OPERATING EXPERIENCES WITH A VOLTAGE SOURCE CONVERTER (HVDC LIGHT) ON THE GAS PLATFORM TROLL A

by

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Summary

Voltage source converter (HVDC Light®) and cable wound Motorformer (Very High Voltage motor) are novel technologies that enable powering of offshore installation with electrical power from shore. On the gas platform Troll A, the world's first HVDC

Figure 1 Troll and Kollsnes Gas process

transmission system, which have been designed to operate as an electric drive system based on these technologies, have been installed. Environmentally friendly gas production will thereby be maintained and expanded on Troll A. Onshore the system includes a power transformer and rectifier part of a voltage source converter (VSC). DC submarine cables transmit power to Troll A where the VSC's inverter is directly connected, i.e. in a unit connection; to the cable wound Motorformer acting as a variable-speed synchronous machine. The motor drives a gas compressor. As the compressor speed is variable, the machine is supplied with variable frequency and voltage, from zero to max speed, including smooth starting and acceleration. By means of modest filters on the output of the converter, the motor winding stress is kept at a very low level. This paper describes the installation, testing and operating experiences of the electrical system for Troll A. Aspects include:

- Testing and operation of the onshore station.
- Offshore station installation and converter testing activities and experiences (Onshore, transport, offshore).
- Operation of voltage source converter in an offshore gas process environment.
- Operation, testing and experiences of voltage source converter and motor as a long distance high voltage electrical drive system.

The control system for the offshore converter designed for voltage source (HVDC Light®) transmission applications have been adapted and extensively tested to perform state of the art motor speed and torque control. The control system has been included in the existing platform control and safety system and the interface has been extensively tested during offshore commissioning.
Operation of the gas-train in Troll A includes two independently installed HVDC transmission systems based on voltage source converters operating as electrical drives systems together with Motorformers. The motors connect to large gas compressors are an important part of the gasproduction plant for gas delivery from the North Sea region. The installation on Troll A is the first installation of this type. An important aspect has been to avoid disturbing the operation of the gas production during testing and commissioning of the HVDC transmission system. Special operation modes of the voltage source converter have been developed to simplify testing and future retesting.

Commissioning of the complete gas compression system includes normal operation as well as extreme operation of the HVDC transmission system.
Testing of the voltage source converter has been performed in different steps in order to minimize the work offshore and to eliminate the risk. The offshore converter was completed and tested as much as possible onshore. The system was then secured for offshore transport, sea-fastening. After the transport, including lifting, the sea-fastening was removed and installation completed and the system was partly retested and commissioned.

