Review of HVDC insulated transmission cables technologies

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ABSTRACT

The HVDC technology has an extensive application range in the today and the future network. Insulated cables are the necessary component of its deployment in many occasions. When considering all the network and converter station parameters, it is clearly concluded that a single cable system technology cannot be optimum in all cases. This paper updates the C6.4 paper of JICABLE 2011, by taking into account the new developments and the fast technical evolution of the considered technologies, and the new application fields.

KEYWORDS

HVDC, Mass Impregnated, DC XLPE, Underground, Submarine.

IDENTIFICATION OF THE NEED

During the closing session of JICABLE HVDC 2013 [1], a number of European utilities, i.e. National Grid, Amprion, Svenskä Kraftnät, Stanett, Energinet, Terna, RTE, gave their view about the future use of HVDC transmission technologies. This can be summarized in the Figure 1, where the planned HVDC links are shown.

Figure 1: HVDC transmission links, existing and projects

When looking to this map we can see transmission links that connect:

- Different networks that are independent from each other.
    - In land
    - Across the sea (shallow or deep waters)
- Two remote portion of the same network (electrical highway)
- An offshore station to the mainland
- Two back to back converter stations

This points out the large diversity of the installation constraints that logically results in a different cable design.

In addition a considerable work has been performed regarding the HVDC – HVAC converters principles, technology and topology. Basically converters are classified as VSC (Voltage source converter) or LCC (Line commutated Converters).

This further enlarges the variety of the needs.

Finally, when considering the influence of the length, voltage, current and testing capability, we have a complex set of needs that the authors will try to pair with a HVDC transmission cable system technology.

HVDC TRANSMISSION CABLE SYSTEM TECHNOLOGIES.

HVDC cable systems have a long history. The first HVDC transmission cable (+/-2kV) was installed in 1882 over 57km between Miesbach and Munich. We will detail the different technologies by order of appearance.

Lapped oil filled systems:

The dielectric system of cable and accessories consist in a lapped insulation which is immersed in oil. Joints and terminations are made with the same materials as the cable. This void free insulation presents very good ageing properties (some cables are more than 60 years old). The dielectric system can work in AC and in DC.Pumping station(s) at one or two ends ensure the working pressure of the oil whatever the load of the link.

In practice, the length is limited to 80km.

From a dielectric standpoint, the impulse stress is the dimensioning parameter of the insulation thickness. Practically the mean permanent DC field in operation is up to 30kV/mm.

Maximum conductor temperature is 80°C

Cross section can be up to 3000mm² [2], and voltage up to 800kV [3].

These cables usually have a lead sheath

The thermal resistivity of the insulation is about 5 K.m/W

They can work in VSC and LCC condition, and in HVAC condition.

Maximum operating temperature is 85C, Temperature drop across the insulation has to be considered.

Figure 2 shows a typical design for an oil filled cable.

Figure 2: typical design of an oil filled cable

Lapped mass impregnated systems:

The dielectric system of cable and accessories consist in a lapped insulation which is immersed in viscous oil. Joints are made with the same materials as the cable. Terminations can be oil filled. This insulation presents very good ageing properties (some cables are more than 60 years old). The dielectric system can work in DC only.

For Mass Impregnated Kraft paper cables, the viscous material migrates locally in the insulation as a function of the temperature. This migration must not affect the insulation integrity. This is a key parameter of those cables' design.

The link length is unlimited from a dielectric standpoint. The factory joints are in all aspects similar to the main cable. The factory acceptance test can be performed with a DC stress on an unlimited length. In other terms the only limitation is the voltage drop along the transmission line.

From a dielectric standpoint, the impulse stress is the dimensioning parameter of the insulation thickness. Practically the mean permanent DC field in operation is up to 30kV/mm.

The maximum temperature is traditionally limited to 55°C but few developments have been performed in this respect recent type tests have been performed at 65°C [4]

The voltage can be up to 550kV [5] and the cross section up to 2500mm²

These cables usually have a lead sheath

The thermal resistivity of the insulation is about 5.5 K.m/W

They can work in VSC and LCC condition.

Depending on the cable system, maximum operating temperature is 55 or 65C. Temperature drop across the insulation has to be considered.

Figure 3 shows a typical design for a Mass Impregnated cable.

Figure 3: typical design of a Mass Impregnated cable

Extruded dielectric systems

The dielectric system consists in a polymer compound that is extruded through a die. A subsequent chemical cross-linking reaction is performed. Joints (except factory joints) are made from materials which are different from the cable insulation.

The first use of this technology was back in 1998, with a mean stress of 14kV/mm and 80kV [6] then the stress was raised to 18kV/mm for the 320kV level [7]. Although transmission links were completed, this voltage level was put into service in 2015, now The trend is to go to 20kV/mm. Recently, qualifications at 400kV and 525kV have been performed. [7] [8]. Cross section can be up to 2500mm².

The link length is unlimited from a dielectric standpoint, but presently there is a testing issue when the cable unit length increases, as DC test has been proven inefficient to screen imperfections in XLPE material. [9].

Accessories can be made of rubber, and installed on site in a similar way to the AC cables ones. The proper management of the cable / installed accessory system is qualified through development, type and prequalification tests.

For Land application, the cables have usually an aluminium screen.

The thermal resistivity of the insulation is about 3.5 K.m/W

They can work in VSC and LCC condition, and in HVAC condition

Depending on the cable system, maximum operating temperature is 70 or 90C. Temperature drop across the insulation has to be considered.

Figure 3 shows a typical design for an XLPE land cable.

