DC Returns with Renewables

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Early Installations

Alternating current (ac) is well known to everyone as our homes, commercial entities and factories are supplied by ac. However, early installations were direct current (dc). World's first dc generation station was opened on 4 September 1882 at 257 Pearl Street, New York. This was as a result of the pioneering work of Thomas Alva Edition (Figure 1). Edison's power station began supplying electricity to customers in the First District, covering 0.65 square km area.

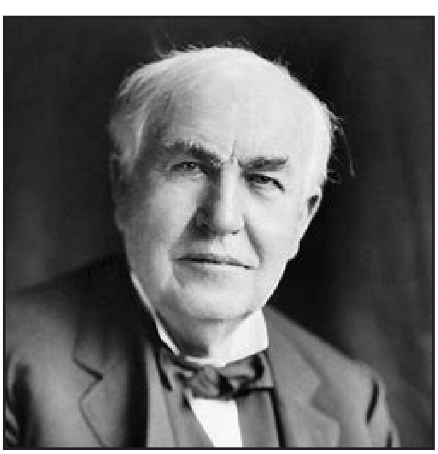
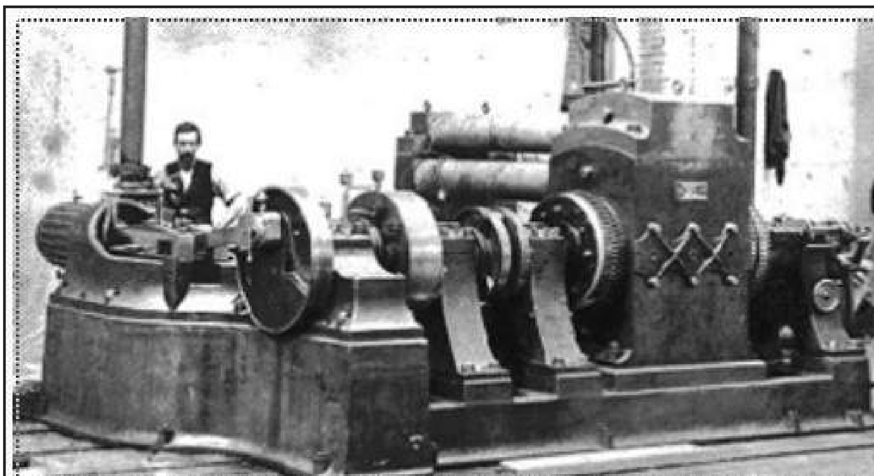


Figure 01 : Thomas Alva Edison (11 Feb 1847 - 18 Oct 1931)

To supply electric power to the lights within Pearl Street's service area, Edison and his team developed the 27-ton "Jumbo" constant-voltage dynamo (Figure 2). There were six dynamos installed at Pearl Street, and each had a capacity of about 100 kW. The dynamos were driven by reciprocating steam engines supplied by four coal-fired boilers.

Edition's project involved the installation of about 24.4 km of underground cables. The original system operated at 110 V dc and used a two-wire configuration. Because of the large amount of costly copper required, Edison quickly changed the cabling into a 220 V, a three-wire design that significantly reduced the amount of copper needed.

Followed by the Pearl Street station, hundreds of improved versions of the Pearl Street design were installed. However, a low-voltage dc system has inherent disadvantages, and the main one was high line losses that limit the distance that the dc electric power can be



Edison's Jumbo dynamo. Courtesy: National Park Service, Edison National Historic Site.

Figure 02 : Edison's Jumbo dynamo

economically transmitted.
By the mid-1880s, ac systems began to compete with Edison's dc system. The invention of the ac transformer by Nikola Tesla permitted the economic and efficient long-distance transmission of electric power at high voltages, thereby resolving the major disadvantage of low-voltage dc systems. Therefore, by the end of the 19th Century, dc systems began a gradual and inevitable decline.

HVDC Transmission

In the 20th Century, all low voltage electrical distributions were ac. Even though most of the high voltage (HV) circuits were also ac, with the invention of the mercury arc valve in 1902 by Peter Cooper Hewitt, there was an interest in dc transmission mainly to connect asynchronous systems. The mercury arc valve is an efficient ac to dc rectifier, and is shown in Figure 3. For example, in 1932, General Electric tested mercury-vapour valves, and constructed a 12 kV dc transmission line to convert 40 Hz generation to serve 60 Hz loads at Mechanicville, New York.

