STANDARDIZATION AND CONTINGENCY STORAGE FOR SUBMARINE CABLE SYSTEMS

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ABSTRACT

In Norway the population of submarine cables in the distribution network (1-170 kV) is extremely diversified. Numerous unique designs, voltage levels and cross sections exists. This contributes to making contingency planning and repairs time-consuming and expensive. The cable systems are commonly characterized by their importance for reliable power delivery in the system and that special competence is needed to build, operate and repair them. New solutions have been found through national collaboration and an effort to standardize. Thirty network owners have entered a co-ownership to establish a contingency storage for standardized submarine cables, joints and terminations thus aiming to reduce costs and repair time in the future. The total investment of approximately 250 MNOK now covers approximately 1200 submarine cable systems. An individual investment for each partner would add up to more than 1 500 MNOK to achieve the same level of contingency preparedness.

INTRODUCTION

Some severe failures in submarine cables systems and new instructions and audits from The Norwegian Energy Regulatory Authority (NVE) has resulted in a much higher vigilance to the contingency planning among Norwegian submarine cable owners the last five years [1-4]. An extensive gap in availability of contingency back-up cables and accessories has been revealed [5]. It has been acknowledged that a large diversity of designs, long delivery times for new cable systems, lack of submarine cable competence within the relatively small grid owner companies are all problems that need to be addressed [6].

Several steps have been taken to strengthen the contingency preparedness among the network owners. A collaboration between thirty submarine cable owners has been established. The goal is to offer a rational alternative for satisfying the demands from the Norwegian Energy Regulatory Authority. This has been achieved by

- Establishing and running a contingency storage
- Entering and managing joint agreements
- Establishing an expert group for technical advice and recommendations
- Standardization

Statistics

The Norwegian power grid has a relatively large share of submarine cable systems, crossing fjords and connecting remote islands to the electrical grid.

In 2016, 78 Norwegian network companies owned a total of 1 931 km 1-24 kV, and 369 km 36-170 kV submarine cable systems [7-8]. The thirty participating companies in the collaboration represent around 900 individual submarine cable systems spread along a 100 000 km coastline. The remaining companies own few and short cable systems, accounting to around 300 systems. Anticipated life time for a submarine cable is usually 40 years. Some key information on the submarine cable systems among the thirty members is shown in the table below.

Table 1 – Data for existing submarine cable systems

1 - 36 kV	**1250 km**
Max depth	550 m
Max length	33 km
Average length	1.5 km
XLPE/paper oil/other	67% / 24 % / 9 %
Unique cable types	54
Cross sections	10 - 630 mm^2
Average building year XLPE / paper-mass-oil	1998 / 1972
72 - 170 kV	**227 km**
Max depth	550 m
Max length	6.75 km
Average length	2.6 km
XLPE/paper oil	56 % / 44 %
Unique cable types	15
Cross sections	50 – 2000 mm^2
Average building year XLPE / paper-oil	1996 / 1973

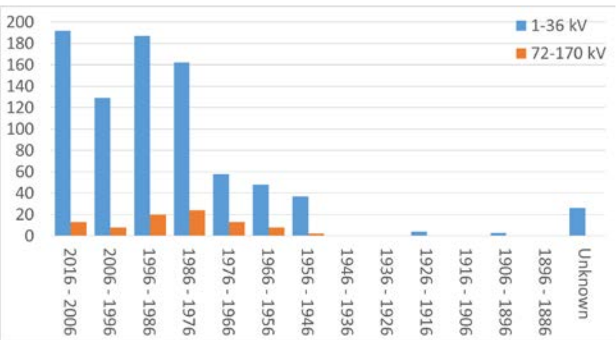

Figure 1 – Reported building year for the submarine cable systems.

Failure rate

There are no specific and detailed failure statistics for the Norwegian submarine cable population. Available data from national, Nordic and international databases are often coarse and lacks detail, and information concerning failure type, equipment type, age, voltage level, protection method, depth of installation and seabed features are not available [9-11]. The collaboration group and its members will work to establish better and more specific failure-statistics in the future.

The failure rate for submarine cables is expected to be between 0.12 and 0.32 pr. 100 km•year based on a mix of international and national data, but the number is very uncertain. For Norway this suggest around 2-7 failures each year.

