Electric Power Transmission – How It Began and from Where

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In the early days of electric power usage, widespread transmission of electric power had two obstacles. First, devices requiring different voltages required specialized generators with their own separate lines. Street lights, electric motors in factories, power for streetcars and lights in homes are examples of the diversity of devices with voltages requiring separate systems. Secondly, generators had to be relatively near their loads (a mile or less for low voltage devices). It was known that longer distance transmission was possible the higher the voltage was raised, so both problems could be solved if transforming voltages from a single universal power line could be done efficiently.

Streetcars created enormous demand for early electricity. This Siemens Tram from 1884 required 500 V DC current, which was typical.

Much of early electricity was DC, which could not easily be increased or decreased in voltage either for long-distance transmission or for sharing a common line to be used with multiple types of electric devices. Companies simply ran different lines for the different classes of loads their inventions required. Due to this specialization of lines, and because transmission was so inefficient, it seemed at the time that the industry would develop into what is now known as a distributed generation system with large numbers of small generators located near their loads.

Early high voltage exterior lighting

High voltage was of interest to early researchers working on the problem of transmission over distance. They knew from elementary electricity principle that the same amount of power could be transferred on a cable by doubling the voltage and halving the current. Due to Joules Law, they also knew that the power lost from heat in a wire is proportional to the square of the current traveling on it, regardless the voltage, and so by doubling the voltage, the same cable would be capable of transmitting the same amount of power four times the distance.

The idea of investing in a central plant and a network to deliver energy produced to customers who pay a recurring fee for service was familiar business model for investors. It was identical to the lucrative gaslight business, or the hydraulic and pneumatic power transmission systems. The only difference was the commodity being delivered was electricity, not gas, and the "pipes" used for delivering were more flexible.

The PG&E in San Francisco in 1879 used two direct current generators from Charles Brush's company to supply multiple customers with power for their arc lamps. This San Francisco system was the first case of utility selling electricity from a central plant to multiple customers. CEC soon opened a second plant with 4 additional generators.
Grand Rapids Electric Light & Power Company, established in March 1880 began operation of the world's first commercial central station hydroelectric power plant, Saturday, July 24, 1880, getting power from Wolverine Chair and Furniture Company's water turbine. It operated a 16-light Brush electric dynamo lighting several storefronts in Grand Rapids, Michigan. It is the earliest predecessor of consumer's energy, Michigan.

Direct current lighting

Early arc lights were extremely bright and the high voltages presented a sparking / fire hazard, making them too dangerous to use indoors. In 1878 inventor, Thomas Edison, saw a market for a system that could bring electric lighting directly into a customer's business or home, a niche not served by arc lighting systems. After devising a commercially viable incandesce light bulb in 1879, Edison went on to develop the first large scale investor-owned electric illumination Utility.

Availability of large-scale generation

Availability of large amounts of power from diverse locations would become possible after ‘ production of turbo generators in 1889. Turbo generator output quickly jumped from 100 kW to 25 megawatts in two decades. Prior to efficient turbo generators, hydroelectric projects were a significant source of large amounts of power requiring transmission infrastructure.

Transformers and alternating currents

When George Westinghouse became interested in electricity, he quickly and correctly concluded that Edison's low voltages were too inefficient to be scaled up for transmission needed for large systems. He further understood that long-distance transmission needed high voltage and that inexpensive conversion technology only existed for alternating current. Transformers would play the decisive role in the victory of alternating current over direct current for transmission and distribution systems. In 1881, Lucien Gaulard and John Dixon Gibbs developed a more efficient device which they dubbed the secondary generator, namely an early step down transformer whose ratio could be adjusted by configuring the connections between a series of wired bobbins around a spindle, from which an iron core could be added or removed as necessary to vary the power output.

The first demonstrative long-distance (34 km, 21 mi) AC line was built in 1884. It was powered by a 2 kV, 130-Hz alternator and featured several Gaulard secondary generators with their primary windings connected in series, which fed incandescent lamps. The system proved the feasibility of AC electric power transmission over long distances.
Between 1884 and 1885, Hungarian engineers Zipernowsky, Bláthy, and Déri from the Ganz company in Budapest created the efficient closed-core coils, as well as the modern electric distribution system. The three had discovered that all former coreless or open-core devices were incapable of regulating voltage, and were therefore impractical. Their joint patent described two versions of a design with no poles, the "closed-core transformer" and the "shell-core transformer".

A very first operative AC line was put into service in 1885 for public lighting. It was powered by two Siemens & Halske alternators rated 30 HP (22 kW), 2 kV at 120 Hz and used 200 series-connected Gaulard 2-kV/20-V step-down transformers provided with a closed magnetic circuit, one for each lamp. Few months later it was followed by the first British AC system at the Grosvenor Gallery, London. It also featured Siemens alternators and 2.4-kV/100-V step-down transformers, one per user, with shunt-connected primaries.

