

MARTIN LINGE WORLD LONGEST AC POWER FROM SHORE DEVELOPMENT

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Abstract

In May 2015, the 161km long Martin Linge submarine cable was successfully energized and tested, setting the world record for the longest High Voltage AC cable.

The Martin Linge field development comprises a power from shore system (onshore installation and subsea cable), a platform, a jack up rig and a Floating Storage Offloading (FSO) unit.

This paper discusses power from shore cost aspect and the criteria which have been considered to select a power from shore concept for Martin Linge field instead of an offshore Gas Turbine power plant which is the current practice in the offshore Oil and Gas industry.

Since in a first approach, for such long step-out distance, the choice of power from shore would have been to select a DC transmission line, the paper discusses also the design and the main technical challenges of this long step-out AC transmission development. Finally, the paper gives feedbacks and lessons learned of this success.

Index Terms —Power From Shore, Subsea Cable, SVC, GIS.

I. INTRODUCTION

Discovered in 1975, Martin Linge offshore gas field (formerly named Hild) and located in the North Sea will be operated by Total Norge which has chosen to base this development with a power from shore concept. The facility is designed for remote control from Total Norge onshore base in Stavanger.

The field will be developed with subsea installation and topside facilities. The processed gas will be then exported to the St Fergus terminal in UK via a new link to the existing Frigg UK Pipeline (FUKA). The oil, water and condensates will be processed and stored on a dedicated storage vessel where water will be separated for reinjection, and oil will be exported via shuttle tankers.

With a step out distance of 161km and a design power of 55MW, this is the world's longest AC submarine cable power supplying an entire offshore Oil and Gas platform from the shore.

This paper discusses the criteria which have been considered to select a power from shore concept instead of an offshore Gas Turbine power plant which is the current practice in the offshore Oil and Gas industry.

Since in a first approach, for such long step-out distance, the choice of power from shore would have been to select a DC transmission line, the paper discusses also the design and the main technical challenges of this long step-out AC transmission development.

Finally, the paper gives feedbacks and lessons learned of this success.

II. PROJECT PRESENTATION

The Martin Linge Field formerly named Hild, is located on the Norwegian Continental Shelf, 75 km North of Frigg, 42 km West of Oseberg, 87 km North-East of Bruce, and 38 km South-East of Alwyn North field. TOTAL E&P Norge is the operator (49%) with Petoro (30%) and Statoil (21%) as partners.

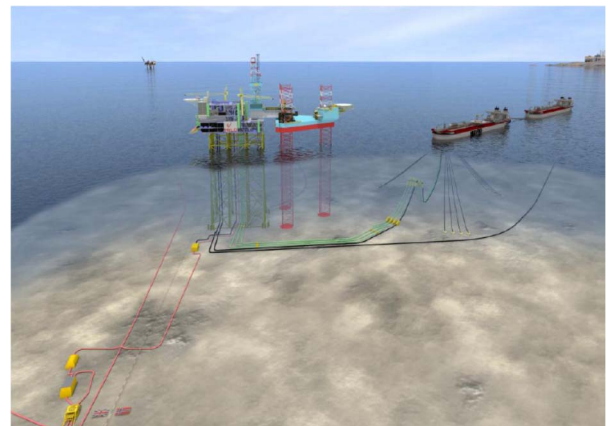


Fig. 1 Martin Linge Power From Shore development

The field development (Fig. 1) comprises a platform with a jack up rig and Floating Storage Offloading unit. The well programme is to drill and complete 6 Brent Gas producers, 4 Frigg Oil producers and 1 produced water injection wells. This offshore development will be supplied with electric power from shore, through a High Voltage AC submarine cable.

The cable route length is 161 km. The estimated maximum power requirement is 55MW while expected load profile is 35 MW. Cable landfall is at Kollsnes and the system is connected to the 300 kV Norwegian national grid.

III. SELECTION OF A POWER FROM SHORE FOR MARTIN LINGE

Conceptual study base case of the Martin Linge project was made with Gas Turbine for the offshore power generation. Power from shore was only an alternative case.

