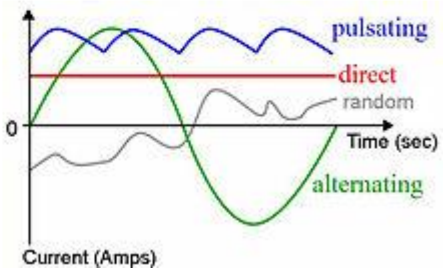
Quantum Mechanics_alternating current



Alternating current (green curve). The horizontal axis measures time; the vertical, current or voltage.

In **alternating current** (**AC**, also **ac**), the flow of Electric charge periodically reverses direction. InDirect current (**DC**, also **dc**), the flow of electric charge is only in one direction. The abbreviations *AC*and *DC* are often used to mean simply *alternating*and *direct*, as when they modify *current* or *Voltage*.[1] [2]

AC is the form in which electric power is delivered to businesses and residences. The usual waveform of an AC power circuit is a sine wave. In certain applications, different waveforms are used, such astriangular or square waves. Audio and radio signals carried on electrical wires are also examples of alternating current. In these applications, an important goal is often the recovery of information encoded (or modulated) onto the AC signal.

Transmission, distribution, and domestic power supply

Main articles: Electric power transmission and Electricity distribution

AC voltage may be increased or decreased with a transformer. Use of a higherVoltage leads to significantly more efficient transmission of power. The power losses in a conductor are a product of the square of the current and the resistanceof the conductor, described by the formula

$$P_{\mathrm{L}} = I^2 R\,.$$

This means that when transmitting a fixed power on a given wire, if the current is doubled, the power loss will be four times greater.

The power transmitted is equal to the product of the current and the voltage (assuming no phase difference); that is,

$$P_{\mathrm{T}} = IV\,.$$

Thus, the same amount of power can be transmitted with a lower current by increasing the voltage. It is therefore advantageous when transmitting large amounts of power to distribute the power with high voltages (often hundreds of kilovolts).

High voltage transmission lines deliver power from electric generation plants over long distances using alternating current. These lines are located in eastern Utah.

However, high voltages also have disadvantages, the main one being the increased insulation required, and generally increased difficulty in their safe handling. In apower plant, power is generated at a convenient voltage for the design of agenerator, and then stepped up to a high voltage for transmission. Near the loads, the transmission voltage is stepped down to the voltages used by equipment. Consumer voltages vary depending on the country and size of load, but generally motors and lighting are built to use up to a few hundred volts between phases.

The utilization voltage delivered to equipment such as lighting and motor loads is standardized, with an allowable range of voltage over which equipment is expected to operate. Standard power utilization voltages and percentage tolerance vary in the different mains power systems found in the world.

Modern high-voltage direct-current (HVDC) electric power transmission systems contrast with the more common alternating-current systems as a means for the efficient bulk transmission of electrical power over long distances. HVDC systems, however, tend to be more expensive and less efficient over shorter distances than transformers.[*citation needed*] Transmission with high voltage direct current was not feasible when Edison, Westinghouse and Tesla were designing their power systems, since there was then no way to economically convert AC power to DC and back again at the necessary voltages.

Three-phase electrical generation is very common. The simplest case is three separate coils in the generator stator that are physically offset by an angle of 120° to each other. Three current waveforms are produced that are equal in magnitude and 120° out of phase to each other. If coils are added opposite to these (60° spacing), they generate the same phases with reverse polarity and so can be simply wired together.

In practice, higher "pole orders" are commonly used. For example, a 12-pole machine would have 36 coils (10° spacing). The advantage is that lower speeds can be used. For example, a 2-pole machine running at 3600 rpm and a 12-pole machine running at 600 rpm produce the same frequency. This is much more practical for larger machines.

If the load on a three-phase system is balanced equally among the phases, no current flows through the neutral point. Even in the worst-case unbalanced (linear) load, the neutral current will not exceed the highest of the phase currents. Non-linear loads (e.g., computers) may require an oversized neutral bus and neutral conductor in the upstream distribution panel to handle harmonics. Harmonics can cause neutral conductor current levels to exceed that of one or all phase conductors.