The concept that is the basis of modern transmission using inexpensive step up and step down transformers was first implemented by Westinghouse in 1886 The modern 3-phase system was developed in Europe, starting in 1889. The International Electro-Technical Exhibition of 1891, in Germany, featured the long-distance transmission of high-power, three-phase AC. The exhibition featured the first long-distance transmission of high-power, three-phase AC, which was generated 175 km away. It successfully operated motors and lights at the fair. The technical advisers and representatives were impressed. As a result of the successful field trial, three-phase current, as far as Germany was concerned, became the most economical means of transmitting electrical energy.

The simplicity of polyphase generators and motors meant that besides their efficiency they could be manufactured cheaply, compactly and would require little attention to maintain. Simple economics would drive the expensive, bulky and mechanically complex DC dynamos to their ultimate extinction. As it turned out, the deciding factor was the availability of low cost step up and step down transformers that meant that all customers regardless of their specialized voltage requirements could be served at minimal cost of conversion. This "universal system" is today regarded as one of the most influential innovations for the use of electricity.

High voltage direct current transmission

The case for alternating current was not clear at the turn of the century and high voltage direct current transmission systems were successfully installed without the benefit of transformers. Rene Thury, who had spent six months at Edison's Menlo Park facility, understood his problem with transmission and was convinced that moving electricity over great distances was possible using direct current. Thury developed this idea into the first commercial system for high-voltage DC transmission. Like Brush's dynamos, current is kept constant, and when increasing load demands more pressure, voltage is increased. This system was successfully used on several DC transmission projects from Hydro generators. The first in 1885 was a low voltage system and the first high voltage system went into service in 1889 in Italy.

Ultimately the AC

Ultimately, the versatility of the Thury system was hampered by the fragility of series distribution, and the lack of a reliable DC conversion technology that would not show up until the 1940s. The AC "universal system" won by force of numbers, proliferating systems with transformers both to couple generators to high-voltage transmission lines, and to connect transmission to local distribution circuits. By using common generating plants for every type of load, important economies of scale were achieved, lower overall capital investment was required, load factor on each plant was increased allowing for higher efficiency, allowing for a lower cost of energy to the consumer and increased overall use of electric power.

By allowing multiple generating plants to be interconnected over a wide area, electricity production cost was reduced. The most efficient available plants could be used to supply the varying loads during the day. Reliability was improved and capital investment cost was reduced, since stand-by generating capacity could be shared over many more customers and a wider geographic area. Remote and low-cost sources of energy, such as hydroelectric power or mine-mouth coal, could be exploited to lower energy production cost.

The first transmission of three-phase alternating current using high voltage took place in 1891 during the international electricity exhibition in Frankfurt. The 15 kV transmission line connected 175 km (109 mi) apart.

Early 20th century

The first 110 kV transmission line in Europe was built around 1912.

Voltages used for electric power transmission increased throughout the 20th century. The first "high voltage" AC power station, rated 4-MW 10-kV 85-Hz, was put into service in 1889 London. The first electric power transmission line in North America operated at 4000 V. It went online on June 3, 1889 for 13 miles. By 1914 fifty-five transmission systems operating at more than 70,000 V were in service, and the highest voltage then used was 150 kV. The first three-phase alternating current power transmission at 110 kV took place in 1907.
In the early 1920s the Pit River – Cottonwood – Vaca-Dixon line was built for 220 kV transporting power from hydroelectric plants in the Sierra Nevada to the San Francisco Bay Area, at the same time the Big Creek – Los Angeles lines were upgraded to the same voltage. Both of those systems entered commercial service in 1923. On April 17, 1929 the first 220 kV line in Germany was completed, running from Brauweiler near Cologne, over Kelsterbach near Frankfurt, Rheinau near Mannheim, Ludwigsburg–Hoheneck near Austria. This line comprises the North-South interconnect, at the time one of the world's largest power systems. The masts of this line were designed for eventual upgrade to 380 kV. However the first transmission at 380 kV in Germany was on October 5, 1957 between the substations in Rommerskirchen and Ludwigsburg–Hoheneck.

The world's first 380 kV power line was built in Sweden, the 952 km Harsprånget – Hallsberg line in 1952. In 1965, the first extra-high-voltage transmission at 735 kV took place on a Hydro-Québec transmission line. In 1982 the first transmission at 1200 kV was in the Soviet Union.

The rapid industrialization in the 20th century made electrical transmission lines and grids a critical part of the economic infrastructure in most industrialized nations. Interconnection of local generation plants and small distribution networks was greatly spurred by the requirements of World War I, where large electrical generating plants were built by governments to provide power to munitions factories; later these plants were connected to supply civil load through long-distance transmission.

In 1926 electrical networks in the United Kingdom began to be interconnected in the National Grid, initially operating at 132 kV.