But eventually, power from shore has been selected for the following reasons:

- Offshore Gas Turbine as power generation would have required installation of 3 Gas Turbine due to the requirement of having N+1 Gas Turbine and would have created a weight issue for the jacket,
- There was and there is still a strong incentive from Norway government to use Power From Shore solution. In fact, all new field developments on the Norwegian shelf shall

study whether power supply from land is expedient. And an overview shall be submitted to authorities of the energy volumes and costs required to supply the facility with power from land, rather than using gas turbines offshore,

- Power from shore and power generation with Gas Turbine were assessed for the project as economically equal,
- It was assessed that the regularity of a power from shore is equal and even better than a Gas Turbine,
- Power from shore is the right choice to reduce local emissions offshore,
- Power from shore increases the sales volumes of Gas which is not burnt offshore by Gas Turbines,
- Power from shore reduces offshore maintenance compare to Gas Turbine power generation.

IV. MARTIN LINGE POWER FROM SHORE, AC OR DC TRANSMISSION?

With the power from shore concept selected, there were 2 possible technical transmissions choice either AC or DC transmission, each solution having advantages and disadvantages.

Even if an AC transmission has a number of drawbacks which limit its use for long step-outs applications; such as high voltage variations between no-load and full-load mode, risks of resonance and reactive power generation by the subsea cable. AC transmission was the solution allowing to not modifying the existing layout, since AC transmission minimizes the number of electrical equipment to install offshore. For an AC transmission only GIS and transformers were required to be installed whereas for a DC transmission solution an additional DC to AC inverter associated with harmonic filter (Fig. 2) would have been required to be installed offshore.

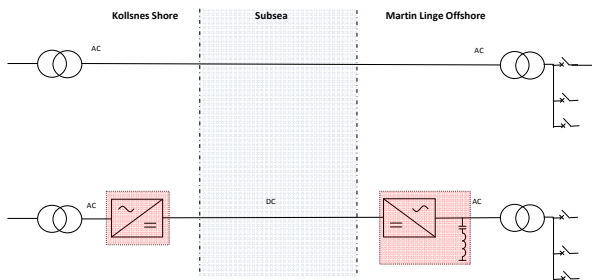


Fig. 2 AC and DC scheme for Martin Linge

Furthermore, from a CAPEX standpoint, AC transmission was cheaper.

Even if an AC transmission was the first preferred choice for the project, the feasibility of an AC transmission had still to be proven for such long step-out distance. Some technical studies were then conducted confirming the feasibility of an AC transmission line for the project. It appears from Fig. 3 that Martin Linge is in fact at the limit of feasibility for an AC transmission at 50Hz.

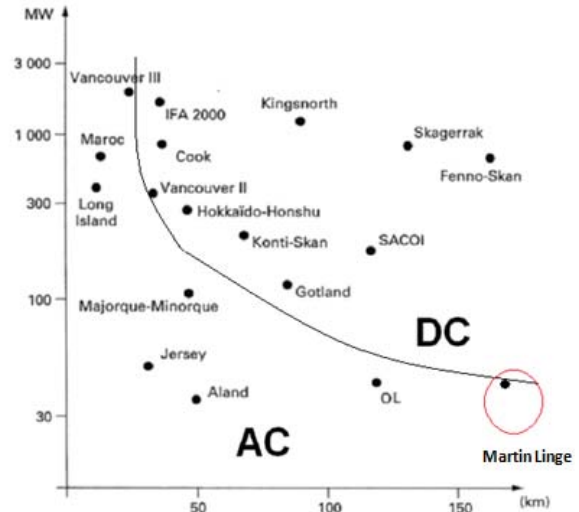


Fig. 3 AC and DC projects through the world

So eventually, it was decided to select an AC transmission for the project.

