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Planning and implementation of HVDC projects including, need, justification, design, integration of wind generation, environmental and economic assessment.

HVDC POWER FROM SHORE

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SUMMARY

There are today 6 operational and 1 planned HVDC links to offshore installations for oil and gas field development. They are all HVDC Voltage Source Converters with a rating up to 100 MW each. The first installation was made successfully during 2005.

This paper describes the HVDC power-from-shore link concept that will transmit energy from land to offshore installations mainly for oil and gas field development and process plants.

KEYWORDS

Power from shore, VSC HVDC, Troll, Valhall, Johan Svedrup

1. INTRODUCTION

This paper describes the HVDC power-from-shore link concept that will transmit energy from land to offshore installations mainly for oil and gas field development and process plants. Possibilities to provide power from shore with more efficient and less polluting generation have been sought for a long time but such solutions have been restricted to short distance ac transmissions. By the invention and ascent of VSC power transmissions a competitive solution for long distance transmissions from shore to platforms has emerged. VSC-HVDC links are increasingly being deployed to connect remote renewables to consumption centers, and to enable cross-border connections, power-from-shore links and city-center in-feeds, where space is a constraint.

The power levels needed in these installations are today in the range of 100 MW, but there is no technology barrier in the transmission system to allow the power to increase to 1.000 MW range and to be able to serve many platforms.

The HVDC link will work as a fire wall, so that events in the platform network do not affect the sending end network. The HVDC station located onshore will also contribute positively to the onshore grid and stabilize the voltage in the connection point.

2. ALTERNATIVES TO PROVIDE POWER TO OFFSHORE INSTALLATIONS

Traditionally power to offshore platforms has been provided by local generation with gas turbines normally with a maximum power output of 30MW. These gas turbines have several drawbacks such as maximum efficiency of approximately 40%, high emissions of CO_2 and NO_x, and high operating and maintenance costs. Over the years some improvements have been achieved on NO_x emissions and higher efficiency, but the main picture remains the same. To combat these emissions, already early during the 90s, the Norwegian authorities required that all new oil field developments to investigate the power from shore alternative to gas turbines.

AC power links have been implemented when power needs are lower and for shorter distances. For medium distances and /or lower power ratings, a FACTs device (STATCOM) has been part of the AC solution to stabilize voltage during operation and fault scenarios. The FACTs device is placed onshore to save space and weight on the offshore platform

The first HVDC Power from Shore application became a reality with the advent of more compact HVDC technologies around 2000. The Troll field became the pilot with 2x44 MW compressor systems, described further later in this article.

Using onshore electricity to run petroleum platforms eliminates the need for local gas-turbine power generation, significantly lowering CO_2 emissions as well as operating and maintenance costs.

The power from shore concept has been largely debated as non-economical. However, over the last years this has turned around. Today most agree that the operating costs are lower than for gas turbines. For larger re-development and new oil fields, the power from shore concept can compete with gas turbines also with respect to investment cost.

The operational costs will be significantly lower with Power from Shore, due to less maintenance, higher reliability and longer life time of the system and its equipment. Power from shore will also improve personnel safety as well as for equipment in a production and processing environment.

3. VSC MADE THE HVDC POWER FROM SHORE VIABLE AND ECONOMIC

The fundamental characteristic of the VSC technology is that it uses components that can switch the current both on and off. The development of the IGBT, which is a transistor with MOS gate to become a high power component has presented itself as answer. Via the voltage in the high impedance MOS gate the current through the transistor is controlled and thus its control requires only low control energy.
In order to use the VSC for power transmission, the direct voltage needs to be increased to such levels as can be effective for medium and high voltage power transmission-distance combinations. Series connection of IGBTs in the same way as is made with conventional thyristors is then the obvious way. For control the energy can be taken from a small voltage divider across each of the series connected transistors.
Converters with simple topology, see figure 1 can be used together with high switching frequencies for both inverter and rectifier operation. The ac-voltage in inverter mode is created by switching very fast between two fixed voltages. With an AC voltage applied outside the reactor the anti-parallel diodes will act as an uncontrolled rectifier. By PWM switching between the valves the direct voltage can be boosted up to a level that would be suitable for proper control.

