Energy Conversion and Power Systems
EEE210

Francis Ting

Xi'an Jiaotong-Liverpool University

Email: *toting@xjtlu.edu.cn*
Room: EE324

February 27, 2017

Overview

Table of Contents

Simple Power System

Every power system has three major components

- Generation: source of power, ideally with a specified voltage and frequency
- Load: consume power; ideally with a constant resistive load
- Transmission system: transmits power; ideally as a perfect conductor

Simple Power System

Every power system has three major components

- Generation: source of power, ideally with a specified voltage and frequency
- Load: consume power; ideally with a constant resistive load
- Transmission system: transmits power; ideally as a perfect conductor

Simple Power System

Every power system has three major components

- Generation: source of power, ideally with a specified voltage and frequency
- Load: consume power; ideally with a constant resistive load
- Transmission system: transmits power; ideally as a perfect conductor

Complications

- No ideal voltage sources exist
- Loads are seldom constant
- Transmission system has resistance, inductance, capacitance, and flow limitations
- Simple system has no redundancy (backup) and so power system will not work if any component fails

Complications

- No ideal voltage sources exist
- Loads are seldom constant
- Transmission system has resistance, inductance, capacitance, and flow limitations
- Simple system has no redundancy (backup) and so power system will not work if any component fails

Complications

- No ideal voltage sources exist
- Loads are seldom constant
- Transmission system has resistance, inductance, capacitance, and flow limitations
- Simple system has no redundancy (backup) and so power system will not work if any component fails

Complications

- No ideal voltage sources exist
- Loads are seldom constant
- Transmission system has resistance, inductance, capacitance, and flow limitations
- Simple system has no redundancy (backup) and so power system will not work if any component fails

Notation – Power

- Instantaneous consumption of energy
- Power Units
  - $\Rightarrow$ Watts = Voltage x Current
  - $\Rightarrow$ kW - $1x10^3$ Watt
  - $\Rightarrow$ MW - $1x10^6$ Watt
  - $\Rightarrow$ GW - $1x10^9$ Watt
- Generation capacity installed in the U.S. is about 900 GW (around 3 kW per person)

Notation – Power

- Instantaneous consumption of energy
- Power Units
  - $\Rightarrow$ Watts = Voltage x Current
  - $\Rightarrow$ kW - $1x10^3$ Watt
  - $\Rightarrow$ MW - $1x10^6$ Watt
  - $\Rightarrow$ GW - $1x10^9$ Watt
- Generation capacity installed in the U.S. is about 900 GW (around 3 kW per person)

Notation – Power

- Instantaneous consumption of energy
- Power Units
  - $\Rightarrow$ Watts = Voltage x Current
  - $\Rightarrow$ kW - $1x10^3$ Watt
  - $\Rightarrow$ MW - $1x10^6$ Watt
  - $\Rightarrow$ GW - $1x10^9$ Watt
- Generation capacity installed in the U.S. is about 900 GW (around 3 kW per person)

Notation – Energy

- Energy: Integration of power over time
- Energy is what people really want from a power system
- Energy Units
  - $\Rightarrow$ Joule = 1 Watt-second [J]
  - $\Rightarrow$ kWh $\rightarrow$ kilowatt-hour (3.6×10^6 J)
- In the U.S., the energy consumption is around 3600 billion kWh, around 13.33 MWh per person ($\approx$ 1.5 kW power continuously)

Table of Contents

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

- Early 1880s - Edison introduced Pearl Street dc system in Manhattan supplying 59 customers
- 1884 - Sprague produced practical dc motor
- 1885 - Invention of transformer by William Stanley
- mid-1880s - Westinghouse / Tesla introduced rival ac system
- Late-1880s - Tesla invented the ac induction motor
- 1893 - First 3-phase transmission line operating at 2.3kV
- 1896 - AC lines delivered electricity from hydro generation at Niagara Falls to Buffalo, 32 km away
- Early 1990s - Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation
- 1920s - Large interstate holding companies control most electricity systems