V. MARTIN LINGE ELECTRICAL ARCHITECTURE

With the selection of an AC power from shore, the challenge was then to design the system in the existing layout with a reduced number of equipment installed offshore. For this purpose it was chosen to design the system without offshore compensation reactor even if it would have improved the current distribution between both cable ends (onshore and offshore). In addition, a system without offshore compensation reactor has the advantage of having a better offshore voltage stability since in case of full offshore load rejection, the offshore reactive power variation seen at the offshore cable end is small compare to the reactive power consumed continuously onshore at Kollsnes.

The single line diagram (Fig. 4) has been designed in order to maximize the availability of the power from shore system, on this purpose redundant equipments are integrated in the system.

2 step-down transformers (300kV/100kV, 80 MVA) equipped with On Load Tap Changer (OLTC) are installed onshore at Kollsnes, these transformers are redundant. The OLTC is here to regulate, during normal load variation, the offshore voltage of the 100kV Martin Linge GIS busbar. The OLTC has a wide range of tap to be able to energize the subsea cable at 80 % of the rated voltage in order to limit voltage stress, inrush current and reactive power steps when energizing the system. The secondary side (100 kV) is solidly earthed to prevent excessive overvoltage in the event of single phase earth faults in the 161 km subsea cable system.

Due to its compactness and availability capability, double busbar systems GIS is installed onshore and offshore. For energizing purpose, the onshore 100 kV GIS cable outgoing feeders is designed for single pole point of wave closing. The onshore GIS normal operating voltage range is from 90.5 kV to 106 kV with possibilities to operate at 80 kV during energizing operations.

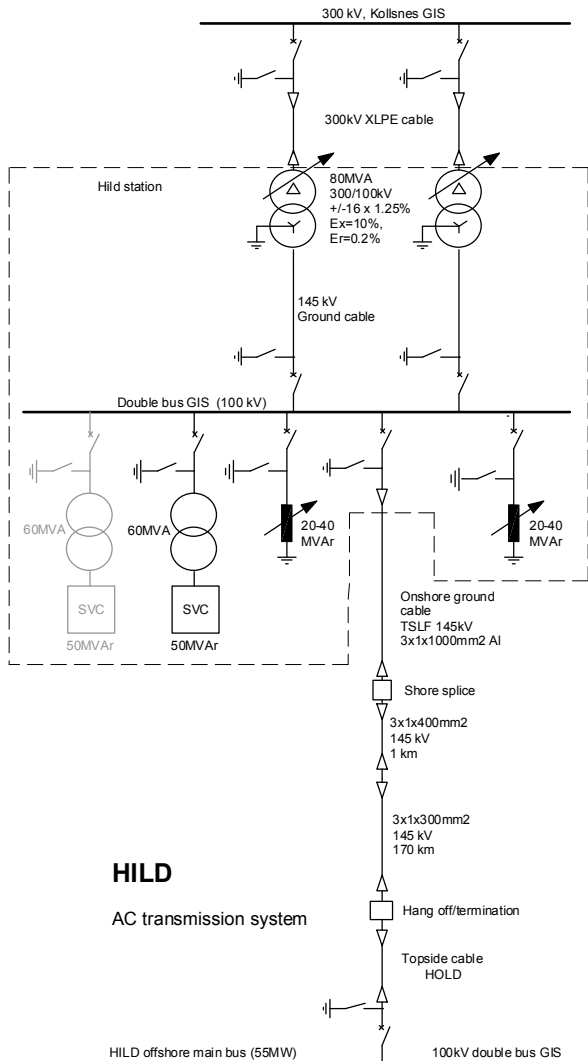


Fig. 4 Martin Linge Power From Shore Single Line Diagram

In order to regulate the 300kV onshore grid power factor, 2 redundant Static Var Compensators (SVC) are installed onshore. The SVC dynamically controls the exchange of reactive power with the grid to zero. Since the SVC control and regulation reacts much faster than the OLTC of the onshore transformer, the SVC is also used to regulate the offshore voltage during transients. This is shown on Fig. 6 where in case of offshore load rejection, the SVC reacts rapidly to reduce the overvoltage, whereas the transformer tap changer would have been too slow to operate. Upon voltage dips of the onshore 300 kV grid, offshore line voltage can drop below 90.5 kV, in this case the SVC switches also to voltage control, except when energizing the subsea cable which is done at minimum output voltage from the step down transformers; in this case the SVC voltage control is suspended. This control strategy (Fig. 5) contributes actively to stabilize the platform voltage, but at the same time it ensures active voltage support to the grid in case of significant voltage dips and ensure fast regulation to be neutral towards the grid with respect to reactive power exchange.

