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G. PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

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Department of Electrical and Electronics Engineering

Bridge Course
On
ELECTRICAL POWER TRANSMISSION SYSTEMS

1. Introduction to Power Generation and Transmission:

An **electric power system** is a network of electrical components deployed to supply, transfer, and use electric power. An example of an electric power system is *the grid* that provides power to an extended area. An electrical grid power system can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centers to the load centers, and the distribution system that feeds the power to nearby homes and industries. Smaller power systems are also found in industry, hospitals, commercial buildings and homes. The majority of these systems rely upon three-phase AC power—the standard for large-scale power transmission and distribution across the modern world. Specialized power systems that do not always rely upon three-phase AC power are found in aircraft, electric rail systems, ocean liners and automobiles.

Electricity is produced at nuclear, fossil fuel, gas and hydroelectric generating stations and at wind generation or other industrial facilities throughout the Province of Ontario. Hydro One operates a network of transmission lines in Ontario, which transmit the electricity over great distances at high voltage (i.e. 115 kV, 230 kV, 500 kV in Ontario) to local transformer stations. There are approximately 280 of these local TS' located throughout the Province of Ontario. The TS' role is to transform the high voltage power input to a lower voltage output that is usable by the energy customers (i.e. large industrial customers and distribution companies). The local distribution companies (LDCs) then supply other customers (i.e. residential and commercial) through the use of smaller distribution stations (DS), pole mounted transformers and pad mounted transformers. This sequence of electricity generation, transmission and transformation to a usable power supply by customers is illustrated in Figure 1.

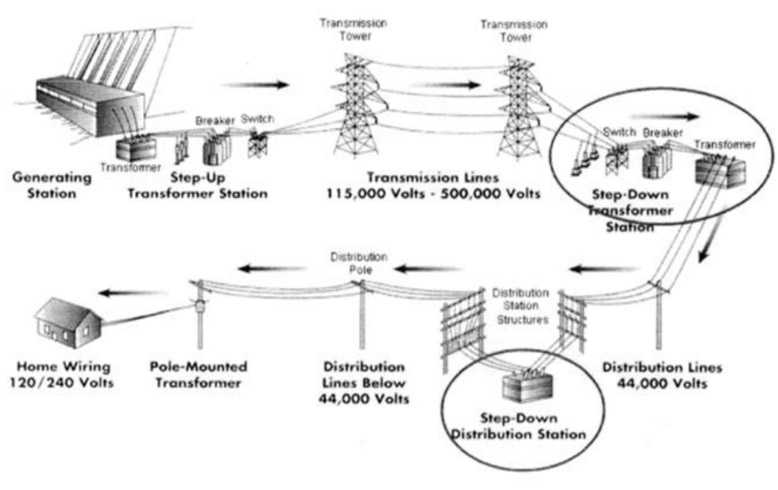

Figure 1. Role of Transmission Line and Transformer Station in Power Delivery to Customers

2. Components of power systems:

Supplies:

All power systems have one or more sources of power. For some power systems, the source of power is external to the system but for others it is part of the system itself—it is these internal power sources that are discussed in the remainder of this section. Direct current power can be supplied by batteries, fuel cells or photovoltaic cells. Alternating current power is typically supplied by a rotor that spins in a magnetic field in a device known as a turbo generator. There have been a wide range of techniques used to spin a turbine's rotor, from steam heated using fossil fuel (including coal, gas and oil) or nuclear energy, falling water (hydroelectric power) and wind (wind power).

Loads:

Power systems deliver energy to loads that perform a function. These loads range from household appliances to industrial machinery. Most loads expect a certain voltage and, for alternating current devices, a certain frequency and number of phases. The appliances found in your home, for example, will typically be single-phase operating at 50 or 60 Hz with a voltage between 110 and 260 volts (depending on national standards).

Conductors:

Conductors carry power from the generators to the load. In a grid, conductors may be classified as belonging to the transmission system, which carries large amounts of power at high voltages (typically more than 69 kV) from the generating centres to the load centres, or the distribution system, which feeds smaller amounts of power at lower voltages (typically less than 69 kV) from the load centres to nearby homes and industry.

