

# Module B2

## *Introduction to the Interconnected Power System Network*



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Module Objectives: Identify the main functions of and the equipment used in the power distribution, transmission, and generation subsystems.

### **B2.0 Introduction**

In this module we present an overview of an electrical power system. The electrical power system is a network of interconnected components which generate electricity by converting different forms of energy, (thermal, hydro, and nuclear are the most common forms of energy converted) to electrical energy; and transmit the electrical energy to load centers to be used by the consumer. The system consists of three main subsystems: the generation subsystem, the transmission subsystem, and the distribution subsystem. Figure B2.1, depicts the typical composition of an electrical power system. Electricity is generated at the generating station, by converting a primary source of energy to electrical energy. The output of the generators is then stepped-up to appropriate transmission levels using a step-up transformer. The transmission subsystem then transmits the power close to the load centers. The power is then stepped-down to appropriate levels. The distribution subsystem then transmits the power close to the customer where it is stepped-down to appropriate levels for use by a residential, industrial, or commercial customer. For a more detailed description of the various aspects of electrical energy, and the various subsystems, the reader is referred to [1-5]. We will provide a brief description of each subsystem, review a few fundamentals of steady-state sinusoidal analysis and three-phase circuits, and provide some fundamental concepts dealing with the representation and analysis of power systems.

### **B2.1 The Generation Subsystem**

Alternating current synchronous generators are the main source of electrical energy. These generators convert energy from a primary form to the electrical form. A more detailed treatment of the generation subsystem is provided in Module G1. Energy is input to the generator in the form of mechanical torque from a prime mover or turbine. The turbine in turn is powered by a moving fluid either steam or water. The current sources of nearly all the electrical energy distributed come from: the conversion of chemical energy of fossil fuels, nuclear fission energy, and the kinetic energy of water. Some renewable sources of energy like wind, solar, and geothermal are also used. The synchronous generators typically range in size from 100 kW to over 1300 MW, and operate at voltage levels from 480 V to 25 kV. The output delivered by the generators is a balanced set of three phase ac voltages.

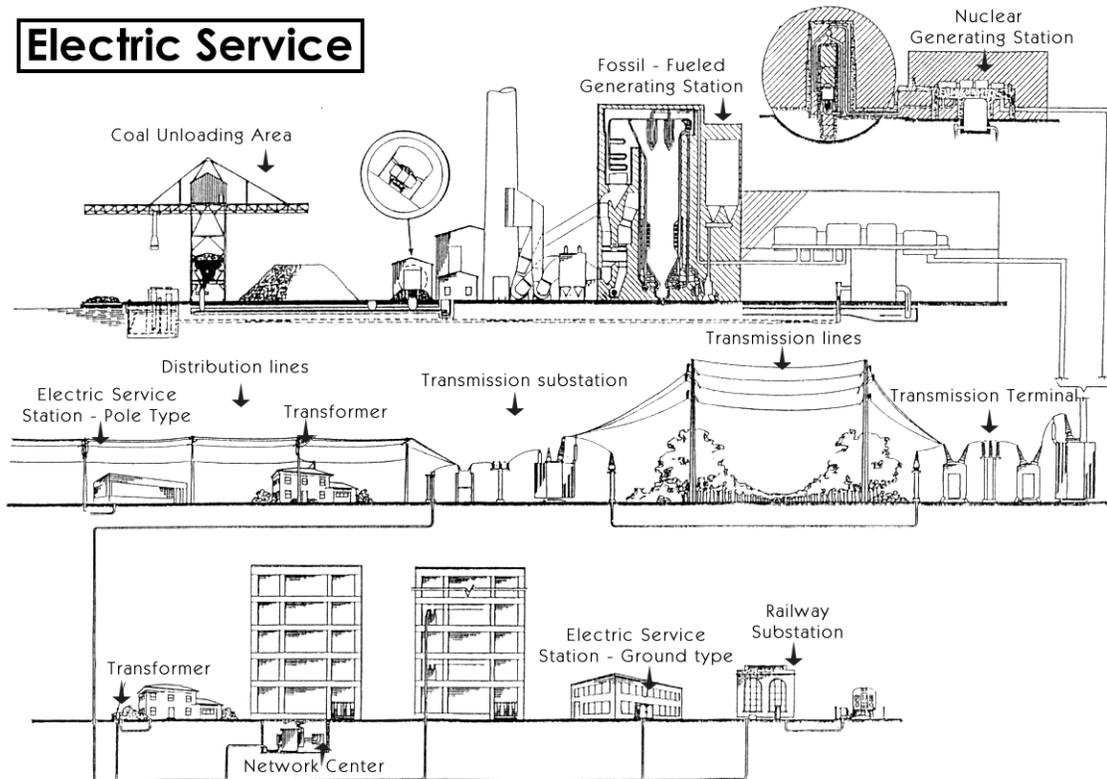


Figure B2.1 The Subsystems of a Power System

In fossil fuel plants, the source of heat energy is due to the combustion of the fossil fuel. When coal is used, crushed coal is conveyed to a pulverizer where the fuel is ground to a consistency of fine powder. The pulverized coal is then fed to burners where it undergoes combustion. The thermal energy produced is then used to heat water in a boiler to produce steam, and stored in the form of internal energy of the steam. The steam flows into the turbine where this internal energy is released as mechanical energy. Alternatively, natural gas or petroleum can also be combusted to produce the source of heat energy.

