Power Systems: The Grid

The Electrical Infrastructure commonly referred to as the GRID is the most important component of the Economic structure of our modern Societies. Without a cheap and reliable energy supply available at every home, Texas would not have a GDP which ranks second in the US.

This presentation is an Introduction to the GRID, with special emphasis on the Texas GRID which is controlled by the **Electric Reliability Council of Texas, Inc.** (**ERCOT**).

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Power Systems: The Grid

❖ Preamble- Part One: Definition

An **electrical grid** is an interconnected network for electricity delivery from producers to consumers. Electrical grids vary in size and can cover whole countries or continents.

The Grid which we are concerned with for our Synchronization Project is primarily in the areas of Texas controlled by ERCOT (Electrical Reliability Council of Texas).

The ERCOT controlled grid in Texas consists of synchronously connected areas, meaning all distribution areas operate with three phase alternating current (AC) frequencies synchronized (so that voltage swings occur at almost the same time). This allows transmission of AC power throughout the area, connecting a large number of electricity generators and consumers and potentially enabling more efficient electricity markets and redundant generation.

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- Preamble- Part Two: ERCOT

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The **Electric Reliability Council of Texas, Inc.** (**ERCOT**) is an American organization that operates Texas's electrical grid, the Texas Interconnection, which supplies power to more than 25 million Texas customers and represents 90 percent of the state's electric load. ERCOT is the first independent system operator (ISO) in the United States and one of nine ISOs in North America.

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❖ Preamble- Part Three: PUC

- The **Public Utility Commission of Texas** (**PUC** or **PUCT**) is a state agency that regulates the state's electric, water and telecommunication utilities, implements respective legislation, and offers customer assistance in resolving consumer complaints.
- In 1975, the Texas Legislature enacted the Public Utility Regulatory Act (PURA) and created the Public Utility Commission of Texas (PUC) to provide statewide regulation of the rates and services of electric and telecommunications utilities.
- Over the years, various changes introduced by legislation have dramatically re-shaped the PUC's mission and focus, shifting from up-front regulation of rates and services to oversight of competitive markets and compliance enforcement of statutes and rules.
- Appointed by the Texas Governor, the three-member commission also regulates the rates and services of transmission and distribution utilities that operate where there is competition, investor-owned electric utilities where competition has not been chosen, and incumbent local exchange companies that have not elected incentive regulation.

Power Systems: The Grid

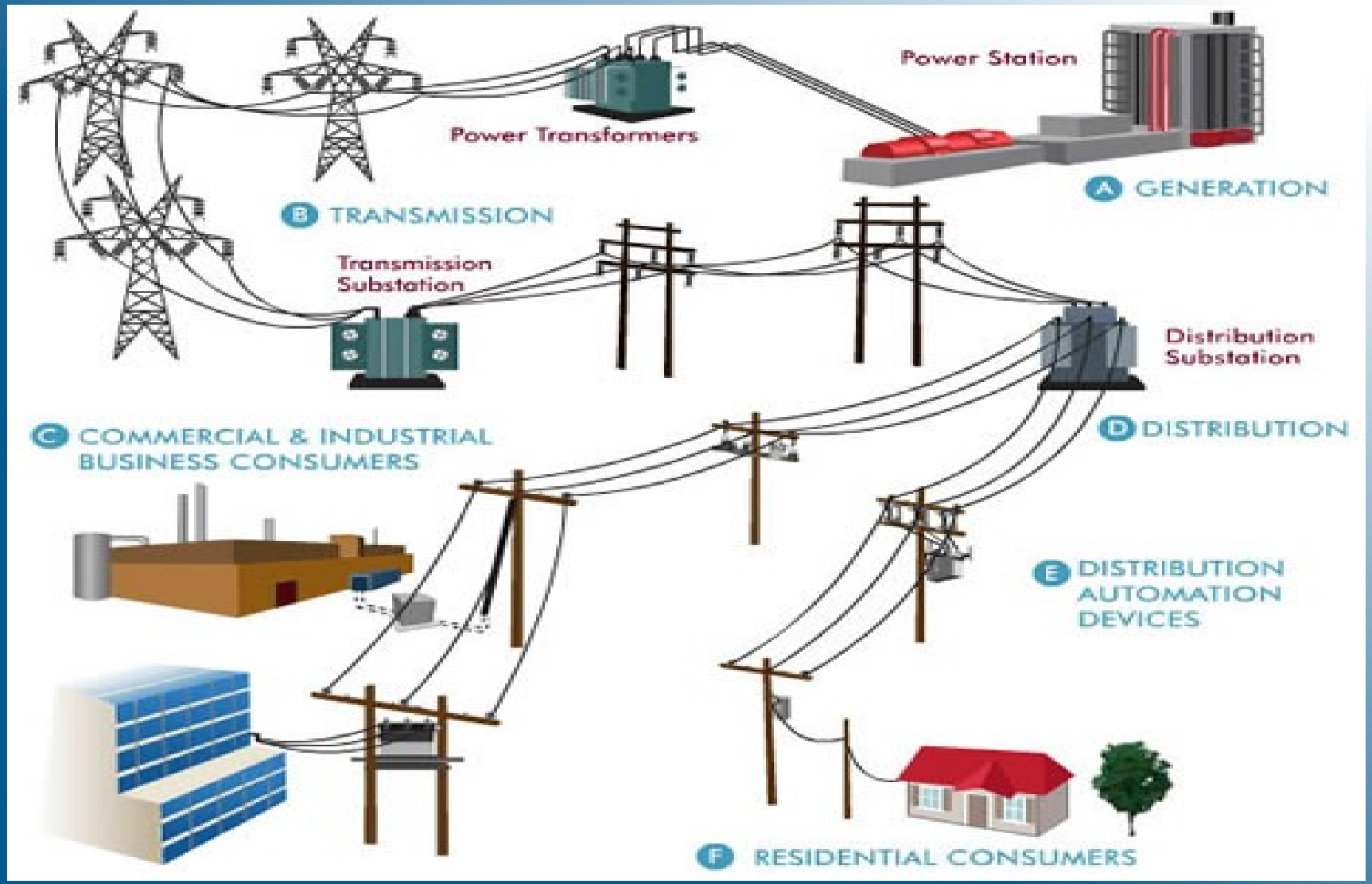
- Preamble- Part Four: Components of the Grid

Before we can begin the discussion about synchronization of the Grid we must have a clear idea of the components of the electrical production facilities and the transmission portions that constitute what is collectively known as the GRID. The Electrical Production system in the **ERCOT** section of Texas is made up of the following components:

1. Power Production Facilities
2. Substations
3. Transmission Lines
4. SCADA Systems

Power Systems: The Grid

- Preamble- Part Five (Pictorial Representation)



Power Systems: The Grid

1. Power Production Facilities: #1
   - ❖ Introduction

Electricity generation is the process of generating electric power from sources of primary energy. For utilities in the electric power industry, it is the stage prior to its delivery (transmission, distribution, etc.) to end users.
Electricity is most often generated at a power plant by electromechanical generators, primarily driven by heat engines fueled by combustion or nuclear fission but also by other means such as the kinetic energy of flowing water and wind. Other energy sources include solar photovoltaics and geothermal power.

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1. Power Production Facilities: #2
   - ❖ Types of Energy Supply: #1

1. **Turbo-machines**
   - ❖ **Steam Turbines**
     - ❖ **Coal Fired**
     - ❖ **Natural Gas**
     - ❖ **Nuclear Energy**
   - ❖ **Combined Cycle Natural Gas Turbines**
2. **Hydro**
3. **Wind**
4. **Solar**

Power Systems: The Grid

1. Power Production Facilities: #3
   - ❖ Types of Energy Supply: #2
     - ❖ Steam Turbine: #1

A **steam turbine** is a machine that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Its modern manifestation was invented by Charles Parsons in 1884.