For three-phase at utilization voltages a four-wire system is often used. When stepping down three-phase, a transformer with a Delta (3-wire) primary and a Star (4-wire, center-earthed) secondary is often used so there is no need for a neutral on the supply side.

For smaller customers (just how small varies by country and age of the installation) only a single phase and the neutral or two phases and the neutral are taken to the property. For larger installations all three phases and the neutral are taken to the main distribution panel. From the three-phase main panel, both single and three-phase circuits may lead off.

Three-wire single-phase systems, with a single center-tapped transformer giving two live conductors, is a common distribution scheme for residential and small commercial buildings in North America. This arrangement is sometimes incorrectly referred to as "two phase". A similar method is used for a different reason on construction sites in the UK. Small power tools and lighting are supposed to be supplied by a local center-tapped transformer with a voltage of 55 V between each power conductor and earth. This significantly reduces the risk ofelectric shock in the event that one of the live conductors becomes exposed through an equipment fault whilst still allowing a reasonable voltage of 110 V between the two conductors for running the tools.

A third wire, called the bond (or earth) wire, is often connected between non-current-carrying metal enclosures and earth ground. This conductor provides protection from electric shock due to accidental contact of circuit conductors with the metal chassis of portable appliances and tools. Bonding all non-current-carrying metal parts into one complete system ensures there is always a lowelectrical impedance path to ground sufficient to carry any fault current for as long as it takes for the system to clear the fault. This low impedance path allows the maximum amount of fault current, causing the overcurrent protection device (breakers, fuses) to trip or burn out as quickly as possible, bringing the electrical system to a safe state. All bond wires are bonded to ground at the main service panel, as is the Neutral/Identified conductor if present.

AC power supply frequencies

Further information: Mains power around the world

The frequency of the electrical system varies by country; most electric power is generated at either 50 or 60 hertz. Some countries have a mixture of 50 Hz and 60 Hz supplies, notably electricity power transmission in Japan.

A low frequency eases the design of electric motors, particularly for hoisting, crushing and rolling applications, and commutator-type traction motors for applications such as railways. However, low frequency also causes noticeable flicker in arc lamps and incandescent light bulbs. The use of lower frequencies also provided the advantage of lower impedance losses, which are proportional to frequency. The original Niagara Falls generators were built to produce 25 Hz power, as a compromise between low frequency for traction and heavy induction motors, while still allowing incandescent lighting to operate (although with noticeable flicker). Most of the 25 Hz residential and commercial customers for Niagara Falls power were converted to 60 Hz by the late 1950s, although some[*which?*] 25 Hz industrial customers still existed as of the start of the 21st century. 16.7 Hz power (formerly 16 2/3 Hz) is still used in some European rail systems, such as in Austria, Germany, Norway, Sweden and Switzerland.

Off-shore, military, textile industry, marine, computer mainframe, aircraft, and spacecraft applications sometimes use 400 Hz, for benefits of reduced weight of apparatus or higher motor speeds.

Effects at high frequencies

Main article: Skin effect

A direct current flows uniformly throughout the cross-section of a uniform wire. An alternating current of any frequency is forced away from the wire's center, toward its outer surface. This is because the acceleration of an Electric charge in an alternating current produces waves of Electromagnetic radiation that cancel the propagation of electricity toward the center of materials with highconductivity. This phenomenon is called Skin effect.

At very high frequencies the current no longer flows *in* the wire, but effectively flows *on* the surface of the wire, within a thickness of a few skin depths. The skin depth is the thickness at which the current density is reduced by 63%. Even at relatively low frequencies used for power transmission (50–60 Hz), non-uniform distribution of current still occurs in sufficiently thick conductors. For example, the skin depth of a copper conductor is approximately 8.57 mm at 60 Hz, so high current conductors are usually hollow to reduce their mass and cost.