Choice of conductors is based upon considerations such as cost, transmission losses and other desirable characteristics of the metal like tensile strength. Copper, with lower resistivity than Aluminum, was the conductor of choice for most power systems. However, Aluminum has lower cost for the same current carrying capacity and is the primary metal used for transmission line conductors. Overhead line conductors may be reinforced with steel or aluminum alloys.

Capacitors and reactors:

The majority of the load in a typical AC power system is inductive; the current lags behind the voltage. Since the voltage and current are out-of-phase, this leads to the emergence of an "imaginary" form of power known as reactive power. Reactive power does no measurable work but is transmitted back and forth between the reactive power source and load every cycle. This reactive power can be provided by the generators themselves, through the adjustment of generator excitation, but it is often cheaper to provide it through capacitors, hence capacitors are often placed near inductive loads to reduce current demand on the power system (i.e., increase the power factor), which may never exceed 1.0, and which represents a purely resistive load. Power factor correction may be applied at a central substation, through the use of so-called "synchronous condensers" (synchronous machines which act as condensers which are variable in VAR value, through the adjustment of machine excitation) or adjacent to large loads, through the use of so-called "static condensers" (condensers which are fixed in VAR value).

Reactors consume reactive power and are used to regulate voltage on long transmission lines. In light load conditions, where the loading on transmission lines is well below the surge impedance loading, the efficiency of the power system may actually be improved by switching in reactors. Reactors installed in series in a power system also limit rushes of current flow, small reactors are therefore almost always installed in series with capacitors to limit the current rush associated with switching in a capacitor. Series reactors can also be used to limit fault currents.

Protective devices

Power systems contain protective devices to prevent injury or damage during failures. The quintessential protective device is the fuse. When the current through a fuse exceeds a certain threshold, the fuse element melts, producing an arc across the resulting gap that is then extinguished, interrupting the circuit. Given that fuses can be built as the weak point of a system, fuses are ideal for protecting circuitry from damage. Fuses however have two problems: First, after they have functioned, fuses must be replaced as they cannot be reset. This can prove inconvenient if the fuse is at a remote site or a spare fuse is not on hand. And second, fuses are typically inadequate as the sole safety device in most power systems as they allow current flows well in excess of that that would prove lethal to a human or animal.

The first problem is resolved by the use of circuit breakers—devices that can be reset after they have broken current flow. In modern systems that use less than about 10 kW, miniature circuit breakers are typically used. These devices combine the mechanism that initiates the trip (by sensing excess current) as well as the mechanism that breaks the current flow in a single unit. Some miniature circuit breakers operate solely on the basis of electromagnetism. In these miniature circuit breakers, the current is run through a solenoid, and, in the event of excess current flow, the magnetic pull of the solenoid is sufficient to force open the circuit breaker's contacts (often indirectly through a tripping mechanism). A better design however arises by inserting a bimetallic strip before the solenoid—this means that instead of always producing a magnetic force, the solenoid only produces a magnetic force when the current is strong enough to deform the bimetallic strip and complete the solenoid's circuit.

In higher powered applications, the protective relays that detect a fault and initiate a trip are separate from the circuit breaker. Early relays worked based upon electromagnetic principles similar to those mentioned in the previous paragraph, modern relays are application-specific computers that determine whether to trip based upon readings from the power system. Different relays will initiate trips depending upon different protection schemes.

This lesson is an Introduction to electrical power generation. By the end of this lesson, the student is expected to be comfortable with the following:

- Definition of electric energy
- Definition of Calorie
- Energy relationships
- Calorific values
- Different sources of energy
- Electrical energy generation arrangement
- Basic power station design considerations

3. Definitions:

Electric Energy:

The ability of electricity to do work. We use electricity in our day to day activities such as lighting, heating, lifting, etc...

Joule: (J, SI unit of energy):

Work done by a force of 1 Newton, to move (unit mass) of anything a distance of 1 meter along the direction of the force.

Calorie: (cal, SI unit of heat):

The amount of heat (energy) needed to raise the temperature of 1 gram (g) of water by 1 degree Celsius.