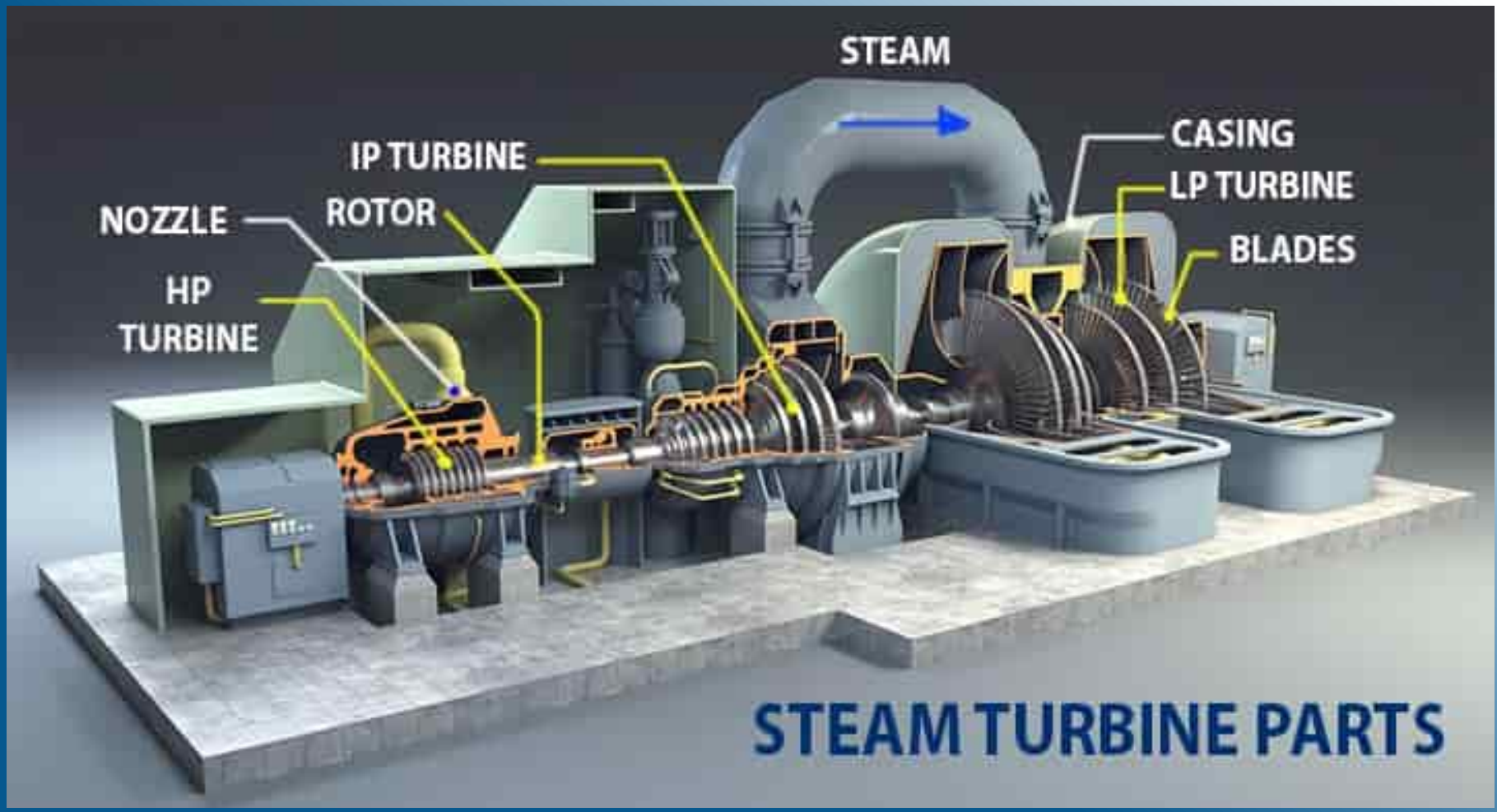
Fabrication of a modern steam turbine involves advanced metalwork to form high-grade steel alloys into precision parts using technologies that first became available in the 20th century; continued advances in durability and efficiency of steam turbines remains central to the energy economics of the 21st century.

The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency from the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible expansion process. Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator.

About 85% of all electricity generation in the United States in the year 2018 was by use of steam turbines.

Power Systems: The Grid

1. Power Production Facilities: #4
   - ❖ Types of Energy Supply: #3
     - ❖ Steam Turbine: #2



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1. Power Production Facilities: #5
   - ❖ Types of Energy Supply: #4
     - ❖ Steam Turbine: #3

Power Systems: The Grid

1. Power Production Facilities: #6
   - ❖ Types of Energy Supply: #5
     - ❖ Coal-fired power Station: #1

A **coal-fired power station** or **coal power plant** is a thermal power station which burns coal to generate electricity. Coal-fired power stations generate a third of the world's electricity.
A coal-fired power station is a type of fossil fuel power station. The coal is usually pulverized and then burned in a pulverized coal-fired boiler. The furnace heat converts boiler water to steam, which is then used to spin turbines that turn generators. Thus chemical energy stored in coal is converted successively into thermal energy, mechanical energy and, finally, electrical energy.
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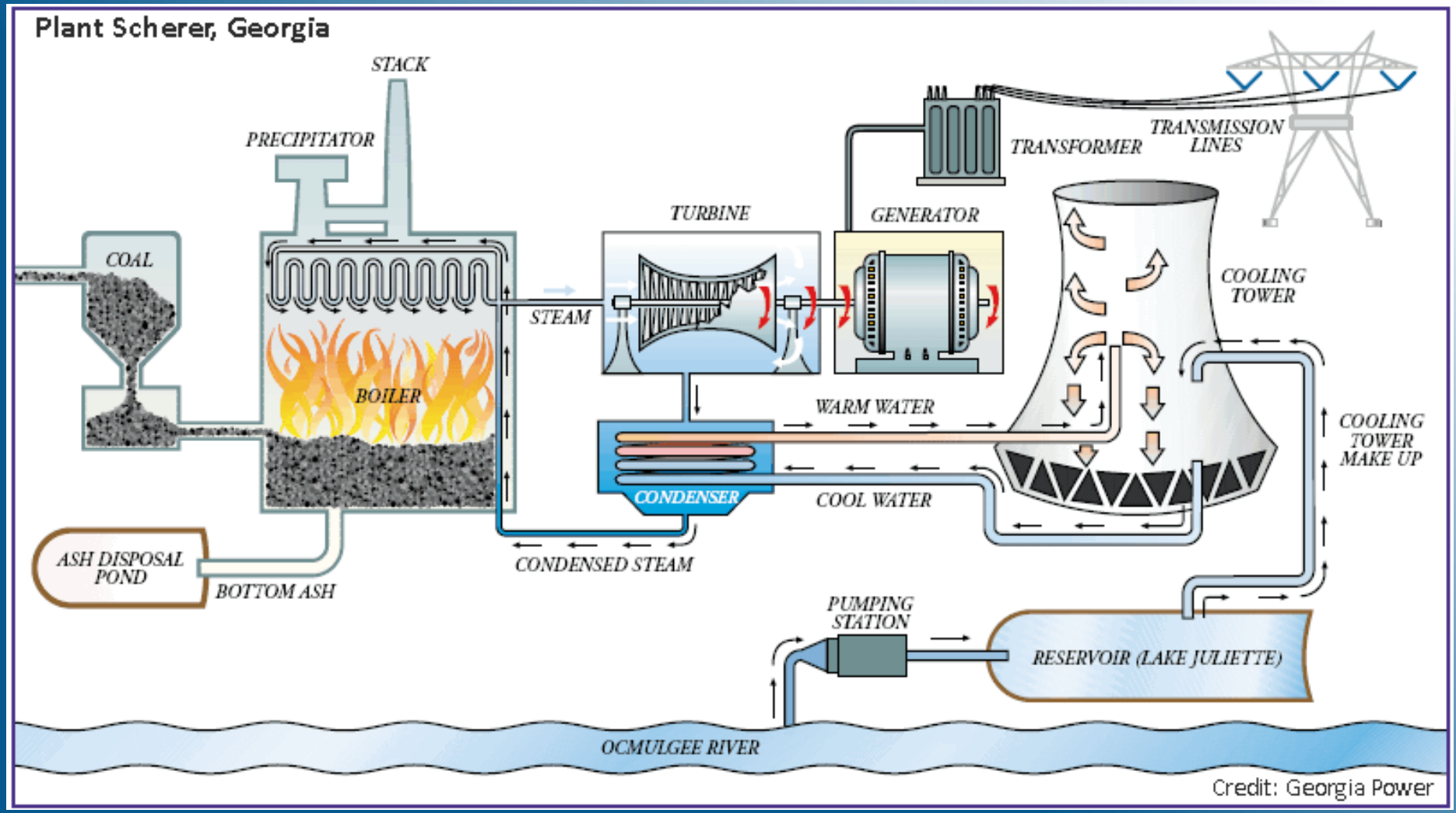
1. Power Production Facilities: #7
   - ❖ Types of Energy Supply: #6
     - ❖ Coal-fired power Station: #2



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1. Power Production Facilities: #8
   - ❖ Types of Energy Supply: #7
     - ❖ Coal-fired power Station: #3

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1. Power Production Facilities: #9
   - ❖ Types of Energy Supply: #8
     - ❖ Coal-fired power Station: #4

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1. Power Production Facilities: #10
   - ❖ Types of Energy Supply: #9
     - ❖ Nuclear Power Plant: #1

A **nuclear power plant** (sometimes abbreviated as **NPP**) is a thermal power station in which the heat source is a nuclear reactor. As is typical of thermal power stations, heat is used to generate steam that drives a steam turbine connected to a generator that produces electricity. As of 2018, the International Atomic Energy Agency reported there were 450 nuclear power reactors in operation in 30 countries around the world.

U.S. nuclear electricity generation capacity peaked in 2012 at about 102,000 MW when there were 104 operating nuclear reactors. At the end of 2020, there were 94 operating reactors with a combined generation capacity of about 96,555 MW.

Nuclear plants are usually considered to be base load stations since fuel is a small part of the cost of production and because they cannot be easily or quickly dispatched. Their operations, maintenance, and fuel costs are at the low end of the spectrum, making them suitable as base-load power suppliers.