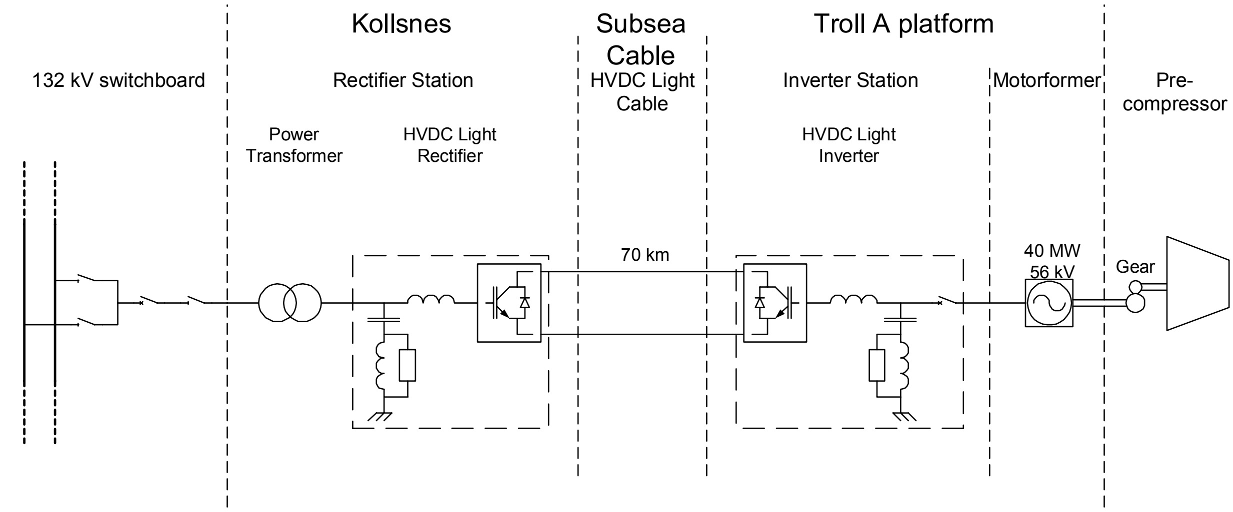


Figure 2 Simple single line diagram

The Motorformers had, after tests in the manufacturer's workshop, been transported by sea to the yard and installed in the gas production module before the offshore transport. The final electrical installation between the converters and motors were done on the platform, followed by successful commissioning and production.

2 Electrical drive system push gas to shore

Troll A is the largest gas production platform on the Norwegian shelf. Annually producing about 40 % of the total Norwegian gas production, Troll A can produce up to 120 million cubic meters of gas per day. Today, the reservoirs own pressure transports the gas to the onshore processing plant at Kollsnes. At Kollsnes, the condensate, water and gas are separated and the gas is compressed and transported through pipelines to the European continent.

As gas is being taken out of the reservoir, the pressure decreases. In order to maintain production capacity, offshore pre-compression of the gas has become necessary.

Based on two compressor train and use of gas turbines for driving the compressors it is estimated that for this project, annual emissions of some 230,000 tonnes of CO_2 and 230 tonnes of NO_x would result. Avoidance of such emissions is a relief for the environment, and with the CO_2 taxation in effect on the Norwegian shelf, such emissions would also impose a significant operating cost [1].

3 Electrical Drive System with HVDC Light technology

Together with Statoil – the operator of Troll A – ABB developed the alternative system illustrated in Figure 2. The system is based on ABB's novel technologies HVDC Light and Motorformer [2]. The two technologies have been successfully employed on shore since 1997 and 1998, respectively, but never before on an offshore installation and not together operating as an electric drive system. The system uses power from the onshore electrical grid to drive the compressors on the platform, thus avoiding greenhouse gas emissions from the platform. The system gives the following advantages:

- High availability 99 %
- Increased life length 30 years
- Increased efficiency
- Reduction of CO_2 by 65 %
- Reduction of SO_X and NO_X
- Less maintenance and shorter maintenance shutdowns.
- Gas traditionally used for running offshore turbines can be exported

Two identical compressor and drive systems have been installed in the first phase, and went into operation in the fall of 2005. Next phases with additional two compressors and drive systems, are envisaged to be taken into operation approximately 2011 and two more in 2014.

3.1 HVDC Light® converters.

With HVDC Light, the use of series-connected power transistors has allowed connecting voltage-source converters to networks – at voltage levels that have not previously been technically possible to reach [3]. This can be used for power transmission, for reactive power compensation and for harmonic/flicker compensation. With fast "vector control", this converter offers the ability to control active and reactive power independently while imposing low levels of harmonics, even in weak grids. The powerful and robust Industrial HVDC Control, MACH 2^{TM}, proven in multiple HVDC Light and SVC (Static Var Compensator) installations to date, governs the converters.

In HVDC Light, Pulse Width Modulation (PWM) is used for generation of the fundamental voltage. Using PWM, the magnitude and phase of the voltage can be controlled freely and almost instantaneously within certain limits. PWM VSC is therefore a close to ideal component in the transmission network.

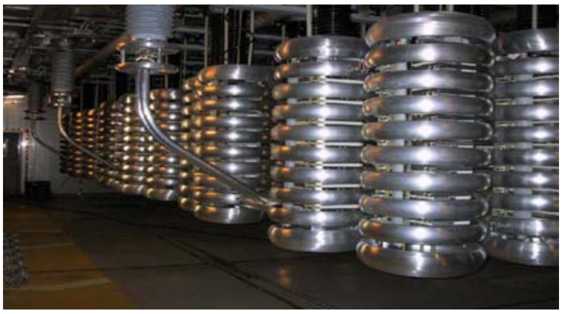


Figure 3 IGBT valve

On the Troll A platform, the HVDC Light converter feeds the variable-speed synchronous machine, by conversion of the incoming dc voltage from the sub sea cables. As the desired compressor speed is variable, the machine is supplied with variable frequency and variable voltage, from zero to max speed (0-63 Hz) and from zero to max voltage (0-56 kV), including smooth starting and acceleration. The drive system operates equally well at 0.5 Hz as at 50 Hz. By means of modest filters on the output of the converter, the motor winding stress is kept at a safe and low level.

