Experience in service of HVDC cables, prospects of extruded polymer insulations

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ABSTRACT

In this paper, the experience of existing HVDC connection in Denmark is given, where focus is on loading possibilities and fault statistics. Furthermore, the prospects of using extruded cables for new DC installations in Denmark are explained.

KEYWORDS

Submarine Cables, HVDC interconnections, Denmark, Skagerrak, Kontek, Kontiskan, Greatbealt, Cobra, Extruded HVDC Cables, Test, Transmission system operator.

INTRODUCTION

Denmark is geographically placed in the transit between the mainland of Europe and Northern Europe. The country has therefore had international interconnection since 1965, when the first DC connection between Norway and Denmark was established. Since then, the DC connection to Norway has been strengthened, as well as AC and DC connections to Sweden and Germany and a DC interconnection between Eastern and Western Denmark have been established.

The reason for choosing DC for these connections is to ensure separation of the frequency systems in central Europe and Northern Europe. This is even the main reason for choosing a DC solution for connecting the Eastern and Western part of Denmark, which is only a 58 km long cable connection.

Furthermore, most future interconnections will have to be DC, but it is now decided to ask for extruded DC cables in parallel with MIND solutions where applicable.

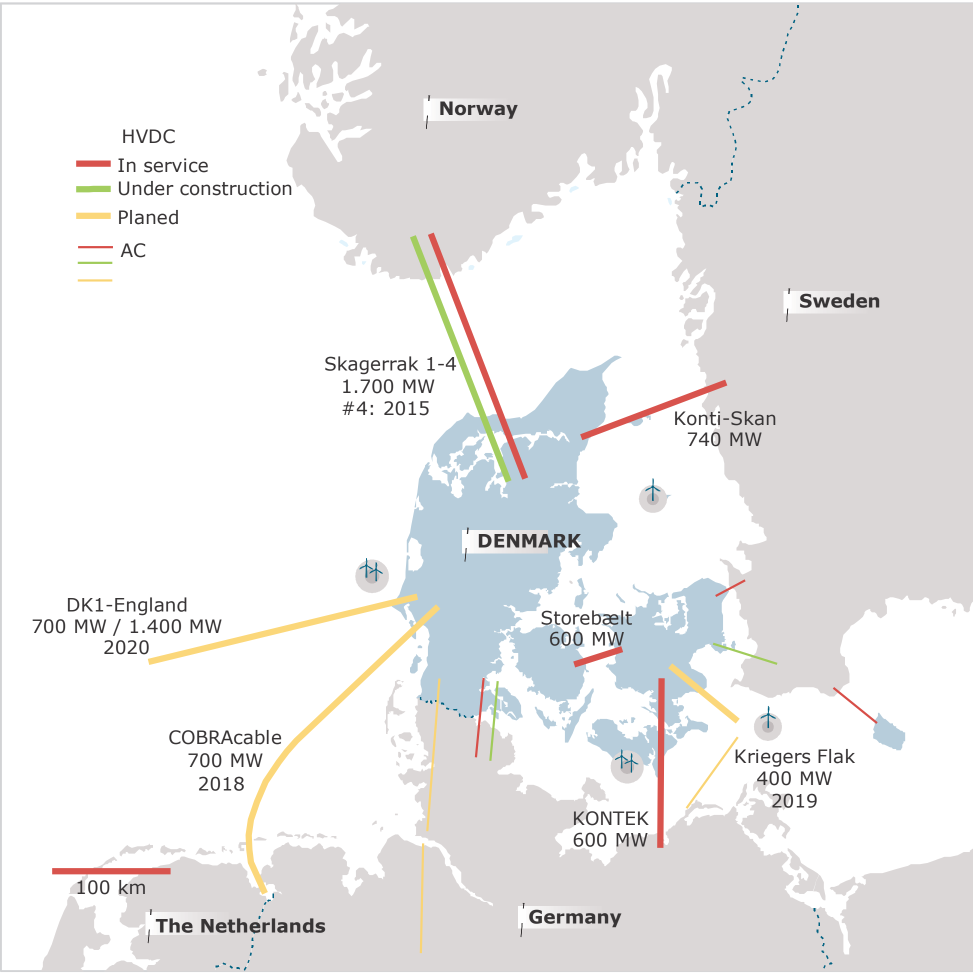

Fig. 1: Map of Denmark with Interconnections.

