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High voltage DC power distribution: a panoramic view

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Abstract. High voltage DC power systems (HVDC) provide essential technical advantages in relation with the AC classical distribution networks: increasing the capacity and the stability in a natural and efficient way, simultaneously with the decoupling of some local disturbances that may occur in their subsystems and the easy interconnection of power AC grids with different parameters. In addition, the increased share of renewable energy sources and the fact that their production takes place in concentrated areas, often away from the consumption areas, require the existence of distribution facilities in the field of GW power levels, with flexible connectivity possibilities. The paper presents general aspects regarding the configuration and the main components of a HVDC power system, implementation in several representative applications.

Keywords: power systems; DC power distribution; static power converters.

1. Introduction

HVDC is a technology used on an industrial scale for over 60 years [1]. HVDC is the most suitable solution for efficient and reliable distribution of electricity, at high energy levels (GW power, hundreds of kV DC voltage levels) and over relatively long distances, being able to mix inputs and connect networks with different parameters. The absence of reactive power circulation on the distribution lines, the fact that DC the cable's own capacity does not introduce reactive currents, leads to the corresponding minimization of losses [2]. HVDC could be implemented with the development of the power electronics industry and the related control structures, which allowed the development of dedicated static converters for transforming the energy from AC to DC and vice versa and the control of the power circulation at such energy levels [2-5]. Thus, it is possible to speak of classic HVDC systems, which use thyristor in the static converters (at power levels in the range 1…3 GW). New structures can be made with IGBT

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transistors, with high efficiency (for power levels between 100… 1200MW), over medium or long distances [6]. Both systems can use distribution lines placed above ground, underground or submarine [2].
The following chapters review the structures of HVDC systems, with a description of the basic components. Finally, several applications launched worldwide are presented and conclusions regarding this technology are highlighted.

2. HVDC - Generalities and configurations

An HVDC system consists of the following main components (Fig. 1) [2,6]:
- A station for the conversion of energy from AC to DC;
- An inverter station, for the conversion of energy from DC to AC;
- AC lines;
- DC buses.

Regarding the comparative analysis of the distribution systems in DC, respectively DC, in Fig. 2 the pillar configurations and the costs represented by each component are presented, including losses [7].

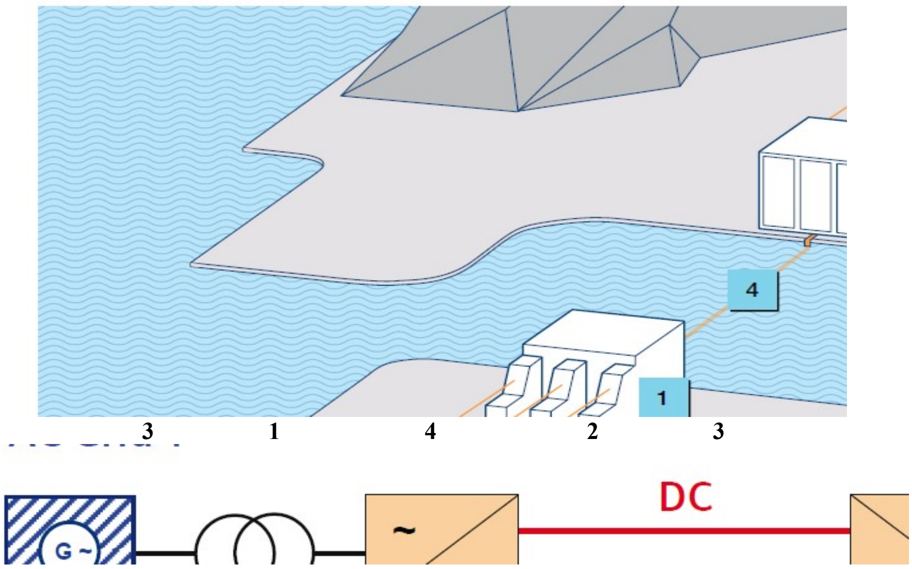
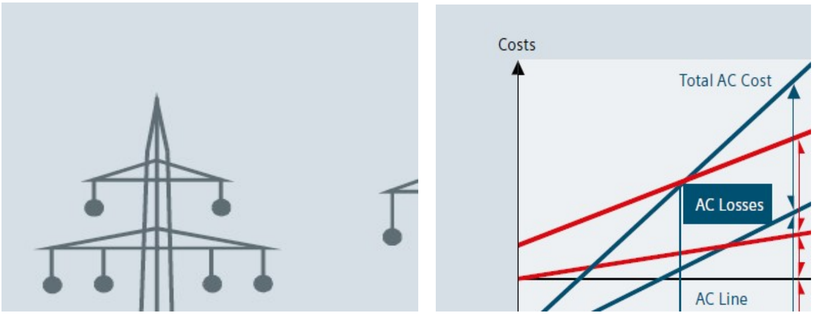