The Moscow–Kashira system originally built in Germany and installed in Russia in 1951, and the first commercial HVDC line between the mainland of Sweden and the island of Gotland built-in 1954, marked the beginning of the modern era of HVDC transmission. Mercury arc valves were common in systems designed up to 1972. The Nelson River Bipole 1 system in Manitoba, Canada is recognised as the last

Figure 03 : Probably the last operating mercury arc rectifier in the world; this is still serving students at the Department of Electrical and Electronic Engineering, University of Peradeniya

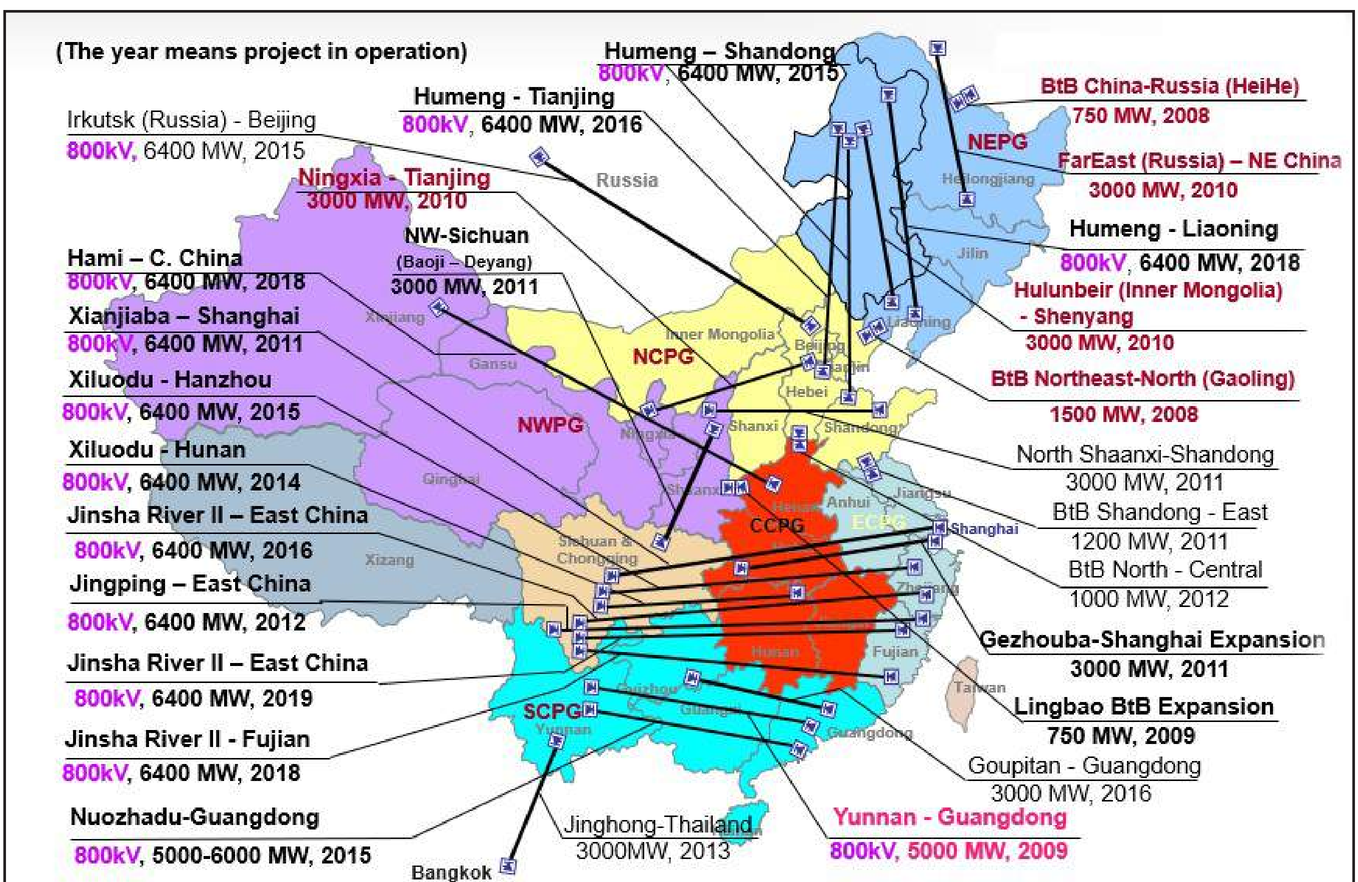


Figure 04 : HVDC connections in China

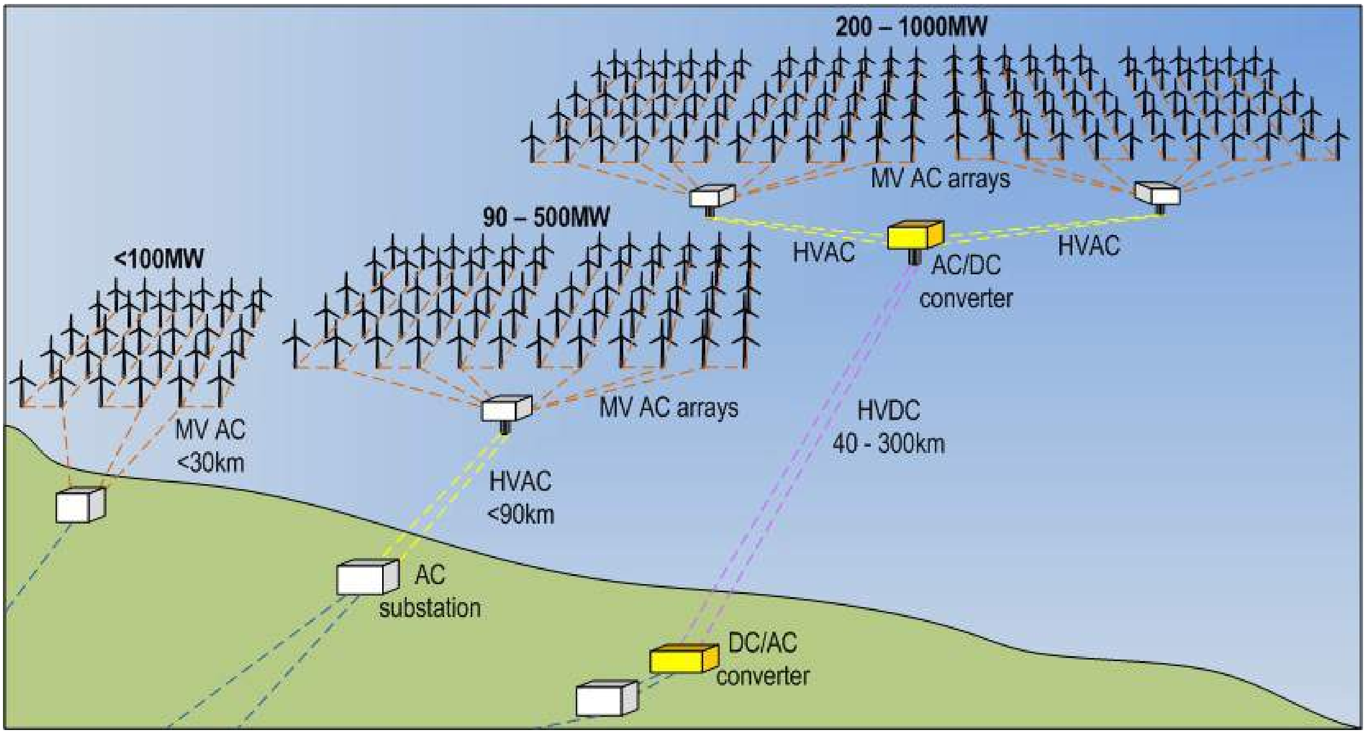


Figure 05 : Offshore wind farm connections

mercury arc HVDC system.
After the development of the silicon controlled rectifier (SCR) or thyristor in 1956 by power engineers at General Electric, all mercury arc HVDC systems have been either shut down or converted to use solid-state devices. The first complete HVDC scheme based on thyristor was the Eel River scheme in Canada, which was built by General Electric and went into service in 1972. Today, there are a large number of thyristor-based HVDC schemes operating in the world, while China being the pioneers. Figure 4 shows the HVDC schemes operating or planned in China as of 2020. Changji-Guquan, the world's first ±1,100 kV ultra-HVDC link, set a new world record in terms of voltage level, transmission capacity and distance. It is capable of transporting 12,000 megawatts over 3,000 km.

More HVDC schemes were developed due to some inherent advantages of dc schemes compared to their ac counterparts. There is a limit to the distance that bulk ac can be transmitted unless some form of reactive compensation is employed.
For long overhead lines, either alternating current with reactive compensation or direct current may be used. If undersea crossings greater than around 50 km are required, then, because of the capacitive charging current of ac cables, dc is the only alternative.

