HVDC Transmission Systems

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Table of Contents

Introduction

High voltage transmission lines are necessary to transport power from generating stations to load centers, where the voltage is then "stepped down" to a voltage level suitable for the end-user. Power plants are often located near an energy source, such as a coal mine or gas line, to minimize fuel transportation costs. These power plants are typically located in remote areas, away from heavily populated load-centers; therefore, transporting the electricity generated economically is important. This is accomplished by transmitting the generated power at a high voltage (stepping up at the power plant and stepping down at the substation using a transformer at both ends).

Using high voltages minimizes the amount of power lost in the delivery of power to the load centers. For a given quantity of power, doubling the voltage will deliver the same amount of power at half the current flow, and doubling the voltage reduces the power losses by a factor of four. High voltage cannot readily be used for lighting or motors, so transmission-level voltages must be reduced for end-use equipment.

Alternating current is easily transformed from one voltage level to another, making it ideally suited for power delivery and AC power is the world standard. Since almost the inception of the electric power industry, alternating current (AC) has been used to power homes, businesses, and industries. There are over 700,000 miles of high voltage alternating current (HVAC) transmission lines in the United States.

HVAC power systems require that each generator operates in synchrony. In the U.S., there are three electric power grids, as shown in Figure 1.

The three grids, Eastern Interconnection, Western Interconnect, and The Electric Reliability Council of Texas (ERCOT), make up the electric power grid in the U.S. Because of technical, operational issues, the three grids are not synchronized and operate independently.

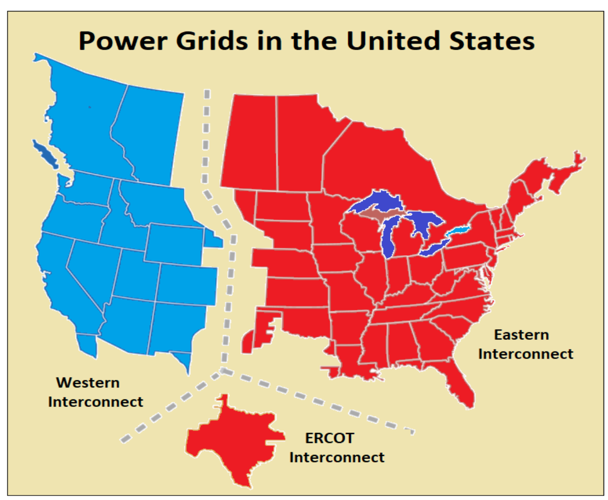

Figure 1

In addition to HVAC transmission lines, there are approximately 6,000 miles of High Voltage Direct Current (HVDC) transmission lines in the U.S. HVDC allows power transmission between AC transmission systems that are not synchronized. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. HVDC also allows the transfer of power between grid systems running at different frequencies, such as 50 Hz and 60 Hz. This improves the stability and economy of each grid by allowing the exchange of power between incompatible networks.

The problems with the widespread adoption of HVDC have been the difficulty of converting the voltage from one level to another for transmission and the high cost of converter stations. Practical conversion of power between HVAC and HVDC systems became possible with the development of power electronics devices such as mercury-arc valves and, starting in the 1970s, semiconductor devices such as thyristors, integrated gate-commutated thyristors (IGCTs), MOS-controlled thyristors (MCTs) and insulated-gate bipolar transistors (IGBT).

HVDC lines have typically been used to transfer large amounts of power over long distances. They are now being considered to move electricity generated from wind in high-quality wind resource regions to other parts of the country. If properly configured, HVDC transmission could also help mitigate operational issues with wind and solar generation, such as a mismatch in generation in relation to the need for increased ancillary services associated with renewable generation. This can be accomplished by effectively moving electricity generated from wind or solar resources from areas of high penetration to areas with lower penetration.

Increased grid interconnection through HVDC transmission would enable more flexibility in power transmission from regions with excess renewable resources to regions with high electricity demand. Since HVDC is decoupled from the HVAC system, the transfer can be achieved with minimal impact on the underlying HVAC transmission system.

The amount of equipment required for HVDC impacts its' applicability. The cost of an HVDC transmission system depends on many factors such as power capacity to be transmitted, type of transmission medium (submarine or land-based), environmental considerations, access to easements rights-of-way (ROWs), and cost of converter stations and associated equipment.

For shorter distances, the investment in HVDC converter stations and related assets may be larger than comparable AC transmission lines. HVDC lines used in renewable integration require the availability of large generation potential at or near the HVDC terminals. HVDC technology is the predominant technology used for submarine cables. For long-distance AC transmission using cables, the reactive power flow due to the large cable capacitance will limit the maximum possible transmission distance. Hence, HVDC lines are the only viable options for long-distance submarine cables. As a rough rule of thumb, HVDC begins to make economical sense at distances of 125 miles or more for overhead transmission and around 40 miles for submarine cables.

Worldwide, there has been a renewed resurgence and interest in developing HVDC transmission projects for the interregional economic transfer of electric power. In the United States, several HVDC projects are in the planning pipeline to facilitate the integration of renewable resources in remote host regions to distant load centers.

History

The first commercial HVDC link was developed by ASEA in 1954 to deliver power between mainland Sweden and the island of Gotland. The line was rated at 100 kV and had the capacity to deliver 20 megawatts (MW) of power. See the photo on the right.


Photo of Gotland Sweden HVDC link in 1954.

In the 1970s, HVDC lines were constructed with solid-state converter devices like thyristor valves. HVDC that uses thyristor valves is also known as line-commutated converter (LCC) HVDC. In the mid-1990s, voltage-source converters (VSCs) were commercialized for HVDC applications. In recent years, power electronics devices like insulated-gate bipolar transistors (IGBTs), gate turn-off (GTO) thyristors, and integrated gate-commutated thyristors (IGCTs) have made smaller HVDC systems more economical.

