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## **HVDC Mass-Impregnated Cables for the future**

HVDC Mass-Impregnated (MI) cables is a well proven, robust and mature technology and the preferred solution for long distance submarine transmission of large amounts of electrical energy at the highest voltage levels. This technology has for many decades been in service for a large number of power transmission links worldwide and has through an extensive track record proven excellent service reliability at a voltage level up to 525 kV and a power rating exceeding 800 MW per cable.

Continuous research and development in design, materials, testing, manufacturing processes and installation techniques have made it possible to constantly push the limits for voltage levels, power transmission capacity and installation depths. The product quality is ensured with a robust design in combination with well proven and established manufacturing processes following the highest standards.

HVDC MI cable systems have:

- Excellent service reliability
- Proven life-time of more than 40 years
- Vast experience at the highest voltage levels (500–525 kV)
- More than 10 years' operational experience at deep waters (>1500 m)

### **Excellent service reliability**

Since the first 100 kV HVDC MI cable system was installed in the 1950's several thousand kilometres have been installed worldwide, and the service experience is very good. Internal failures are extremely rare. On the occasions where failures have occurred, the majority are caused by external damages such as fishing gear or anchors hitting and damaging the cable. To avoid outages it is of utmost importance to protect the cables by e.g. burying, subsea rock installation or cast iron shells.

It is in the nature of long submarine cables that joints are required. The maximum continuous manufacturing lengths are limited by the capacity of the manufacturing equipment, and the maximum installation lengths by the cable laying vessel. Joints are therefore inevitable and considered as an integrated part of submarine cable systems, and they do not introduce weaknesses on MI cables.

HVDC MI cable systems are operated with the two available converter technologies (line commutated converters and voltage source converters). The stresses imposed on the cable systems in normal operation and transient conditions differ for the two converter technologies, but nevertheless MI cable systems have outstanding performance.

### **Proven life-time of more than 40 years**

The MI cable technology has displayed an exceptional capability to resist aging. One of the first HVDC MI cable systems operating at 250 kV was put in service in 1977 between Denmark and Norway (the Skagerrak Interconnection). The cable system has been in service for 45 years, is still in operation, and there have been no failures caused by internal origin (insulation breakdowns). Some years ago an unprotected part of the cable was damaged by a fishing trawl, making it possible to cut a sample of the cable and perform a thorough investigation and analysis of the condition of the cable. Even after exceeding the 40 year design life-time, there were no signs of electrical, chemical or mechanical ageing of any of the components of the cable. This confirms the reliability and longevity of well designed, manufactured and installed HVDC MI cable systems, and is a firm proof of a life-time expectancy of more than 40 years.

### **Vast experience at the highest voltage levels (500–525 kV)**

The interconnectors Montenegro – Italy (Mon.Ita), Germany – Norway (NordLink) and UK – Norway (NSL), all operating at 500–525 kV, are among the numerous recently installed cable links employing the mature and well proven MI technology. Since the first 500 kV MI cable system was put in service in 2007, more than 4400 km of MI cable has been installed and is operating at this voltage level.

**More than 10 years' operational experience at deep waters (>1500 m)**

MI cable systems have proven the ability to be installed and operated in very deep waters. Several cables are installed in depths of more than 1000 m, and the deepest ones exceeding 1500 m water depth have flawless operation for more than ten years.

**The future for mass impregnated cable systems**

Many large 500–525 kV HVDC MI cable projects with a total cable length of approximately 7600 km are under realization and planned to be in service by the end of this decade. With these projects the accumulated length of 500–525 kV HVDC MI cables will exceed 12000 km.

Extruded HVDC cables have limited service experience at the 320 kV level and absolutely no practical operational experience at 525 kV, it is therefore a considerable uncertainty with regards to the reliability and longevity of extruded HVDC cable systems at the highest voltage levels. The technical challenge is not linearly dependent on increasing voltage. The insulation system of a 525 kV XLPE cable system is aged 20–30 times more rapidly than a 320 kV cable system. Joints are inevitable on long cables. As opposed to joints on MI cables, the joints on extruded cables introduce interfaces which represent weaknesses and increased risk of failure. In addition the number of joints is much higher on extruded HVDC cables due to shorter continuous manufacturing lengths.

All major 500–525 kV HVDC interconnectors developed in the past years have been realized with MI technology, and the same applies for the ongoing 500 kV deep water cable links Crete – Attica (Ariadne Interconnection S.P.L.C) and Italy – Sicily – Sardinia (Tyrrhenian Link). The former will be installed down to 1200 m water depth and the latter to 2200 m water depth.

525 kV HVDC mass impregnated cables have been successfully qualified to a maximum water depth of 3000 m according to the relevant Cigre recommendations. This breakthrough is paving the way for realizing highly reliable and powerful HVDC interconnections in deeper waters than ever before.

Currently the highest operating voltage of HVDC MI cable systems is 525 kV and thousands of kilometres are operating flawlessly at this voltage level. The voltage level of MI cable systems is not limited to 525 kV, and 600 kV MI cables are already qualified and available in the market.