Since the current tends to flow in the periphery of conductors, the effective cross-section of the conductor is reduced. This increases the effective AC resistance of the conductor, since resistance is inversely proportional to the cross-sectional area. The AC resistance often is many times higher than the DC resistance, causing a much higher energy loss due to ohmic heating (also called I^2R loss).

Techniques for reducing AC resistance

For low to medium frequencies, conductors can be divided into stranded wires, each insulated from one other, and the relative positions of individual strands specially arranged within the conductor bundle. Wire constructed using this technique is called Litz wire. This measure helps to partially mitigate skin effect by forcing more equal current throughout the total cross section of the stranded conductors. Litz wire is used for making high-Q inductors, reducing losses in flexible conductors carrying very high currents at lower frequencies, and in the windings of devices carrying higher radio frequency current (up to hundreds of kilohertz), such as switch-mode power supplies and radio frequency transformers.

Techniques for reducing radiation loss

As written above, an alternating current is made of Electric charge under periodicacceleration, which causes radiation of electromagnetic waves. Energy that is radiated is lost. Depending on the frequency, different techniques are used to minimize the loss due to radiation.

Twisted pairs

At frequencies up to about 1 GHz, pairs of wires are twisted together in a cable, forming a twisted pair. This reduces losses from Electromagnetic radiation andinductive coupling. A twisted pair must be used with a balanced signalling system, so that the two wires carry equal but opposite currents. Each wire in a twisted pair radiates a signal, but it is effectively cancelled by radiation from the other wire, resulting in almost no radiation loss.

Coaxial cables

Coaxial cables are commonly used at audio frequencies and above for convenience. A coaxial cable has a conductive wire inside a conductive tube, separated by a dielectric layer. The current flowing on the inner conductor is equal and opposite to the current flowing on the inner surface of the tube. The electromagnetic field is thus completely contained within the tube, and (ideally) no energy is lost to radiation or coupling outside the tube. Coaxial cables have acceptably small losses for frequencies up to about 5 GHz. For microwavefrequencies greater than 5 GHz, the losses (due mainly to the electrical resistance of the central conductor) become too large, making Waveguides a more efficient medium for transmitting energy. Coaxial cables with an air rather than solid dielectric are preferred as they transmit power with lower loss.

Waveguides

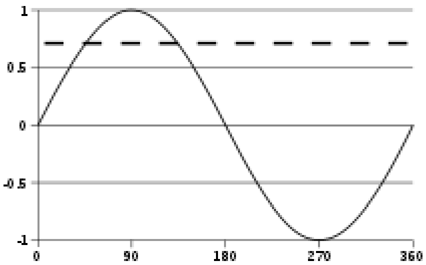
Waveguides are similar to coax cables, as both consist of tubes, with the biggest difference being that the waveguide has no inner conductor. Waveguides can have any arbitrary cross section, but rectangular cross sections are the most common. Because waveguides do not have an inner conductor to carry a return current, waveguides cannot deliver energy by means of an Electric current, but rather by means of a *guided* Electromagnetic field. Although surface currents do flow on the inner walls of the waveguides, those surface currents do not carry power. Power is carried by the guided electromagnetic fields. The surface currents are set up by the guided electromagnetic fields and have the effect of keeping the fields inside the waveguide and preventing leakage of the fields to the space outside the waveguide.

Waveguides have dimensions comparable to the wavelength of the alternating current to be transmitted, so they are only feasible at microwave frequencies. In addition to this mechanical feasibility, electrical resistance of the non-ideal metals forming the walls of the waveguide cause dissipation of power (surface currents flowing on lossy conductors dissipate power). At higher frequencies, the power lost to this dissipation becomes unacceptably large.

Fiber optics

At frequencies greater than 200 GHz, waveguide dimensions become impractically small, and the ohmic losses in the waveguide walls become large. Instead, fiber optics, which are a form of dielectric waveguides, can be used. For such frequencies, the concepts of voltages and currents are no longer used.