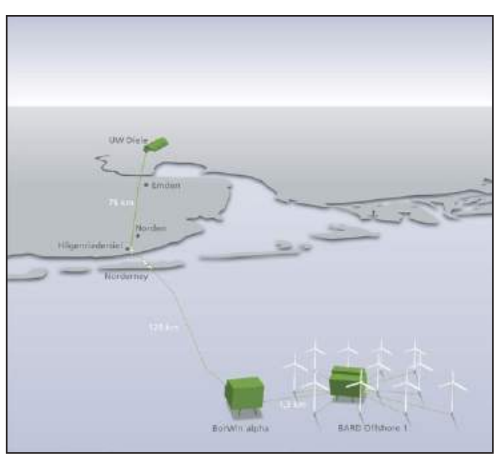


Figure 06 : BARD Offshore 1 connection

Further, HVDC allows the interconnection of two large ac systems without having to ensure synchronism (e.g. the U.K.-France cross-channel link of 2000 MW) and the interconnection between networks of different frequency (e.g. the connections between north and south islands in Japan, which use 50 Hz and 60 Hz systems).
Since about 2000, an alternative technology using voltage source converters (VSC), has become available although at lower power levels than thyristor-based HVDC. The valves of VSC HVDC use semiconductor devices such as Insulated Gate Bipolar Transistor (IGBT) that can be turned on and off (compared to thyristors that can only turn on and commutated using some extra circuitry). This ability to turn the valves on and off allows the converters to synthesise a voltage wave of any frequency, phase and magnitude, within the rating of the equipment.

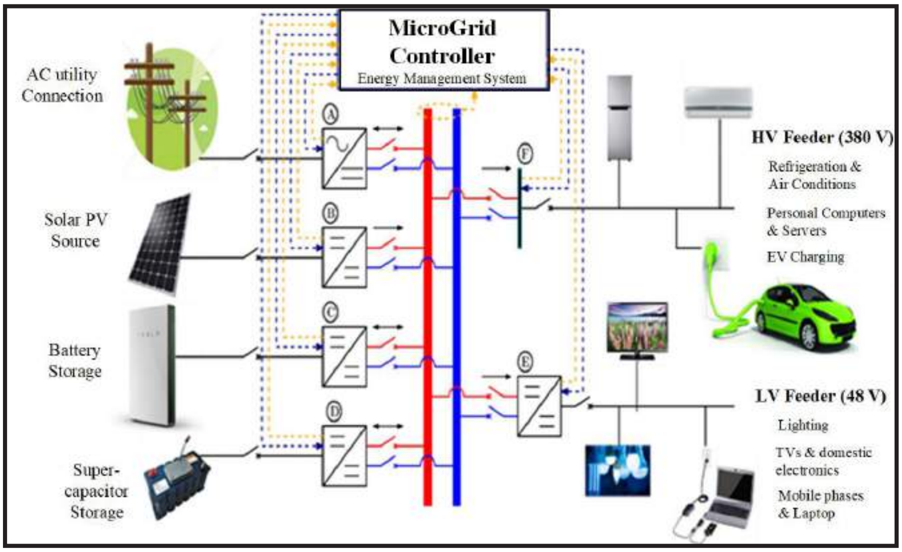


Figure 07 : Hub of a Dc Microgrid Developed by the Department of Electrical and Electronic Engineering, University of Peradeniya

DC for Renewable Connections

Today there is a growing interest for offshore wind farms. For large offshore sites that are far away from the main grid and generate 100s of MW of power, HVDC has become a preferred choice. Figure 5 shows the possible connection considerations for offshore wind farms. For offshore wind farms having generated power and distance of 200 MW, 300 km to 1000 MW, 40 km, HVDC is the preferred choice.

The German grid operator TenneT has already connected a number of offshore wind farms using HVDC technology. BARD Offshore 1 is the first offshore wind farm to be connected by HVDC. It employed more than 100 km of submarine cables. This connection is shown in Figure 6. With an output of 800 megawatts (MW), BorWin2 is the first large-scale offshore connection that TenneT has implemented. Since January 2015, two offshore wind farms Global Tech I having a capacity of 400 MW and Veja Mate having a capacity of 400 MW have been feeding wind energy into the German power grid via BorWin2. It employsVoltage-Sourced Converter based HVDC, and the total cable length is 200 km, out of which 125 km are submarine cables.

DC in Medium and Low Voltage Networks

Currently, power produced by a photovoltaic (PV) system undergoes a dc to dc and dc to ac transformation before consumed by the loads. At the load end also a conversion from ac to dc takes place as many loads such as LED lights, entertainment equipment and computer equipment are internally operated with dc. To reduce losses associated with power conversion stages, thus increasing the efficiency of PV utilisation and conserving the energy utilisation, dc MicroGrid becoming an attractive solution (Figure 7).

One of the bottlenecks for the uptake of renewable energy sources is their intermittency and variability. Therefore, unless supported by the main grid or integrated with energy storage, they cannot reliably supply the loads. Energy storage such as batteries, flywheels, and fuel cells either are inherently dc or have an internal dc bus that can be easily integrated to a dc grid. Therefore, with the realisation of the dc MicroGrid, dc will soon conquer the whole spectrum of the power industry.

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