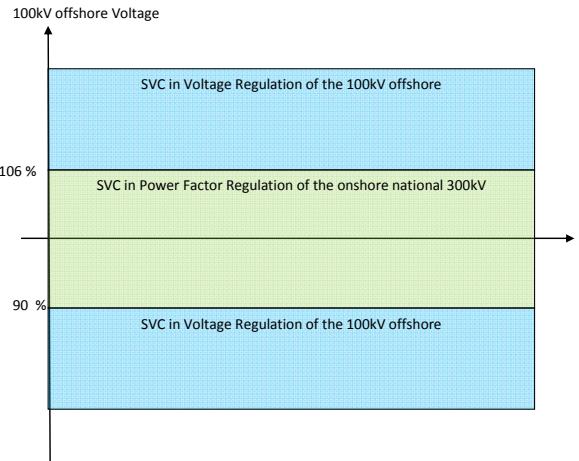


Fig. 5 SVC control strategy

The overall reactive power compensation requirement at steady state is at a maximum of 75 MVAR with a dynamic requirement of approximately 50 MVAR maximum. The concept has been to design the SVC for 50 MVAR and to combine it with an oil filled 3 phase reactor. In combination with the SVC, it is considered that the reactor provides base compensation to the subsea cable charging current while the SVC provides a dynamic reserve. This is also the best solution from a loss point of view as the reactor losses are smaller than SVC losses. The SVC is of power electronics type with fast response and high frequency switched semiconductor devices so as to minimize harmonic rejection on the network. For availability purpose, 2 redundant reactors are installed. These onshore reactors have tap changer allowing reactive power adjustment between 20MVAR to 40MVAR each to accommodate design uncertainties mainly regarding the capacitance of the cable which is the main reactive power contributor.

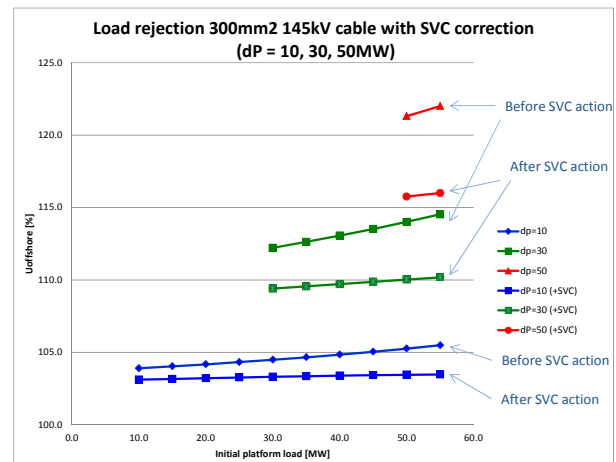


Fig. 6 Load rejection with SVC operation during transient

The subsea cable itself has been selected with a cross section of 300 mm² (copper) and an insulation class of 145 kV. The onshore land cable is spliced to the subsea cable at the landfall. For the last 1 km close to landfall an increased cross section of 500 mm² has been considered due to the thermal conditions uncertainties of the cable in the landfall area.

