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The Challenges of Offshore Power System Construction – Troll A, Electrical Power Delivered Successfully to an Oil and Gas Platform in the North Sea

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Abstract

In February 2005 the world's first offshore HVDC transmission was successfully commissioned. It consists of two parallel 40 MW transmissions connecting the Troll A gas platform in the North Sea, with the mainland 132 kV grid via compact polymeric DC cables. A compact and lightweight offshore module was designed by ABB in collaboration with the client Statoil. The project has allowed valuable experience in the design and construction of high voltage plant in a salt laden, hostile environment to be obtained. With safety as a primary consideration, considerable experience in offshore construction techniques has been gained. The success of the Troll project has been one of the key components for British Petroleum, who in June 2005 placed a second offshore HVDC Light order with ABB for their 78 MW transmission to the Valhall field. The engineering design and construction challenges overcome in these pioneering offshore projects is directly transferable to the new high power, high voltage, offshore substations required to enable, safe, reliable operation of the future very large offshore wind farms.

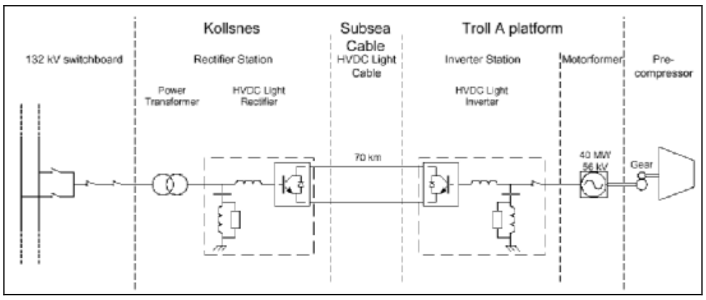
Introduction

Voltage source converter (VSC) HVDC and cable wound high voltage motor (High Voltage Motor) are novel technologies that enable powering of offshore installations with electrical power from shore.

Troll A in the North Sea is 65 km west of Bergen in Norway, and is the world's first HVDC transmission system, which has been designed to operate as an electric drive system based on these technologies. Gas production capacity will now be maintained and expanded on Troll A – economically and with environmental benefits, as the use of more gas turbines can be now be avoided. The Troll system includes a voltage source converter (VSC) on shore and DC cables for transmission of power to the offshore platform. On the Troll A offshore platform, another VSC is directly

Troll A Platform with the HVDC Unit (Central)

connected, i.e. in a unit connection, to a cable wound high voltage motor 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 variable voltage, from zero to max speed, including smooth starting and acceleration.



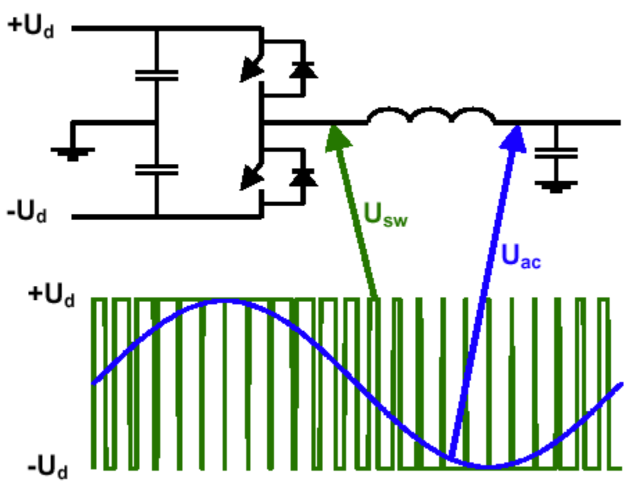
Simplified Single Line Diagram

Reducing costs and emissions with power from shore

On most offshore installations, power supply generators and large compressors are driven by onboard gas turbines or diesel engines. Many of these have total efficiencies as low as 20-25 % under the best of conditions. The result is emission of large amounts of CO_2 gas and unnecessary high fuel consumption. The Kyoto Protocol supports trading of greenhouse gas emissions. CO2 emissions can therefore represent a real and considerable operating cost. On the Norwegian shelf, CO2 taxation already today in effect, makes CO2 emissions costly even without such trading. If electrical power can be supplied from shore – for power supply as well as compressor drivers – CO2 emissions from offshore installations are eliminated. This leads to a significant cost saving for oil companies. In addition, transmission of electrical energy from shore involves less maintenance, longer lifetime and higher availability than gas turbines and diesel engines. If the transmission equipment can be located on decommissioned installations offshore, the postponed removal cost for the installation can be an important factor as well.

VSC HVDC – rectifying, inverting and controlling

[1] With VSC based HVDC, the use of series-connected power transistors has allowed the connecting of voltage-source converters to networks at voltage levels hitherto beyond reach. 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, proven in multiple VSC based HVDC and SVC installations to date, governs the converters.



Pulse Width Modulation

In VSC based HVDC, Pulse Width Modulation (PWM) is used for the generation of the fundamental voltage. Using PWM, the magnitude and phase of the voltage can be controlled freely and almost instantaneously within certain limits. This allows independent and very fast control of active and reactive power flows. Pulse Width Modulation based VSC is therefore a close to ideal component in the transmission network. From a system point of view, it acts as a zero-inertia motor or generator that can control active and reactive power almost instantaneously. Furthermore, it does not contribute to the short-circuit power, as the AC current can be controlled.