Fig. 1. The main components of a HVDC:
1-rectifier station; 2-inverter station; 3-AC lines; 4-DC lines [2,6].

It can be seen from Fig. 2 the fact that, depending on the concrete conditions of the system implementation, there is a critical distance from which the HVDC becomes more cost effective in relation to the distribution in AC. It can be seen from Fig. 2 the fact that, depending on the concrete conditions of the system implementation, there is a critical distance from which the HVDC becomes more cost effective in relation to the distribution in AC. The line cost and the corresponding losses reductions (support pillars and cables), but also the higher investment costs of HVDC systems (mainly related to the static energy conversion elements) were taken into account.



a) b)

Fig. 2. Comparative presentation of: a) tower configurations (AC, DC); b) stations (AC, DC terminals), lines (AC, DC lines), losses (AC, DC losses) and total costs [6].

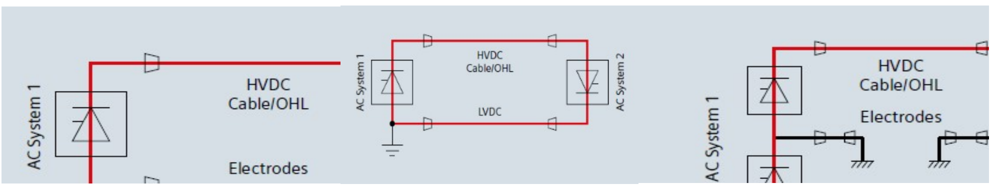
The HVDC system configurations can be (Fig.3) [7]:

- Monopolar, with a current path through the earth;
- Monopolar, with both wired current paths;
- Bipolar, with a current path through the earth (or wired).

The configurations in Fig. 3a, b is suitable for long distances (especially in submarine connections). The bipolar systems (Fig. 3c) provide flexibility, through the possibility of operating in monopolar regime, in case of fault, or for maintenance operations.

Also, in order to reduce the investment costs, bipolar systems can also work without the medium current path (through earth or wired).

HVDCs are the optimal solutions for delivery of the energy produced by high power wind power plants, in offshore platforms. A structure dedicated to this purpose is presented in Fig. 4. The energy taken from each unit separately, in AC, is transported (submarine) in DC (after a rectifier process), converted in AC and injected into the onshore network [8, 9]. Regarding the HVDC structure, this may be one of the configurations shown in Fig. 3.



a) b) c)

Fig. 3. HVDC configurations [7]: a) monopolar, with a current path through the earth; b) monopolar, with both wired current paths; c) bipolar, with a current path through the earth.

In addition to the positive technical effects, the HVDC is at the same time an environmentally friendly solution and can be integrated without major compromises. However, a few aspects must be recognized, especially related to static power converters: noise (due to switching of power devices and filters), visual impact of power plants (especially due to the dimensions imposed by high voltages), electromagnetic compatibility and the use of current paths (earth, water) in monopolar or bipolar differential configurations [7].

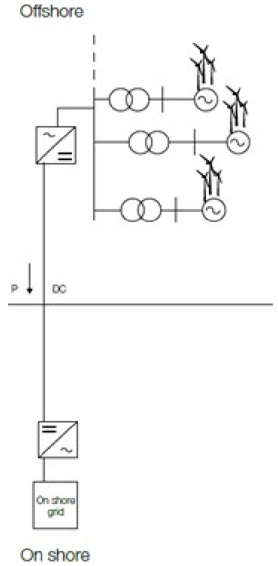


Fig. 4. HVDC for offshore wind power stations [8].