In the United States, the first commercial HVDC project was the 500 kV Pacific DC Intertie connecting Bonneville Power Administration (BPA) in the Pacific Northwest to Los Angeles Department of Water and Power (LADWP) in California. The project was completed in 1970.

The line was built to deliver low-cost hydropower from the BPA region to load centers in southern California.

Another important HVDC line in the Western Interconnection region is the Intermountain HVDC Transmission link (also known as Path 27) between an LADWP converter station in California and the Intermountain Converter Station in Utah. The line is a bipolar line capable of operating at ±500 kV and can transmit up to 2,400 MW of power. In the Eastern Interconnection, the longest-operating HVDC link is the Quebec – New England Transmission line. The line operates at ±450 kV and can transmit up to 2 … W. This li … deliver low-cost hydropower from the Hydro Queb … of Massachusetts.

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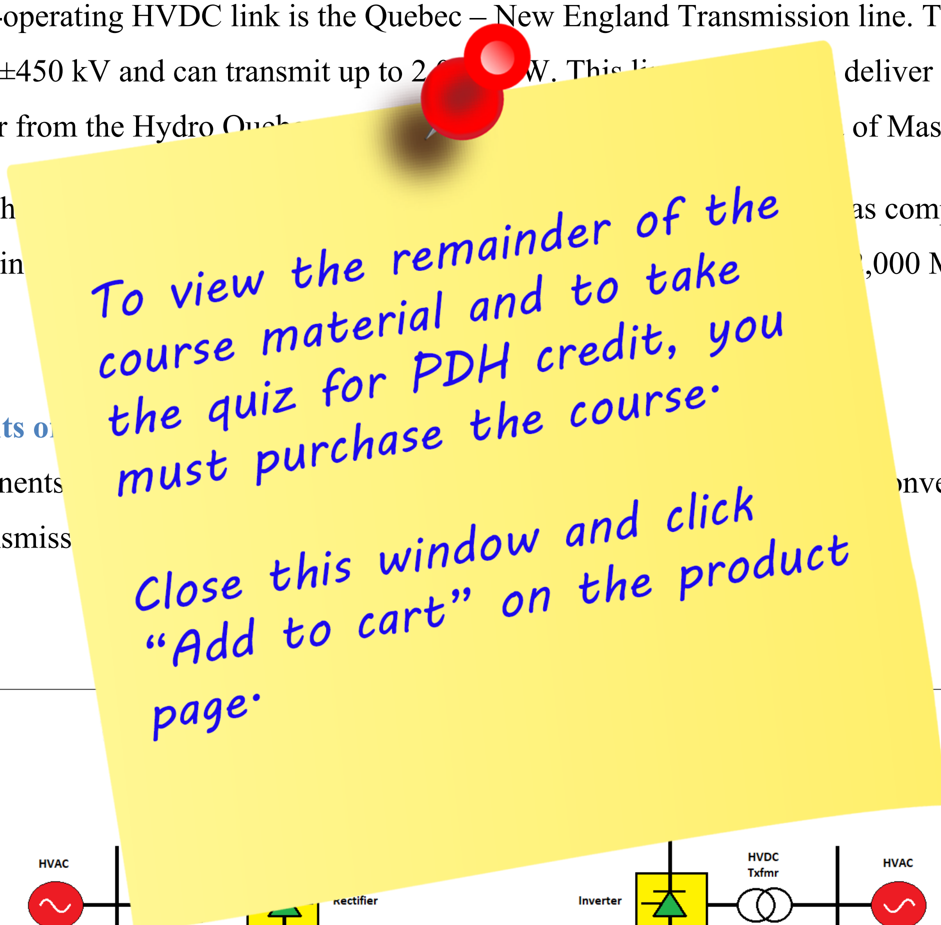

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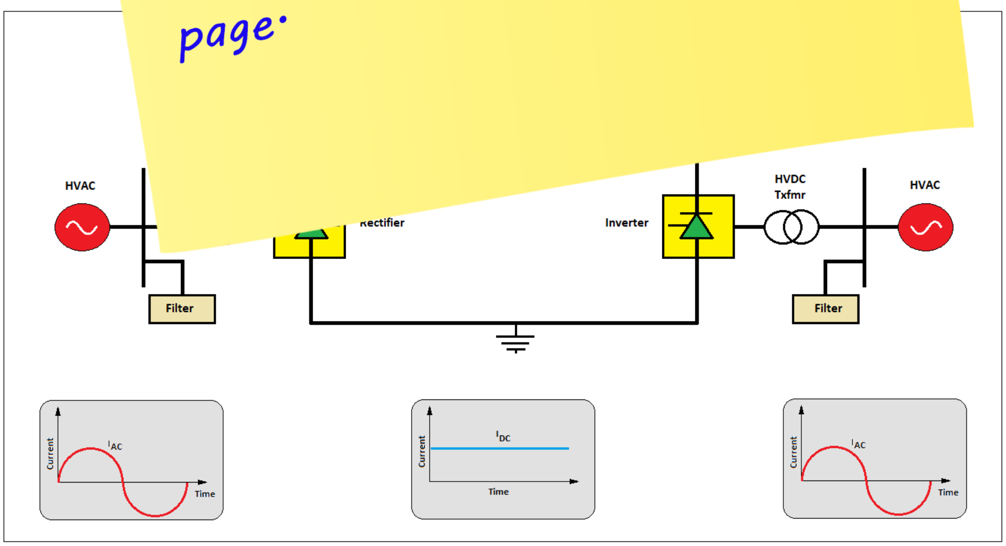

Figure 2