EXPERIENCE OF HVDC AT ENERGINET.DK

Since 1965 Denmark has installed numerous interconnections of either Flat Type Oil Filled (FTOF) or Mass Impregnated (MIND) DC cables, operated with up to 500 kV. We will in the following summarise the services history of these connections.

Please notice that for 700 km installed cable oil paper insulated DC cable with a mean service life of 24 year (and up to 48 years) so far, Energinet.DK has never experienced any internal electrical failures, but only oil spills due to falling lead sheaths of flat type cables and external damages of submarine cable where the cables have not been buried.

Konti-Skan

In 1965 the first DC connection between western Denmark and Sweden was constructed. This connection, Konti-Skan 1 (or 1.1), includes a 23 km long FTOF submarine cable, and was operated as a monopole with earth electrodes for sea water return. The connection was driven at 250 kV, with a capacity of 250 MW, and used mercury arc valves for the LCC connection. The first cable laid, had a design fault in the lead structure and had to be de-rated significantly. Therefore, a new Konti-Skan 1 connection (or Konti-Skan 1.2) was installed in 1971, at the cost of the manufacturer. Since 1971, Konti-Skan 1.2 has been operated in parallel with Kont-iSkan 1.1, which has survived until now. Konti-Skan 1.1 is however scheduled for replacement in 2014.

In 1988, a second Konti-Skan connection was constructed, using thyristors for the converter scheme and in 2006, the converter scheme of connection pole 1 was also replaced with similar thyristors, with a power rating of 350 MW. Konti-Skan connection 2 was originally a FTOF such as Konti-Skan 1, but was in 1991 replaced with a MIND cable.

The Konti-Skan connection has been out for repair of the lead sheet a number of times.

Fig. 2: Two core flat type oil filled cable (FTOF) as in operation in Konti-Skan and Kontek.

It should be noticed that the two-core FTOF cables (still single pole) of Konti-Skan, has in the past also served as an emergency supply to the island of Læsø, when the 20 kV AC connection has been out of service. In this situation, the DC connection has been coupled with two phases connected to the two cores of one of the cables, and the third phase to the lead sheath/grounding system. The AC system is then operated with a floating neutral. This possibility will however be removed, with the replacement of Konti-Skan connection 1.1 in 2014.

Skagerrak

The first Skagerrak connection to Norway, from 1976, was originally a 250 kV DC MIND connection with an earth electrode for seawater return. In 1977, a second connection was established and driven as a bipole connection together with the first connection, at 275 kV.

A third connection was installed in 1993, and can currently be operated at 350 kV, with a capacity of 440 MW. When the third connection was established, the current direction of the second connection was changed, such that Skagerrak connections 1 and 2 are today operated as two monopoles in parallel connected in series with the third pole.

Today the first Skagerrak connection, using the same oil-filled 37 year old cable, is operated at 275 kV, together with the second Skagerrak cable from 1977, with a total capacity of two times 275 MW.

Skagerrak poles 1 and 2 both have a submarine cable part with a 800 mm^2 Cu conductor and MIND insulation. The armour is a double counter helically wounded steel wires. The third pole is a 1400 mm^2 Cu cable with MIND insulation, and the same armouring type as for poles 1 and 2. The three connections are a combination of a 127 km long submarine cable and a 113 km long overhead line. All three submarine cables have had successful operation, with only a number of external damages on pole 1 and 2, which were not buried after installation.

The latest DC connection, Skagerrak 4, which is the fourth interconnection between Denmark and Norway, is built with the newest VSC converter technology. Nevertheless, the cable is Mass Impregnated Non Draining (MIND) because of a needed voltage level of 525 kV and an operation with polarity reversal due to a bipolar operation with the LCC connection of Skagerrak 3. The operation capacity of connection 4 is 715 MW at maximum voltage.

This new connection pole 4 is in contrast to poles 1-3, only formed of cables. The connection therefore consists of 104 km underground cable, single core MIND non-armoured, as well as a 140 km submarine cable, single core MIND, 1600 mm^2 Cu.

When all 4 connections are in operation, driven at 275 kV, 275 kV, 350 kV and 525 kV respectively, the total capacity is 1700 MW.

