Over Head Transmission Lines

132-33 kv

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History

The first transmission of electrical impulses over an extended distance was demonstrated on July 14, 1729 by the physicist Stephen Gray, in order to show that one can transfer electricity by that method. The demonstration used damp hemp cords suspended by silk threads (the low resistance of metallic conductors not being appreciated at the time).

However the first practical use of overhead lines was in the context of telegraphy. By 1837 experimental commercial telegraph systems ran as far as 13 miles (20 km). Electric power transmission was accomplished in 1882 with the first high voltage transmission between Munich and Meshach. 1891 saw the construction of the first three-phase alternating current overhead line on the occasion of the International Electricity Exhibition in Frankfurt, between Lau fen and Frankfurt.

In 1912 the first 110 kV-overhead power line entered service followed by the first 220 kV-overhead power lines in 1923. In the 1920s RWE AG built the first overhead line for this voltage and in 1926 built a Rhine crossing with the pylons of Voerde, two masts 138 meters high.

In Germany in 1957 the first 380 kV overhead power line was commissioned (between the transformer station and Rommerskirchen). In the same year the overhead line traversing of the Strait of Messina went into service in Italy, whose pylons served the Elbe crossing 1. This was used as the model for the building of the Elbe crossing 2 in the second half of the 1970s which saw the construction of the highest overhead line pylons of the world. Starting from 1967 in Russia, and also in the USA and Canada, overhead lines for voltage of 765 kV were built. In 1982 overhead power lines were built in Russia between Elektrostal and the power station at Ekibastusz, this was a three-phase alternating current line at 1150 kV (Power line). In 1999, in Japan the first power line designed for 1000 kV with 2 circuits were built, the Kita-Iwaki Power line. In 2003 the building of the highest overhead line commenced in China, the Yangtze River Crossing.

Electric power transmission or "high-voltage electric transmission"

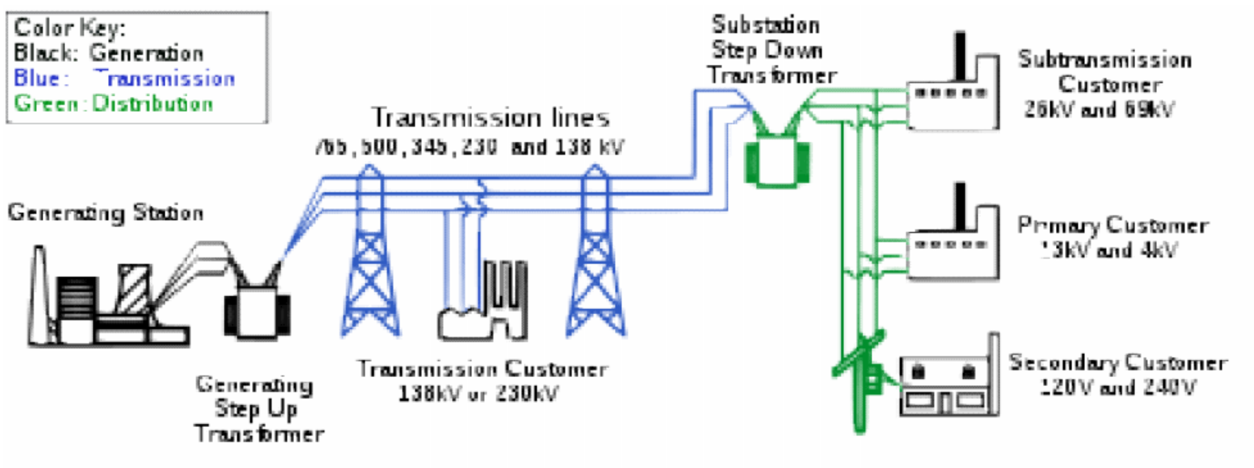
Is the bulk transfer of electrical energy, from generating power plants to substations located near population centers? This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as electric power distribution. Transmission lines, when interconnected with each other, become high-voltage transmission networks. In the US, these are typically referred to as "power grids" or just "the grid", while in the UK the network is known as the "national grid." North America has three major grids: The Western Interconnection; The Eastern Interconnection and the Electric Reliability Council of Texas (or ERCOT) grid.

Historically, transmission and distribution lines were owned by the same company, but over the last decade or so many countries have liberalized the electricity market in ways that have led to the separation of the electricity transmission business from the distribution business.

Transmission lines mostly use three-phase alternating current (AC), although single phase AC is sometimes used in railway electrification systems. High-voltage direct-current (HVDC) technology is used only for very long distances (typically greater than 400 miles, or 600 km); submarine power cables (typically longer than 30 miles, or 50 km); or for connecting two AC networks that are not synchronized.[*citation needed*]

Electricity is transmitted at high voltages (110 kV or above) to reduce the energy lost in long distance transmission. Power is usually transmitted through overhead power lines. Underground power transmission has a significantly higher cost and greater operational limitations but is sometimes used in urban areas or sensitive locations.