An important weight and space saving is due to the direct connection of the motor to the converter without the use of a transformer. The optimum design in respect to voltage and current for a given power level (40 MW) for the Motorformer matched very well the optimum for a HVDC Light transmission system.

3.2 HVDC Light Cable – transporting the power

The HVDC Light Cable is an extruded polymer cable. For High Voltage AC, there has been a technology shift from paper insulated to extruded polymer insulated cables.

The cable is designed with a 300-mm^2-copper conductor surrounded by a polymeric insulating material, which is very strong and robust. The water sealing of the cable is designed with a seamless layer of extruded lead and finally two layers of armouring steel wire for the mechanical properties of the cable. The strength and the flexibility make the HVDC Light cables well suited for severe installation conditions and deep waters in the North Sea.

3.3 Motorformer – driving the compressor

The launch of an innovative cable technology in 1998 raised the prospect of increasing motor voltage ratings to radically higher levels. The innovation was the use of HV cables replacing Vacuum Pressure Insulated (VPI) windings of electrical machines [4].

The HV cable-winding concept was first applied to an electric generator [5]. A number of these generators have already entered service. The concept has now been applied to motors, with the development for a synchronous machine.

Figure 4 40 MW Motorformer

4. Installation and testing

Factory testing of the complete electrical drive system (HVDC Light, dc cable and Motorformer) was not practically possible due to power, size, cost and time constraints.

Instead testing had to be done both at factory with test in simulated environment and on site testing both onshore as well as offshore.

- Factory testing
  - Equipment test
  - Small scale drive system test
  - Factory system test of controls and drive system
- Installation
  - Onshore station
  - Offshore station
  - Sea fastening & transport
- Commissioning
  - Onshore station
  - Offshore station onshore
  - Offshore commissioning

The onshore activities (installation and commissioning) for the offshore module were from

August 2003 to April 2004. The module was lifted to the platform in May 2004. The offshore installation and commissioning was then completed in February 2005 for the drive systems and in August 2005 for the complete gas trains.

4.1 Factory testing

All individual components are factory tested before transported to site and sub-systems are tested as much as possible beforehand.
The system tests started in the factory in Ludvika with the Factory System Test (FST) which is a test of the complete, or close to complete, HVDC control system. The control system during the FST is connected to the HVDC simulator with the main circuits modeled. The extensive testing in FST is the primary testing of the control and protection system. The system tests performed at site are a repetition of some of the tests performed in the FST but now with the actual main circuits connected to the real AC and DC systems.
An extensive part of the FST is to create a number of faults and disturbances. These tests should only selectively be repeated during the on site acceptance testing stage, since a large amount of faults and disturbances may degrade the lifetime of the connected main circuit equipment and/or cause a risk of instabilities in the surrounding AC networks.
One important design objective is to make the electrical drive system and the process as unaffected by onshore electrical disturbances as possible, i.e. ride through capability. This capability is illustrated in the two figures below which show the voltages both onshore and offshore for two types of major onshore disturbances, one single phase fault and one three phase fault directly outside the Kollsnes station.

