Analyse secondary information on the competition between Westinghouse and Edison to supply electricity to cities

In the late nineteenth century, Edison favoured generating and supplying direct current (DC) electricity while Westinghouse promoted the use of alternating current (AC) electricity.

Edison had the initial advantage that the technology for generating DC was well established and DC worked well over short distances. However, DC could only be generated and distributed at the voltages at which it was used by consumers. This meant that currents in conductors were large, leading to huge and expensive energy losses over distances of more than one or two kilometres. To supply a large city required many power stations throughout the city and an unattractive proliferation of wires to carry the required current.

The great advantage of AC was that, through the use of transformers the voltage could be stepped up or down as required. This meant that AC could be generated at moderately low voltages, stepped up to high voltages for transmission over great distances and stepped down again to lower voltages for consumers. The higher voltage meant that AC could be transmitted over greater distances than DC, with smaller energy losses. Power stations could be fewer and further apart and conductors could be lighter.

The economic advantages of AC, including the smaller energy losses and the economy of scale in needing fewer power stations further apart, along with the unattractive web of wires required for DC, supported Westinghouse's solution to the supply of electricity over Edison's. AC received a boost in popularity with Tesla's invention of the induction motor which operates only on AC.

Competition was not always open and fair. Edison had a vested interest in DC as he owned hundreds of DC power stations and all of his many electrical inventions to that time ran on DC. Edison attempted to prove that AC was very dangerous by electrocuting animals on stage and convincing authorities to use AC for the first electric chair. He resorted to legal tactics in an attempt to have AC banned and to prevent its use with his inventions. Edison seems to have unreasonably shunned AC electricity. Demonstrations (such as the Chicago World Fair and Frankfurt/Lauffen) eventually swayed observers to notice AC as superior transmission.

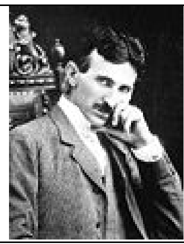
Westinghouse eventually undercut Edison on two major the projects – the Chicago World Fair and production of a hydroelectric plant at Niagara Falls (to Buffalo, 30 km away), due to the superiority of AC and their lower-costed bids. AC was recognized as superior due to less attenuation and power loss, letting it become cheaper. AC eventually came to be the dominant form in which electricity is generated world-wide.

But DC has the advantage of not causing losses through electromagnetic radiation or magnetic induction. With solid-state switching it is now relatively simple to change between DC and AC at high or low voltages. High voltage DC transmission is now practicable. Scientists are striving to develop super-conducting wires for power transmission. If they do, DC could become the preferred current for long distance transmission.

THE WAR OF CURRENTS

Introduction

In the "**War of Currents**" era (sometimes, "***War of the Currents***" or "***Battle of Currents***") in the late 1880s, George Westinghouse and Thomas Edison became adversaries due to Edison's promotion of direct current (DC) for electric power distribution over the alternating current (AC) advocated by Westinghouse and Nikola Tesla.

		
Thomas Edison, American inventor and businessman, was known as "The Wizard of Menlo Park" and pushed for the development of a DC power network.	George Westinghouse, American entrepreneur and engineer, backed financially the development of a practical AC power network.	Nikola Tesla, Serbian-American inventor, physicist, and electro-mechanical engineer, was known as "The Wizard of The West" and was instrumental in developing AC networks.

During the initial years of electricity distribution, Edison's direct current was the standard for the United States and Edison was not disposed to lose all his patent royalties. Direct current worked well with incandescent lamps that were the principal load of the day, and with motors. Direct current systems could be directly used with storage batteries, providing valuable load-levelling and backup power during interruptions of generator operation. From his work with rotary magnetic fields, Tesla devised a system for generation, transmission, and use of AC power. He partnered with George Westinghouse to commercialize this system. Westinghouse had previously bought the rights to Tesla's polyphase system patents and other patents for AC transformers from Lucien Gaulard and John Dixon Gibbs.