A key limitation in the distribution of electricity is that, with minor exceptions, electrical energy cannot be stored, and therefore must be generated as needed. A sophisticated system of control is therefore required to ensure electric generation very closely matches the demand. If supply and demand are not in balance, generation plants and transmission equipment can shut down which, in the worst cases, can lead to a major regional blackout, such as occurred in California and the US Northwest in 1996 and in the US Northeast in 1965, 1977 and 2003. To reduce the risk of such failures, electric transmission networks are interconnected into regional, national or continental wide networks thereby providing multiple redundant alternate routes for power to flow should (weather or equipment) failures occur. Much analysis is done by transmission companies to determine the maximum reliable capacity of each line which is mostly less than its physical or thermal limit, to ensure spare capacity is available should there be any such failure in another part of the network.



Overhead transmission

Contiguous United States power transmission grid consists of 300,000 km of lines operated by 500 companies.

High-voltage overhead conductors are not covered by insulation. The conductor material is nearly always an aluminum alloy, made into several strands and possibly reinforced with steel strands. Copper was sometimes used for overhead transmission but aluminum is lower in weight for only marginally reduced performance and much lower in cost. Overhead conductors are a commodity supplied by several companies worldwide. Improved conductor material and shapes are regularly used to allow increased capacity and modernize transmission circuits. Conductor sizes range from 12 mm^2 (#6 American wire gauge) to 750 mm^2 (1,590,000 circular mils area), with varying resistance and current-carrying capacity. Thicker wires would lead to a relatively small increase in capacity due to the skin effect that causes most of the current to flow close to the surface of the wire.

Today, transmission-level voltages are usually considered to be 110 kV and above. Lower voltages such as 66 kV and 33 kV are usually considered sub transmission voltages but are occasionally used on long lines with light loads. Voltages less than 33 kV are usually used for distribution. Voltages above 230 kV are considered extra high voltage and require different designs compared to equipment used at lower voltages.

Since overhead transmission lines are uninsulated, design of these lines requires minimum clearances to be observed to maintain safety. Adverse weather conditions of high wind and low temperatures can lead to power outages: wind speeds as low as 23 knots (43 km/h) can permit conductors to encroach operating clearances, resulting in a flashover and loss of supply.[2] Oscillatory motion of the physical line can be termed gallop or flutter depending on the frequency and amplitude of oscillation.

High Voltage Lines in Washington State

Bulk power transmission

A transmission substation decreases the voltage of incoming electricity, allowing it to connect from long distance high voltage transmission, to local lower voltage distribution. It also reroutes power to other transmission lines that serve local markets. A transmission substation may include phase-shifting or voltage regulating transformers. This is the PacifiCorp Hale Substation, Orem, Utah, USA.

Engineers design transmission networks to transport the energy as efficiently as feasible, while at the same time taking into account economic factors, network safety and redundancy. These networks use components such as power lines, cables, circuit breakers, switches and transformers. The transmission network is usually administered on a regional basis by an entity such as a regional transmission organization or transmission system operator.

Transmission efficiency is hugely improved by devices that increase the voltage, and proportionately reduce the current in the conductors, thus keeping the power transmitted nearly equal to the power input. The reduced current flowing through the line reduces the losses in the conductors. According to Joule's Law, energy losses are directly proportional to the square of the current. Thus, reducing the current by a factor of 2 will lower the energy lost to conductor resistance by a factor of 4.

This change in voltage is usually achieved in AC circuits using a *step-up transformer*. DC systems require relatively costly conversion equipment which may be economically justified for particular projects, but are less common currently.

A transmission grid is a network of power stations, transmission circuits, and substations. Energy is usually transmitted within a grid with three-phase AC. Single phase AC is used only for distribution to end users since it is not usable for large polyphone induction motors. In the 19th century, two-phase transmission was used but required either three wires with unequal currents or four wires. Higher order phase systems require more than three wires, but deliver marginal benefits.

The synchronous grids of Eurasia.

The capital cost of electric power stations is so high, and electric demand is so variable, that it is often cheaper to import some portion of the needed power than to generate it locally. Because nearby loads are often correlated (hot weather in the Southwest portion of the US might cause many people to use air conditioners), electricity often comes from distant sources. Because of the economics of load balancing, wide area transmission grids now span across countries and even large portions of continents. The web of interconnections between power producers and consumers ensures that power can flow, even if a few links are inoperative.