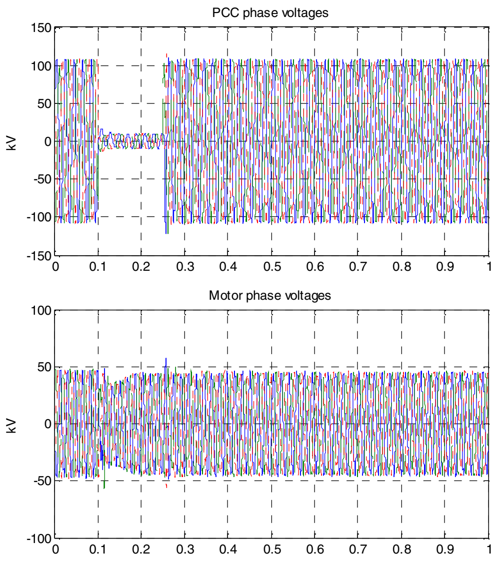


Figure 6 Three phase fault outside Kollsnes

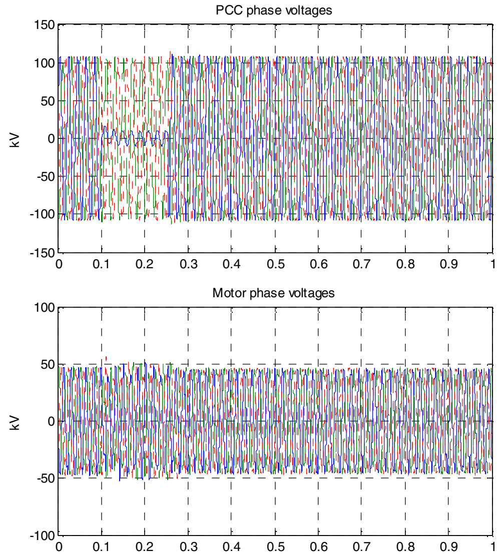
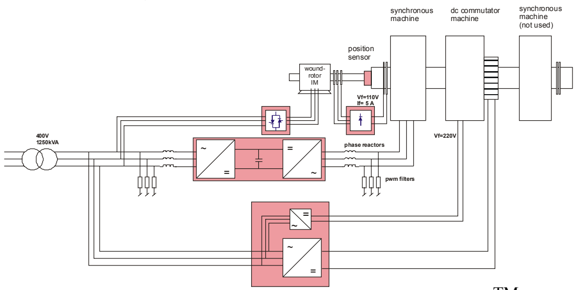


Figure 7 Single phase fault outside Kollsnes

4.2 Drive system testing

An extensive test program was set up to verify that the modification of the HVDC Light transmission system including the MACH 2™ controls could be used as a complete drive system. Furthermore the control modifications needed for the adaptation were identified. The test set up used a 120 kW synchronous machine representing the motor and a dc machine representing the compressor load. The excitation system and speed sensors were emulated



to ensure that the interface to MACH 2™ was identical to the real system. A model of the HVDC Light was also set up in order to get a complete

Figure 8 Low scale test set up

true-to-scale system as possible.
With this system it was possible to verify:

- Normal start / stop.
- Load and reference variations
- Encoder and excitation malfunction
- AC system disturbances, i.e. ride through
- The machine models used in the digital simulations.
- Operator training and demonstrations

4.3 Installation and commissioning of the offshore module.

The installation and commissioning of the offshore module was performed in onshore in Haugesund. All main electrical equipment including the controls, IGBT valve cooling and auxiliary power were installed in the module. It was then possible to perform all testing and commissioning activities up to high voltage energization. High voltage energization was not possible to be performed due to the limited access of high voltage; it was later proved not to cause a problem.
After the commissioning was complete the equipment was prepared for transport to offshore by sea-fastening of the equipment.

When the module was installed on the platform the sea-fastening was removed and the interface cables including the high voltage dc cables were connected in the module. Some of the already performed commissioning testes were repeated to ensure that the transport had not created any unwanted changes. Once this was performed the system was ready for high voltage testing.

Even though the testing went quite smoothly the progress was very much affected by special offshore conditions with harsh weather and special working procedures.

4.4 Installation and commissioning of the onshore station.

The installation and commissioning of the onshore station in Kollsnes outside Bergen was performed in parallel with the work for the module. One of the characteristics of the HVDC Light technology is the capability to operate as a Static Var Compensator (SVC). This makes it possible to operate the onshore station with high voltage and power towards the main ac voltage grid without being connected to the dc cable or the other station. This enabled that commissioning of the onshore station was almost complete when commissioning of the drive system started.

4.5 Commissioning of the electrical drive system.

Once commissioning of the individual parts of the drive system was complete commissioning of the complete electrical drive system was made in steps:

- Stand alone operation of the onshore station.
- High voltage dc energization.
- Operation without motor.
- Spin test.
- Commissioning of complete compressor train.

A special operation mode used during commissioning was developed to enable operation of the converters and dc cable without connecting the motor. The purpose of that mode was to enable testing with variable frequency and voltage of the converter.

The spin test was completed before handing the system over to STATOIL for commissioning of the complete gas pre-compression process train.

A final performance test was then performed at a later stage when the complete system could be loaded close to full power.

