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Recent Trends in HVDC Transmission Systems

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Abstract

Beginning with a brief historical perspective on the development of High Voltage Direct Current (HVDC) transmission systems, this paper presents an overview of the status of HVDC systems in the world today. It then reviews the underlying technology of HVDC systems, and discusses the HVDC systems from a design, construction, operation and maintenance points of view. The paper then discusses the recent developments in HVDC technologies. The paper also presents an economic and financial comparison of HVDC system with those of an AC system; and provides a brief review of reference installations of HVDC systems. The paper concludes with a brief set of guidelines for choosing HVDC systems in today's electricity system development. An high-voltage, direct current (HVDC) electric power transmission system uses direct current for the bulk transmission of electrical power, in contrasts with the more common alternating current systems. For long-distance transmission, HVDC systems may be less expensive and suffers lower electrical losses. For underwater power cables, HVDC avoids the heavy currents required by the cable capacitance. For shorter distances, the higher cost of DC conversion equipment compared to an AC system may still be warranted, due to other benefits of direct current links. HVDC allows power transmission between unsynchronized AC distribution systems, and can increase system stability by preventing cascading failures from propagating from one part of a wider power transmission grid to another. (Rugby, 2001, 45-99)

Keywords: Asynchronous, HVDC, Grid, Power Electronics, IGBT

Introduction

The modern form of HVDC transmission uses technology developed extensively in the 1930s in Sweden at ASEA. Early commercial installations included one in the Soviet Union in 1951 between Moscow and Kashira, and a 10–20 MW system between Gotland and mainland Sweden in 1954. The longest HVDC link in the world is currently the Xiangjiaba-Shanghai 2,071 km (1,287 mi) 6400 MW link connecting the Xiangjiaba Dam to Shanghai, in the People's Republic of China. In 2012, the longest HVDC link will be the Rio Madeira link connecting the Amazonas to the São Paulo area where the length of the DC line is over 2,500 km (1,600 mi).

In today electricity industry, in view of the liberalisation and increased effects to conserve the environment, HVDC solutions have become more desirable for the following reasons:

Environmental advantages

- Economical (cheapest solution)
- Asynchronous interconnections
- Power flow control
- Added benefits to the transmission (stability, power quality etc.)

Historical Perspective on HVDC Transmission

- It has been widely documented in the history of the electricity industry, that the first commercial electricity
- Generated (by Thomas Alva Edison) was direct current (DC) electrical power. The first electricity
- Transmission systems were also direct current systems. However, DC power at low voltage could not be
- Transmitted over long distances, thus giving rise to high voltage alternating current (AC) electrical systems.

Literature References

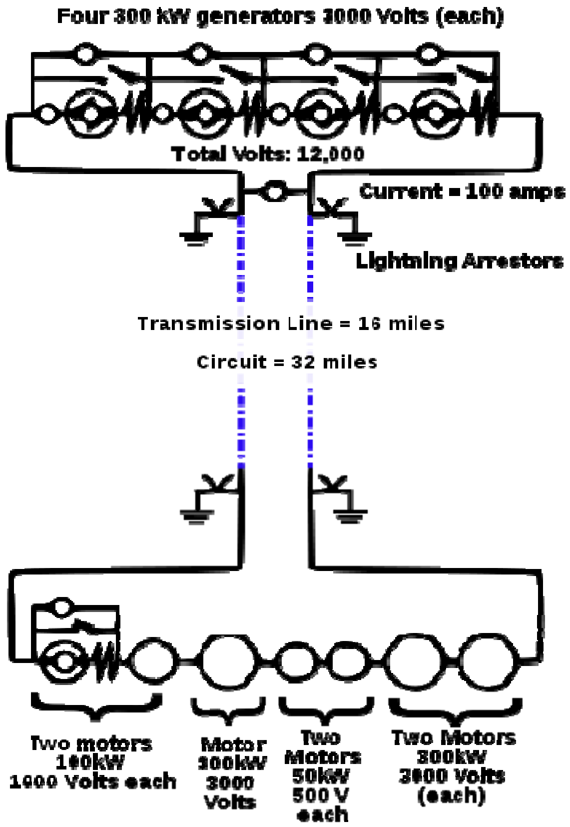
Practical manipulation of high power high voltage DC became possible with the development of high power electronic rectifier devices such as mercury arc valves and, more recently starting in the 1970s, high power semiconductor devices such as high power thyristors and 21st century high power variants such as integrated gate-commutated thyristors (IGCTs), MOS controlled thyristors (MCTs) and gate turn-off thyristors (GTOs). A similar high power transistor device called the insulated-gate bipolar transistors (IGBT) has recently been used in these applications.