The unvarying (or slowly varying over many hours) portion of the electric demand is known as the *base load* and is generally served best by large facilities (which are therefore efficient due to economies of scale) with low variable costs for fuel and operations. Such facilities might be nuclear or coal-fired power stations, or hydroelectric, while other renewable energy sources such as concentrated solar thermal and geothermal power have the potential to provide base load power. Renewable energy sources such as solar photovoltaic's, wind, wave, and tidal are, due to their intermittency, not considered "base load" but can still add power to the grid. The remaining power demand, if any, is supplied by peaking power plants, which are typically smaller, faster-responding, and higher cost sources, such as combined cycle or combustion turbine plants fueled by natural gas.

A high-power electrical transmission tower.

Long-distance transmission of electricity (thousands of kilometers) is cheap and efficient, with costs of US$0.005–0.02/kWh (compared to annual averaged large producer costs of US$0.01–0.025/kWh, retail rates upwards of US$0.10/kWh, and multiples of retail for instantaneous suppliers at unpredicted highest demand moments). Thus distant suppliers can be cheaper than local sources (e.g., New York City buys a lot of electricity from Canada). Multiple **local sources** (even if more expensive and infrequently used) can make the transmission grid more fault tolerant to weather and other disasters that can disconnect distant suppliers.

Long distance transmission allows remote renewable energy resources to be used to displace fossil fuel consumption. Hydro and wind sources can't be moved closer to populous cities, and solar costs are lowest in remote areas where local power needs are minimal. Connection costs alone can determine whether any particular renewable alternative is economically sensible. Costs can be prohibitive for transmission lines, but various proposals for massive infrastructure investment in high capacity, very long distance super grid transmission networks could be recovered with modest usage fees.

Grid input

At the generating plants the energy is produced at a relatively low voltage between about 2.3 kV and 30 kV, depending on the size of the unit. The generator terminal voltage is then stepped up by the power station transformer to a higher voltage (115 kV to 765 kV AC, varying by country) for transmission over long distances.

Classification by operating voltage

Overhead power transmission lines are classified in the electrical power industry by the range of voltages:

- Low voltage – less than 1000 volts, used for connection between a residential or small commercial customer and the utility.
- Medium Voltage (Distribution) – between 1000 volts (1 kV) and to about 33 kV, used for distribution in urban and rural areas.
- High Voltage (sub transmission less than 100 kV; sub transmission or transmission at voltage such as 115 kV and 138 kV), used for sub-transmission and transmission of bulk quantities of electric power and connection to very large consumers.
- Extra High Voltage (transmission) – over 230 kV, up to about 800 kV, used for long distance, very high power transmission.
- Ultra High Voltage – higher than 800 kV.

Structures

Structures for overhead lines take a variety of shapes depending on the type of line. Structures may be as simple as wood poles directly set in the earth, carrying one or more cross-arm beams to support conductors, or "armless" construction with conductors supported on insulators attached to the side of the pole. Tubular steel poles are typically used in urban areas. High-voltage lines are often carried on lattice-type steel towers or pylons. For remote areas, aluminum towers may be placed by helicopters. Concrete poles have also been used. Poles made of reinforced plastics are also available, but their high cost restricts application.

Each structure must be designed for the loads imposed on it by the conductors. The weight of the conductor must be supported, as well as dynamic loads due to wind and ice accumulation, and effects of vibration. Where conductors are in a straight line, towers need only resist the weight since the tension in the conductors approximately balances with no resultant force on the structure. Flexible conductors supported at their ends approximate the form of a centenary, and much of the analysis for construction of transmission lines relies on the properties of this form.

A large transmission line project may have several types of towers, with "tangent" ("suspension" or "line" towers, UK) towers intended for most positions and more heavily constructed towers used for turning the line through an angle, dead-ending (terminating) a line, or for important river or road crossings. Depending on the design criteria for a particular line, semi-flexible type structures may rely on the weight of the conductors to be balanced on both sides of each tower. More rigid structures may be intended to remain standing even if one or more conductors is broken. Such structures may be installed at intervals in power lines to limit the scale of cascading tower failures.

Foundations for tower structures may be large and costly, particularly if the ground conditions are poor, such as in wetlands. Each structure may be stabilized considerably by the use of guy wires to counteract some of the forces applied by the conductors.