The experience of the commissioning of the electrical drive system is that the systems tested during factory testing and onshore worked very well and the efforts had to be placed on the interface not possible to test previously. The interface was however easy to correct.

One of the important issues during the design of the electrical drive system has been the harmonics ranging from low order harmonics up to very high frequency. The desire to have low weight on an offshore platform gives the optimum solution that the Motorformer should not be exposed to excessive harmonics. The design philosophy has therefore been to install filters with the same filtering capacity that is normally required in a high voltage installation and not allow for large harmonics to be absorbed by the Motorformer. The harmonic generation from a HVDC Light converter is primarily at the switching frequency (2 kHz) and above while there is almost no generation of harmonics in the low frequency range (5, 7, 11 and 13:th harmonic), which is common in a normal thyristor control drive. However some low order harmonics are expected due to imperfections in both converter-switching as well as motor design.

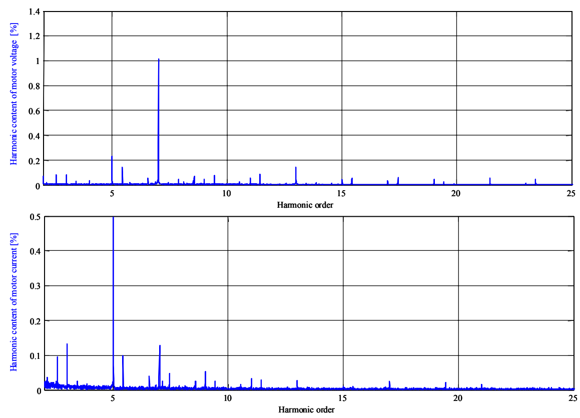


Figure 9 Harmonic motor voltage and current

The harmonics were measured as part of the commissioning and proved to be well below the design criteria. Above are two curves showing voltages and currents harmonic content for a typical normal operating mode.

One can observe that dominant harmonic is 5th in motor current and 7th in motor voltage. This is due to that the voltage harmonic generation from the converter and motor are in phase for the 7th harmonic while they are in opposite phase for 5th.

5 First year in operation

The electrical drive system that Statoil and ABB have developed has operated according to all expectations. Some modifications have been implemented after commissioning. These modifications relate to situations regarding:

- Platform black-out
- Emergency or process shut down and start up
- Alarm presentations to the operators

Due to operational strategy on the platform it has shown that certain control systems could have been implemented in the platform's own control, rather than as part of the MACH 2 controls. This applies e.g. to the compressor pipeline's by-pass valves.

Even if there are control rooms, operators and discipline specialists both onshore and offshore it has proved that almost no problems exist regarding the collective, daily operations, or maintenance.

The Motorformers have performed according to the onshore factory acceptance tests and operate on the offshore compressor skid with vibration levels below expected levels.

The wide field of state-of-the-art equipment and control systems required an extensive training programme. This was prepared by Statoil, together with ABB, both in Sweden and Norway. Dedicated training was later carried out for operators and maintenance teams at Kollsnes and Troll A. Still, continued training will always be a field of necessity, where adapted competence should be given to selected, small groups. This should be a continued activity.

Based on experiences and statements from Statoil's onshore/offshore operators and discipline specialists the EDS' have performed exceptionally well from day 1 with no shutdowns of the EDS system after ½ year of operation. The new motor drives, developed from the state-of-the-art network systems with HVDC Light / Motorformer technology, has proved to gratify even the pessimists.

6. Conclusions

Voltage source converter (HVDC Light) and cable wound Motorformer are novel technologies, which have been designed to operate as an electric drive system, have been installed, commissioned and operated on the offshore platform in Troll. The conclusion from commissioning and first year in operation is that the system work as expected where especially the new technologies have worked extremely well and the problems that were encountered, and corrected, were all related to interface issues. The important lesson learned is that extensive qualification programs and testing both factory testing and on site commissioning is the key if new technology should be successfully introduced.

Figure 10 Troll A with two electrical drives installed.

Foto: Dag Myrestrand, Statoil

The technology using HVDC Light now makes it possible to supply electric power from shore to offshore installations.

Using a HVDC Light transmission system as a long distance electrical drive system and adapting it to special requirements arising from offshore gas production has shown to be possible.

9. References

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