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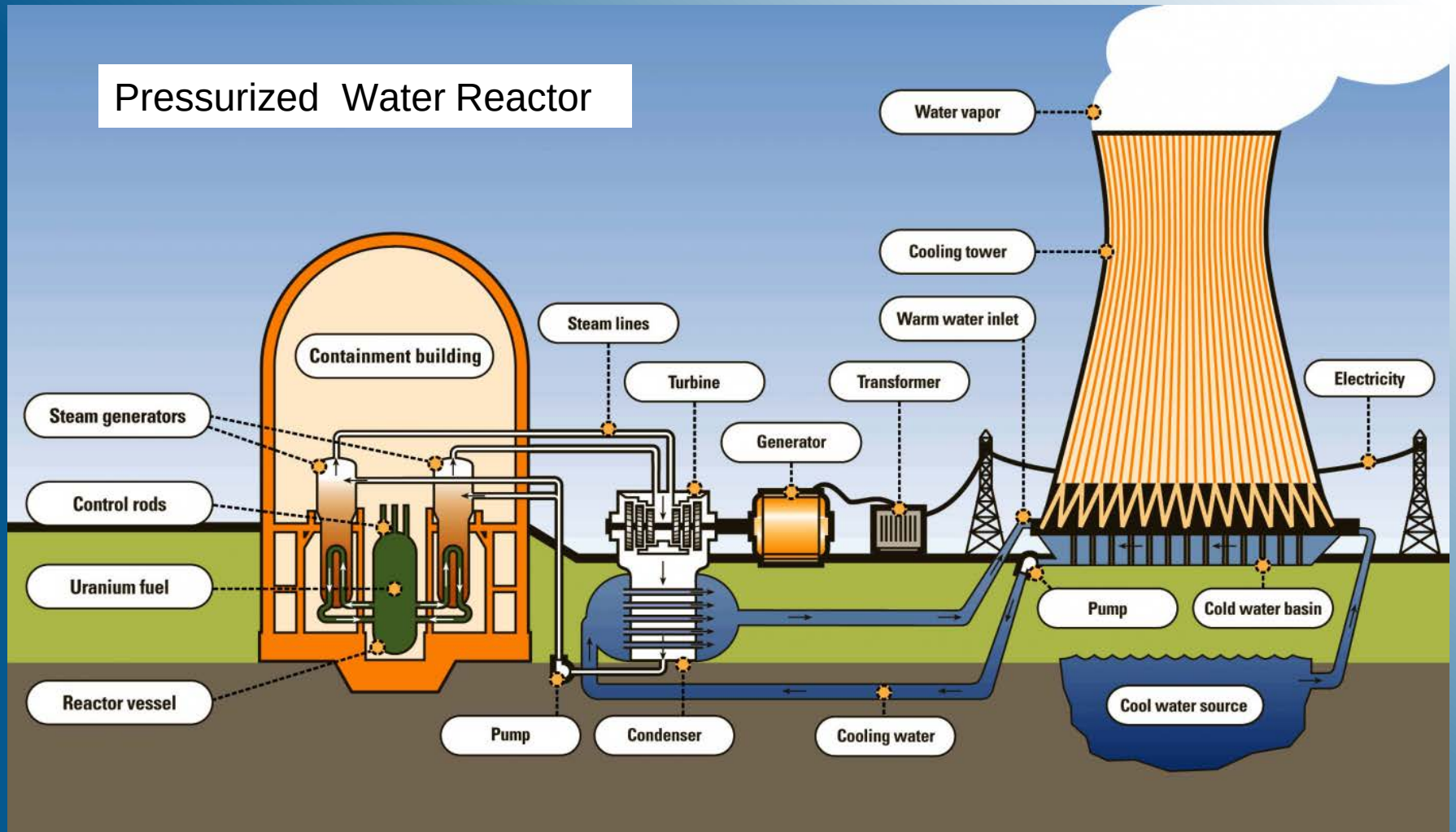
1. Power Production Facilities: #11
   - ❖ Types of Energy Supply: #10
     - ❖ Nuclear Power Plant: #2



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1. Power Production Facilities: #12
   - ❖ Types of Energy Supply: #11
     - ❖ Nuclear Power Plant: #3

The **South Texas Project Electric Generating Station** (also known as **STP**, **STPEGS**, **South Texas Project**), is a nuclear power station southwest of Bay City, Texas, United States. STP occupies a 12,200-acre (4,900 ha) site west of the Colorado River about 90 miles (140 km) southwest of Houston.

It consists of two 4-Loop, Westinghouse Pressurized Water Reactors, each with a net rated production capacity of 1,280 MWe and is cooled by a 7,000-acre (2,800 ha) reservoir.

The STPEGS reactors are operated by the STP Nuclear Operating Company (STPNOC). Ownership is divided among NRG Energy at 44 percent, San Antonio municipal utility CPS Energy at 40 percent and Austin Energy at 16 percent.

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1. Power Production Facilities: #13
   - ❖ Types of Energy Supply: #12
     - ❖ Nuclear Power Plant: #4

Power Systems: The Grid

1. Power Production Facilities: #14
   - ❖ Types of Energy Supply: #13
     - ❖ Nuclear Power Plant: #5

Power Systems: The Grid

1. Power Production Facilities: #15
   - ❖ Types of Energy Supply: #14
     - ❖ Nuclear Power Plant: #6

Comanche Peak Nuclear Power Plant is located in Somervell County Texas. The nuclear power plant is located 40 miles (64 km) southwest of Ft. Worth and about 60 miles (97 km) southwest of Dallas. It relies on nearby Squaw Creek Reservoir for cooling water. The plant has about 1,300 employees and is operated by Luminant Generation, a subsidiary of Vistra Energy.
Construction of the two Westinghouse pressurized water reactors began in 1974. Unit 1, originally rated at 1,084 MWe, came online on April 17, 1990. Its current, 40-year operating license is valid until February 8, 2030. Unit 2, 1,124 MWe, followed on April 6, 1993 and is licensed to operate until February 2, 2033 when it has to renew its license. As of 2018 Unit 2 was the third-to-last power reactor to come online in the United States, followed only by Units 1 and 2 of Watts Bar Nuclear Generating Station.

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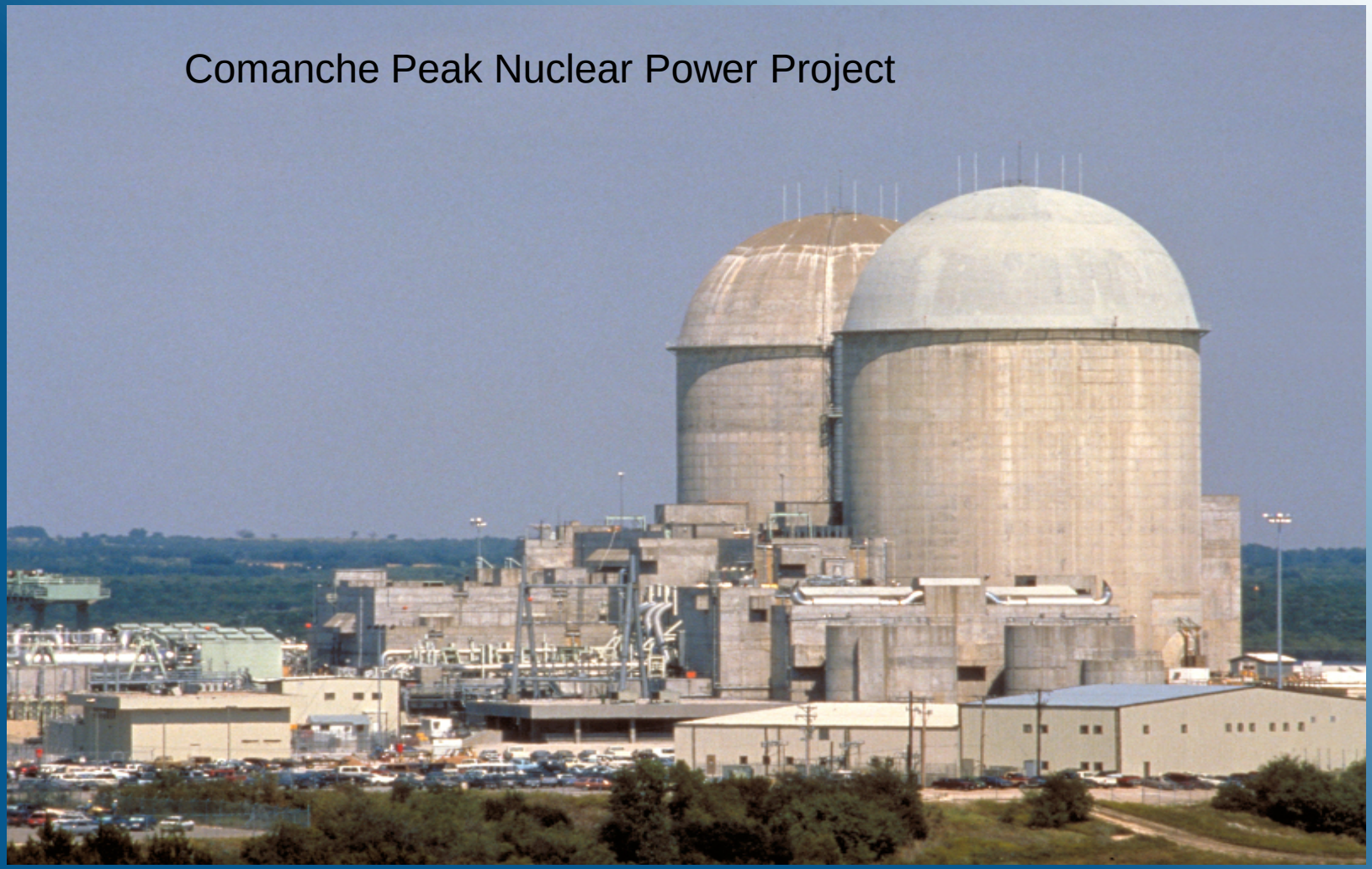
1. Power Production Facilities: #16
   - ❖ Types of Energy Supply: #15
     - ❖ Nuclear Power Plant: #7