SOLUTION

Expertise/Expert group

A technical reference group has been formed with experts from Norwegian grid companies who own submarine cable systems. The purpose of the group is to give technical advice and recommendations within all phases of a submarine cable system life cycle, such as early planning, engineering, survey, procurement, installation, maintenance, diagnostics and fault localization. It involves establishing standardized technical specifications and working methods to rationalize and work more efficient.
The group publishes its work through technical brochures which are in practice available for all Norwegian submarine cable system owners.
A web-based database for sharing information on quantity, quality and localization of distributed contingency material has been established and is administrated by the secretary of the reference group.

Standardization

It has been acknowledged that a single international standard covering submarine cables does not exist. A big part of the standardization work has thus been to combine national experience and relevant international standards and recommendations to create a Norwegian submarine cable system technical specification from 12 kV up to 170 kV. This has been done by combining land cable standards from IEC [12-14] and CENELEC [15-16] with CIGRE technical brochures [17-19] which secures that the cable system will endure in a marine environment. An important criterion has been that all equipment for such important and expensive installations is type tested prior to manufacturing. Another important aspect is that cable systems should have a life expectancy of at least 40 years and be as maintenance free as possible. The most relevant international and European publications are listed in table 2.

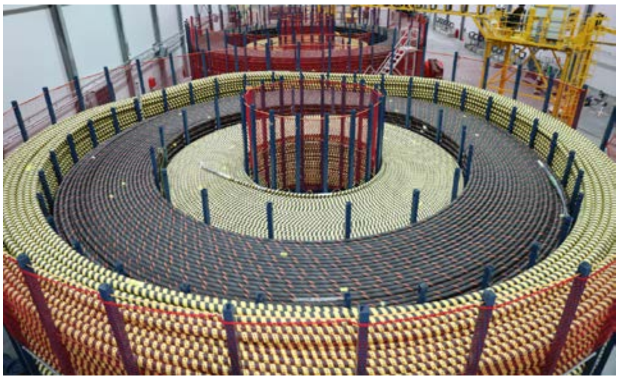

Figure 2 – Sectionalized turntable with three submarine cables.

Table 2 – List of relevant standards

IEC 60502	Extruded land cables 1.2-36 kV
IEC 60840	Extruded land cables 36-170 kV
IEC 63026*	Extruded submarine cables 7.2-72.5 kV
HD 632	Extruded land cables 42-170 kV
HD 620	Extruded land cables 7.2-42 kV
CIGRÉ TB490	Recommendations for testing submarine cables 36-550 kV
CIGRÉ TB623	Recommendations for (mechanical) testing submarine cables
CIGRE TB722	Recommendations for additional testing of submarine cables

*Not yet published

International standard IEC 63026 for submarine cables with extruded insulation and their accessories for rated voltages from 6 kV up to 60 kV is anticipated to be published within a year and will be incorporated in the Norwegian technical specification for submarine cable systems.

Back-up cables

Five different cables have been designed, tested and produced in close cooperation between the network owners, the technical reference group and cable manufacturers. The cross sections and voltage levels were chosen so that as many as possible of the network owners' installed cables could be replaced/covered. The main idea is that a full replacement of all three phases for the longest and deepest HV submarine cable system should be possible. For MV systems it is anticipated that jointing will be the preferable solution, even though a full replacement is made possible with the back-up cables. The length, age and condition must be evaluated for each of the cable systems. The location of the failure will also heavily influence the choice of repair. Oil/paper cables is anticipated to be replaced by XLPE cables if they fail.

The cable designs were chosen to achieve a long lifetime (dry design) and maintenance free. High ampacity (Cu-conductors) and high mechanical tolerance was chosen for versatile installation scenarios. For this torsion balanced armour is chosen for deep water installation down to 400-550 m. The armour also serves as mechanical protection against steep and rocky sea beds. For the single core cables, a round Cu-armour was chosen for lower losses, while the three core cables were designed with galvanized steel armour. The cables are protected against corrosion with a layer of bitumen and yarn.

Table 3 – Summary of standardized cables

#	Cable type	Length
1	170 kV 1x400 mm^2 TKZA	19 km
2	170 kV 1x800 mm^2 TKZA	22 km
3	24 kV 3x50 mm^2 TSVA	10 km
4	24 kV 3x95 mm^2 TSVA	10 km
5	36 kV 3x240 mm^2 TSRA	10 km

Back-up accessories

Contingency repair accessories, tools and materials are made available to the members companies. This includes complete repair joints for all stored cables with relative short installation time and deep water (400-550 m) capacity.
For the medium voltage level, transition joints from all stored cables to most of the extruded cables in the network, regardless of manufacturer, has been designed and produced. Terminations has also been procured but has been considered to be a standardized and highly available accessory since they are also used on land cables. A replacement program for materials with expiration date is established.