In contrast to boilers using fossil fuel to supply steam for power generation, nuclear reactors provide an economic alternative. In the United States, there are two commonly used light water reactors. They are the boiling-water reactor (BWR), and the pressurized-water reactor (PWR). In the BWR, a single loop is involved in the heat exchange process. Feedwater is pumped into the reactor pressure vessel where steam is generated and directly fed to the turbine. In the PWR, two loops in series are involved in the heat exchange process. Water at high pressure is pumped through the reactor pressure vessel and the steam generators by the reactor coolant pump in the primary loop. This loop then exchanges heat with the steam generator through which feedwater is pumped via a secondary loop. The steam obtained in the secondary loop is fed to the turbine.

The turbine is a device used to convert the stored energy of high-pressure and high-temperature steam into rotational energy. The steam fed to the turbine is passed through a series of stages, each of which consist of stationary blades and moving blades attached to a rotor. The stationary blades accelerate the steam to high velocity, and this kinetic energy is converted into shaft rotation by the moving blades. The turbine then provides the rotational energy to the synchronous generator.

Combustion turbines are an important part of the utility system generation mix. The combustion turbine has characteristics that make it attractive both for generation to meet peak loads and for base-load operation. Combined cycle plants using combustion turbines, heat recovery steam generators, and a steam turbine have the advantage of superior heat rates.

In a simple cycle combustion turbine, air at atmospheric pressure and temperature is compressed to raise its temperature and pressure. The pressurized air is partly combusted with fuel and passed to the turbine. The fuel used could be gaseous, or liquid fuels, or combinations of different fuels.

The gases exhausting from the combustion turbine are quite hot. In a combined cycle plant, these gases are used to generate steam for a steam turbine. This system incorporates some of the features of a conventional fossil-fired unit.

With the advent of energy consciousness, and the drive to improve energy efficiency, cogeneration has become an important source of energy production. Electricity is produced sequentially with thermal energy. Two different schemes are normally used in co-generation. In the topping system electricity is first produced ("on top"). Waste heat is used in some industrial process or to provide heating. In the bottoming system, the heat energy is first used in the process. Waste heat from the process is used to produce electricity ("on bottom").

In a hydroelectric plant, the electrical energy is derived from falling water. Water is typically stored by a dam. It is then delivered using pen-stocks or pipes to the hydraulic turbine, which in turn supplies mechanical energy to the generator. Hydraulic turbines are of two basic types, impulse and reaction. The impulse turbine is also known as the Pelton wheel. It is used in high-head plants, where the head (fall of water) is 305 meters or more. The impulse turbine usually has a horizontal shaft. In the Pelton wheel, kinetic energy is derived by converting the fall of water into one or more high-velocity jets located around the periphery of the wheel and directed into spoon-shaped buckets. Reaction type turbines are of two general types, Francis and propeller. In both types the water passages are completely filled with water. The energy which drives the wheel is in both kinetic and "pressure head" form.

The output of the generators is fed to a unit transformer which steps-up the voltage to the appropriate transmission level.

## B2.2 The Transmission Subsystem

**T**he electrical power produced at generating stations is transported or moved to areas close to load locations by the transmission subsystem. Transmission lines are a major component of this subsystem.

Transmission lines could be underground or overhead. The latter kind are more common. Transmission line voltages range from 115 kV to 765 kV. Overhead transmission lines span long distances and use bare conductors. As a result, they must be connected by insulated mechanical connections to towers or poles which support them. A transmission line consists of conductors, insulators, mechanical supports, and usually shield wires. Aluminum conductor, steel reinforced (ACSR), conductors are most commonly used for high-voltage transmission lines. Compared to other conductor material, they have low cost and high strength-to-weight ratio. Suspension type insulators are used. The material most commonly used for insulators is porcelain. New polymer materials are now being used for making insulators. Shield wires are used to protect the energized conductors from lightning.

Underground transmission is mainly used in urban areas. The most extensive system in the United States is that of Consolidated Edison Company in the New York City area. Underground lines consist of oil-filled cables placed in elaborate duct systems. Underground lines cost on an average, about 8-15 times more than overhead lines. Underground cables also have the disadvantage of poor accessibility.