Mathematics of AC voltages



A sine wave, over one cycle (360°). The dashed line represents the root mean square (RMS) value at about 0.707

Alternating currents are accompanied (or caused) by alternating voltages. An AC voltage *v* can be described mathematically as a function of time by the following equation:

$$v(t) = V_{\text{peak}} \cdot \sin(\omega t),$$

where

- V_{peak} is the peak voltage (unit: volt),
- ω is the angular frequency (unit: radians per second)
    - The angular frequency is related to the physical frequency, f (unit = hertz), which represents the number of cycles per second, by the equation $\omega = 2\pi f$.
- t is the time (unit: second).

The peak-to-peak value of an AC voltage is defined as the difference between its positive peak and its negative peak. Since the maximum value of $\sin(x)$ is +1 and the minimum value is −1, an AC voltage swings between $+V_{\text{peak}}$ and $-V_{\text{peak}}$. The peak-to-peak voltage, usually written as V_{pp} or $V_{\text{P-P}}$, is therefore $V_{\text{peak}} - (-V_{\text{peak}}) = 2V_{\text{peak}}$.

Power and root mean square

Main article: AC power

The relationship between voltage and the power delivered is

$$p(t) = \frac{v^2(t)}{R}$$ where R represents a load resistance.

Rather than using instantaneous power, $p(t)$, it is more practical to use a time averaged power (where the averaging is performed over any integer number of cycles). Therefore, AC voltage is often expressed as a root mean square (RMS) value, written as $V_{\rm rms}$, because

$$P_{\rm time\ averaged} = \frac{{V^2}_{\rm rms}}{R}.$$

For a sinusoidal voltage:

$$\begin{aligned} V_{\rm rms} &= \sqrt{\frac{1}{T}\int_0^T [V_{pk}\sin(\omega t + \phi)]^2 dt} \\ &= V_{pk}\sqrt{\frac{1}{2T}\int_0^T [1 - \cos(2\omega t + 2\phi)] dt} \\ &= V_{pk}\sqrt{\frac{1}{2T}\int_0^T dt} \\ &= \frac{V_{pk}}{\sqrt{2}} \end{aligned}$$

The factor $\sqrt{2}$ is called the crest factor, which varies for different waveforms.

- For a triangle waveform centered about zero
  $$V_{\rm rms} = \frac{V_{\rm peak}}{\sqrt{3}}.$$
- For a square waveform centered about zero
  $$V_{\rm rms} = V_{\rm peak}.$$
- For an arbitrary periodic waveform $v(t)$ of period T:
  $$V_{\rm rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t) dt}.$$

Example

To illustrate these concepts, consider a 230 V AC mains supply used in many countries around the world. It is so called because its root mean square value is 230 V. This means that the time-averaged power delivered is equivalent to the power delivered by a DC voltage of 230 V. To determine the peak voltage (amplitude), we can rearrange the above equation to:

$$V_{\mathrm{peak}} = \sqrt{2}\, V_{\mathrm{rms}}.$$

For 230 V AC, the peak voltage V_{peak} is therefore $230V \times \sqrt{2}$, which is about 325 V. The peak-to-peak value $V_{\mathrm{P-P}}$ of the 230 V AC is double that, at about 650 V.

History

The first alternator to produce alternating current was a dynamo electric generator based on Michael Faraday's principles constructed by the French instrument maker Hippolyte Pixii in 1832.[3] Pixii later added a commutator to his device to produce the (then) more commonly used direct current. The earliest recorded practical application of alternating current is by Guillaume Duchenne, inventor and developer of electrotherapy. In 1855, he announced that AC was superior to Direct current for electrotherapeutic triggering of muscle contractions.[4]

Alternating current technology had first developed in Europe due to the work ofGuillaume Duchenne (1850s), The Hungarian Ganz Works (1870s), Sebastian Ziani de Ferranti (1880s), Lucien Gaulard, and Galileo Ferraris.