Table 4 – Summary of contingency accessories.

#	Accessory type
S1-S5	Rigid repair joints for cable types 1 to 5. Pre-moulded joint body.
O3-O5	Rigid repair joints for cable types 3-5 against any type of submarine cable. Taped joint body. 16-240 mm^2 conductor cross section. Different armour design/size. Dry and wet designs.
T1-T5	Terminations for cable types 1 to 5.

Storage Facilities

A warehouse has been built to store the contingency equipment. The location was chosen considering several aspects, such as access from both sea and land, climatic stable, ice free, deep and sheltered harbour, and a strategic geographical location for logistics. The location is also in close vicinity of several marine and offshore company premises, giving easy access to equipment and experienced personnel. Regulations from The Norwegian Energy Regulatory Authority implies strict access control and technical building safety.

Figure 2 – Contingency storage facilities with moveable pickup tower.

Table 5 – Summary of warehouse specifications

Area	2500 m^2
Turntables	3x1600 tonne. 16 m diameter
Drums	2 x 35 tonne cable drums with interchangeable barrels and detachable flanges for truck transport.
Mobile pickup towers	2 x 20 tonne. Loading in/out or movement of cable between turntables
Crane	20 tonne bridge/traveling crane
Pulling machines	2 x 4 tonne traction force. Flexible for land or marine use.
Equipment	Flexible cable rollers and chute. Forklift Drum spooling machine.
Shelves	Sprinkled shelve section for large crates and boxes.

Marine vessels

Secure access to marine vessels for fault localization and installation is a key factor for reducing outage time and cost of energy not supplied. This has been ensured through joint agreements between the cooperating members and marine companies. The contracts cover the entire Norwegian coast and has specific demands concerning availability and mobilization time. To lower the cost of vessel waiting time, the same contingency vessels are hired for planned maintenance and inspection of the members submarine cable systems. This also contributes to knowledge and familiarization of the marine crews to the submarine cable systems locations and specialities.

Repair joint competence

A key factor is competence to perform the installation of submarine cable repair joints, which is an expertise which demands special training and experience. The individual grid companies install too few submarine cable systems per year to have this competence in-house. Again, access to competent personnel has been ensured through joint agreements with specific demands to quality, availability and mobilization time.

FUTURE WORK

The first phase of the submarine cable project which entailed research, planning and procurement of the contingency concept is now complete. The next phase will focus on administration of the frame-contracts with cable and accessory manufacturers, marine vessels and jointers, training, as well as keeping the warehouse updated and fully equipped. Submarine cable systems will fail, but when they do, the necessary equipment, knowledge and resources will be available. New contingency preparedness projects are being launched in Norway to utilize the same ideas for other critical components such as large power transformers and GIS switchgear.
To create better and more specific failure-statistics in the future, a specialized reference group and its members may be the solution.

CONCLUSION

The current highly diversified Norwegian submarine cable population will with time become more standardized, and repair time will become much lower as a significant share of Norwegian network owners have entered a co-ownership to establish a contingency storage of standardized submarine cables, joints and terminations. The total investment of approximately 250 MNOK now covers approximately 1200 submarine cable systems. An individual investment for each partner would add up to more than 1 500 MNOK to achieve the same level of contingency preparedness.

The contingency storage, in addition to technical advice from the expert group, will enable any partner experiencing a cable failure to immediately start repair or replacing activity without any delay. Access to marine vessels for inspections and installation has been secured through joint agreements.

MISCELLANEOUS

Acknowledgments

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[13] IEC 60840 - *Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) – Test methods and requirements*

[14] IEC 63026 - *Submarine power cables with extruded insulation and their accessories for rated voltages from 6 kV (Um = 7,2 kV) up to 60 kV (Um = 72,5 kV) - Test methods and requirements*

[15] CENELEC HD 620 - *Distribution cables with extruded insulation for rated voltages from 3,6/6 (7,2) kV up to and including 20,8/36 (42) kV*

[16] CENELEC HD 632 - *Power cables with extruded insulation and their accessories for rated voltages above 36 kV (Um = 42 kV) up to 150 kV (Um = 170 kV)*

[17] CIGRÉ TB490 - *Recommendations for testing of long AC submarine cables with extruded insulation for system voltage above 30 (36) to 500 (550) kV* (2012)

[18] CIGRÉ TB623 - *Recommendations for mechanical testing of submarine cables* (2015)

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