Kontek

The Kontek connection is a 400 kV, 600 MW, monopole HVDC connection between Denmark and Germany. The Kontek connection was originally installed as a two core flat type oil filled cable (FTOF) under a single lead sheath (see Fig.2), but driven as a single pole with sea return,

Close and Return

and was first commissioned in 1995. The connection consisted of a 101 km long underground cable and a 50 km submarine cable, both of the FTOF type. However, a systematic crack formation in the lead sheath over time resulted in oil leakage from cable joints on the cable, which had joints for approximately every 1 km. The submarine cable, only 15 years old, therefore had to be exchanged in 2010, while the underground cable could be repaired. Today, the Kontek connection consists of the 18 year old LPOF underground cables, and a new 50 km long single core MIND submarine cable.

There were no "off the shelf" joints available for connecting a 2x800 mm^2 Cu FTOF underground cable, to the 1850 mm^2 single core Cu MIND submarine cable. It was therefore chosen to use open air terminations for the connection of the two designs, but in order to reduce the visual effect; these open air terminations were placed indoors in buildings, partly buried to a depth of 15 m at the three landings in Denmark.

Fig. 3: Indoor air insulated terminations for the Kontek connection between Denmark and Germany.

The Kontek connection is operated at 400 kV, with a capacity of 600 MW.

Great Belt connection

In 2010, a 100 year old dream of Denmark was realised, when the Eastern and Western part of the country were electrically connected with a HVDC cable.
The Great Belt connection is formed of a 25 km long single core MIND underground cable, and a 32 km long single core, armoured MIND, submarine cable. The submarine cable is a 1700 mm² and 2000 mm^2 Cu cable, and the underground cable is a 2000 mm^2 Cu cable, operated at 400 kV with a capacity of 600 MW.

Denmark is a transit country, having the Western part frequency connected to the mainland of Europe, with long HVAC lines into Germany, and the Eastern part frequency dependent of Northern Europe, with AC connections into Sweden. In order to keep frequency independence between the Northern part of Europe, and the mainland of Europe, it was necessary to use a DC connection between these two parts of Denmark.

FUTURE PROJECTS AT ENERGINET.DK

During the past few years, detailed studies of a 300 km DC connection between The Netherlands and Denmark have been carried out, and the possibilities for a 600 km DC connection between Denmark and the UK are being investigated.
Furthermore plans have been developed for a DC cable connection to the 600 MW offshore windfarm at Kriegers Flak, enabling connection to the nearby windfarms in German waters. These DC developments assume using VSC converter technology, with 320 kV cables having extruded polymer insulation (XLPE) as main alternatives. The grid connection of the Krigers Flak wind farm is due for commissioning no later than 2020.

ENERGINET.DK'S VIEW ON USING XLPE FOR NEW HVDC CABLES

In the following we will try to share the thoughts on the future use of Extruded DC cable in the Danish transmission grid.

300/320 kV VSC and XLPE HVDC Cables

With a population of only 5.5 million and a limited amount of heavy industry, the Danish grid is not very large. Furthermore, the amount of spare power available in Denmark, in case of failures, is limited. Therefore, in order to keep the system voltage within limits, only a maximum of 600 MW is allowed to be lost on a single interconnection, especially in and out of the two frequency zones separating Denmark. Another 100 MW can be reserved for regulation. This makes a fairly economical size limit for using 2 pole Extruded DC cables together with a VSC converter solutions with ±300 kV or ±320 kV, which also seems to have become an industry standard. For these voltages, extruded HVDC cable solutions have been offered for some time, and this solution is being considered for future interconnections.

Submarine cable – higher risk

Denmark is for most part surrounded by water, and all application of DC connections in Denmark will have a significant Submarine cable part. This has to be considered when evaluating a new technology, due to the time and complexity of rectifying any build in faults.

The large amount of offshore cables, causes higher risk, when considering a new technology with very little or no in-service experience.

When considering extruded HVDC cable technology at the previously mentioned voltage level of 300/320 kV, and for making up for some of the present lack of in-service experience, Energinet.DK actively works for:

- following the development of the suppliers,
- involvement with international work on standardised testing and
- solid in-house understanding of the technology

VSC / LCC – Polarity reversal

VSC converter solutions, that do not require polarity reversal to change power direction, have in recent years,

developed tremendously, and is now considered a well proven technology with losses close to the LCC solution.
VSC has therefore quickly become the preferred technology, especially for connection of large scale offshore production. This has been reflected in the development of extruded DC cables that seems to have been concentrated on cables designed for service without polarity reversal. Due to this evolvement, cable designed for polarity reversal is now lacking a bit behind, with regards to voltage levels and number of capable manufactures.