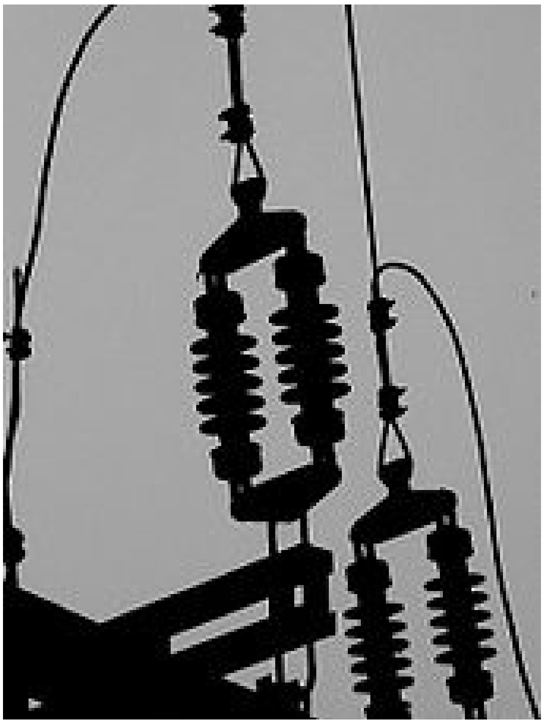
Power lines and supporting structures can be a form of visual pollution. In some cases the lines are buried to avoid this, but this "undergrounding" is more expensive and therefore not common.

For a single wood utility pole structure, a pole is placed in the ground, then three crossarms extend from this, either staggered or all to one side. The insulators are attached to the crossarms. For an "H"-type wood pole structure, two poles are placed in the ground, and then a crossbar is placed on top of these, extending to both sides. The insulators are attached at the ends and in the middle. Lattice tower structures have two common forms. One has a pyramidal base, then a vertical section, where three cross arms extend out, typically staggered. The strain insulators are attached to the cross arms. Another has a pyramidal base, which extends to four support points. On top of this a horizontal truss-like structure is placed.

Insulators

Insulators must support the conductors and withstand both the normal operating voltage and surges due to switching and lightning. Insulators are broadly classified as either pin-type, which support the conductor above the structure, or suspension type, where the conductor hangs below the structure. The invention of the strain insulator was a critical factor in allowing higher voltages to be used. At the end of the 19th century, the limited electrical strength of telegraph-style pin insulators limited the voltage to no more than

69,000 volts. Up to about 33 kV (69 kV in North America) both types are commonly used. At higher voltages only suspension-type insulators are common for overhead conductors. Insulators are usually made of wet-process porcelain or toughened glass, with increasing use of glass-reinforced polymer insulators. However, with rising voltage levels and changing climatic conditions, polymer insulators (silicone rubber based) are seeing increasing usage. China has already developed polymer insulators having a highest system voltage of 1100kV and India is currently developing a 1200kV (highest system voltage) line which will initially be charged with 400kV to be upgraded to a 1200kV line.[citation needed]



Ceramic insulators

Suspension insulators are made of multiple units, with the number of unit insulator disks increasing at higher voltages. The number of disks is chosen based on line voltage, lightning withstand requirement, altitude, and environmental factors such as fog, pollution, or salt spray. In cases where these conditions are suboptimal, longer insulators must be used. Longer insulators, with longer creepage distance for leakage current, are required in these cases. Strain insulators must be strong enough mechanically to support the full weight of the span of conductor, as well as loads due to ice accumulation, and wind.

Porcelain insulators may have a semi-conductive glaze finish, so that a small current (a few mill amperes) passes through the insulator. This warms the surface slightly and reduces the effect of fog and dirt accumulation. The semiconducting glaze also ensures a more even distribution of voltage along the length of the chain of insulator units.

Polymer insulators by nature have hydrophobic characteristics providing for improved wet performance. Also, studies have shown that the specific creepage distance required in polymer insulators is much lower than that required in porcelain or glass. Additionally, the mass of polymer insulators (especially in higher voltages) is approximately 50% to 30% less than that of a comparative porcelain or glass string. Better pollution and wet performance is leading to the increased use of such insulators.

Insulators for very high voltages, exceeding 200 kV, may have grading rings installed at their terminals. This improves the electric field distribution around the insulator and makes it more resistant to flash-over during voltage surges.

Conductors

Aluminum conductors reinforced with steel (known as ACSR) are primarily used for medium and high voltage lines and may also be used for overhead services to individual customers. Aluminum conductors are used as it has the advantage of lower resistivity/weight than copper, as well as being cheaper. Some copper cable is still used, especially at lower voltages and for grounding.

While larger conductors may lose less energy due to lower electrical resistance, they are more costly than smaller conductors. An optimization rule called *Kelvin's Law* states that the optimum size of conductor for a line is found when the cost of the energy wasted in the conductor is equal to the annual interest paid on that portion of the line construction cost due to the size of the conductors. The optimization problem is made more complex due to additional factors such as varying annual load, varying cost of installation, and by the fact that only definite discrete sizes of cable are commonly made.