History of Power Systems

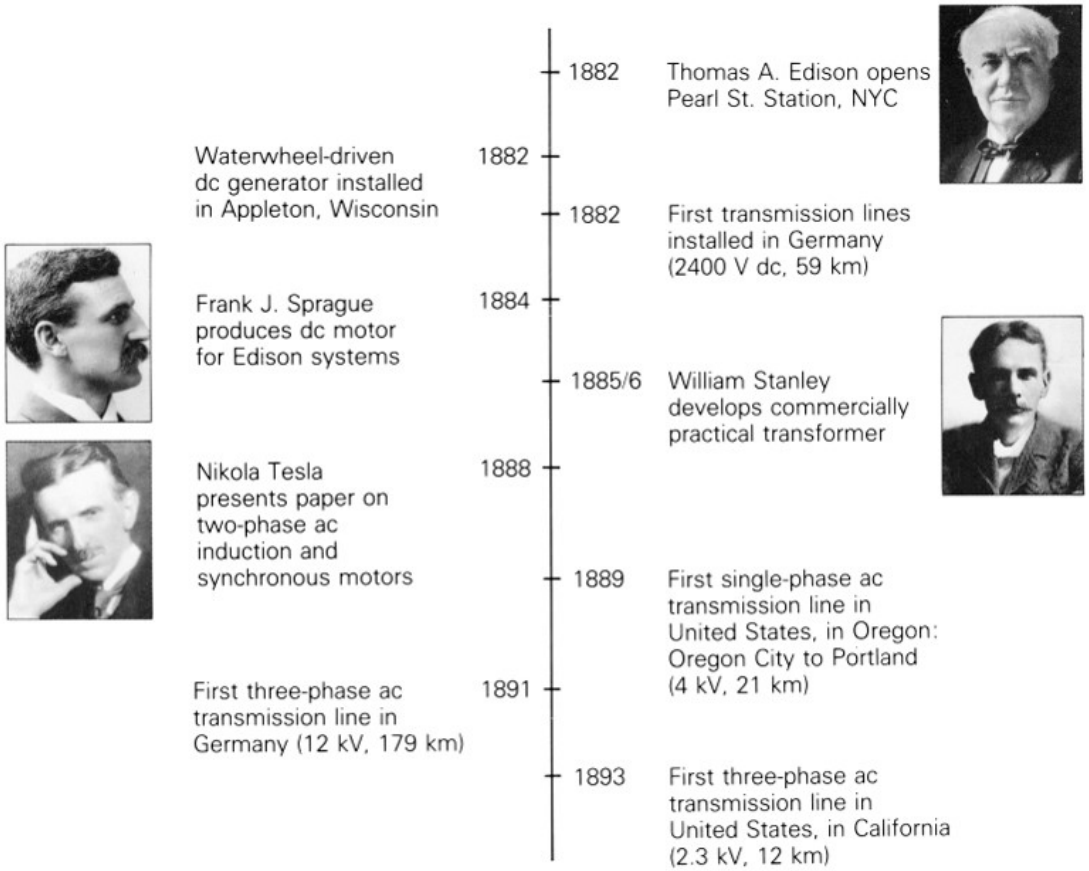


FIGURE 1.1 Milestones of the early electric utility industry [1] (H.M. Rustebakke et al., Electric Utility Systems Practice, 4th Ed. (New York: Wiley, 1983). Reprinted with permission of John Wiley & Sons, Inc. Photos courtesy of Westinghouse Historical Collection)