However, for interconnections, with both converter stations onshore, there will still be cases where Energinet.DK with the current development of VSC technology, will have to consider LCC solutions with polarity reversal, due to the lower price of LCC, and maybe even due to the different grid properties of a total LCC converter solution.

For extruded HVDC cables Energinet.DK therefore also follows the development the field of cables for polarity reversal, so there would be a free choice between Extruded and MIND cables for the LCC connections, where MIND cables nowadays prevails.
We, however, also have to admit that the development on VSC solutions in the future could even out the differences between VSC and LCC.

Benefits of the XLPE technology

When the choice stands between MIND and extruded HVDC solutions, Energinet.DK has decided, that with the increasing number of capable suppliers, the two technologies will be evaluated equally. Therefore the inherent benefits of the extruded technology will have full impact on the on the choice of technology.

The most obvious benefit of extruded cables, is the higher allowed conductor temperature, of often 70℃ compar ed to only 50-55℃ of MIND cables. For Energinet.DK purposes (2 pole connections of up to maximum 600 MW as described above), this allows for solutions with aluminium conductors, which should make price competitive options, with both lower installation and cable cost.

Another decisive factor is often the availability of production facilities at short notice, as this is often the case with grid connections for offshore wind farms. Furthermore, production time is also an issue for long interconnections where delivery over a period of more than two years is normally not acceptable. In both cases the extruded HVDC solution is often seen to have an advantage over MIND.

WHAT WILL ENERGINET.DK CONSIDER WHEN PURCHASING EXTRUDED HVDC CABLES?

As indicated above it is not an easy matter to purchase a new technology, such as Extruded HVDC cables, and in the following we will try to account for some of Energinet.DK's main evaluation criteria related to extruded HVDC cables:

- Testing
  - Development
  - Prequalification
  - Type Test
- Technical Knowledge
  - Material
  - DC fields
- Experience

The bullet points may look like normal evaluation scheme, but to design and manufacturing of cable, and especially of accessories, for an extruded HVDC cable system this is generally considered very different from AC systems and more complex. This is for instance with respect to significant material properties and the calculations of electrical fields, why emphasis may be focused towards more general evaluation of the manufactures in depth knowledge.

Testing

Energinet.dk actively participates in different Cigré working groups. This is partly in order to be updated on most recent developments, but also in order to contribute as one of few Transmission System Operators (TSO) represented in Cigré working groups.

In 2012, Cigré Working Group B1.32 Published Cigré Technical Brochure 496 - "Recommendation for testing DC extruded for power transmission at a rated voltage up to 500 kV" [1] (updating Technical Brochure 219). It is the opinion of Energinet.DK that the recommendations of Cigré in TB 496, provide a good basis for assessing an extruded cable system. Formal test requirement to prequalification and type testing will therefore be according to this recommendation.

Technical Knowledge

As the recommendation in TB 496 states, each test is based on today's knowledge, and the behaviour and properties of insulation materials in a DC field, which are not necessarily fully understood (or described). As a customer, we must therefore to a high degree rely on the skills and technical knowledge of the manufacturer. This is especially the case when it comes to measuring appropriate parameters, and making appropriate models as well as relevant development tests.

Maintaining a god contact with manufacturers in between projects, and asking for more all round technical explanations of design choices, should ensure that a sufficient evaluation of technical ability can be made.

Experience

In-service experience of extruded HVDC connection at 300/320 kV is currently not available since the first systems are just being installed. Therefore, experience from lower voltages levels is partly used, with the awareness that design rules may not be scalable for HVDC in the same way as for HVAC designs.

SUMMARY

Energinet.dk has extensive experience with oil paper insulated HVDC cables, without any larger electrical faults of cables with mean service life of 24 years and even up to 48 years old. The in service length of HVDC cables is already approximately 700 km, with plans for more than doubling during the coming years.

With recent technology development, and large scale HVDC projects in the pipeline, Energinet.dk has started planning for purchase and installation of extruded HVDC cables for future projects. So far considerations for HVDC extruded, only involve up to ±320 kV, with a tender specification already under preparation, for the grid connection of "Krigers Flak" Offshore wind farm / Interconnection to Germany in the Baltic Sea.

REFERENCES

[1] Cigré B1.32, Technical Brochure 496 "Recommendation for testing DC extruded for power transmission at a rated voltage up to 500 kV"

GLOSSARY

VSC Voltage Source Converter (no pole reversal)
LCC Line Commutated Converter (w. pole reversal)
TSO Transmission System Operator
XLPE Extruded Polymer insulation