Since a conductor is a flexible object with uniform weight per unit length, the geometric shape of a conductor strung on towers approximates that of a centenary. The sag of the conductor (vertical distance between the highest and lowest point of the curve) varies depending on the temperature. A minimum overhead clearance must be maintained for safety. Since the temperature of the conductor increases with increasing heat produced by the current through it, it is sometimes possible to increase the power handling capacity (update) by changing the conductors for a type with a lower coefficient of thermal expansion or a higher allowable operating temperature.

Power lines sometimes have spherical markers "of one color" to meet International Civil Aviation Organization recommendations.

Bundle conductors

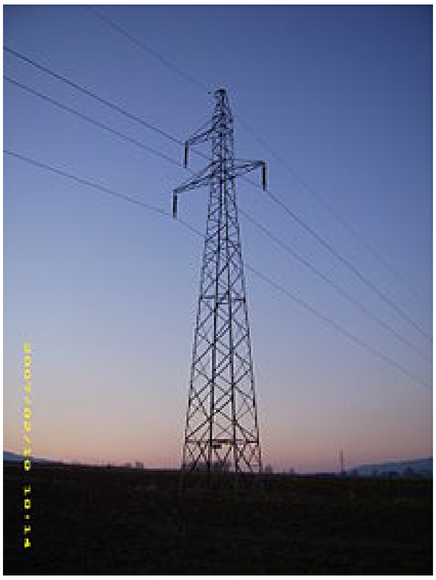
Bundle conductors are used to reduce corona losses and audible noise. Bundle conductors consist of several conductor cables connected by non-conducting spacers. For 220 kV lines, two-conductor bundles are usually used, for 380 kV lines usually three or even four. American Electric Power is building 765 kV lines using six conductors per phase in a bundle. Spacers must resist the forces due to wind, and magnetic forces during a short- circuit.

Bundle conductors are used to increase the amount of current that may be carried in a line. Due to the skin effect, ampacity of conductors is not proportional to cross section, for the larger sizes. Therefore, bundle conductors may carry more current for a given weight.

A bundle conductor results in lower reactance, compared to a single conductor. It reduces corona discharge loss at extra high voltage (EHV) and interference with communication systems. It also reduces voltage gradient in that range of voltage.

As a disadvantage, the bundle conductors have higher wind loading.

Circuits



Single 3-phase circuit carried by electricity pylon, with ground wire

A *single-circuit transmission line* carries conductors for only one circuit. For a three-phase system, this implies that each tower supports three conductors.

Typical double-circuit line

A *double-circuit transmission line* has two circuits. For three-phase systems, each tower supports and insulates six conductors. Single phase AC-power lines as used for traction current have four conductors for two circuits. Usually both circuits operate at the same voltage.

In HVDC systems typically two conductors are carried per line, but rarely only one pole of the system is carried on a set of towers.

In some countries like Germany most power lines with voltages above 100 kV are implemented as double, quadruple or in rare cases even decuple power line as rights of way are rare. Sometimes all conductors are installed with the erection of the pylons; often some circuits are installed later. A disadvantage of double circuit transmission lines is that maintenance works can be more difficult, as either work in close proximity of high voltage or switch-off of 2 circuits is required. In case of failure, both systems can be affected.

The largest double-circuit transmission line is the Kita-Iwaki Power line.

Ground wires

Overhead power lines are often equipped with a ground conductor (shield wire or overhead earth wire). A ground conductor is a conductor that is usually grounded (earthed) at the top of the supporting structure to minimize the likelihood of direct lightning strikes to the phase conductors. The ground wire is also a parallel path with the earth for fault currents in earthed neutral circuits. Very high-voltage transmission lines may have two ground conductors. These are either at the outermost ends of the highest cross beam, at two V-shaped mast points, or at a separate cross arm. Older lines may use surge arrestors every few spans in place of a shield wire; this configuration is typically found in the more rural areas of the United States. By protecting the line from lightning, the design of apparatus in substations is simplified due to lower stress on insulation. Shield wires on transmission lines may include optical fibers (OPGW), used for communication and control of the power system.

Medium-voltage distribution lines may have the grounded conductor strung below the phase conductors to provide some measure of protection against tall vehicles or equipment touching the energized line, as well as to provide a neutral line in Wyes wired systems.

Insulated conductors

While overhead lines are usually bare conductors, overhead insulated cables are rarely used, usually for short distances (less than a kilometer). Insulated cables can be directly fastened to structures without insulating supports. An overhead line with bare conductors insulated by air is typically less costly than a cable with insulated conductors.

A more common approach is "covered" line wire. It is treated as bare cable, but often is safer for wildlife, as the insulation on the cables increases the likelihood of a large wing-span raptor to survive a brush with the lines, and reduces the overall danger of the lines slightly. These types of lines are often seen in the eastern United States and in heavily wooded areas, where tree-line contact is likely. The only pitfall is cost, as insulated wire is often costlier than its bare counterpart. Many utility companies implement covered line wire as jumper material where the wires are often closer to each other on the pole, such as an underground riser/Pothead, and on recloses cutouts and the like.