In 1876, Russian engineer Pavel Yablochkov invented a lighting system based on a set of induction coils where the primary windings were connected to a source of AC. The secondary windings could be connected to several 'electric candles' (arc lamps) of his own design.[5][6] The coils Yablochkov employed functioned essentially as transformers.[5]

In 1878, the Ganz factory, Budapest, Hungary, began manufacturing equipment for electric lighting and, by 1883, had installed over fifty systems in Austria-Hungary. Their AC systems used arc and incandescent lamps, generators, and other equipment.[7]

A power transformer developed by Lucien Gaulard and John Dixon Gibbs was demonstrated in London in 1881, and attracted the interest of Westinghouse. They also exhibited the invention in Turin in 1884.

The war of Currents

Main article: War of Currents

The Advantage of DC systems over the early AC systems.

During the initial years of Electricity distribution, Edison's direct current was the standard for the United States, and Edison did not want to lose all his patent royalties.[8] Direct current worked well with incandescent lamps, which were the principal load of the day, and with motors. Direct-current systems could be directly used with storage batteries, providing valuable load-leveling and backup power during interruptions of generator operation. Direct-current generators could be easily paralleled, allowing economical operation by using smaller machines during periods of light load and improving reliability. At the introduction of Edison's system, no practical AC motor was available. Edison had invented a meter to allow customers to be billed for energy proportional to consumption, but this meter worked only with direct current. A bipolar open-corepower transformer developed by Lucien Gaulard and John Dixon Gibbs was demonstrated in London in 1881, and attracted the interest of Westinghouse. They also exhibited the invention in Turin in 1884. However these early induction coils with open magnetic circuits are inefficient at transferring power to loads. Until about 1880, the paradigm for AC power transmission from a high voltage supply to a low voltage load was a series circuit. Open-core transformers with a ratio near 1:1 were connected with their primaries in series to allow use of a high voltage for transmission while presenting a low voltage to the lamps. The inherent flaw in this method was that turning off a single lamp (or other electric device) affected the voltage supplied to all others on the same circuit. Many adjustable transformer designs were introduced to compensate for this problematic characteristic of the series circuit, including those employing methods of adjusting the core or bypassing the magnetic flux around part of a coil.[9]

The direct current systems did not have these drawbacks, giving it significant advantages over early AC systems.

The Ganz AC system counter

The prototype of ZBD. transformer is on display at the Széchenyi István Memorial Exhibition,Nagycenk, Hungary

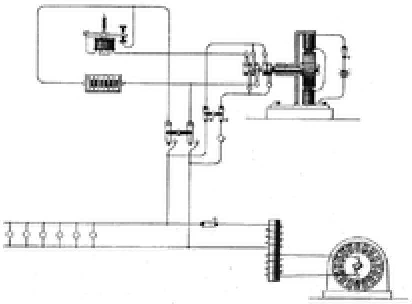
The Hungarian "ZBD" Team (Károly Zipernowsky,Ottó Bláthy, Miksa Déri). They were the inventors of the first high efficiency, closed core shunt connection transformer. The three also invented the modern power distribution system: Instead of former series connection they connect transformers that supply the appliances in parallel to the main line.Blathy invented the AC Wattmeter, and they invented the essential Constant Voltage Generator.

In the autumn of 1884, Károly Zipernowsky, Ottó Bláthy and Miksa Déri (ZBD), three engineers associated with the Ganz factory, had determined that open-core devices were impracticable, as they were incapable of reliably regulating voltage.[10] In their joint 1885 patent applications for novel transformers (later called ZBD transformers), they described two designs with closed magnetic circuits where copper windings were either a) wound around iron wire ring core or b) surrounded by iron wire core.[9] The two designs were the first application of the two basic transformer constructions in common use to this day, which can as a class all be termed as either core form or shell form (or alternatively, core type or shell type), as in a) or b), respectively (see images).[11][12][13][14] The Ganz factory had also in the autumn of 1884 made delivery of the world's first five high-efficiency AC transformers, the first of these units having been shipped on September 16, 1884.[15] This first unit had been manufactured to the following specifications: 1,400 W, 40 Hz, 120:72 V, 11.6:19.4 A, ratio 1.67:1, one-phase, shell form.[15] In both designs, the magnetic flux linking the primary and secondary windings traveled almost entirely within the confines of the iron core, with no intentional path through air (see Toroidal cores below). The new transformers were 3.4 times more efficient than the open-core bipolar devices of Gaulard and Gibbs.[16]