Power Systems: The Grid

1. Power Production Facilities: #17
   - ❖ Types of Energy Supply: #16
     - ❖ Nuclear Power Plant: #8



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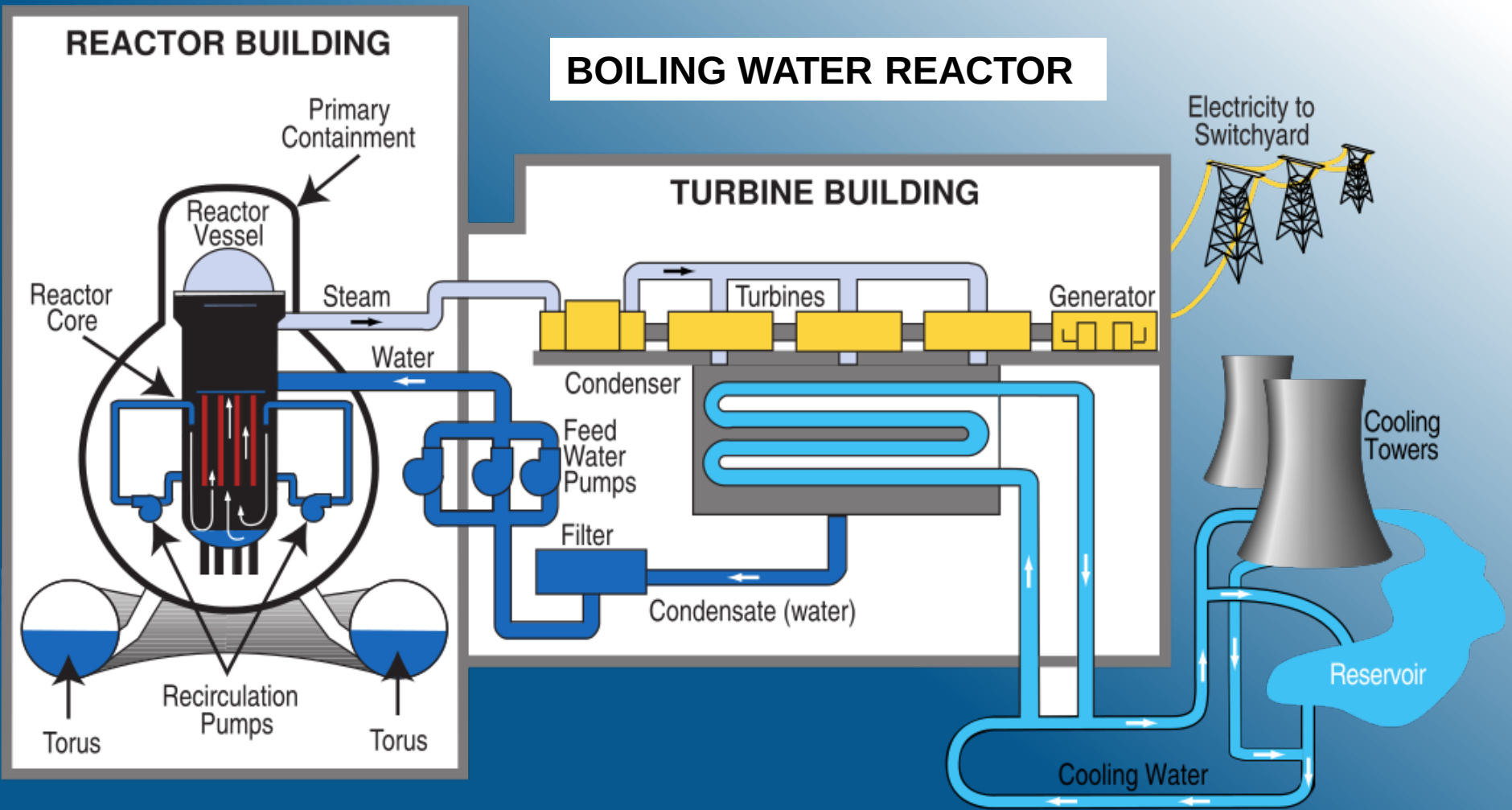
1. Power Production Facilities: #18
   - ❖ Types of Energy Supply: #17
     - ❖ Nuclear Power Plant: #9



Power Systems: The Grid

1. Power Production Facilities: #19
   - ❖ Types of Energy Supply: #18
     - ❖ Nuclear Power Plant: #10

The Enrico Fermi Boiling Water Reactor, nuclear generating Station near Monroe, Michigan,

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1. Power Production Facilities: #20
   - ❖ Types of Energy Supply: #19
     - ❖ Hydro-electric Power Facilities: #1

Hydroelectricity, or **hydroelectric power**, is electricity produced from hydropower. In 2018, hydropower generated 16.6% of the world's total electricity and 70% of all renewable electricity, and was expected to increase by about 3.1% each year for the next 25 years.
Hydropower is produced in 150 countries, with the Asia-Pacific region generating 33 percent of global hydropower in 2018. China is the largest hydroelectricity producer, with 920 TWh of production in 2018, representing 16.9% of domestic electricity use.
The cost of hydroelectricity is relatively low, making it a competitive source of renewable electricity. With a dam and reservoir it is also a flexible source of electricity, since the amount produced by the station can be varied up or down very rapidly (as little as a few seconds) to adapt to changing energy demands. Once a hydroelectric complex is constructed, the project produces no direct waste, and it generally has a low output level of greenhouse gases.

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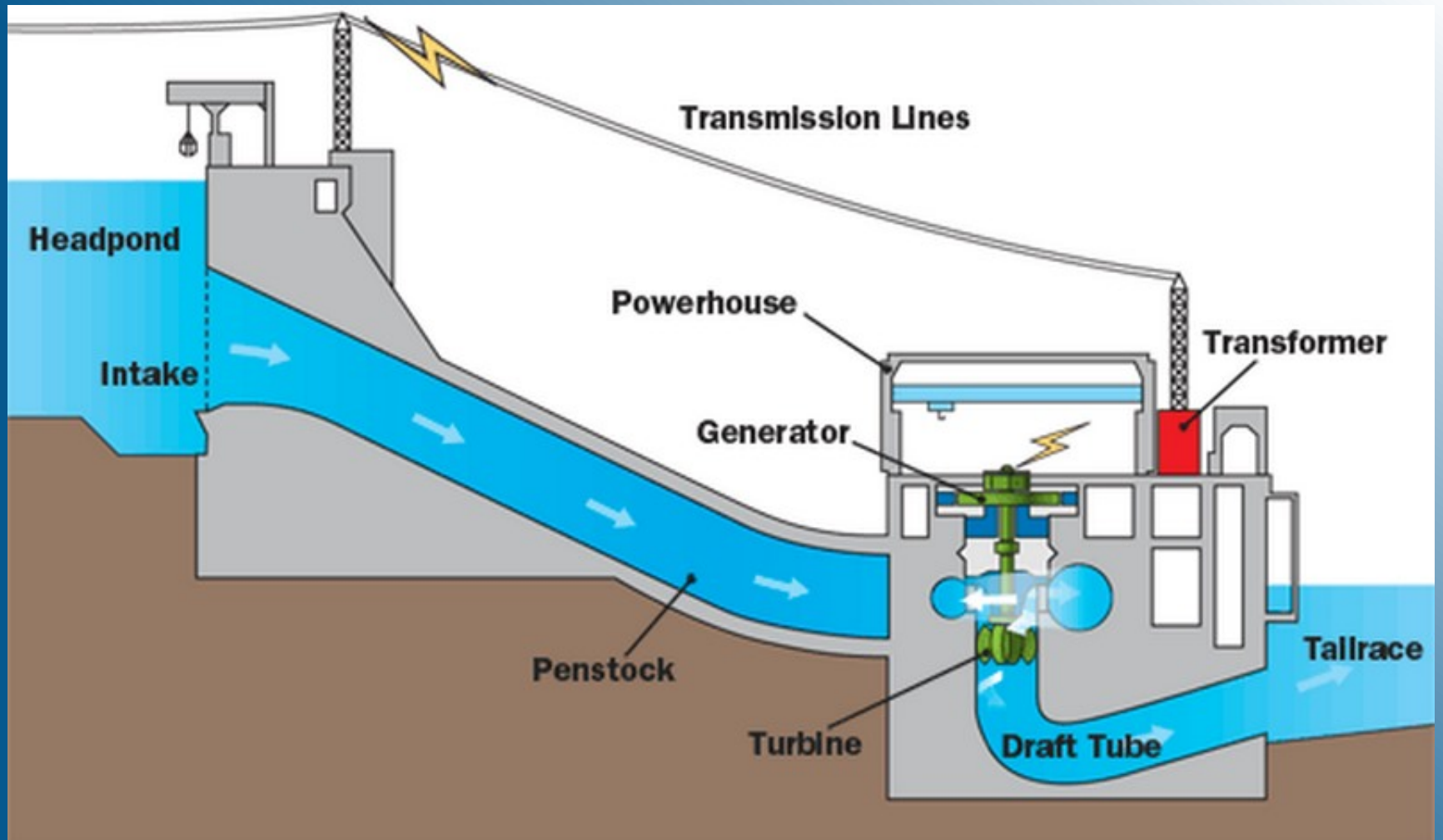
1. Power Production Facilities: #21
   - ❖ Types of Energy Supply: #20
     - ❖ Hydro-electric Power Facilities: #2