Table of Contents

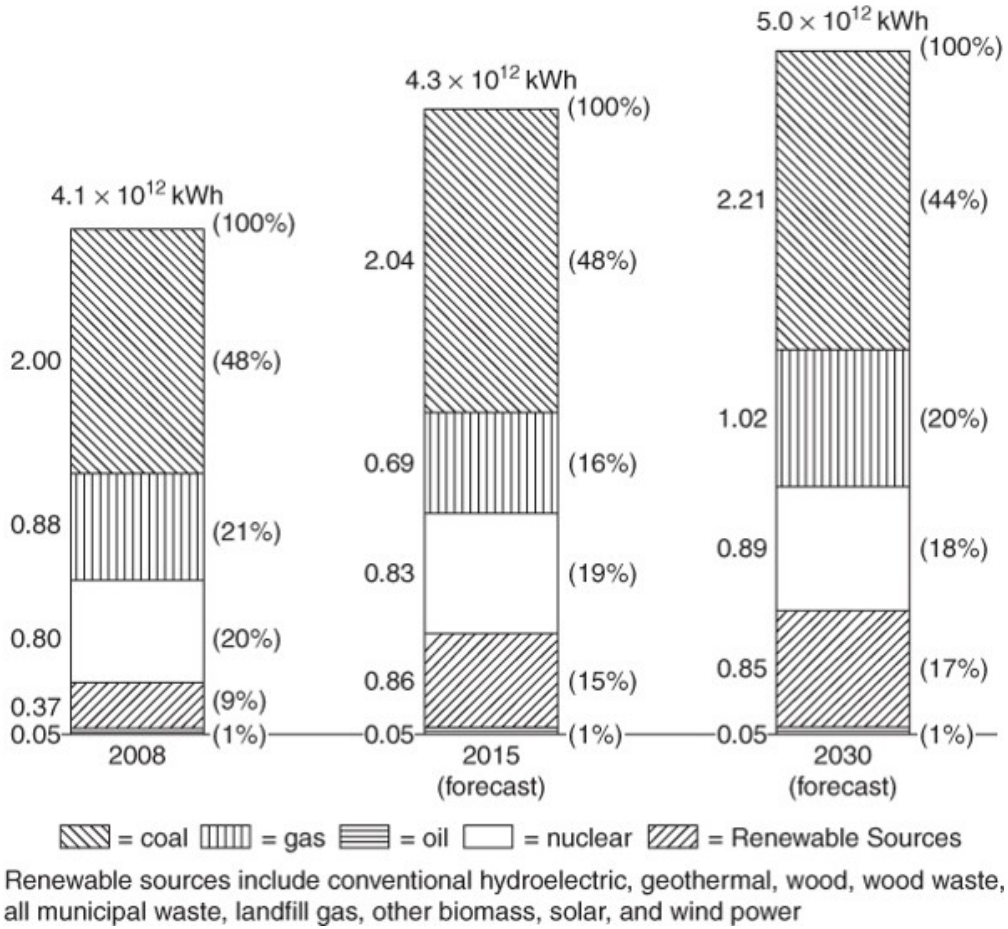
Present Trends

- The U.S. is shifting away from a dependence on the direct use of fossil fuels
- Electric power industry contributes 3% to the real gross domestic product (GDP)
- Continual use of coal due to large amount of U.S. coal reserves, sufficient for the next 500 years
- Continual consumption of natural gas in the long term as gas-fired turbines are safe, clean, and efficient

Present Trends

FIGURE 1.4

Electric energy generation in the United States, by principal fuel types [2, 3] (U.S. Energy Information Administration, Existing Capacity by Energy Source—2008, www.eia.gov; U.S. Energy Information Administration, Annual Energy Outlook 2010 Early Release Overview, www.eia.gov)



Renewable sources include conventional hydroelectric, geothermal, wood, wood waste, all municipal waste, landfill gas, other biomass, solar, and wind power

Future Trend: Smart Grid

- Transmission and distribution grids in the U.S. are aging and stressed by operational uncertainties
- The grid faces new challenges never envisioned when they were installed many decades ago
- Many agreed that smart grid is the solution to this situation

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Future Trend: Smart Grid

- The objective of smart grid is to provide reliable, high-quality electric power in an environmentally friendly and sustainable manner
- A smart grid has the following attributes:
  1. Self-healing from power system disturbances,
  2. Enables active participation by consumers in demand response,
  3. Operates resiliently against both physical and cyber attacks,
  4. Provides quality power that meets 21st century demands,
  5. Accommodates all generation and energy storage technologies,
  6. Enables new products, services, and market, and
  7. Optimizes asset utilization and operating efficiency

Table of Contents

Vertical Monopolies

- Within a particular geographic market, the electric utility had an exclusive franchise
- In return for this exclusive franchise, the utility had the obligation to serve customers at rates determined jointly by utility and regulators
- It was money making (cost plus) business

Vertical Monopolies

- Within a particular geographic market, the electric utility had an exclusive franchise
- In return for this exclusive franchise, the utility had the obligation to serve customers at rates determined jointly by utility and regulators
- It was money making (cost plus) business

Vertical Monopolies

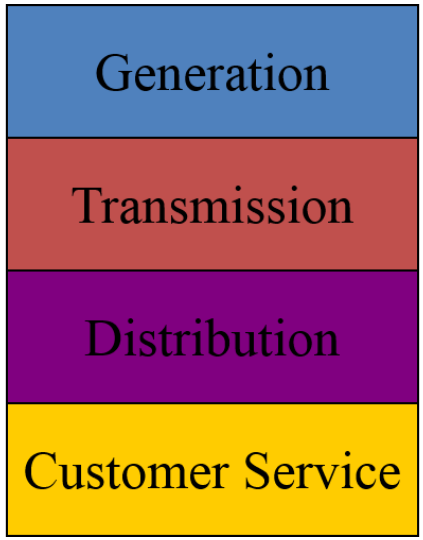
- Within a particular geographic market, the electric utility had an exclusive franchise
- In return for this exclusive franchise, the utility had the obligation to serve customers at rates determined jointly by utility and regulators
- It was money making (cost plus) business

Vertical Monopolies

- Within a particular geographic market, the electric utility had an exclusive franchise
- In return for this exclusive franchise, the utility had the obligation to serve customers at rates determined jointly by utility and regulators
- It was money making (cost plus) business