The ZBD patents included two other major interrelated innovations: one concerning the use of parallel connected, instead of series connected, utilization loads, the other concerning the ability to have high turns ratio transformers such that the supply network voltage could be much higher (initially 1,400 to 2,000 V) than the voltage of utilization loads (100 V initially preferred).[17][18] When employed in parallel connected electric distribution systems, closed-core transformers finally made it technically and economically feasible to provide electric power for lighting in homes, businesses and public spaces.[19][20] Bláthy had suggested the use of closed cores, Zipernowsky had suggested the use ofparallel shunt connections, and Déri had performed the experiments;[21] The other essential milestone was the introduction of 'voltage source, voltage intensive' (VSVI) systems'[22] by the invention of constant voltage generators in 1885.[23] Ottó Bláthy also invented the AC electricity meter to complete the competition of AC and DC technology.[24][25][26][27][28] Transformers today are designed on the principles discovered by the three engineers. They also popularized the word 'transformer' to describe a device for altering the emf of an electric current,[19][29] although the term had already been in use by 1882.[30][31]In 1886, the ZBD engineers designed, and the Ganz factory supplied electrical equipment for, the world's first power station that used AC generators to power a parallel connected common electrical network, the steam-powered Rome-Cerchipower plant.[32] The reliability of the AC technology received impetus after the Ganz Works electrified a large European metropolis: Rome in 1886.[32]

Sebastian Ziani de Ferranti went into this business in 1882 when he set up a shop in London designing various electrical devices. Ferranti believed in the success of alternating current power distribution early on, and was one of the few experts in this system in the UK. In 1887 the London Electric Supply Corporation (LESCo) hired Ferranti for the design of their power station at Deptford. He designed the building, the generating plant and the distribution system. On its completion in 1891 it was the first truly modern power station, supplying high-voltage AC power that was then "stepped down" for consumer use on each street. This basic system remains in use today around the world. Many homes all over the world still have electric meters with the Ferranti AC patent stamped on them.

The city lights of Prince George, British Columbia viewed in a motion blurred exposure. The AC blinking causes the lines to be dotted rather than continuous.



Westinghouse Early AC System 1887
(US patent 373035)

William Stanley, Jr. designed one of the first practical devices to transfer AC power efficiently between isolated circuits. Using pairs of coils wound on a common iron core, his design, called an induction coil, was an early transformer. The AC power system used today developed rapidly after 1886, and included contributions by Nikola Tesla (licensed to George Westinghouse) and Carl Wilhelm Siemens. AC systems overcame the limitations of the Direct current system used by Thomas Edison to distribute electricity efficiently over long distances even though Edison attempted to discredit alternating current as too dangerous during the War of Currents.

The first commercial power plant in the United States using three-phasealternating current was at the Mill Creek No. 1 Hydroelectric Plant near Redlands, California, in 1893 designed by Almirian Decker. Decker's design incorporated 10,000-volt three-phase transmission and established the standards for the complete system of generation, transmission and motors used today.

The Ames Hydroelectric Generating Plant (spring of 1891) and the original Niagara Falls Adams Power Plant (August 25, 1895) were among the first hydroelectric AC-power plants.

The Jaruga Hydroelectric Power Plant in Croatia was set in operation on 28 August 1895. The two generators (42 Hz, 550 kW each) and the transformers were produced and installed by the Hungarian company Ganz. The transmission line from the power plant to the City of Šibenik was 11.5 kilometers (7.1 mi) long on wooden towers, and the municipal distribution grid 3000 V/110 V included six transforming stations.

Alternating current circuit theory developed rapidly in the latter part of the 19th and early 20th century. Notable contributors to the theoretical basis of alternating current calculations include Charles Steinmetz, Oliver Heaviside, and many others.[33][34] Calculations in unbalanced three-phase systems were simplified by the symmetrical components methods discussed by Charles Legeyt Fortescue in 1918.

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