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1. Power Production Facilities: #22
   - ❖ Types of Energy Supply: #21
     - ❖ Hydro-electric Power Facilities: #3

The Three Gorges Dam in China

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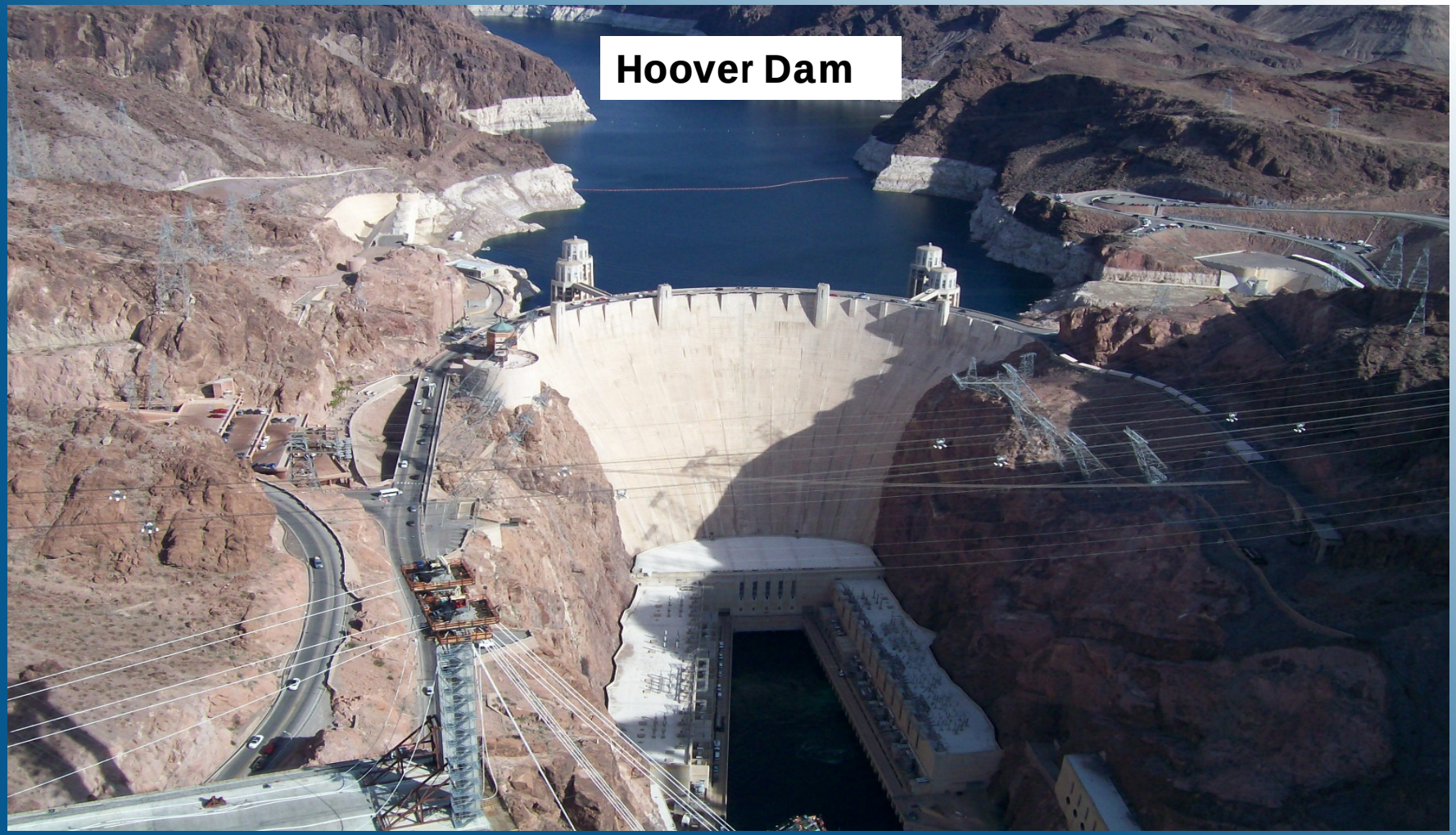
1. Power Production Facilities: #23
   - ❖ Types of Energy Supply: #22
     - ❖ Hydro-electric Power Facilities: #4



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1. Power Production Facilities: #24
   - ❖ Types of Energy Supply: #23
     - ❖ Hydro-electric Power Facilities: #5

Power Systems: The Grid

1. Power Production Facilities: #25
   - ❖ Types of Energy Supply: #24
     - ❖ Wind Turbines: #1

- ❖ A **wind turbine** is a device that converts the wind's kinetic energy into electrical energy.
- ❖ Wind turbines are manufactured in a wide range of sizes, with either horizontal or vertical axes.
- ❖ Multi-turbine installations are referred to as wind farms.
- ❖ Advances in Semiconductor technologies of high voltages have played a significant role in the rise of wind and photovoltaic (PV) power systems.
- ❖ In these types of systems power electronics is used to convert the electric power generated by wind turbine generators to the form required by the electric grid operators and the associated regulatory Agencies responsible for the stability of the Grid.

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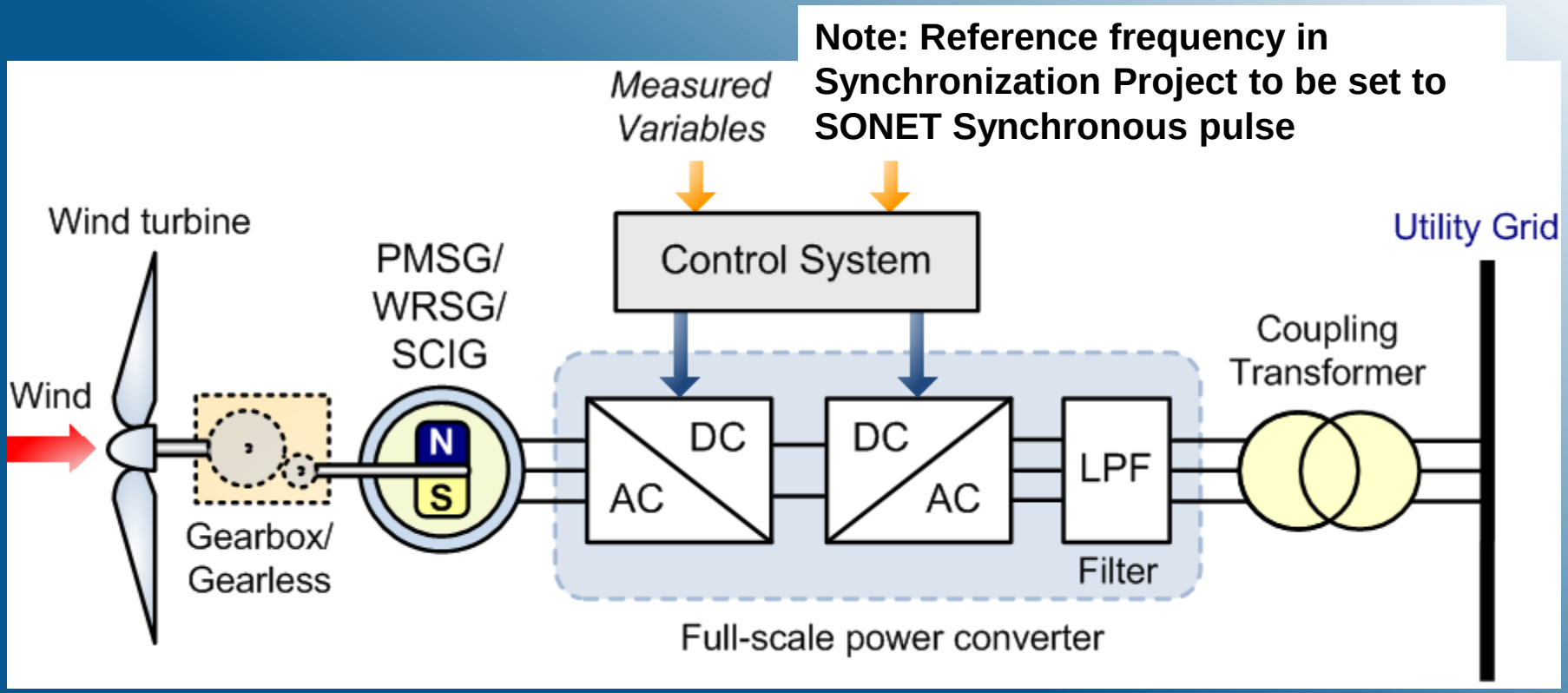
1. Power Production Facilities: #26
   - ❖ Types of Energy Supply: #25
     - ❖ Wind Turbines: #2