VI. MARTIN LINGE DESIGN CONSIDERATIONS

For the selection of the subsea cable cross section and system operating voltage of the transmission line, different cable cross sections and transmission voltages (90kV, 100kV and 110 kV) have been evaluated and compared through an iterative process. The main studies made were:

- Load flow analysis with current and voltage distribution along the cable
- Cable losses
- Voltage transient studies (harmonics, inrush, load impact and rejections...)
- Fault level studies
- Analysis of site conditions and installation

Regarding the operating transmission voltage, 100kV has been finally chosen as being the best trade-off between several criteria which are listed and described here under:

- During normal operation, from no load to full load, the OLTC of the step-down transformers (300kV/100kV) shall operate between +/- 10% of the rated voltage,
- During transient mode (e.g. load rejection or load impact) the voltage variation offshore shall not exceed +/- 20%,
- Another criterion to design the system has been to minimize the losses which have an impact on the OPEX of the power from shore system. As shown (Fig. 7), the choice of having an operating voltage of 100kV is a losses tradeoff compare to 90kV and 110kV of transmission voltage.

Losses at full load 55MW, PF=0.9	90kV	100kV	110kV
300mm ² cable	6,8MW	6,1MW	5,9 MW

Fig. 7 Losses at full load

Regarding the design of the cable, it shall be kept in mind that there is a different behavior between a subsea cable and an overhead line; for instance, the cable cross section for an overhead line is mainly inductive; when you increase the voltage you reduce the current and the cross section of the line; this is not the case for a long subsea cable transmission line since the capacitance of the subsea cable generates a large amount of reactive power (Fig. 8) which contributes to increase the charging current and the cable cross section when you increase the voltage.

$$Q = 2\pi \cdot f \cdot C \cdot U^2$$

Where Q: reactive power
C: capacitance
f: frequency
U: line to line voltage

Fig. 8 Cable reactive power

An increase of the cable cross section has been also investigated, but as shown (Fig. 9) at 100kV of operating voltage, by increasing the cable cross section (from 300mm² to 400mm²), the current transferred by the cable is higher (from 455 A to 503 A); this is due to the capacitance of the cable which increases along with the cable cross section.

Operating current at full load 55MW, PF=0.9	Operating voltage of 90kV	Operating voltage of 100kV	Operating voltage of 110kV
300mm ² cable	434 A	455 A	487 A
400mm ² cable	471 A	503 A	544 A

Fig. 9 Full load current conditions

The cable selected for Martin Linge has been finally chosen with a copper cross section of 300 mm² and an insulation class of 145 kV for an operating voltage of 100kV. In the worst pessimistic thermal and installation conditions the current capability of this cable is 472A for an operating current of 455A at full load (55MW). This cable selection and operating voltage have been found as being the best trade off regarding all the here above criteria assessed in the different studies made.

A 145kV insulation class cable has been chosen instead of 123kV insulation class cable since the 145kV cable has a smaller capacitance which reduces the amount of reactive power and charging current generated by the cable. Another benefits of the 145kV insulation class is the reduction of voltage stress on the cable when it operates at 100kV compared to a 123 kV insulation class, this has a positive effect on the long term ageing of the cable.

To keep under control the power from shore design and performances such as cable losses, resonance frequencies, voltage variation and reactive power generated by the cable, it is recommended to have from the cable manufacturer guaranteed value on the cable resistance, inductance and capacitance. Tolerances on these values shall be given to all the parties involved prior to the contract award. These values shall be verified during the factory cable tests.

The target for the cable capacitance is to have a tolerance better than the IEC 60840 (<8%), some manufacturers are able to guarantee less than 4%.

The cable resistance shall be given at minimum ambient seabed temperature and at maximum conductor core operating temperature in order to assess the resistance damping effect on electrical resonances at start up and during operation.

Since a long subsea cable behaves like a large capacitor, the discharge time of the cable, when it is not connected to earth or to any load, shall be determined to assess the requirements of additional equipment for discharging cable to earth (e.g. through earth resistor or directly to earth).

Due to the large impedance of this long subsea cable, there is a low short circuit power available offshore on the Martin Linge platform, therefore it has been chosen to connect the export compressor VSD directly on the 100kV GIS where the short circuit power is the largest in order to minimize the disturbances of the current harmonics rejection on the offshore grid. This choice has the additional benefit of having a smaller 100kV/11kV distribution transformer which doesn't need to be sized to feed the 2x8MW export compressors.