On the Troll A platform, the VSC based HVDC 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, acceleration and braking. 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.

There is no communication between the rectifier control on shore and the motor control on the offshore platform the only quantity that needs to be detected in both ends of the transmission is the DC-link voltage. With little energy storage in the DC-link, the motor control system is designed such that it can follow even rapid changes in the power flow at the opposite end, without disturbances to the motor operation. Robust control means reducing nuisance tripping.

The VSC based HVDC converter design for Troll A is based on a two-level bridge, midpoint capacitor grounded. The design philosophy enables steady state and dynamic operation, with extremely low levels of induced ground currents. This feature is one of the critical factors for implementing an HVDC system in an offshore environment. There is no need for any cathode protection in conjunction with the installation.

Operation with variable frequency in one end and fixed grid frequency in the other does not require main circuit equipment that differs from the normal design. The design principles adopted for normal transmission system applications also applies for an electrical drive system. The same offshore design could therefore also be used to feed a local AC network.

4 VSC HVDC Cable – transporting the power

The VSC based HVDC concept includes another development: The VSC based HVDC Cable. It is an extruded polymer cable. For High Voltage AC, there has been a technology shift from paper insulated to extruded polymer cables. The corresponding development to produce an extruded HVDC cable has resulted in a flexible and cost effective cable that is an important part of the VSC based HVDC concept.

The cable is designed with a 300-mm2-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 in counter helix for the mechanical properties of the cable. The strength and the flexibility make the VSC based HVDC cables well suited for severe installation conditions and deep waters in the North Sea.

HVDC Light Cable

Demands on HVDC offshore

Space and weight are scarce resources on offshore installations. Particularly in the light of these constraints, the VSC based HVDC concept offers important advantages: Since the filters are small, VSC based HVDC can be made compact and lightweight compared to other solutions.

Apart from the obvious needs to make the converter station compact and lightweight, the Troll A offshore environment places a number of other demands on the converter station and equipment. Examples include:

- Safety for personnel as well as for equipment in the gas (hydrocarbons), from the production and processing, environment.
- The offshore environment is very tough. Salt and humid air imposes severe requirements on the choice of materials and surface treatment.
- Integration of the control system towards the process control and shut down systems on the platform.

Installation of the HVDC Light Unit

Troll A HVDC Light Unit in Position

The high voltage equipment has been installed inside a compact module offshore and indoor building onshore. The ventilation system in the module/building has been designed to protect the high-voltage equipment and the electronics from salt laden and humid air. The main circuit equipment is therefore exposed to lower environmental requirements than a normal outdoor installation. Which allows for a more compact design. The ventilation also has to consider the airborne losses. An advantage of being offshore in the North Sea is of course that cold (5-11 °C) water for cooling is readily available. Another requirement for the ventilation system comes from the possible presence of gas in the area. Both the installation onshore as well as the offshore has been over pressurized to ensure that no gas can enter high voltage areas. In case gas is detected, the system is tripped and deenergized directly.

Experience and Lessons Learned

The design and construction of an offshore HVDC Light connection to Troll A, presented new and pioneering engineering challenges. The safe and reliable operation of this critical offshore power supply unit required good cooperation between all parties associated with the project.

Key success factors

1 Planning and decision phase

- High focus on finding an environmental appropriate solution.
- Early selection of a suitable electrical solution (HVDC light technology)
- Sufficient time to study, mature and qualify the technical solution and establish confidence among the project partners.
- Building trust through open, close and good cooperation between top expertise in the Troll partners and ABB during engineering and qualification of the technical solutions

2 Execution phase

- Continued open, close and good cooperation.
- Common and joint approach to problem solving
- Ability and willingness to find win-win solutions on difficult technical, commercial and contractual challenges.

3 Summary – Lessons learnt

- Very high focus on Safety
- When introducing innovative solutions it was important to have early and close involvement with the client and sufficient time to study and understand the new technical solutions
- Highly qualified personnel with high integrity, involved in problem solving
- Involvement of local knowledge and establish good relations with the relevant industry experts

Whilst the technical issues presented engineers within the project team with new challenges, the pioneering nature of the engineering design required excellent communications between like minded experts, in an open environment of co-operation.

Future Power Transmission for Offshore Wind

The HVDC Light technology described in this paper has been successfully applied to an oil and gas platform 65km offshore in approximately 300m of water. Safety and reliable performance in a hostile salt laden environment were identified as critical factors for the success of this project. It has been demonstrated that the design and construction of reliable power transmission systems offshore and in deep water is possible.

With several gigawatts of offshore wind generation in Europe now in the advanced stages of planning, the demand for reliable power transmission to shore is increasing. Troll A has demonstrated that many of the challenges of offshore bulk power transfer have been addressed with the successful implementation and completion of the HVDC Light link.

These valuable lessons learned by engineers and highlighted in this paper may help reduce the technical and hence financial risks faced by offshore windfarm developers currently considering alternative designs for the connection of future very large offshore renewable energy projects.

References

[1] New application of voltage source converter (VSC) HVDC to be installed on the gas platform Troll CIGRE 2004 Mats Hyttinen, Jan – Olof Lamell, Tom F Nestli

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