Power Systems: The Grid

1. Power Production Facilities: #27
   - ❖ Types of Energy Supply: #26
     - ❖ Wind Turbines: #3



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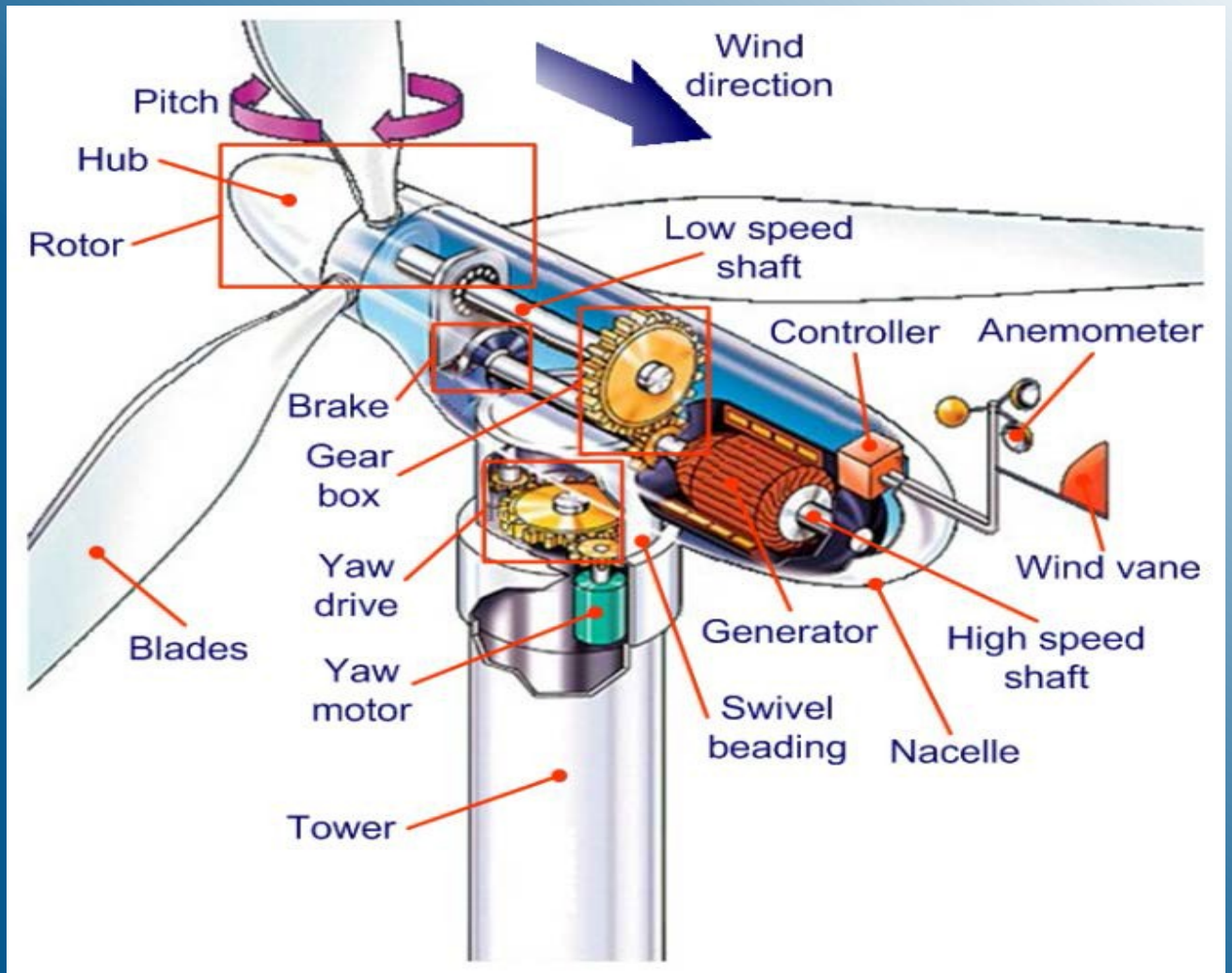
1. Power Production Facilities: #28
   - ❖ Types of Energy Supply: #27
     - ❖ Wind Turbines: #4

Wind turbine generator (WTG) Components



Power Systems: The Grid

1. Power Production Facilities: #29
   - ❖ Types of Energy Supply: #28
     - ❖ Wind Turbines: #5

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1. Power Production Facilities: #30
   - ❖ Types of Energy Supply: #29
     - ❖ Photovoltaic: #1

A **photovoltaic power station**, also known as a **solar park**, **solar farm**, or **solar power plant** is a large-scale photovoltaic system (PV system) designed for the supply of merchant power into the electricity grid. They are differentiated from most building-mounted and other decentralised solar power applications because they supply power at the utility level, rather than to a local user or users. The generic expression **utility-scale solar** is sometimes used to describe this type of project.

The solar power source is via photovoltaic modules that convert light directly to electricity. However, this differs from, and should not be confused with concentrated solar power, the other large-scale solar generation technology, which uses heat to drive a variety of conventional generator systems. Both approaches have their own advantages and disadvantages, but to date, for a variety of reasons, photovoltaic technology has seen much wider use in the field. As of 2019, concentrator systems represented about 3% of utility-scale solar power capacity.[1][2]

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1. Power Production Facilities: #31
    - ❖ Types of Energy Supply: #30
        - ❖ Photovoltaic: #2

Power Systems: The Grid

1. Power Production Facilities: #32
   - ❖ Types of Energy Supply: #31
     - ❖ Photovoltaic: #3

Power Systems: The Grid

2. Substation: #1
   - ❖ Introduction: #1

A **substation** is a part of an electrical generation, transmission, and distribution system. Substations transform voltage from high to low, or the reverse, or perform any of several other important functions. Between the generating station and consumer, electric power may flow through several substations at different voltage levels. A substation may include transformers to change voltage levels between high transmission voltages and lower distribution voltages, or at the interconnection of two different transmission voltages. Substations may be owned and operated by an electrical utility, or may be owned by a large industrial or commercial customer. Generally substations are unattended, relying on SCADA for remote supervision and control.
Substations may be described by their voltage class, their applications within the power system, the method used to insulate most connections, and by the style and materials of the structures used.

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2. Substation: #2
    - ❖ Introduction: #2

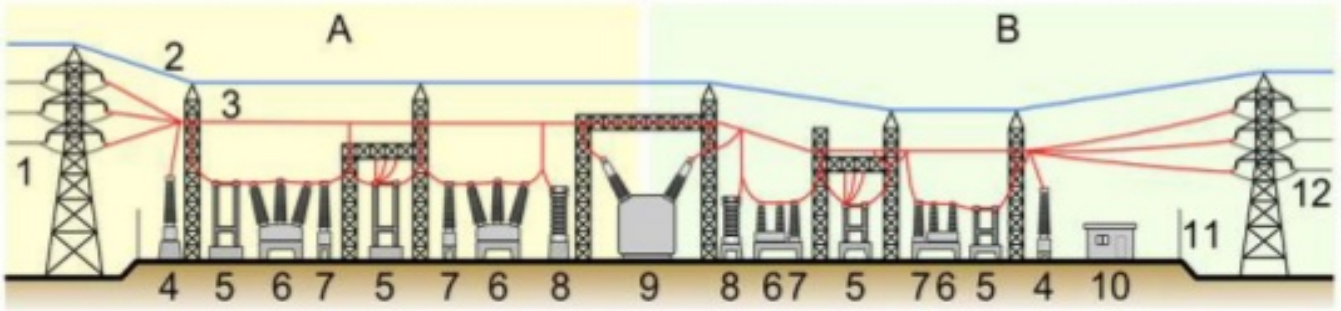
This part of the presentation is an outline of the major component which make up the Electric Power Substation portion of the Power Grid. The main components of a substation are:

1. Power Transformers
2. Current Transformers
3. Voltage Transformers
4. SCADA (Supervisory Control and Data Acquisition)

Power Systems: The Grid

2. Substation: #3
   - ❖ Sub-station Layout

Sub-station Layout



A:Primary power lines' side
1. Primary power lines
2. Ground wire
3. Overhead lines
4. Transformer for measurement of electric voltage
5. Disconnect switch
6. Circuit breaker
7. Current transformer
8. Lightning arrester

B: Secondary power lines' side
7. Current transformer
8. Lightning arrester
9. Main transformer
10. Control building
11. Security fence
12. Secondary power lines

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2. Substation: #4
   - ❖ Substation Rendering

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2. Substation: #5
   - ❖ High Voltage Substation

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2. Substation: #6
    - ❖ Power Transformer: #1

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2. Substation: #7
   - ❖ Power Transformer: #2

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2. Substation: #8
    - ❖ High Voltage Circuit Breaker