Since the offshore platform fully relies on the subsea cable which is not redundant, it is paramount to monitor the electrical and thermal conditions of the cable.

For the thermal monitoring it can be done by DTS (Distributed Temperature Sensor) based on the use of

optic fibers embedded into the subsea cable. There is nevertheless a distance limitation to such thermal monitoring; for instance, using single mode fibre, the distributed thermal monitoring could reach up to approximately 50 km. In this case, it is recommended to monitor the cable at each end in order to monitor at least 100km of cable distance. This should be sufficient since the worst thermal conditions for the cable are at landfall and inside the J-Tube which are located at both ends of the cable; so covered by the DTS monitoring.

For the electrical conditions of the cable, this is more challenging since there are currently no tools available for such long distances and voltages level. Such monitoring tools shall be developed based for instance on Time Domain Reflection (TDR) or partial discharge measurement (if feasible).

Since normal operating voltage range for the Onshore GIS busbar will be between 90.5 to 106 kV while the system must be able to operate at 80 kV during energizing operations, the selectivity studies and protection settings shall take into account these different operating conditions.

When assessing the overall cable length, the total length shall include a length allowance to compensate navigation accuracy in the laying length, normally a 0.5% of the total length is considered for such allowance.

The spare cable length used to repair the subsea cable (in case of possible failure) shall be stored under cover to protect the cable from rain and prevent water soaking. If the cable is water soaked it can freeze during winter and experience has shown that the inside coils can be frozen for a significant time due to the large thermal inertia of the cable.

VI. LESSONS LEARNED

In order to secure the basic engineering phase and the detail engineering phase, the operator shall invest in conceptual and pre-project definition. In particular, the performance requirements which are key in ensuring good power from shore studies shall be well defined during these periods. A document defining the power from shore performances requirements shall be established. This document is the design basis for the sizing of the power from shore system. This document shall establish and define the performance requirements in terms of:

- Voltage variation (steady state and transient) at offshore point of connection;
- Reactive power exchange toward the onshore external grid;
- Total harmonic emission towards the onshore external grid;
- Minimum short circuit requirements at offshore point of connection;
- PCF availability requirement

In order to check and validate the performances of the power from shore system, during the tests and commissioning period, several relevant operating scenarios to be tested shall be also defined inside this document.

Regarding the contractual strategy; as it has been the case for Martin Linge (Fig. 10), having a Power from Shore split in several part implies an involvement of multiple contractors in one system, this requires a greater effort on interfaces from end client. A contractual strategy with one package for the onshore plant and the subsea cable would have been better.