Kilocalorie (kcal):

The amount of heat (energy) needed to raise the temperature of 1 kilogram (kg) of water by 1 degree Celsius. 1 kcal = 1,000 cal = 4.184 kJ

Fuel:

Material that can be burned to release energy.

Calorific value of fuels: Estimated amount of heat available from fuel.

These definitions are important as they will be used from time to time in this course. The student is encouraged to commit these to memory.

4. Energy and Energy Relationships:

Energy is defined as the ability to do work. We can simplify the forms in which we encounter energy in our daily life into three forms as follows:

1. Mechanical energy (Measured in N.m → Newton-meter = Joule): Ability to move things.

2. Thermal energy (Measured in Cal or KCal → Calorie or Kilocalorie): Ability to heat things.

3. Electrical energy (Measured in Watt.sec → Watt-second): Ability to use electricity to do work.

All the above forms of energy are interchangeable. Since they can be used to do work and thus can be expressed using the same unit of measurement. The Joule!. The following table summarizes the relationship among energy units

Table 1: Relationship among energy units

Energy form Comparison	Unit	Calorie equivalence	Joule equivalence
Heat→Mech	.	1 calorie	4.18 Joules
Heat→Mech	1 C.H.U	453.6 calories	1896 Joules
Heat→Mech	1 B.TH.U	252 calorie	1053 Joules
Elec→Mech	1 Watt.sec	0.24 calories	1 Joule
Elec→Mech	1 Kwh	860 KCal	$3.6*10^{-6}$ Jouls
No climate constraints	Cold climates need regulation		

5. Sources of energy

The following table shows a comparison of the five most prominent sources of energy and how they measure up against each other.

Table 2: Energy sources

Particulars	solar power	Wind power	Hydro power	Fuel power	Nuclear power
Initial cost	High	High	High	Lowest	Highest

Running cost	High	High	Low	Highest	Least
Reserves	Day time only	permanent	permanent	limited	abundant
Cleanliness	High	High	Highest	Lowest	Low
Simplicity	complex	complex	simplest	complex	Most complex
Reliability	Low	Low	Highest	Low	High

It must be noted that besides the above energy sources there are some other less used energy sources as follows:

- Geothermal energy
- Tidal energy
- Wave energy

6. Electrical energy generation arrangement:

For electrical energy to be successfully generated we need an efficient arrangement of the following parts or system.

a. Prime mover:

The part of the electrical generating system responsible in converting other forms of energy into rotating mechanical energy. eg a steam turbine converts heat energy into mechanical energy.

b. Alternator:

The part of the electrical generating sytem responsible for converting mechanical energy into electrical energy.

These working together in a closed system are called prime mover - alternator combination.

7. Power generation fundamental problem:

Electrical energy is the most used form of energy everywhere. As seen in part 3, electrical energy is a result of conversion from other forms of energy that are abundant in nature. Those other forms of energy are usually generated and utilized at will.

Unfortunately, bulk storage of electrical energy for a long duration is not possible yet. This is the fundamental problem in electrical energy generation.

Electrical energy must be generated and transmitted to the point of consumption at the instant of demand. This instant is usually less than a second.

8. Basic power station design considerations:

Electric power generating stations are used to provide bulk electric power economically. To achieve this goal careful consideration must be given to the following points when designing a power station:

- Selection and placement of power generating equipment for maximum return from minimal expenditure for the working life of the station.
- The plant designed must provide cheap; reliable and continous service.

When the above objectives are achieved by a power station design, good and reliable service can be guaranteed to the consumers by the utility company involved.

9. Basic Definition/Terminology:

Alternating Current (AC) – Electric current in which the direction of the current's flow is reversed or alternated at 60Hz in the U.S.

Audible Noise (AN) – A measure in units of decibels on a logarithmic scale. Because human hearing is not equally sensitive to all frequencies of sound, certain frequencies are given more "weight." Noise levels capable of being heard by humans are measured in A-weighted decibels (DBA).

Conductors (Power Lines) – Metal cables used for carrying electric current.

Corona – Electrical breakdown of the air near high voltage conductors into charged particles.