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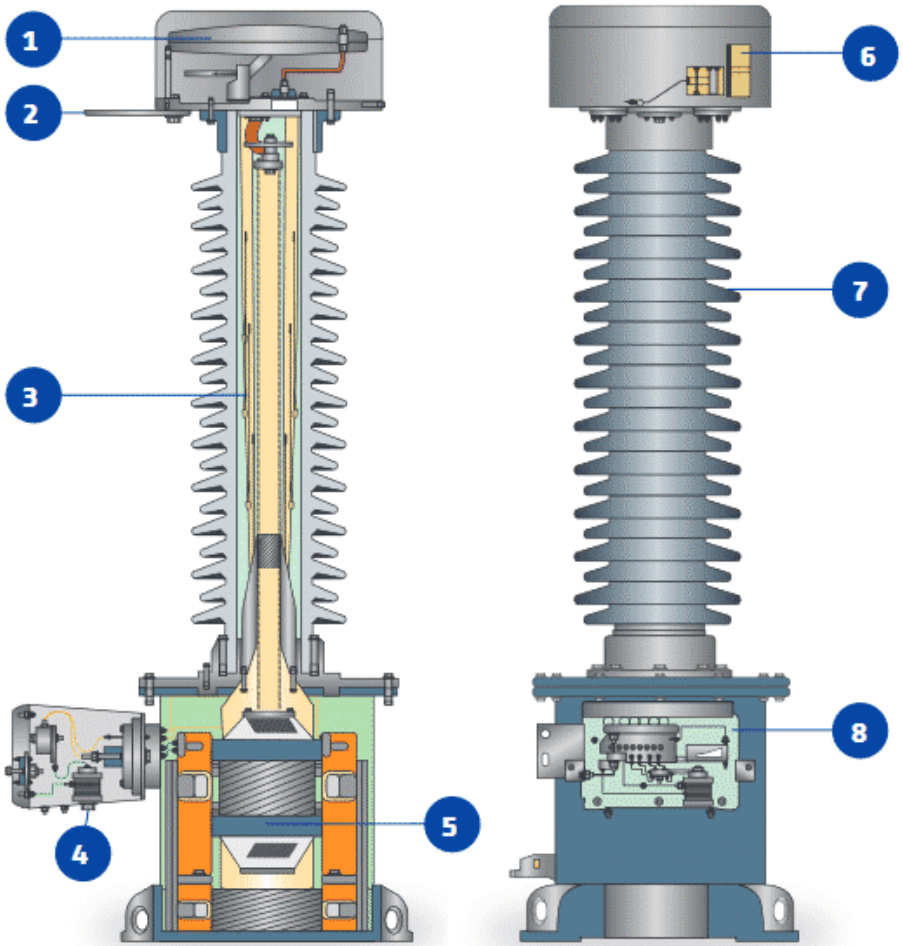
2. Substation: #9
   - ❖ Voltage Transformer: #1



1. Expansion bellow
2. Primary terminal
3. Bushing
4. Secondary terminal box
5. Core / coil assembly
6. Oil-level indicator
7. Porcelain or composite insulator
8. Secondary terminal box

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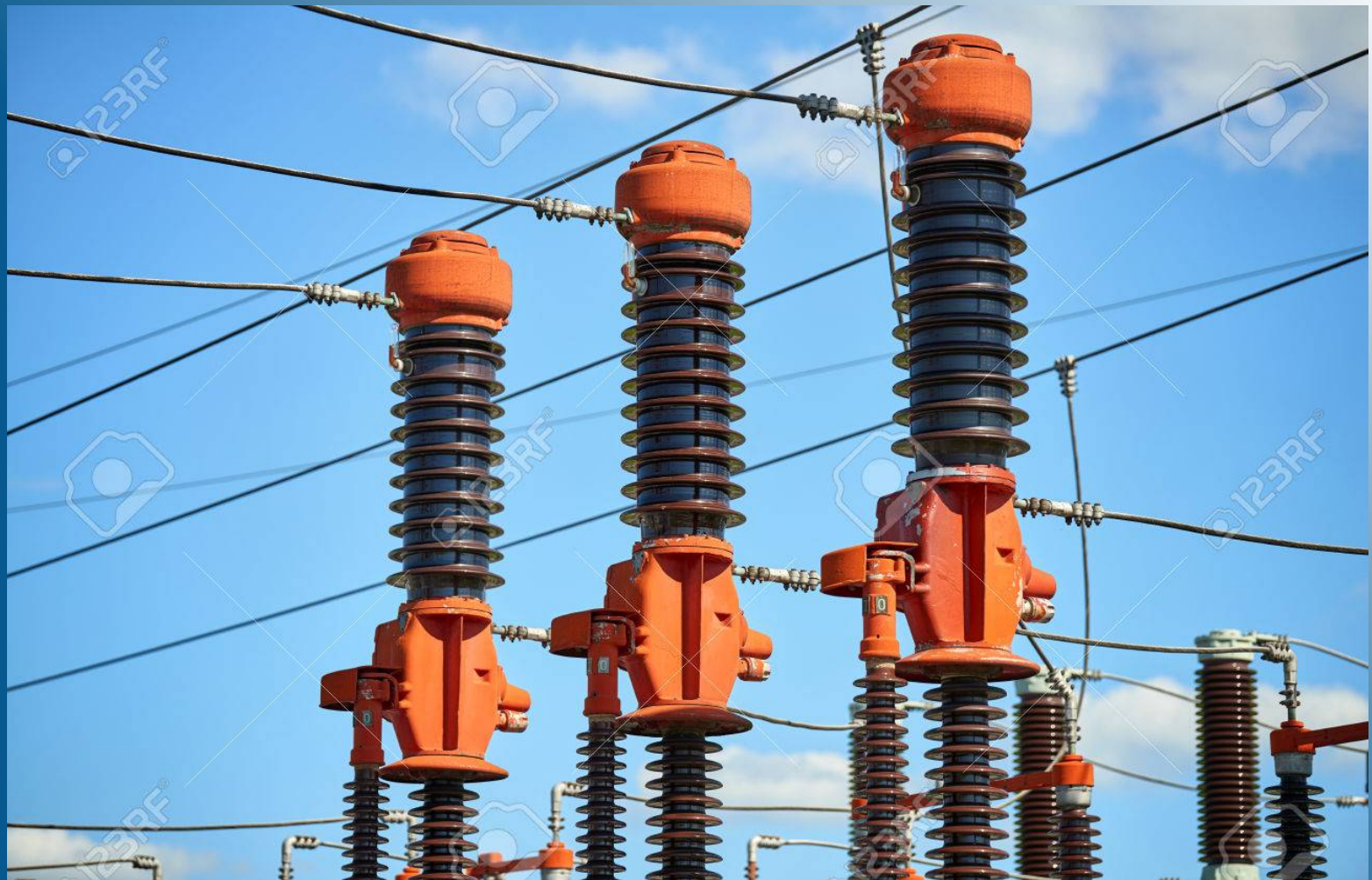
2. Substation: #10
    - ❖ Voltage Transformer : #2



Power Systems: The Grid

2. Substation: #11
   - ❖ Current Transformer

Power Systems: The Grid

3. Transmission Systems: #1

❖ Introduction

Electric power transmission is the bulk movement of electrical energy from a generating site (power plant), to an electrical substation. The interconnected lines which facilitate this movement are known as a *transmission network*. This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as electric power distribution. The combined transmission and distribution network is part of electricity delivery, known as the electrical grid.

Efficient long-distance transmission of electric power requires high voltages. This reduces the losses produced by heavy current. Transmission lines use high-voltage alternating current. The voltage level is changed with transformers, stepping up the voltage for transmission, then reducing voltage for local distribution and then use by customer

The wide area synchronous grid of Texas, also known as an "interconnection" directly connects many generators delivering AC power with the same relative *frequency* to many consumers. This GRID falls under the jurisdiction of the PUC of Texas and the Electric Reliability Council of Texas (ERCOT) grid).

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3. Transmission Systems: #2
   - ❖ 345 KV Transmission Line from STNP

South Texas Nuclear Power Project in Background

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3. Transmission Systems: #3
   - ❖ Dual 345 KV Transmission Lines

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3. Transmission Systems: #4
   - ❖ 138 KV Transmission Line: #1

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3. Transmission Systems: #5
   - ❖ 138 KV Transmission Towers