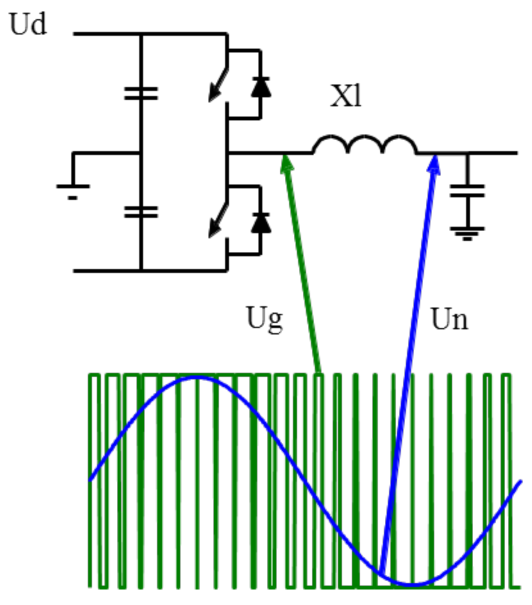

Figure 1 shows one phase of a VSC converter using PWM

Power from shore was investigated already with conventional thyristor converter transmissions, but as such converters need a network source for commutation it never became economic. In a VSC the current can be switched on and off by controlling the semiconductor valves. It can control both active and reactive power independently, and there is no need for a network to commutate against. Thus VSC can supply passive networks, that is areas which lack rotating machines, and even start such networks from the transmission, so called black start. From a system point of view the converter acts as a motor or generator without mass that can control active and reactive power almost instantaneously. It does so without contributing to the short circuit power as the AC current can be controlled.

The active power flow between the converter and the AC network is controlled by changing the phase angle (δ) between the fundamental frequency voltage generated by the converter Ug and the AC bus voltage. The power is calculated according to the formula assuming a loss-less reactor:

$$P = \frac{Ug * Un * \sin\delta}{Xl}$$

The reactive power flow is determined by the amplitude of Ug, according to the formula below. The amplitude of Ug is controlled by the width of the pulses from the converter.

$$Q = \frac{Ug * (Ug - Un * \cos\delta)}{Xl}$$

The maximum fundamental voltage out from the converter depends on the DC voltage. Reactive power generation and consumption of an HVDC Light converter can be used for compensating the needs of the connected network within the rating of a converter. As the rating of the converters is based on maximum currents and voltages the reactive power capabilities of a converter can be traded against the active power capability. The combined active /reactive power capabilities can most easily be seen in a P-Q diagram, see example below in Figure 2.

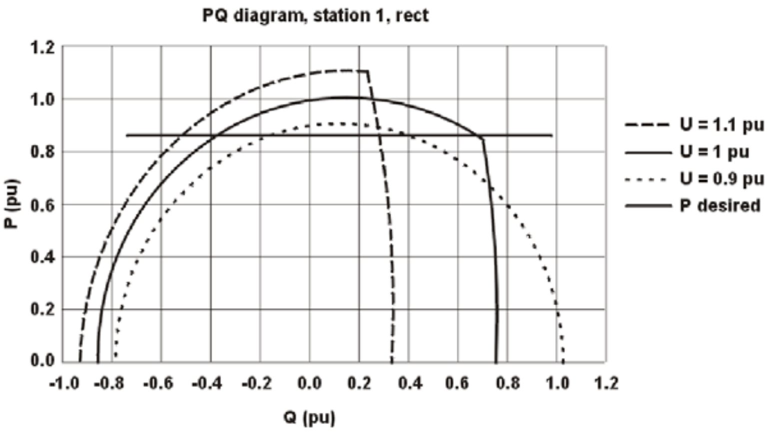

Figure 2 Typical P/Q diagram

The reactive power capabilities can be used to control the AC voltages of the networks connected to the converter stations. The voltage control of a station constitutes an outer feedback loop and giving the reactive current order in such a way that the set voltage on the network bus will be kept.

With this Voltage-Sourced Converter (VSC) technology it is feasible provide HVDC links for flexible, long-distance transmission of electricity. The possibility to provide power from shore to platform networks without needing any generation improves considerably the economics of HVDC transmissions.

The first HVDC power from shore installation was the Troll A in which HVDC was used as a Variable Speed Drive (VSD).