Current – The flow of electricity or the movement of electrons through a conductor typically measured in watts.

Direct Current (DC) – Electric current flows continuously in the same direction as contrasted with alternating current.

Distribution Line – A line that carries electricity at lower voltages of 12kV to 44kV and is used to distribute power drawn from high-voltage transmission systems to end-use customers.

Electric & Magnetic Fields (EMF) – Invisible areas of energy,often referred to as radiation, that are associated with the use of electric power. EMFs fall into one of two radioactive categories – non-ionizing (low-level of radiation) or ionizing (high-level of radiation).

Electric Load – Electricity consumers, such as residences, businesses, and government centers that use electricity.

Electric Power Transmission – The process by which large amounts of electricity produced are transported over long distances for eventual use by consumers.

Energy – The amount of work that can be done by electricity, typically measured in kilowatt-hours (kWh) or megawatthours (MWh).

Foundation – System that transfers to the ground the various dead and live loads of the transmission structure and conductors.

Generation – The production of electric energy. Fossil fuels, wind turbines, solar panels, and other technologies are used to generate electricity.

Insulators – Used to contain, separate, or support electrical conductors.

Interconnection – Points on a grid or network where two or more transmission lines are connected at a substation or switching station, or where one stage of the energy supply chain meets the next.

Load Center – A particular geographical area where energy is used. Most commonly refers to an area within a utility’s service territory where energy demand is highest (i.e., cities, major industrial areas, etc.).

National Electrical Safety Code (NESC) – The NESC is the U.S.standard of the safe installation, operation, and maintenance of electric power systems.

Power – Rate at which electricity does work. Measured in watts or kilowatts (kW) or megawatts (MW).

Rights-of-Way (ROW) – A legal land right, easement, set aside♣ for the transmission line structure and conductors needed for clearances and maintenance activities.

Shield and Ground Wire – Wires used primarily for protection, from lightning strikes and corresponding surges.

Substation – A part of an electrical transmission system that transforms voltage from high to low, or the reverse.

Switching Station – A part of an electrical transmission system, that ties two or more electric circuits together through switches, to permit a circuit to be disconnected, or to change the electric connection between circuits.

Transmission Line – A line that carries electricity at voltages of 69kV or greater and is used to transmit electric power over relatively long distances, usually from a central generating station to main substations.

Transmission Structures – Used to keep high-voltage conductors (power lines) separated from their surroundings and from each other.

Voltage – Electric "pressure" measured in volts. Power♣ systems are typically measured in 1,000s volts or kV.

Watt – Unit of electrical power. 1MW is one million watts.

10. Why do we need new transmission?

- Meet regulatory reliability and public policy requirements
  - Public Policy
  - Least Cost
  - Economic
- Meet the growing need for safe, reliable electricity
- Connect new generation sources to the grid
- Improve reliability, efficiency
- Renewable portfolio standards and
- integrating renewable Access additional resources to reduce cost,
- diversify risk Reduce congestion
- Improve economic

National Electric Grid: The electric grid is a complex interconnected system of electric transmission lines linking generators to loads.

Transmission Line - Normally carries electricity at voltages of 69 kV or greater and is used to transmit electric power over relatively long distances, usually from a central generating station to main substations.

Distribution Line - Normally considered to be a line that carries electricity at lower voltages of 12kV to 44kV and is used to distribute power drawn from high-voltage transmission systems to end-use customers.

Conductor alternatives:

Typically aluminum or copper conductors are used.

- Aluminum is preferred over copper for its lower cost and lighter weight, however, this comes at the price of some energy loss that doesn't occur with copper.
- Aluminum Conductor Steel Reinforced (ACSR) – includes steel strands wrapped around aluminum conductors to add strength. This is the most commonly used conductor.

11. Goals of Transmission Planning:

Meet policy requirements

- Renewable portfolio
- standards Energy efficiency
- Greenhouse Gas emissions.

Meet reliability needs

- Peak loads
- Normal and abnormal conditions

Meet customer needs

- Cost effective/economical
- Provide uninterrupted service

Meet the public's needs

- Minimize impacts to land uses,
- private lands, and the environment