines because of the geometry of coil placement around the rotor.

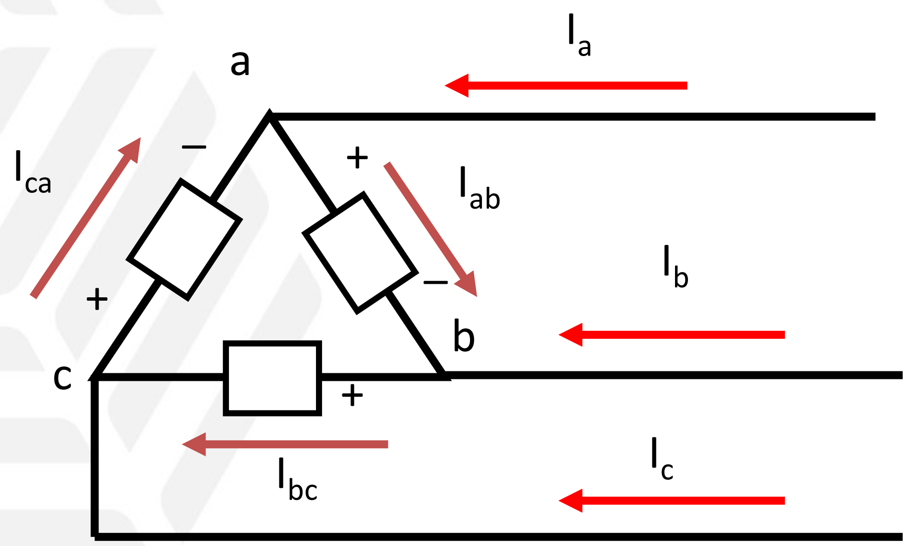


Three Phase Power (cont.)

Wye (Star) Connected

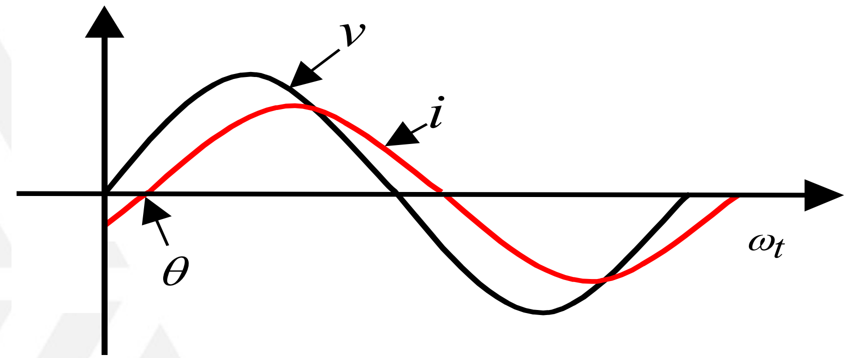


Delta Connected



Different Types of Power

- Because electric power systems are not purely resistive, the voltage and current waveforms are not always in phase.
- The phase difference affects how much work can be done. There are three types of power to fully describe the phase shift in the steady state:
  - **Active Power** (Watts, W) (P): Power that is consumed to perform work, and is represented by the component of voltage and current that are in phase.
  - **Reactive Power** (Volt Amperes Reactive, VAR) (Q): Power that is consumed to maintain electric and magnetic fields, and is represented by the component of voltage and current that are out of phase.
  - **Apparent Power** (Volt Amperes, VA) (S): The power that is measured by taking measurements of the instantaneous voltage and current.



$$P = \frac{1}{2\pi}\int_0^{2\pi} \rho(t)\; d\omega t = \frac{1}{2\pi}\int_0^{2\pi} \frac{V_{max}\; I_{max}}{2}\,[\cos\theta - \cos(2\omega t - \theta)]\; d\omega t$$

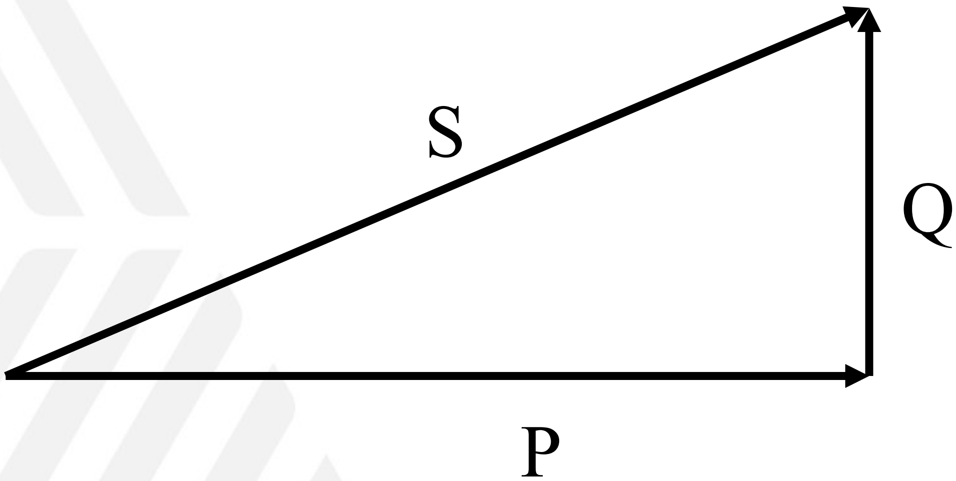
$$P = \frac{V_{max}\; I_{max}}{2}\cos\theta = V_{rms}\, I_{rms}\cos\theta$$

Power factor

$$S \equiv V\, I^*$$

The Power Triangle

- Because dealing with the math associated with waveforms can be complicated, it is common for engineers to use steady state values.
- The power triangle shows the relationship between active, reactive, and apparent power in the steady-state condition.
- Any amount of reactive power results in additional current flow.
  - Systems are typically inductive due to overhead lines
  - Capacitors are used to compensate for the system's natural inductance



$$S \equiv V\, I^{*}$$

$$S = P + j\, Q$$

Part 2: Characteristics of Modern Electricity Systems

Characteristics of Modern Transmission Systems in North America

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Electrical Characteristics

- Three wire balanced
- Frequency: 60 Hz
- Voltage: 69 kV- 765 kV
- Power: 100's-1000's of MW
- Scale: 100s of miles
- Primary overhead, some underground
- Supplied by central generation
- Operated as a network
- The majority of generation

Operational Characteristics

- Federally regulated
  - Interstate commerce
- Ownership
  - Some private
    - American Electric Power
    - Puget Sound Energy
  - Some federal organizations
    - Bonneville Power Administration
    - Tennessee Valley Authority

Characteristics of Modern Distribution Systems in North America

Electrical Characteristics

- Four wire unbalanced with single and double phase laterals
- Frequency: 60 Hz
- Voltage: <50 kV
- Power: <100 MW (Generally)
- Scale: < 20 miles (Generally)
- Overhead and/or underground
- Supplied by sub-transmission systems
- Generally operated radially
- Minimal generation, but increasing

Operational Characteristics

- Regulated
  - Enforced requirements
  - Regulated rates of return
- Ownership
  - Investor Owned
  - Municipal
  - Public Utility District
  - Rural Co-operative