The Troll A project consisting of two transmission systems each rated 40 MW, went into operation October, 2005, delivering power from shore of variable voltage and frequency to two 40 MW gas pre-compressors. As a result Troll A daily gas production capacity has increased from around 85 million scm per day to well over 100 million scm per day.

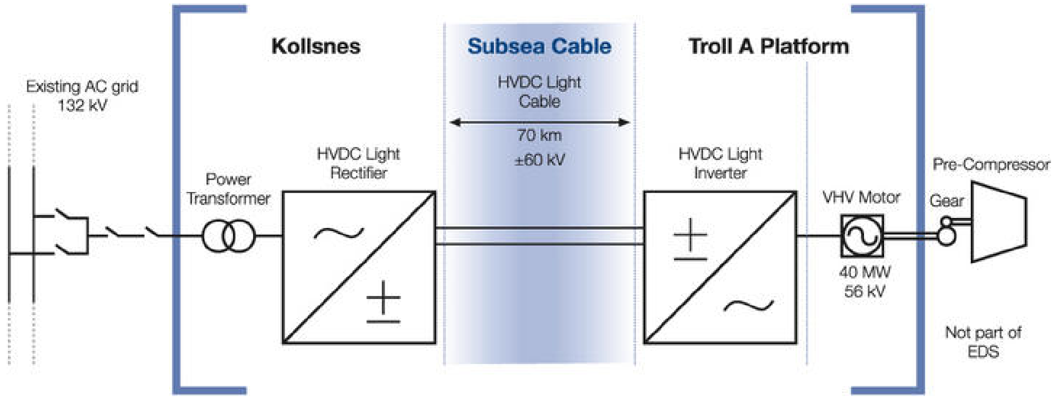

Figure 3 Troll A application single line diagram.

The onshore rectifier station at Kollsnes is connected through a standard power transformer to an existing 132 kV network with a breaker. From the rectifier station approximately 70 km length of HVDC Light cables lead to the offshore inverter station module, placed on the Troll A platform. In the inverter station the ac output is directly fed to the high voltage motor driving the compressor. The converter works as a variable speed drive with motor speed and torque control. Thus the HVDC link control includes features for providing output with varying voltage 0-56 kV and frequency 0-60 Hz including starting from zero and brought up to the required power.

4. INTERACTION WITH THE OFF-SHORE GRID AND THE SUPPLYING NETWORK

The primary purpose of power from shore transmission link is to feed power offshore, but the HVDC system will have a number of important features (ancillary services) both for the sending and receiving networks. The HVDC link will also act as a “firewall” between the two networks

The HVDC converter located onshore will be a tool for network support to the onshore AC network as the VSC converter can operate as a STATCOM. The positive effects may include:

- Give voltage support during AC faults and stabilize the AC voltage during an AC system restoration process
- Stabilize the AC voltage during switching in the AC network and reduce the number of AC transformer tapchanger operations (resulting in less tapchanger maintenance)
- Defer other investments in the AC network to stabilize the AC voltage or supply reactive power.

These features should be investigated in the early part of the planning together with the owner of the onshore grid. An outcome of an investigation may also be that it is economical to slightly increase the rating of the onshore converter station. It is important to point out that this will only have an effect on the components in the onshore station. The rating of the offshore station and the HVDC cables will remain unchanged.

The main features for the receiving network are:

- Control of AC voltage, reactive power and frequency
  This control can be done independent of the sending station
- Direct On Line start of large asynchronous machines
  The direct on line start includes the case in which a large motor at the platform is started when the transmission system is close to its maximum capacity. This function has been demonstrated in the Valhall project (78 MW 150/0 kV) were start of 15 MW machine was studied. The studies showed that the VSC converter compensates for the active and reactive power needed by the accelerating motor.
- Black start facility
  This is when the offshore station is energized from the onshore station and the DC cable, and then started up after an outage offshore.

5. SCHEMES IN OPERATION AND UNDER CONSTRUCTION

Discussion and development of power from shore first started for the Norwegian continental shelf in the North Sea. One additional reason for this is the Norwegian emission taxes, which further favors the economics of the power from shore concept compared to local generation on platforms. The first installations, Troll 1 & 2 for Statoil, were delivered 2005. The excellent performance from these installations led to the installation of Troll 3&4 that have been in operation since 2015.

Figure 4 below shows lifting of the module over to the topside and a photo of the platform with the new HVDC Light and pre-compressor modules installed.