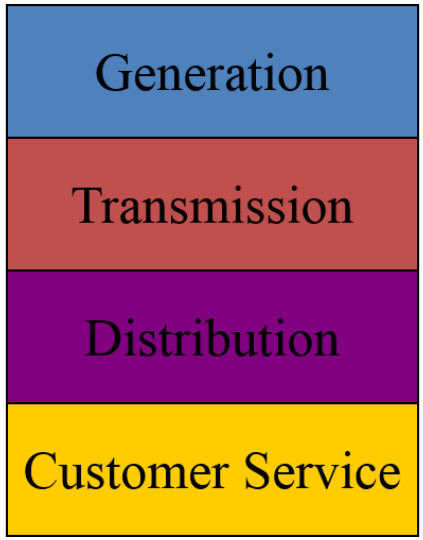
Vertical Monopolies

- Within its service territory, each utility was the only player in a town
- Neighboring utilities functioned more as colleagues than competitors
- Utilities gradually interconnected their systems so by 1970, transmission lines crisscrossed North America, with voltages up to 765 kV



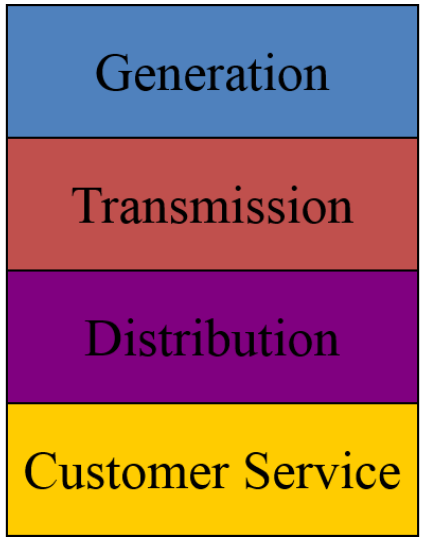
Vertical Monopolies

- Within its service territory, each utility was the only player in a town
- Neighboring utilities functioned more as colleagues than competitors
- Utilities gradually interconnected their systems so by 1970, transmission lines crisscrossed North America, with voltages up to 765 kV



Vertical Monopolies

- Within its service territory, each utility was the only player in a town
- Neighboring utilities functioned more as colleagues than competitors
- Utilities gradually interconnected their systems so by 1970, transmission lines crisscrossed North America, with voltages up to 765 kV



Utility Restructuring

- The vertical monopolies is being replaced by a horizontal structure whereby generating companies, transmission companies, and distribution companies are owned separately by private sectors
- In 1992, the U.S. passed the Energy Policy Act, shifting regulatory power from state to federal
- In 1996, the Transmission Open Access (TOA) was introduced

Utility Restructuring

- The vertical monopolies is being replaced by a horizontal structure whereby generating companies, transmission companies, and distribution companies are owned separately by private sectors
- In 1992, the U.S. passed the Energy Policy Act, shifting regulatory power from state to federal
- In 1996, the Transmission Open Access (TOA) was introduced

Utility Restructuring

- The vertical monopolies is being replaced by a horizontal structure whereby generating companies, transmission companies, and distribution companies are owned separately by private sectors
- In 1992, the U.S. passed the Energy Policy Act, shifting regulatory power from state to federal
- In 1996, the Transmission Open Access (TOA) was introduced

Utility Restructuring

- TOA facilitates competition in wholesale generation
- As a result, a broad range of Independent Power Producers (IPPs) bid in the open energy market to match energy supply and demand
- In future, the retail structure of power distribution may resemble the existing structure of the telecommunication industry; consumers hold the right to choose their electric supplier

Utility Restructuring

- TOA facilitates competition in wholesale generation
- As a result, a broad range of Independent Power Producers (IPPs) bid in the open energy market to match energy supply and demand
- In future, the retail structure of power distribution may resemble the existing structure of the telecommunication industry; consumers hold the right to choose their electric supplier

Utility Restructuring

- TOA facilitates competition in wholesale generation
- As a result, a broad range of Independent Power Producers (IPPs) bid in the open energy market to match energy supply and demand
- In future, the retail structure of power distribution may resemble the existing structure of the telecommunication industry; consumers hold the right to choose their electric supplier

Goal: Customer Choice

Utility Restructuring

- The objectives of electric utility restructuring are to increase competition, decrease regulation, and in the long run lower consumer prices
- The benefits of breaking up vertically integrated utilities will not be realized if the independent generating and transmission companies are able to exert market power
- Market power refers to the ability of seller to maintain prices above competitive levels for a significant period of time; done by collusion or deliberately creating and exploiting transmission congestion

Table of Contents

Computers

- Computers and computer programs are used by engineer in power system planning
- Four major programs in power system
  1. Power-flow programs - compute the voltage magnitude, phase angles, and transmission-line power flows for a network under steady-state operating condition
  2. Stability programs - study power systems under disturbance conditions to determine whether synchronous generators and motors remain in synchronism
  3. Short-circuits programs - Compute three-phase and line-to-ground faults in power system networks in order to select circuit breakers, and determine relay settings
  4. Transients programs - Compute the magnitudes and shapes of transient over voltages and currents that result from lightning strikes and line-switching operations

The End