War of Currents: AC vs DC

Global electrification began in the late 19th century, famously involving a no-holds-barred commercial contest between Thomas Edison promoting Direct Current (DC) on the one hand, and George Westinghouse marketing Alternating Current (AC) on the other. Westinghouse had licensed Nikola Tesla's AC intellectual property. Both contestants cut their teeth on coal-fired steam engines, soon graduating to hydroelectric generators. The generators converted mechanical energy into electrical, by the motion of a turbine in a magnetic field – the same physical principle of electromagnetic induction used in contemporary fossil fuel, nuclear, and hydropower plants. Mechanical motion in a magnetic field naturally produces AC electromagnetic power in oscillating electrical and magnetic fields. Edison built commutators that switched the polarity of electrical contacts, in sync with the oscillating fields, to convert the natural AC power output to DC. This technique was difficult to scale, particularly for larger hydroelectric plants. Consequently, Westinghouse won the war, clinching victory at Niagara Falls for a market defining hydropower project. Since then, AC transmission and distribution lines dominate worldwide electricity infrastructure. AC power generation has only recently been challenged by the growth of solar and wind power.

Electromagnetic induction generators work well for individual power delivery, but not when connected to a common electrical grid network. Maintaining a stable grid frequency and voltage becomes difficult. Synchronous generators (SGs) were developed in the early 20th century, in which voltage and frequency are independently controlled for the AC electric grid in a stable manner. Grid codes evolved for this setup. It is vital for solar photovoltaic (PV) project developers to understand the fundamentals of how SGs drive an AC grid, to integrate their PV systems – as explained in our guide "Managing Solar Energy". The SG voltage is controlled by an independent, external DC excitation current injected in the rotor magnetic field windings, while the frequency is set by the spinning motion of the rotor. Mechanical momentum of the SG provides physical inertia in the grid. The inertia of a SG machine is measured in seconds, and that of the whole grid network in MW-seconds.

AC dominates global electricity grids, but complicating factors arise in maintaining a synchronized frequency and stable voltage levels across long distances. Frequency deviations outside a narrow range require control responses at different timescales, ranging from sub-second fast frequency response to frequency restoration over tens of minutes. Voltage drops from inductive effects have to be locally compensated by reactive power along the grid network. Voltage fluctuations occur more rapidly than frequency disturbances. Phenomena such as inter-area oscillations have led to grid blackouts through cascading voltage and or frequency instabilities. Sub-synchronous oscillations can shut down power plants. DC grid networks do not carry such baggage.

If semiconductor technology was as advanced as it is now in the late 19th century, with thyristors for high-voltage/medium-voltage operations and renewables for large-scale DC power generation sources, the contest between Edison and Westinghouse might have had a different outcome. DC power flow is necessary for long-distance underwater power transmission. A growing number of electrical loads internally run on DC. Although DC lost out in the late 19th-early 20th century, it will continue to gain ground in the modern electricity grid.