3. HVDC- basic components

AC-DC Converter

AC-DC conversion is performed (in classical systems) via the thyristors rectifiers. Such a structure, with 12 pulse, is shown in Fig. 5 [7].

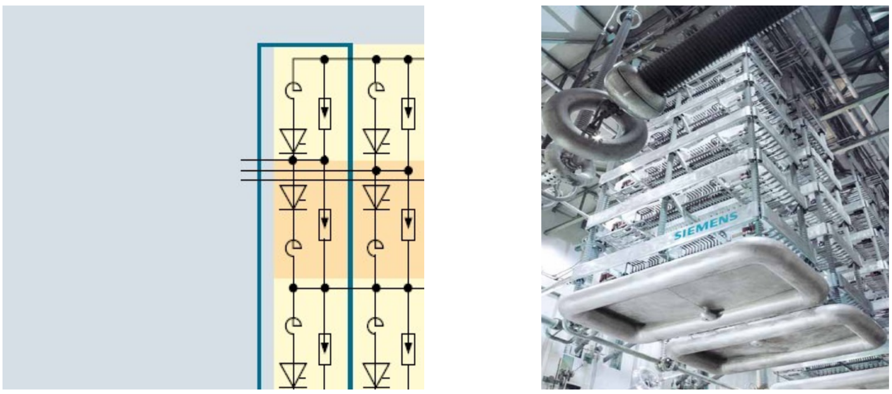


Fig. 5. 12 pulses controlled rectifier (AC-DC conversion) scheme and picture [7].

The power transformer

The 12-pulse rectifier is powered by a dedicated transformer with two secondary (Yy0 and YD5) windings. The construction of the transformer is special from the point of view of the insulation, due to the values of the AC and DC voltages. An overview of this component is shown in Fig. 6 [7].

Fig. 6. Overview of the transformer [7].

DC switching components

Similar to AC networks, HVDC systems use separation, switching and protection devices. Switching is done with equipment in SF6, adapted to DC circuits.
Recent approaches to switching in HVDC have proposed hybrid configurations (electromechanical + static commutation), capable of switching fault currents (Fig. 7) [10]. The electromechanical component (UFD) together with the static switch (LCS) ensure current flow under normal operating conditions, with minimal losses. In the event of overload, the current flow is taken over by the main static breaker, which is capable of switching the circuit under such conditions. The operation of the hybrid switching can be analyzed from the current diagram, shown in Fig. 8 [10].

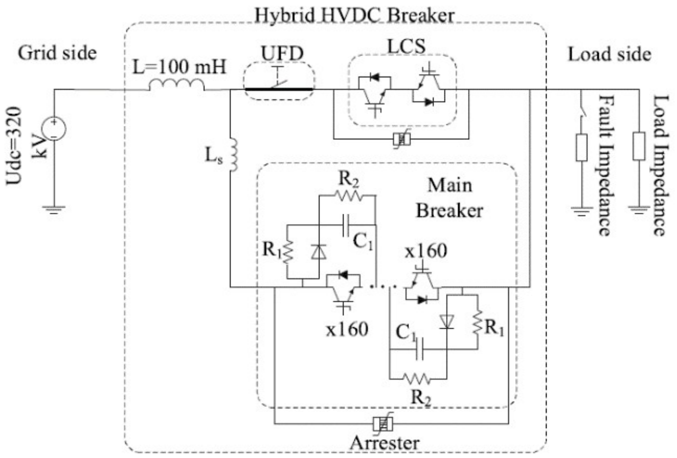


Fig. 7. Hybrid switching breaker schematics [10].

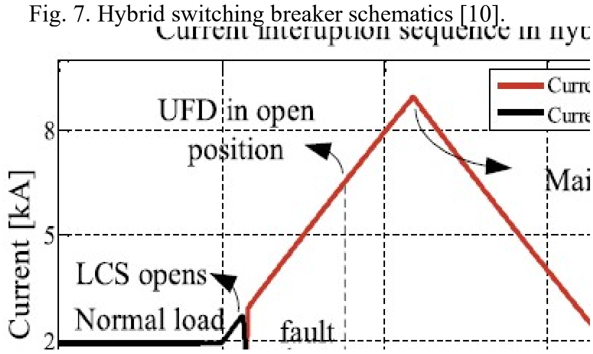


Fig. 8. Hybrid switching breaker current diagram [10].