Losses

Transmitting electricity at high voltage reduces the fraction of energy lost to resistance, which is around 7%. For a given amount of power, a higher voltage reduces the current and thus the resistive losses in the conductor. For example, raising the voltage by a factor of 10 reduces the current by a corresponding factor of 10 and therefore the I^2R losses by a factor of 100, provided the same sized conductors are used in both cases. Even if the conductor size (cross-sectional area) is reduced 10-fold to match the lower current the I^2R losses are still reduced 10-fold. Long distance transmission is typically done with overhead lines at voltages of 115 to 1,200 kV. At extremely high voltages, more than 2 MV between conductor and ground, corona discharge losses are so large that they can offset the lower resistance loss in the line conductors. Measures to reduce corona losses include conductors having large diameter; often hollow to save weight, or bundles of two or more conductors.

Transmission and distribution losses in the USA were estimated at 6.6% in 1997 and 6.5% in 2007. In general, losses are estimated from the discrepancy between energy produced (as reported by power plants) and energy sold to end customers; the difference between what is produced and what is consumed constitute transmission and distribution losses.

As of 1980, the longest cost-effective distance for DC electricity was 7,000 km (4,300 mi) (4,000 km (2,500 mi) for AC), although all present transmission lines are considerably shorter.

In an alternating current circuit, the inductance and capacitance of the phase conductors can be significant. The currents that flow in these components of the circuit impedance constitute reactive power, which transmits no energy to the load. Reactive current causes extra losses in the transmission circuit. The ratio of real power (transmitted to the load) to apparent power is the power factor. As reactive current increases, the reactive power increases and the power factor decreases. For systems with low power factors, losses are higher than for systems with high power factors. Utilities add capacitor banks and other components (such as phase-shifting transformers; static VAR compensators; physical transposition of the phase conductors; and flexible AC transmission systems, FACTS) throughout the system to control reactive power flow for reduction of losses and stabilization of system voltage.

Sub transmission

Sub transmission is part of an electric power transmission system that runs at relatively lower voltages. It is uneconomical to connect all distribution substations to the high main transmission voltage, because the equipment is larger and more expensive. Typically, only larger substations connect with this high voltage. It is stepped down and sent to smaller substations in towns and neighborhoods. Sub transmission circuits are usually arranged in loops so that a single line failure does not cut off service to a large number of customers for more than a short time. While sub transmission circuits are usually carried on overhead lines, in urban areas buried cable may be used.

There is no fixed cutoff between sub transmission and transmission, or sub transmission and distribution. The voltage ranges overlap somewhat. Voltages of 69 kV, 115 kV and 138 kV are often used for sub transmission in North America. As power systems evolved, voltages formerly used for transmission were used for sub transmission, and sub transmission voltages became distribution voltages. Like transmission, sub transmission moves relatively large amounts of power, and like distribution, sub transmission covers an area instead of just point to point.

Transmission grid exit

At the substations, transformers reduce the voltage to a lower level for distribution to commercial and residential users. This distribution is accomplished with a combination of sub-transmission (33 kV to 132 kV) and distribution (3.3 to 25 kV). Finally, at the point of use, the energy is transformed to low voltage (varying by country and customer requirements—see mains power systems).

High-voltage direct current

High voltage direct current (HVDC) is used to transmit large amounts of power over long distances or for interconnections between asynchronous grids. When electrical energy is required to be transmitted over very long distances, it is more economical to transmit using direct current instead of alternating current. For a long transmission line, the lower losses and reduced construction cost of a DC line can offset the additional cost of converter stations at each end. Also, at high AC voltages, significant (although economically acceptable) amounts of energy are lost due to corona discharge, the capacitance between phases or, in the case of buried cables, between phases and the soil or water in which the cable is buried.

HVDC is also used for long submarine cables because over about 30 km length AC can no longer be applied. In that case special high voltage cables for DC are built. Many submarine cable connections - up to 600 km length - are in use nowadays.

HVDC links are sometimes used to stabilize against control problems with the AC electricity flow. The power transmitted by an AC line increases as the phase angle between source end voltage and destination ends increases, but too great a phase angle will allow the generators at either end of the line to fall out of step. Since the power flow in a DC link is controlled independently of the phases of the AC networks at either end of the link, this stability limit does not apply to a DC line, and it can transfer its full thermal rating. A DC link stabilizes the AC grids at either end, since power flow and phase angle can be controlled independently.