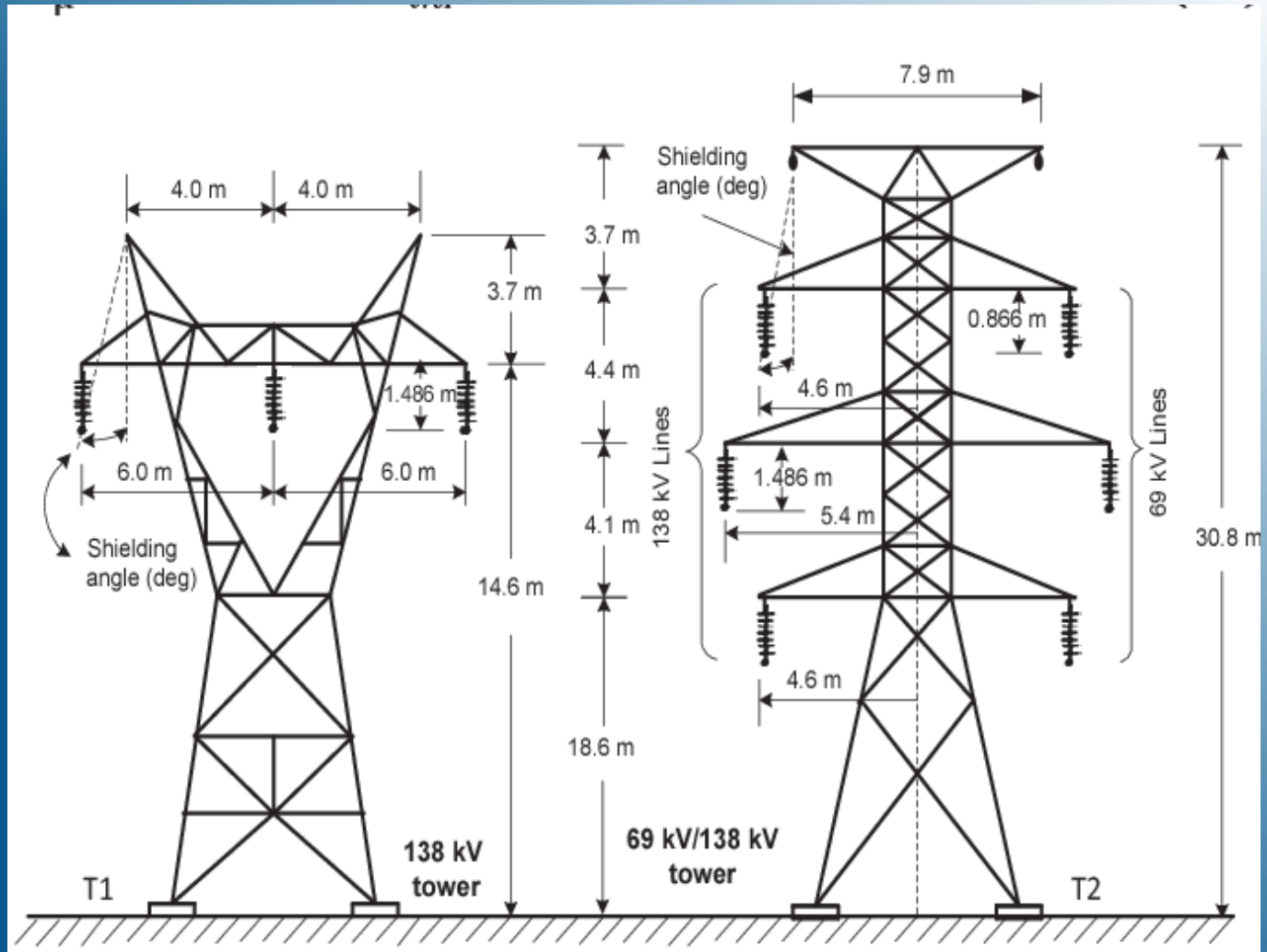

Fig. 2. Transmission towers for 69 and 138 kV power lines T1[21], T2 [22].

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3. Transmission Systems: #6
   - ❖ 69 KV Transmission Line

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3. Transmission Systems: #7
   - ❖ Distribution Substation: #1

A *distribution substation* transfers power from the transmission system to the distribution system of an area. It is uneconomical to directly connect electricity consumers to the main transmission network, unless they use large amounts of power, so the distribution station reduces voltage to a level suitable for local distribution.

A distribution substation may include transformers to change voltage levels between high transmission voltages and lower distribution voltage.

Distribution Substations may be owned and operated by an electrical utility, or may be owned by a large industrial or commercial customer. Generally distribution substations are unattended, relying on SCADA for remote supervision and control.

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3. Transmission Systems: #8
   - ❖ Distribution Substation: #2

Power Systems: The Grid

3. Transmission Systems: #9
   - ❖ Distribution Substation: #3

Power Systems: The Grid

3. Transmission Systems: #10
   - ❖ Distribution Substation: #4

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3. Transmission Systems: #11
   - ❖ Distribution Substation: #5

Power Systems: The Grid

4. SCADA Systems: #1

This portion of the presentation is concerned with the SCADA (Supervisory Control and Data Acquisition) Systems. These system provide the control functions on the voltage and current on the line and load sides of the substation.
The relays are used to provide isolation in the event of the occurrence of a voltage or current fault.

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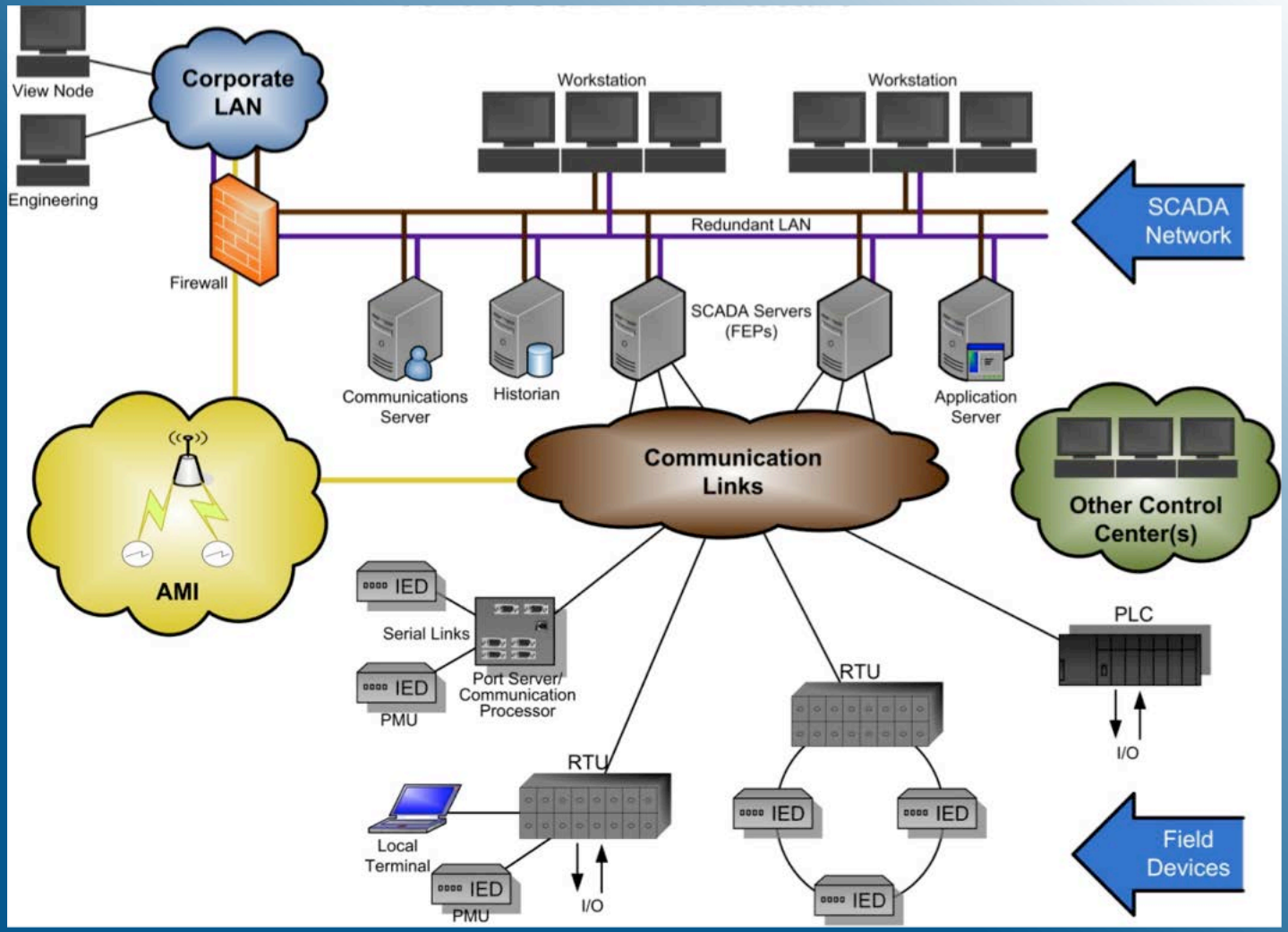
4. SCADA Systems: #2
   - ❖ Introduction: #1

Supervisory control and data acquisition (**SCADA**) is a control system architecture comprising computers, networked data communications and graphical user interfaces (GUI) for high-level supervisory management, while also comprising other peripheral devices like: Remote Terminal Units (RTU), programmable logic controllers (PLC), Intelligent Electronic Devises (IED) and discrete proportional-integral-derivative (PID) controllers to interface with the component parts of the GRID.

The SCADA concept was developed to be a universal means of remote-access to a variety of local control modules, which could be from different manufacturers and allowing access through standard automation protocols. In Electrical Power Systems, the SCADA systems are used as distributed control systems to manage the entire GRID, at the Production Plants and the Substations.

Power Systems: The Grid

4. SCADA Systems: #3
   - ❖ Introduction: #2



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4. SCADA Systems: #4
   - ❖ Remote Terminal Units

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4. SCADA Systems: #5
   - ❖ Programable Logic Controller

Programable Logic Controller

Power Systems: The Grid

4. SCADA Systems: #6
   - ❖ Intelligent Electronic Device

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4. SCADA Systems: #7
   - ❖ Rack of Control Devices