The voltage inverter

The energy conversion from DC to AC is performed using voltage inverters, with fully controllable power devices (GTO / IGCT, IGBT) [6, 11-13].
Fig. 9 shows the topologies of the inverters, in correspondence with the power devices used, respectively the overall image of such equipment [6].

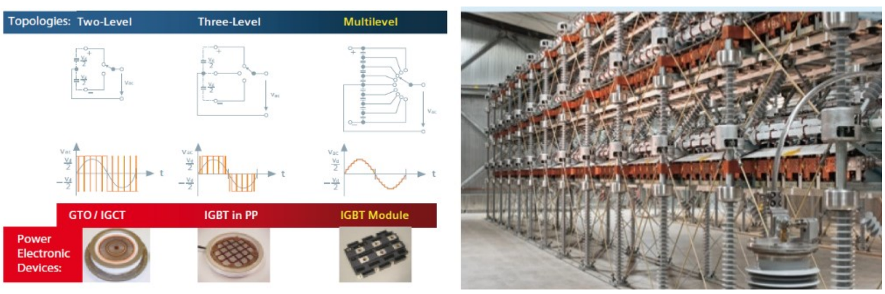


Fig. 9. a) Topologies and switching devices used in the construction of voltage inverters [6];
b) a voltage inverter picture.

Other HVDC components

HVDC systems are supported by a number of passive circuit and auxiliary elements, such as:

- AC and DC filter coils;
- Harmonic filters in AC and DC;
- Capacitive compensators for the reactive energy in AC;
- Suppressors for surge protection;
- Insulators arranged on the airlines and on the active or passive equipment;
- Electrical cables of special construction etc.

An important component of this technology is the control and protection system. As a rule, the controls and protections are distributed, the monitoring being carried out through a SCADA dedicated application [7].

4. Some implemented HVDC systems worldwide

A synthetic image, highlighting the evolution in terms of voltage and power levels of HVDC applications, is shown in Fig. 10 [2].

Current applications access voltage levels of 1,100kV at 13GW, of more than 2,000km [2].

The following are some selected applications made worldwide.

With implementation Between 2012-2014, the HVDC network "Southern Hami-Zhengzhou" (China), has a length of 2,210km, the voltage level being ± 800kV, at 8GW, Fig. 11 [14].

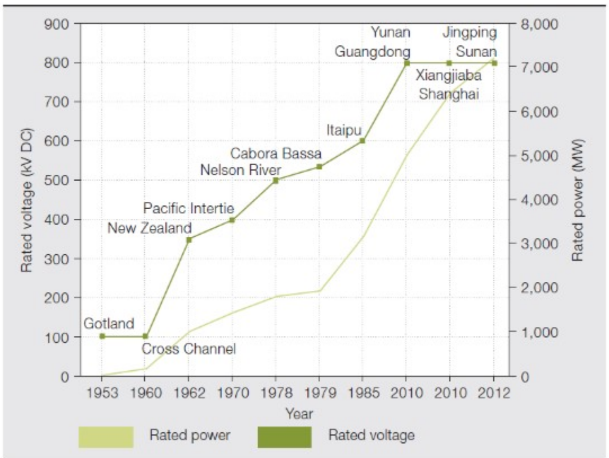


Fig. 10. Synthesized evolution of HVDC technology in applications, on approx. 60 years [2].

Fig. 11. HVDC Network "Southern Hami-Zhengzhou" [14].

Baixas-Santa Llogaia (France-Spain) is part of the trans-European electricity transmission network, with a length of 65km, at ± 320kV and 1GW-Fig. 12 [15].