The advantage of HVDC is the ability to transmit large amounts of power over long distances with lower capital costs and with lower losses than AC. Depending on voltage level and construction details, losses are quoted as about 3% per 1,000 km. High-voltage direct current transmission allows efficient use of energy sources, remote from load centers.

In a number of applications HVDC is more effective than AC transmission. Examples include:

- Undersea cables, where high capacitance causes additional AC losses. (e.g., 250 km Baltic Cable between Sweden and Germany, the 600 km NorNed cable between Norway and the Netherlands, and 290 km Basslink between the Australian mainland and Tasmania)
- Endpoint-to-endpoint long-haul bulk power transmission without intermediate 'taps', for example, in remote areas
- Increasing the capacity of an existing power grid in situations where additional wires are difficult or expensive to install
- Power transmission and stabilization between unsynchronised AC distribution systems
- Connecting a remote generating plant to the distribution grid, for example Nelson River Bipole
- Stabilizing a predominantly AC power-grid, without increasing prospective short circuit current
- Reducing line cost. HVDC needs fewer conductors as there is no need to support multiple phases. Also, thinner conductors can be used since HVDC does not suffer from the skin effect
- Facilitate power transmission between different countries that use AC at differing voltages and/or frequencies
- Synchronize AC produced by renewable energy sources

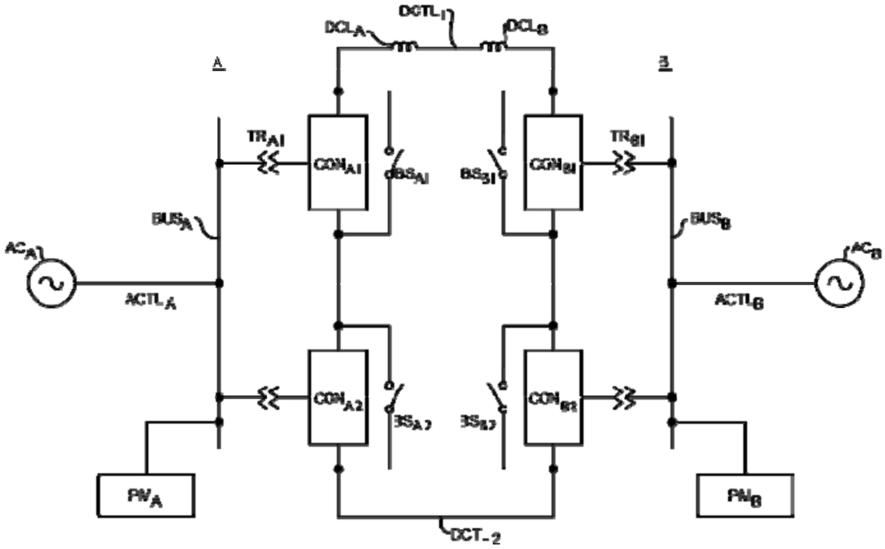
Long undersea / underground high voltage cables have a high electrical capacitance, since the conductors are surrounded by a relatively thin layer of insulation and a metal sheath while the extensive length of the cable multiplies the area between the conductors. The geometry is that of a long co-axial capacitor. Where alternating current is used for cable transmission, this capacitance appears in parallel with load. Additional current must flow in the cable to charge the cable capacitance, which generates additional losses in the conductors of the cable. Additionally, there is a dielectric loss component in the material of the cable insulation, which consumes power.