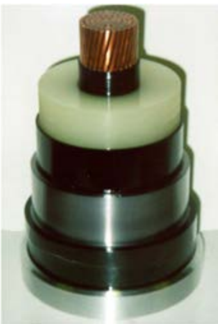

Figure 4: typical design of an XLPE land cable

Lapped superconductive systems

Just like resistive HVDC cable systems, a superconducting HVDC cable system consists of a (superconducting) cable connected to terminations. Additionally, a liquid nitrogen cooling system provides the cable cooling and is commonly located in close proximity to the terminations, and (if necessary) cable joints. The superconducting power cable itself consists of a cable core that is housed inside a cable cryostat. Liquid nitrogen circulates inside the cable cryostat, providing cooling for the cable, as it needs to be operated at cryogenic temperatures (commonly between 65 and 72 K (- 208 to – 201 C). Superconducting power cables commonly employ a lapped paper insulation made from PPLP (Polypropylene Laminated Paper). Suitable superconductors for superconducting HVDC power cables are Bismuth-Strontium-Calcium-Copper-Oxide (BSCCO) and Yttrium-Barium-Copper-Oxide (YBCO).

Owing to the active cooling via liquid nitrogen, the cable system is thermally independent from its surroundings, the cryostat losses (which are on the order of 1 W/m) are the only thermal interaction between the cable and its surroundings

Such system has been tested up to a voltage class of 200 kV DC according to Electra recommendation 189 (april 2000). Superposed lightening impulse shots up to 600 kV were successfully applied on this system submitted to 200 kV DC. [10]

They can work in VSC and LCC condition, and in HVAC condition

Figure 3 shows a typical design for a superconductive HVDC cable.

Figure 5: typical design of a superconductive HVDC cable.

HVDC TRANSMISSION CABLE SYSTEM COMBINED WITH IDENTIFIED NEEDS

In the following we will try to pair the transmission technologies with different applications.

Exceptions can always be found against general statements and the complex parameters of cable environment constraints (temperature, allowed ground temperature increase, laying method), the way the transmission losses are accounted for, the OPEX and CAPEX, may result in specific technical solutions.

The working gradient can balance the insulation thermal resistivity.

Higher voltage, with, the same cross section can balance a lower operating temperature.

Land connexions

High power short length

This is typically the case of back to back converter stations. It is the area where the properties of superconductive cables find their best use. In addition they have no influence on the environment.

Electrical highways.

These links are long and intended to transport some GW. Now oil filled cables are rejected because of environmental constraints. Mass impregnated cables have been used at 550kV for the land portions of Skagerrak 4 (700mW/cable). However the main inland installation experience is made with XLPE insulated cables with more than 30000km of installed cable AC and DC [11]. In case there is a HVDC network grid, i.e. mutiterminal, multisource, bi-directional, the voltage depends on many factors that are under study in CIGRE JWG B4-C1 65. The main following characteristics make XLPE insulated cables best fitted for this application:

- Easy transportation
- Easy jointing of unit length
- Short bending radius
- Reduced maintenance

Figure 3 shows an example of XLPE cable installation.

Figure 6: example of XLPE cable installation.

Submarine connections

Export cable from dispersed generation (i.e. windmills).

The AC three core cable has to be reviewed as it was evaluated as the overall best fitted and cheapest solution in many cases. [12]

This is a short or medium length connection, which is needed for each windmill field. For these lengths, testing of the delivered length is feasible, AC testing and DC testing. Presently there is no submarine DC grid. The access to the grid could be made onshore with a dedicated converter station. Here a high standardisation level is needed.

The cable system which best fit these requirements is the extruded one. The voltage could be a well experienced voltage such as 320kV.

Figure 7 shows an example of export XLPE cable installation.

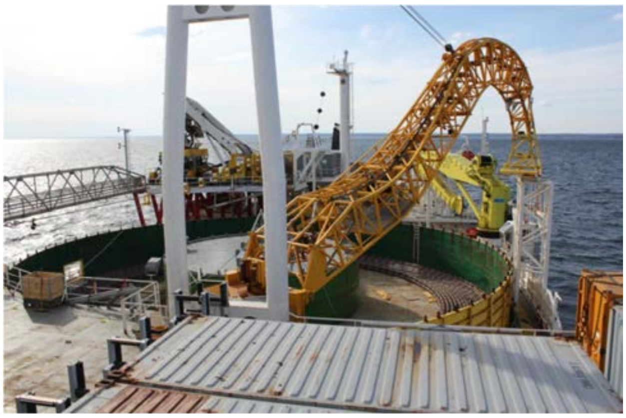

Figure 7: example of export XLPE cable installation.

Long cable systems for interconnection of same or different networks.

In these large projects, the cable system is custom designed. Due to the higher working electrical stress, the lapped mass impregnated technology is of lighter weight that the XLPE cable. The factory acceptance test of the complete delivery length is only feasible in DC, which may be considered not fully satisfactory for extruded cable systems.

The voltage, cross section and temperature range are optimised on a case basis.

Figure 8 shows an example of HVDC interconnection cable installation.

Figure 8: example of HVDC interconnection cable installation

CONCLUSION

In spite of the large diversity of the installation constraints, the pairing of the different HVDC insulated transmission system technologies to the application cases is quite similar to the conclusion of the JICABLE 2011 round table:

- " For Long Submarine links: MIND (Mass impregnated Non Draining) insulation is still the most suitable and economic.
- For land based links: DC XLPE cable.
- For high power to transmit over shorter length: land

HVDC superconductive cable

and

- For high power submarine links that have to work in AC and DC: SCOF
- The different working stresses result in different optimum cross section and voltage depending on the technology."

The new technological milestone is that very likely the extruded cable systems will definitely replace the SCOF ones, as it is already the case for land AC cable systems.

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