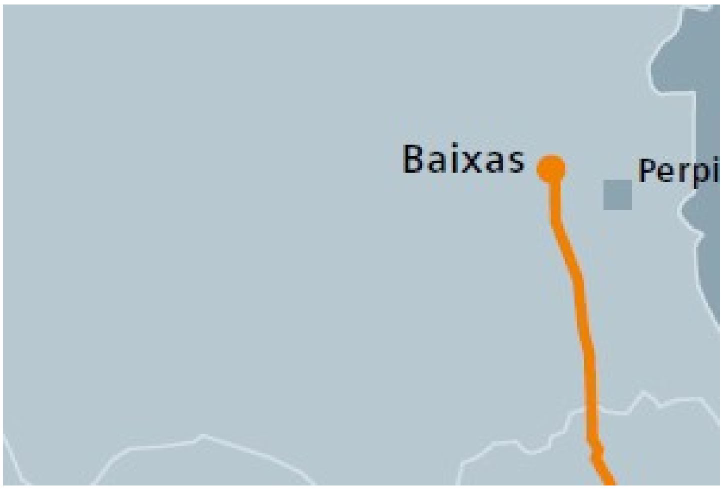


Fig. 12. Baixas-Santa Llogaia Network [15].

The connection between Scotland and England is made by an underwater network of 420km, at ± 600kV and 2.2GW - Fig. 13 [16].

Fig. 13. HVDC connection between Scotland and England [16].

The Nordic and Baltic countries are connected by a HVDC network, with 670MW (unipolar), at 450kV, with overground, submarine and underground routes (171km in total) - Fig. 14 [16].

Fig. 14. HVDC connection between Finland and Estonia [16].

Between England and the Netherlands, the HVDC network is capable of transporting 1GW at ± 450kV, at a distance of 260km, submarine - Fig. 15 [16].

Fig. 15. HVDC connection between England and the Netherlands [16].

A renewable energy HVDC implementation is shown in Fig. 16. It represents the HVDC connection of 75km submarine cable and 90km underground cable, between the offshore wind turbine platform and Dörpen/West - Germany. The network works at 320kV (monopolar) voltage and 800MW power [17].

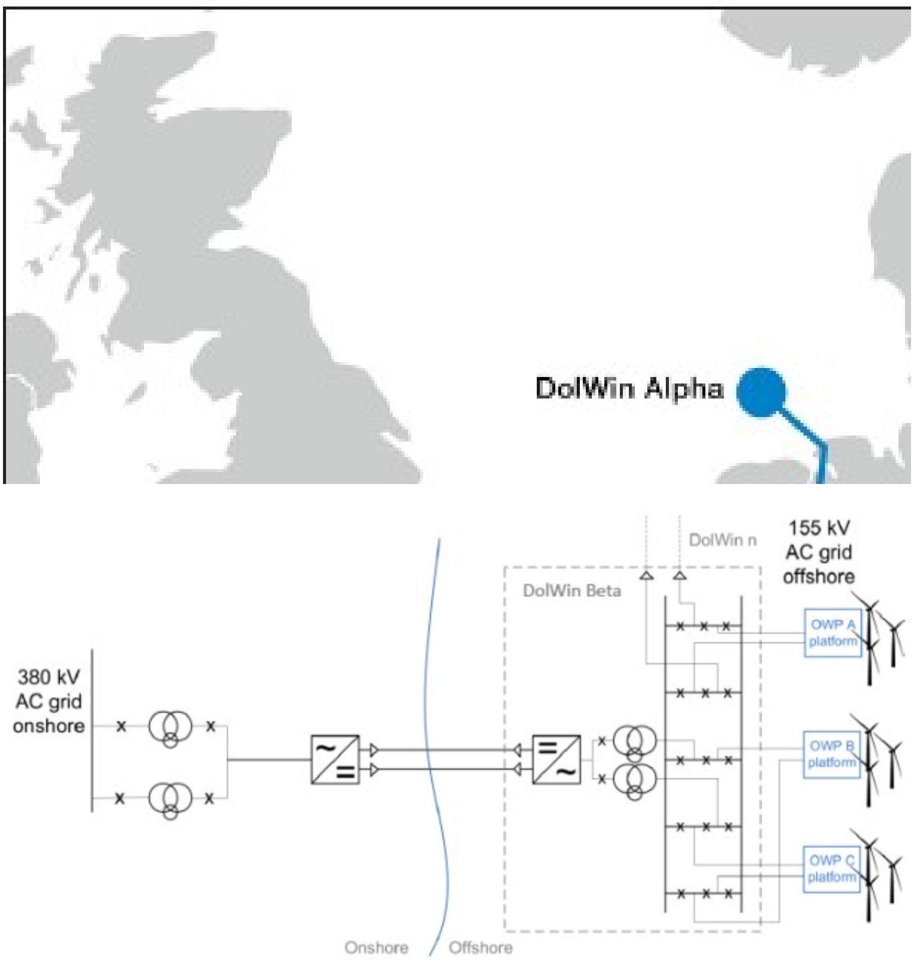


Fig. 16. HVDC connection "offshore" - "onshore" (Germany) [16].