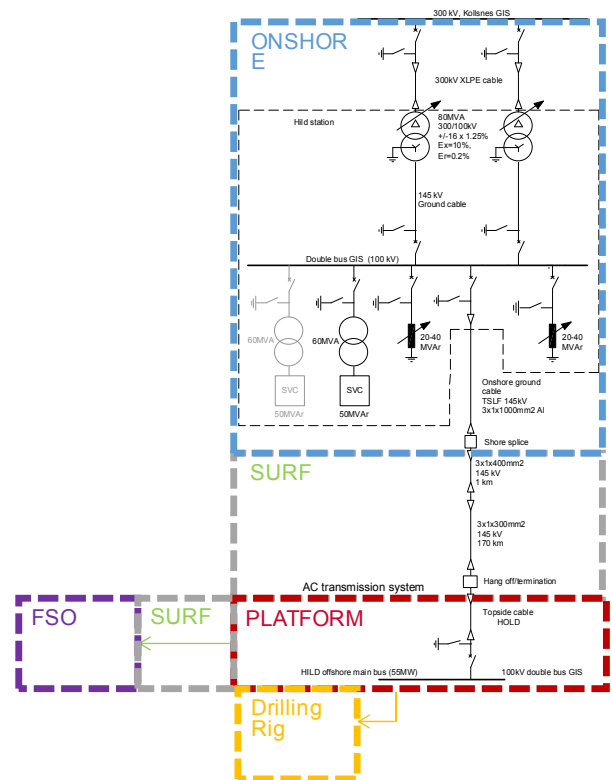


Fig. 10 Project split in several parts

During the basic engineering phase, it shall be checked carefully that electrical equipments are specified in accordance with the assumptions made in the simulations to design the Power From Shore. For Martin Linge, during the basic engineering phase, the value of the remanent flux of the magnetic core, used to simulate the voltage drop associated with the transformer energizing, has not been correctly specified. During the detail engineering phase, the result has been having an higher voltage drop when design data has been received from the transformer manufacturer.

The operator shall be prepared for numerous data requests from contractors. Providing quality data results in simulations close to actual system behavior. This can be achieved by editing a project data book. This document shall gather all the project detailed data (grid data, main equipment datasheet of the PFS,...). It shall be updated all the along the project, this will allow for contractors and company:

- finding in only one document all data used for simulations and studies
- update easily simulations and studies knowing the latest data modified

The measurements made during the tests of the subsea cable at site have shown that there is a good correlation between the simulations made and the reality.

Regarding the choice of dielectric oil for transformer and reactor; a special attention shall be paid when specifying the use of synthetic ester Midel oil since repetitive failure during FAT of transformers have shown that the associated design rules of this type of oil are not well-known by manufacturers, when the operating voltage is above 90kV.

Point of wave closing of the subsea cable GIS feeder has proven to be very efficient. The subsea cable energizing test has shown that the inrush current when energizing the subsea cable was limited to 1.6 pu which is

quite low (Fig. 11). The voltage and current transients/vari- ations are also of short duration, limited to few 50Hz cycle.

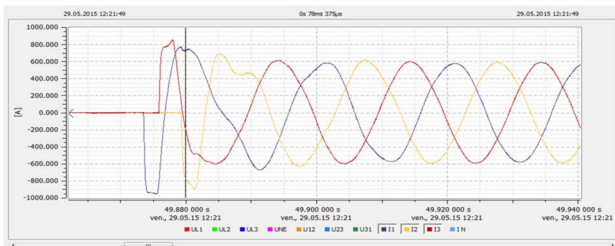


Fig. 11 Subsea cable current during energisation

But it has also to be noted that the POW closing gives large zero sequence current when energizing a long subsea cable, the protection scheme shall consider this aspect.

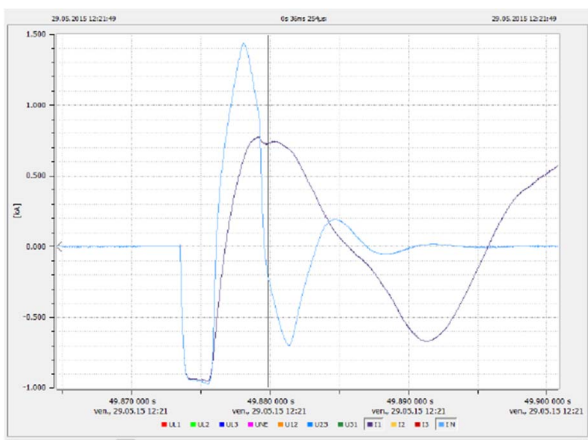


Fig. 12 Zero sequence current when closing first pole

When the first pole is closed, the current flowing through this pole is a pure zero sequence current which circulates through the cable conductor, cable capacitance, earth and different neutral points of the onshore installation. Curve here above (Fig. 12) shows that phase current and zero sequence current are merged when the first pole is closed.

Regarding the SVC dynamic response; the high dynamic response capability of a SVC helps minimizing voltage disturbances when energizing the subsea cable. It can be seen hereunder (Fig. 13) that the SVC reacts quickly (≈ 20 msec) to start absorbing the reactive power injected by the subsea cable on the 100kV busbar.