In other words, to transmit AC power as AC when needed in either direction between Seattle and Boston would require the (highly challenging) continuous real-time adjustment of the relative phase of the two electrical grids. With HVDC instead the interconnection would: (1) Convert AC in Seattle into HVDC. (2) Use HVDC for the three thousand miles of cross country transmission. Then (3) convert the HVDC to locally synchronized AC in Boston, and optionally in other cooperating cities along the transmission route. One prominent example of such a transmission line is the Pacific DC Intertie located in the Western United States.

Limitations

The amount of power that can be sent over a transmission line is limited. The origins of the limits vary depending on the length of the line. For a short line, the heating of conductors due to line losses sets a thermal limit. If too much current is drawn, conductors may sag too close to the ground, or conductors and equipment may be damaged by overheating. For intermediate-length lines on the order of 100 km (62 mi), the limit is set by the voltage drop in the line. For longer AC lines, system stability sets the limit to the power that can be transferred. Approximately, the power flowing over an AC line is proportional to the site of the phase angle of the voltage at the receiving and transmitting ends. Since this angle varies depending on system loading and generation, it is undesirable for the angle to approach 90 degrees. Very approximately, the allowable product of line length and maximum load is proportional to the square of the system voltage. Series capacitors or phase-shifting transformers are used on long lines to improve stability. High-voltage direct current lines are restricted only by thermal and voltage drop limits, since the phase angle is not material to their operation.

Up to now, it has been almost impossible to foresee the temperature distribution along the cable route, so that the maximum applicable current load was usually set as a compromise between understanding of operation conditions and risk minimization. The availability of industrial Distributed Temperature Sensing (DTS) systems that measure in real time temperatures all along the cable is a first step in monitoring the transmission system capacity. This monitoring solution is based on using passive optical fibers as temperature sensors, either integrated directly inside a high voltage cable or mounted externally on the cable insulation. A solution for overhead lines is also available. In this case the optical fiber is integrated into the core of a phase wire of overhead transmission lines (OPPC). The integrated Dynamic Cable Rating (DCR) or also called Real Time Thermal Rating (RTTR) solution enables not only to continuously monitor the temperature of a high voltage cable circuit in real time, but to safely utilize the existing network capacity to its maximum. Furthermore it provides the ability to the operator to predict the behavior of the transmission system upon major changes made to its initial operating conditions.

Control

To ensure safe and predictable operation the components of the transmission system are controlled with generators, switches, circuit breakers and loads. The voltage, power, frequency, load factor, and reliability capabilities of the transmission system are designed to provide cost effective performance for the customers.

Load balancing

The transmission system provides for base load and peak load capability, with safety and fault tolerance margins. The peak load times vary by region largely due to the industry mix. In very hot and very cold climates home air conditioning and heating loads have an effect on the overall load. They are typically highest in the late afternoon in the hottest part of the year and in mid-mornings and mid-evenings in the coldest part of the year. This makes the power requirements vary by the season and the time of day. Distribution system designs always take the base load and the peak load into consideration.

The transmission system usually does not have a large buffering capability to match the loads with the generation. Thus generation has to be kept matched to the load, to prevent overloading failures of the generation equipment.

Multiple sources and loads can be connected to the transmission system and they must be controlled to provide orderly transfer of power. In centralized power generation, only local control of generation is necessary, and it involves synchronization of the generation units, to prevent large transients and overload conditions.

In distributed power generation the generators are geographically distributed and the process to bring them online and offline must be carefully controlled. The load control signals can either be sent on separate lines or on the power lines themselves. To load balance the voltage and frequency can be used as a signaling mechanism.

In voltage signaling, the variation of voltage is used to increase generation. The power added by any system increases as the line voltage decreases. This arrangement is stable in principle. Voltage based regulation is complex to use in mesh networks, since the individual components and set points would need to be reconfigured every time a new generator is added to the mesh.

In frequency signaling, the generating units match the frequency of the power transmission system. In droop speed control, if the frequency decreases, the power is increased. (The drop in line frequency is an indication that the increased load is causing the generators to slow down.)

Wind turbines, v2g and other distributed storage and generation systems can be connected to the power grid, and interact with it to improve system operation.

Failure protection

Under excess load conditions, the system can be designed to fail gracefully rather than all at once. Brownouts occur when the supply power drops below the demand. Blackouts occur when the supply fails completely.

Rolling blackouts (also called load shedding) are intentionally engineered electrical power outages, used to distribute insufficient power when the demand for electricity exceeds the supply.

