Allegheny Highlands Alliance
Protecting Our Mountains for Future Generations
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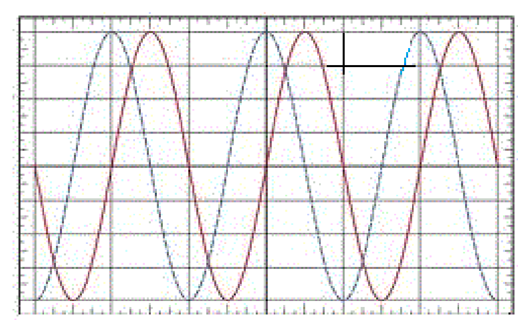
Electric Power and Its Transmission

Energy is needed for almost everything we do. The rapid, efficient transfer of energy between different forms and distant locations was made possible by the development of electric power in the late 1800s. Electric power generation, transmission and distribution systems provide the context through which we evaluate conventional and alternative energy sources today. These notes introduce fundamental concepts of electricity and electric power.

Energy, Power, and Work. Work refers to movement against an opposing force in the opposite direction i.e., force·distance. <u>Energy</u> is the capacity for doing Work. <u>Power</u> is the rate of energy production, transmission, or consumption. Mechanical, electrical, chemical and other forms of energy can all be converted into one another. All forms of energy eventually convert into heat. A kilowatt second of energy is required to lift a mass of one kilogram a distance of one meter against the force of gravity at the earth's surface. A kilowatt of power is required to produce a kilowatt second of energy in one second. Many different units are used to specify quantities of energy and power; kilowatts are often used for electric power, horsepower for mechanical power, and BTU for heat.

Electrical Quantities and Units. These can be defined in many different ways and for different multiples (kilograms vs. grams, millimeters vs. meters, etc.). Here we'll define an <u>ampere hour</u> as our fundamental unit of electrical <u>charge</u>, approximately equal to the charge on a fresh alkaline AAA battery. The term electric current refers to movement of charge past a point in a wire or other conducting medium; the unit of one <u>ampere</u> corresponds to a movement of one ampere second of charge per second. An electric field in a medium provides the energy to move charged particles. A <u>kilovolt</u> (kilowatts/ampere) is the electric field difference required to impart one kilowatt second of energy to a particle with one ampere second of charge. Its role is analogous to that of water pressure in a pipe.



Alternating Current (AC) The very first municipal power systems transmitted and distributed electrical energy using direct current (DC), with voltage and current both constant as functions of time. However, the advantages of alternating current were soon realized, and AC current came into use. In the graphic, the horizontal axis represents time and the vertical represents both voltage and current. The blue curve represents voltage and the red curve represents current. Both have the repeating, back-and-forth character of a sine curve. The red curve (current) is horizontally offset from the blue curve (voltage) by a time interval equal to one fourth of the common period of both curves. This fraction (¼) is measured as an angle and called a phase difference; in this case a 90º phase difference because ¼ = 90/360.

The number of repetitions per second is called the frequency, and the time between each and the next is called the period. Frequency usually remains nominally constant throughout a network and is linked to rotational frequency of the generator. A frequency of 60 herz (repetitions/second) is universally used by power systems in the USA. The offset between the phases of current and voltage is also measured by a quantity called power factor which varies between 0 and +1 and indicates the proportion of the power applied to the network (Apparent Power) that is delivered to the Load (Real Power), rather than being exchanged back and forth to maintain electric and magnetic fields (Reactive Power)

An AC signal with zero phase difference between current and voltage is termed in-phase, or Resistive, with time-averaged voltage drop proportional to current. The constant of proportionality is called Resistance. Reactance is the opposition of an element to a change of electric current or voltage due to that element's Inductance or Capacitance. Electrical Engineers generally combine Resistance and Reactance into a single two- dimensional quantity called Impedance and treated mathematically as a complex number.

- **Generators, Motors and Transformers.** Generators turn mechanical power (such as that produced by turbines) to electrical power. Motors reverse this and convert electrical power to mechanical power. Transformers raise and lower the voltage of AC signals, while maintaining almost the same power by a corresponding current change.

- **Transmission/Distribution Lines**. There are several advantages to the use of AC:

  i. For efficiency of energy transmission, it is generally advantageous to use the highest voltage not otherwise precluded, since the real power transmitted on a line is proportional to the square of the voltage drop. However, High voltage DC lines are still used to connect networks whose phases are not synchronized and for other reasons.

  ii. Transformers are available to convert the level of an AC voltage as desired with minimal loss of real power; it is harder to raise the voltage of a DC signal.

  iii. Generators and motors are more easily designed and built, do not require brushes, and are safer and more reliable.

AC voltages range from 120 and 240 volts, used for final distribution to homes, to hundreds of kilovolts, used for long distance transmission. Electrical power lines are usually made of bare metal and are suspended high in the air, especially when they carry high voltages. This is for safety and because they need to dissipate heat. Transmission lines of substantial length usually transmit electrical energy as three phase power through multiple conductors. In this arrangement, the three sub-signals are generally tapped off points 120 degree apart on a rotary generator winding. The combined signal is superior for powering motors, one of the main power applications in businesses.

Today's electrical power "grid" is a complex network composed mostly of AC generating stations, high-voltage transmission lines, sub-stations connecting them, and lower-voltage distribution lines. Their optimal configuration is the object of great investment and is highly controversial from the points of view of economy, reliability, societal and environmental impacts, politics and legal structure.