Transformers are an important part of the transmission subsystem. The transformer is a static device which transfers electrical energy from one circuit magnetically coupled with another. In doing so, they can transform voltage levels in the magnetically coupled circuits. Different types of transformers are used in the transmission subsystem. Power transformers are used to step-up, or step-down voltages. On load tap changing transformers are

used to regulate voltages. Auto-transformers are used for most ties between moderate-voltage and high voltage transmission circuits. Phase shifting transformers are used to regulate the flow of real power.

Switchgear constitutes an essential component of the transmission subsystem. Under normal operating conditions, it provides the means to perform routine switching operations, e.g., disconnecting and isolating various equipment for maintenance, inspection, or replacement, transferring load, isolating regulators, etc. Under abnormal conditions, switchgear provides the means for automatically isolating parts of the system in trouble to prevent damage and to localize the problem. The main components of the switchgear include, circuit breakers, disconnecting switches, fuse, instrument transformers, buses and connections, supporting insulators, protective and control relays, and control switches.

A substation houses all equipment involved in the switching or regulating of electricity. Substations can be large or small. Control can be automatic or manual.

### **B2.3 The Distribution Subsystem**

**T**he sub-transmission designates the circuits, which deliver energy from the transmission subsystem to the distribution subsystem. Usually the transmission substations supply the sub-transmission system, but it is still referred to as the sub-transmission. Many sub-transmission systems were previously transmission lines. Load growth and demand for more power resulted in the transmission voltage being too low. As a result, voltages from 230 kV down to 35 kV are found in sub-transmission systems.

The distribution subsystem includes the primary circuits and the distribution substations that supply them, the distribution transformers, the secondary circuits, including the components all the way up to the entrance of the customer's premises, and the protective and control devices. The primary circuit is three-phase and is operated in the 12-14 kV range. In several instances, the voltage level in the primary circuit is currently in the 25-35 kV range. The secondary circuits serve most of the customers at levels of 120/240 volts, single-phase, 208/120 volts, three-phase, or 480/277 volts three-phase.

The various other components used in the distribution subsystem include: distribution transformers, automatic circuit reclosers, cut-outs, surge arresters, separable connectors, capacitors and voltage regulators, and metering.

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## PROBLEMS

### B2.1 Group Activity on the Three Subsystems of a Power System

Your base group should provide the answers to the following questions.

- #1. Generation Subsystem
- #2. Transmission Subsystem
- #3. Distribution Subsystem
- #4. How the Transmission System Really Works

A 4-tape video series is available which will help you in answering many of these questions. All students should view all tapes, but only one set of answers should be submitted for each group.

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## QUESTIONS

### Generation Subsystem

- 1 What are the three primary means of generating electricity?
- 2 What is the most common means of generating electricity in your home state?
- 3 Why are combined cycle units used?
- 4 At what range of voltages do generators deliver power?
- 5 How are the nuclear fuel rods prepared?
- 6 How is nuclear fission controlled?
- 7 A simulation was used to describe nuclear fission in the tape. Based on this simulation, explain how fission occurs in your own words.
- 8 What are the two types of nuclear reactors in the U.S.?
- 9 Describe the process of generating steam in a pressurized water reactor.
- 10 Name three methods of generating electricity using alternative energy sources.

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### Transmission Subsystem

- 1 Why is the voltage at the generator boosted for the purpose of transmission?
- 2 How are voltages boosted and reduced?
- 3 What are the common voltages used for the transmission system?
- 4 Other than for boosting and reducing voltages, what other purposes are transformers used for?
- 5 What kind of conductors are normally used in transmission lines?
- 6 What are the types of tower structure materials used?
- 7 How are faults and disturbances on the transmission system sensed?
- 8 How are faulted sections of the transmission system isolated?
- 9 What devices are used to measure voltages and currents?
- 10 What are FACTS devices?

*Distribution Subsystem*

- 1 What are the common voltage levels used in the distribution system?
  - 2 What are the two types of distribution systems commonly used?
  - 3 How are distribution systems isolated for repair and maintenance?
  - 4 What is the type of distribution system preferred in large urban cities?
  - 5 What are the various means of controlling voltages in distribution systems?
  - 6 At what voltage is power delivered to residential customers?
  - 7 How are distribution circuits protected against faults and disturbances?
  - 8 Are underground distribution systems more economical than overhead distribution systems? If not, why?
  - 9 Where is metering done to measure usage?
  - 10 What does an on load tap changing transformer do?
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References

- Rustebakke, H. M., Electric Utility Systems and Practices, Fourth Edition, John Wiley & Sons, New York, 1983.
- Bergen, A. R., Power System Analysis, Prentice-Hall Inc., New Jersey, 1986.
- Gross, C. A., Power System Analysis, Second Edition, John Wiley & Sons, New York, 1986.
- Del Toro, V., Electric Power Systems, Prentice Hall, New Jersey, 1992.
- El-Hawary, M. E., Electrical Power Systems Design and Analysis, Reston Publishing Company Inc., Reston, 1983.