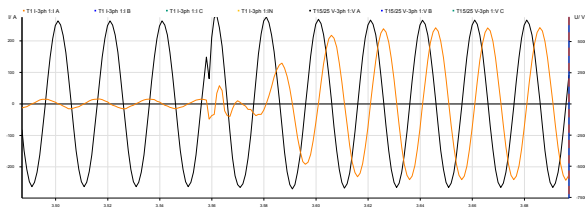


Fig. 13 SVC current (orange curve) and 100kV voltage (black curve) during subsea cable energizing

100kV voltage disturbance is of short duration and it can be seen (Fig. 14) that the cable filters the high frequency voltage harmonics after the cable energizing transient.

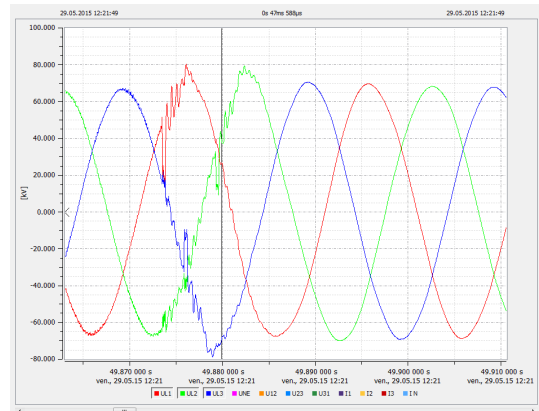


Fig. 14 100kV 3 phase voltage during subsea cable energizing

The subsea cable integrity shall be checked after laying. It is recommended making a TDR (Fig. 15) and a LIRA measurement of the subsea cable:

- during the FAT
- before laying
- after laying

This is to check that the cable has not been damaged by transportation and offshore installation.

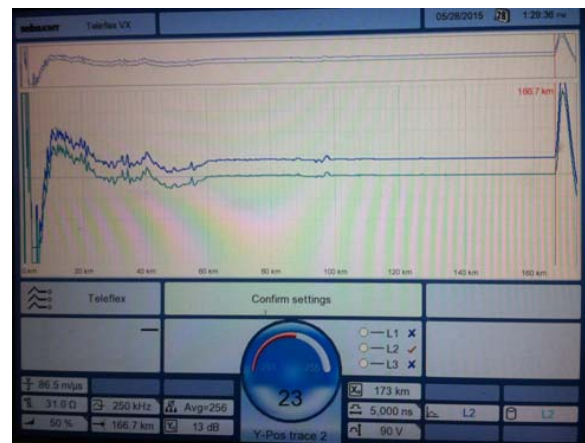


Fig. 15 TDR comparison between FAT and after laying

VII. CONCLUSIONS

The Oil&Gas industry faces more and more the challenge of reducing its environmental impact and CO2 emissions; the power from shore development of Martin Linge is in line with this objective to curb CO2 emissions.

From a technical standpoint, Martin Linge power from shore shows the feasibility of supplying on remote location an offshore Oil and Gas platform with an AC transmission.

The final design has been the result of many studies made during the basic engineering phase which have refined and optimized the initial design. These studies are paramount to secure and ensure the success of the detail design engineering phase where it is usually too late to make major technical changes.

With discoveries of remote fields, in sensitive environmental locations such as Arctic, the offshore industry will require power from shore solution where AC transmission won't be possible anymore and where DC transmission will be the only possibility. The next step to these developments will be then to have "subsea to

shore" concept where the full field development will be made subsea with power from shore.

VIII. ABBREVIATIONS

AC: Alternating Current
CAPEX: Capital Expenditure
DC: Direct Current
DTS: Distributed Temperature Sensor
FAT: Factory Acceptance Tests
FSO: Floating Storage Offloading
GIS: Gas Insulated Switchgear
HVDC: High-Voltage Direct Current
LIRA: Line Resonance Analysis
OLTC: On Load Tap Changer
OPEX: Operating Expenditure
PF: Power Factor
PFS: Power From Shore
SVC: Static Var Compensator
TDR: Time Domain Reflectometry
VSD: Variable Speed Drive
WHRU: Waste Heat Recovery Units

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