Finally, a possible future HVDC super grid that would interconnect the various European countries and the regions around Europe's borders – including North Africa, Kazakhstan, and Turkey is presented in Fig. 17 [21]. It is envisaged that a European super grid would:

- lower the cost of power;
- pool load variability and power station unreliability;
- allow for wider use of renewable energy;
- decrease Europe's dependence on imported fuels.

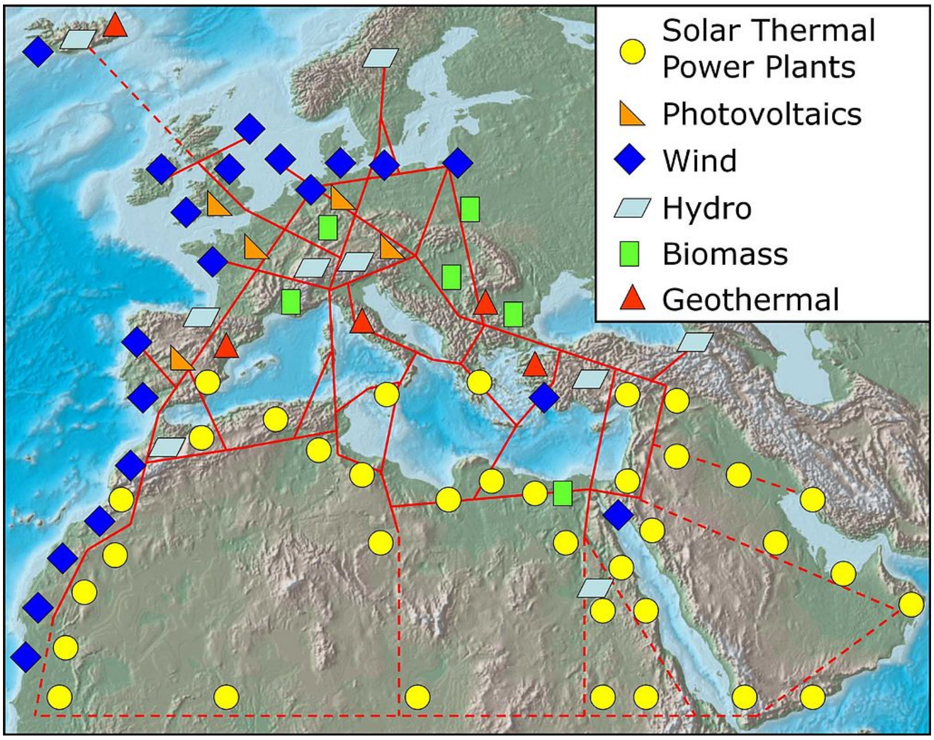


Fig. 17. The future proposed European super grid.

5. Conclusions

HVDC technology, developed with the power electronics component industry, represents the most efficient infrastructure for transporting electricity at high power levels and over long distances.

At the same time, HVDC offers more stability and higher efficiency, with the possibility of interconnecting energy systems with different parameters.

The impact on the environment is also diminished, the current paths, especially on pillars, occupying smaller areas, the compatibility problems around the lines are also reduced.

The technology imposed the development of a dedicated industry, both for the active and the passive components (listed in the previous chapters), for high levels of voltage at which they operate.

HVDC will not completely replace the AC current electricity distribution systems. The distribution in AC will keep its place in time, even and at high levels of power. An example is the AC Kita-Iwaki network (Japan), which operates up to 1,100kV/4000A, at 430km, mounted on pillars with an average height of 108m [19].

In conclusion, what is known as "The war of currents - Tesla versus Edison" [20], does not have a winner, but is rather an armistice.

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