Several undercurrents lay beneath this rivalry. Edison was a brute-force experimenter, but was no mathematician. AC cannot really be understood or exploited without a substantial understanding in mathematics and mathematical physics, which Tesla had. Tesla had worked for Edison but was undervalued. Bad feelings were exacerbated because Tesla had been cheated by Edison of promised compensation for his work. Edison would later come to regret that he had not listened to Tesla and used alternating current.

POWER TRANSMISSION

The competing systems

Edison's DC distribution system consisted of generating plants feeding heavy distribution conductors, with customer loads (lighting and motors) tapped off it. The system operated at the same voltage level throughout; for example, 100 volt lamps at the customer's location would be connected to a generator supplying 110 volts, to allow for some voltage drop in the wires between the generator and load. The voltage level was chosen for convenience in lamp manufacture; high-resistance carbon filament lamps could be constructed to withstand 100 volts, and to provide lighting performance economically competitive with gas lighting. At the time it was felt that 100 volts was not likely to present a severe hazard of electrocution.

Howeverthe voltage drop due to the resistance of the system conductors was so high that generating plants had to be located within a mile (1–2 km) or so of the load. Higher voltages could not so easily be used with the DC system because there was no efficient low-cost technology that would allow reduction of a high transmission voltage to a low utilization voltage.

In the alternating current system, a transformer was used between the (relatively) high voltage distribution system and the customer loads. Lamps and small motors could still be operated at some convenient low voltage. However, the transformer would allow power to be transmitted at much higher voltages, of say, ten times that of the loads. For a given quantity of power transmitted, the wire size would be inversely proportional to the voltage used; or to put it another way, the allowable length of a circuit, given a wire size and allowable voltage drop, would increase approximately as the square of the distribution voltage. This had the practical significance that fewer, larger, generating plants could serve the load in a given area. Large loads, such as industrial motors or converters for electric railway power, could be served by the same distribution network that fed lighting, by using a transformer with a suitable secondary voltage.

Early transmission analysis

Edison's response to the DC system limitations was to generate power close to where it was consumed (today called, distributed generation) and install large conductors to handle the growing demand for electricity, but this solution proved to be costly (especially for rural areas which could not afford building a local station or paying for massive amounts of very thick copper wire), impractical (including, but not limited to, inefficient voltage conversion), and unmanageable. Edison and his company, though, would have profited extensively from the construction of the multitude of power plants required for introducing electricity to many communities.

Direct current could not easily be changed to higher or lower voltages. This meant that separate electrical lines had to be installed in order to supply power to appliances that used different voltages, for example, lighting and electric motors. This led to a greater number of wires to lay and maintain, wasting money and introducing unnecessary hazards.

Alternating current could be transmitted over long distances at high voltages, at lower current for lower voltage drops (thus with greater transmission efficiency), and then conveniently stepped down to low voltages for use in homes and factories. When Tesla introduced a system for alternating current generators, transformers, motors, wires and lights in November and December of 1887, it became clear that AC was the future of electric power distribution, although DC distribution was used in downtown metropolitan areas for decades thereafter.

Low frequency (50 - 60 Hz) alternating currents can be more dangerous than similar levels of DC since the alternating fluctuations can cause the heart to lose coordination, inducing fibrillation, which then rapidly leads to death within six to eight minutes from anoxia of the brain and medulla. High voltage DC power can be more dangerous than AC, however, since it tends to cause muscles to lock in position, stopping the victim from releasing the energised conductor once grasped. However, any practical distribution system will use voltage levels quite sufficient for a dangerous amount of current to flow, whether it uses alternating or direct current. Since the precautions against electrocution are similar, ultimately, the advantages of AC power transmission outweighed this theoretical risk, and it was eventually adopted as the standard worldwide.