Communications

Operators of long transmission lines require reliable communications for control of the power grid and, often, associated generation and distribution facilities. Fault-sensing protective relays at each end of the line must communicate to monitor the flow of power into and out of the protected line section so that faulted conductors or equipment can be quickly de-energized and the balance of the system restored. Protection of the transmission line from short circuits and other faults is usually so critical that common carrier telecommunications are insufficiently reliable, and in remote areas a common carrier may not be available. Communication systems associated with a transmission project may use:

- Microwaves
- Power line communication
- Optical fibers

Rarely, and for short distances, a utility will use pilot-wires strung along the transmission line path. Leased circuits from common carriers are not preferred since availability is not under control of the electric power transmission organization.

Transmission lines can also be used to carry data: this is called power-line carrier, or PLC. PLC signals can be easily received with a radio for the long wave range.

Optical fibers can be included in the stranded conductors of a transmission line, in the overhead shield wires. These cables are known as optical ground wire (*OPGW*). Sometimes a standalone cable is used, all-dielectric self-supporting (*ADSS*) cable, attached to the transmission line cross arms.

Some jurisdictions, such as Minnesota, prohibit energy transmission companies from selling surplus communication bandwidth or acting as a telecommunications common carrier. Where the regulatory structure permits, the utility can sell capacity in extra dark fibers to a common carrier, providing another revenue stream.

Health concerns

Many recent large studies, including a large United States study, have failed to find any link between living near power lines and developing any sickness or diseases such as cancer. The study found that it didn't matter how close you were to a power line or a sub-station, there was no increased risk of cancer or illness.

The mainstream scientific evidence suggests that low-power, low-frequency, electromagnetic radiation associated with household currents and high transmission power lines does not constitutes a short or long term health hazard. Some studies have found statistical correlations between various diseases and living or working near power lines, but no adverse health effects have been substantiated for people not living close to power lines.

There are established biological effects for acute *high* level exposure to magnetic fields well above 100 µT. In a residential setting, there is "limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals", in particular, childhood leukemia, *associated with* average exposure to residential power-frequency magnetic field above 0.3 to 0.4 µT. These levels exceed average residential power-frequency magnetic fields in homes which are about 0.07 µT in Europe and 0.11 µT in North America.

Government policy

Historically, local governments have exercised authority over the grid and have significant disincentives to take action that would benefit states other than their own. Localities with cheap electricity have a disincentive to making interstate commerce in electricity trading easier, since other regions will be able to compete for local energy and drive up rates. Some regulators in Maine for example do not wish to address congestion problems because the congestion serves to keep Maine rates low. Further, vocal local constituencies can block or slow permitting by pointing to visual impact, environmental, and perceived health concerns. In the US, generation is growing 4 times faster than transmission, but big transmission upgrades require the coordination of multiple states, a multitude of interlocking permits, and cooperation between significant portions of the 500 companies that own the grid. From a policy perspective, the control of the grid is balkanized, and even former energy secretary Bill Richardson refers to it as a *third world grid*. There have been efforts in the EU and US to confront the problem. The US national security interest in significantly growing transmission capacity drove passage of the 2005 energy act giving the Department of Energy the authority to approve transmission if states refuse to act. However, soon after using its power to designate two National Interest Electric Transmission Corridors, 14 senators signed a letter stating the DOE was being too aggressive.

Special transmission

Grids for railways

In some countries where electric trains run on low frequency AC (e.g., 16.7 Hz and 25 Hz) power, there are separate single phase traction power networks operated by the railways. These grids are fed by separate generators in some traction power stations or by traction current converter plants from the public three phase AC network.

Superconducting cables

High-temperature superconductors promise to revolutionize power distribution by providing lossless transmission of electrical power. The development of superconductors with transition temperatures higher than the boiling point of liquid nitrogen has made the concept of superconducting power lines commercially feasible, at least for high-load applications. It has been estimated that the waste would be halved using this method, since the necessary refrigeration equipment would consume about half the power saved by the elimination of the majority of resistive losses. Some companies such as Consolidated Edison and American Superconductor have already begun commercial production of such systems. In one hypothetical future system called a SuperGrid, the cost of cooling would be eliminated by coupling the transmission line with a liquid hydrogen pipeline.

Superconducting cables are particularly suited to high load density areas such as the business district of large cities, where purchase of an easement for cables would be very costly.

Single wire earth return

Single-wire earth return (SWER) or single wire ground return is a single-wire transmission line for supplying single-phase electrical power for an electrical grid to remote areas at low cost. It is principally used for rural electrification, but also finds use for larger isolated loads such as water pumps, and light rail. Single wire earth return is also used for HVDC over submarine power cables.

Wireless power transmission

Both Nikola Tesla and Hidetsugu Yagi attempted to devise systems for large scale wireless power transmission, with no commercial success.

Wireless power transmission has been studied for transmission of power from solar power satellites to the earth. A high power array of microwave transmitters would beam power to a retina. Major engineering and economic challenges face any solar power satellite project.