However, when direct current is used, the cable capacitance is charged only when the cable is first energized or when the voltage is changed; there is no steady-state additional current required. For a long AC undersea cable, the entire current-carrying capacity of the conductor could be used to supply the charging current alone. The cable capacitance issue limits the length and power carrying capacity of AC cables. DC cables have no such limitation, and are essentially bound by only Ohm's Law. Although some DC leakage current continues to flow through the dielectric insulators, this is very small compared to the cable rating and much less than with AC transmission cables.

HVDC can carry more power per conductor because, for a given power rating, the constant voltage in a DC line is the same as the peak voltage in an AC line. The power delivered in an AC system is defined by the root mean square (RMS) of an AC voltage, but RMS is only about 71% of the peak voltage. The peak voltage of AC determines the actual insulation thickness and conductor spacing. Because DC operates at a constant maximum voltage, this allows existing transmission line corridors with equally sized conductors and insulation to carry more power into an area of high power consumption than AC, which can lower costs.

Because HVDC allows power transmission between unsynchronized AC distribution systems, it can help increase system stability, by preventing cascading failures from propagating from one part of a wider power transmission grid to another. Changes in load that would cause portions of an AC network to become unsynchronized and separate would not similarly affect a DC link, and the power flow through the DC link would tend to stabilize the AC network. The magnitude and direction of power flow through a DC link can be directly commanded, and changed as needed to support the AC networks at either end of the DC link. This has caused many power system operators to contemplate wider use of HVDC technology for its stability benefits alone.



The disadvantages of HVDC are in conversion, switching, control, availability and maintenance. HVDC is less reliable and has lower availability than AC systems, mainly due to the extra conversion equipment.

Single pole systems have availability of about 98.5%, with about a third of the downtime unscheduled due to faults. Fault redundant bipole systems provide high availability for 50% of the link capacity, but availability of the full capacity is about 97% to 98%.

The required static inverters are expensive and have limited overload capacity. At smaller transmission distances the losses in the static inverters may be bigger than in an AC transmission line. The cost of the inverters may not be offset by reductions in line construction cost and lower line loss. With two exceptions, all former mercury rectifiers worldwide have been dismantled or replaced by thyristor units. Pole 1 of the HVDC scheme between the North and South Islands of New Zealand still uses mercury arc rectifiers, as does Pole 1 of the Vancouver Island link in Canada. Both are currently being replaced – in New Zealand by a new thyristor pole and in Canada by a three-phase AC link. Efficient designs use Silicon-Controlled Rectifiers (SCR)s (the more common name for thyristors) fired in sequence at 60 Hz to produce a modified sinewave of AC current, similar to the inverter circuitry in modern battery-operated UPSs for computer and telecom use.

In contrast to AC systems, realizing multiterminal systems is complex, as is expanding existing schemes to multiterminal systems. Controlling power flow in a multiterminal DC system requires good communication between all the terminals; power flow must be actively regulated by the inverter control system instead of the inherent impedance and phase angle properties of the transmission line. Multi-terminal lines are rare. One is in operation at the Hydro Québec – New England transmission from Radisson to Sandy Pond. Another example is the Sardinia-mainland Italy link which was modified in 1989 to also provide power to the island of Corsica.

Because the voltages in HVDC systems, up to 800 kV in some cases, exceed the breakdown voltages of the semiconductor devices, HVDC converters are built using large numbers of semiconductors in series.

In general, however, an HVDC power line will interconnect two AC regions of the power-distribution grid. Machinery to convert between AC and DC power adds a considerable cost in power transmission. The conversion from AC to DC is known as rectification, and from DC to AC as inversion. Above a certain break-even distance (about 50 km for submarine cables, and perhaps 600–800 km for overhead cables), the lower cost of the HVDC electrical conductors outweighs the cost of the electronics. (Pansini, 2009, 2)

The conversion electronics also present an opportunity to effectively manage the power grid by means of controlling the magnitude and direction of power flow. An additional advantage of the existence of HVDC links, therefore, is potential increased stability in the transmission grid. (Raghuvir , 2004, 121)

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