Transmission loss

The advantage of AC for distributing power over a distance is due to the ease of changing voltages with a transformer. Power is the product of current x voltage ($P = IV$). For a given amount of power, a low voltage requires a higher current and a higher voltage requires a lower current. Since metal conducting wires have a certain resistance, some power will be wasted as heat in the wires. This power loss is given by $P = I^2R$. Thus, if the overall transmitted power is the same, and given the constraints of practical conductor sizes, low-voltage, high-current transmissions will suffer a much greater power loss than high-voltage, low-current ones. This holds whether DC or AC is used. However, it was very difficult to transform DC power to a high-voltage, low-current form efficiently, whereas with AC this can be done with a simple and efficient transformer. This was the key to the success of the AC system. Modern transmission grids regularly use AC voltages up to 765,000 volts.

Alternating current transmission lines do have other losses not observed with direct current. Due to the skin effect, a conductor will have a higher resistance to alternating current than to direct current; the effect is measurable and of practical significance for large conductors carrying on the order of thousands of amperes. The increased resistance due to skin effect can be offset by changing the shape of conductors.

Current Wars

Edison's publicity campaign

Edison carried out a campaign to discourage the use of alternating current, including spreading information on fatal AC accidents, killing animals, and lobbying against the use of AC in state legislatures. Edison directed his technicians, primarily Arthur Kennelly and Harold P. Brown, to preside over several AC-driven executions of animals, primarily stray cats and dogs but also unwanted cattle and horses. Acting on these directives, they were to demonstrate to the press that alternating current was more dangerous than Edison's system of direct current. Edison's series of animal executions peaked with the electrocution of Topsy the Elephant. He also tried to popularize the term for being electrocuted as being "Westinghoused". He also published an 83-page publication entitled "A Warning! From the Edison Electric Light Co." in which he described the horrible supposed deaths when in contact with Westinghouse's AC systems.

Edison opposed capital punishment, but his desire to disparage the system of alternating current led to the invention of the electric chair. Harold P. Brown, who was at this time being secretly paid by Edison, constructed the first electric chair for the state of New York in order to promote the idea that alternating current was deadlier than DC. Westinghouse supposedly hired the best lawyer of the day to defend Kemmler and to attack electrocution as a 'cruel and unusual form of punishment', which are banned by the Bill of Rights.

When the chair was first used, on August 6, 1890, the technicians on hand misjudged the voltage needed to kill the condemned prisoner, William Kemmler. The first jolt of electricity was not enough to kill Kemmler, and left him only badly injured. The procedure had to be repeated and a reporter on hand described it as "an awful spectacle, far worse than hanging." George Westinghouse commented: "They would have done better using an axe." This led to Edison's credibility being damaged.

Shortly after this, Westinghouse won the bid for illuminating The Chicago World's Fair incorporating the 400th anniversary of the discovery of America by Columbus, undercutting Edison's 1 million dollar bid by half. The 27 million people attending the Fair were suitable impressed by the 100,000 lights powered by 12 AC generators, and, from then on, 80% of appliances were built for AC.

In 1891, the International Electrical Exhibition was held in Frankfurt, Germany. An AC line was set up to carry sizble quantities of electrical power over 180km (Frankfurt to Lauffen). Westinghouse's AC line only lost 23% and this demonstration solidified AC as a reliable source.

Niagara Falls

Experts announced proposals to harness Niagara Falls for generating electricity, even briefly considering compressed air as a power transmission medium. Against General Electric and Edison's proposal, Westinghouse, using Tesla's AC system, won the international Niagara Falls Commission contract. The commission was led by Lord Kelvin and backed by entrepreneurs such as J. P. Morgan, Lord Rothschild, and John Jacob Astor IV. Work began in 1893 on the Niagara Falls generation project and electric power at the Falls was generated and transmitted as alternating current.

Some doubted that the system would generate enough electricity to power industry in Buffalo. Tesla was sure it would work, saying that Niagara Falls had the ability to power the entire eastern U.S. Polyphase alternating current transmission had been previously demonstrated at Mill Creek California, and the Lauffen-Neckar demonstration in 1891. The Chicago World's Fair in 1893 exhibited a complete polyphase generation and distribution system installed by Westinghouse. However, none of the previous demonstration projects were on the scale of power available from Niagara. On November 16, 1896, electrical power was sent from Niagara Falls to industries in Buffalo from the hydroelectric generators at the Edward Dean Adams Station. The hydroelectric generators were built by Westinghouse Electric Corporation using Tesla's AC system patent. The nameplates on the generators bore Tesla's name. To appease the interests of General Electric, the contract to construct the transmission lines to Buffalo using the Tesla patents were given to them.

Competition outcome

AC replaced DC for central station power generation and power distribution, enormously extending the range and improving the safety and efficiency of power distribution. Edison's low-voltage distribution system using DC ultimately lost to AC devices proposed by others: primarily Tesla's polyphase systems. Tesla's Niagara Falls system was a turning point in the acceptance of alternating current. Eventually, Edison's General Electric company converted to the AC system and began manufacture of AC machines. Centralized power generation became possible when it was recognized that alternating current electric power lines can transport electricity at low costs across great distances by taking advantage of the ability to transform the voltage using power transformers.

Alternating current electricity distribution is today the penultimate stage in the delivery (before retail) of electricity to end users. It is generally considered to include medium-voltage (less than 50 kV) power lines, electrical substations and pole-mounted transformers, low-voltage (less than 1000 V) distribution wiring and sometimes electricity meters. Power transformers, installed at substations, could be used to raise the voltage from the generators and reduce it to supply loads. Increasing the voltage reduced the current in the transmission and distribution lines and hence the size of conductors required and distribution losses incurred. This made it more economical to distribute power over long distances. Generators (such as hydroelectric sites) could be located far from the loads.

Alternating current transmission was simpler; the processes involved were recognized as easier, faster and less expensive to implement. This allowed the rapid deployment of bulk transfer systems for electrical power from place to place to bring about the electrification of America. Typically, the main power transmission was between the power plant and a substation near a populated area. Due to the large amount of power involved, the transmission normally took place at high voltage and was transmitted over long distances through overhead high tension lines. Underground power transmission was used only in densely populated areas (such as large cities) because of the high cost of installation and maintenance and because the power losses increase dramatically compared with overhead transmission. Underground high voltage transmission uses much lower voltages to avoid discharge to the surrounding ground, and lower voltages require much thicker wires unless superconductors and cryogenic technology are used. Alternating current power transmission system grids today provide redundant paths and lines for power routing from any power plant to any load center, via any possible route, based on the economics of the transmission path, the cost of power and the perceived importance of keeping a particular load center powered at all times.

Engineers today design alternating current transmission networks in such a way as to transport the energy as efficiently as possible 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.

Remnant and existent DC systems

Electric railways that use a third-rail system generally employ high-current DC power between 500 and 750 volts; railways with overhead catenary lines use a number of power schemes including both high-voltage AC and high-current DC.

High voltage direct current (HVDC) systems are used for bulk transmission of energy from distant generating stations or for interconnection of separate alternating-current systems. These HVDC systems use solid state devices that were unavailable during the War of Currents era. Power is still converted to and from alternating current at each side of the modern HVDC link. The advantages of present HVDC over historic AC systems for bulk transmission include higher power ratings for a given line (important since installing new lines and even upgrading old ones is extremely expensive) and better control of power flows, especially in transient and emergency conditions that can often lead to blackouts.

While direct current power distribution systems for transmission of power at utilization voltage over significant distances is essentially extinct, use of DC power is still common when transmission distances are small, and especially when energy storage or conversion uses batteries or fuel cells. These applications include:

- Vehicle starting, lighting, and ignition systems
- Hybrid and all-electric vehicle propulsion
- Telecommunication plant standby power (wired and cellular mobile)
- Uninterruptible power for computer systems
- Utility-scale battery systems
- "Off-grid" isolated power installations using wind or solar power

In these applications, direct current may be used directly or converted to alternating current using power electronic devices either for use by local AC equipment or for energy transmission by the AC distribution and transmission network. In the future this may provide a way to supply energy to a grid from distributed sources that many not inherently supply energy in the form of alternating current. For example, hybrid vehicle owners may rent the capacity of their vehicle's batteries for load-levelling purposes by the local electrical utility company.