Figure 4. Lifting HVDC module and placed on platform.

The experience from Troll A created also interest for general supply to a platform or a field and had its first installation for the Valhall field for BP in the North Sea, delivered in 2011, which is in operation with excellent performance.

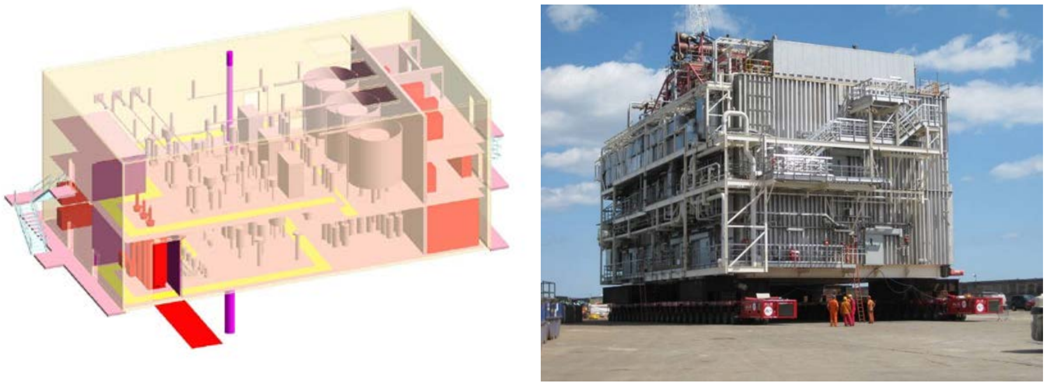

Figure 5: 3-D model of the Valhall offshore HVDC module and module at delivery from yard

The next HVDC power from shore transmission link, now in the design and installation stage, is for the recently discovered Johan Sverdrup offshore field, which is located west of Stavanger on the Norwegian continental shelf (NCS).
The receiving station on the platform will convert the DC power back to AC and for distribution to the offshore electrical loads, see figure 6. For power supply to the platforms the inverter will control the AC voltage and frequency of the platform network and provide black start when necessary.

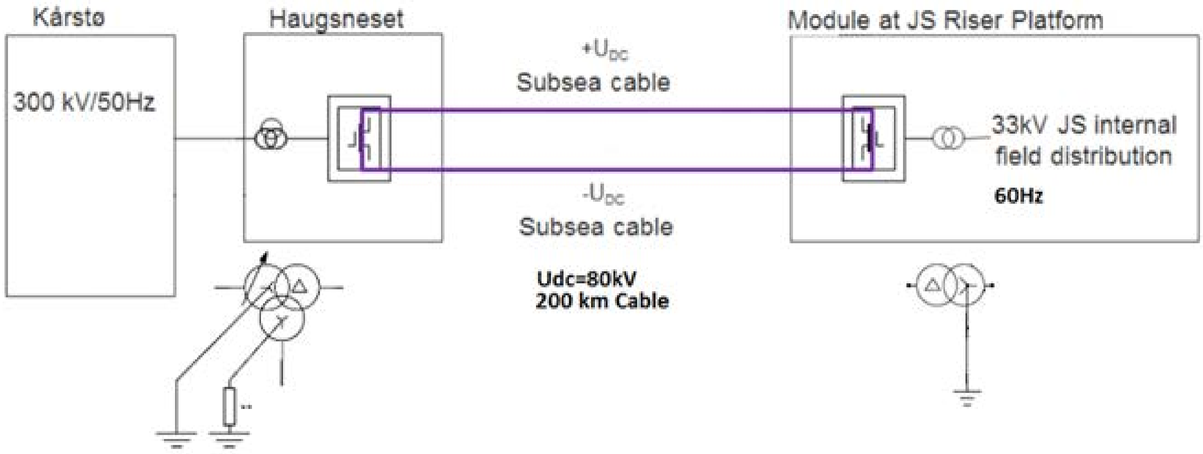

Figure 6. Johan Sverdrup Power from Shore configuration diagram

In this case the power transmission is rated in the order of 100 MW, and the direct voltage can be kept to +/-80 kV or below.
For such a power from shore transmission one important advantage is that the offshore converter can have a compact and lightweight design, which can be placed onto an existing platform or together with other installations on newly built platforms.

6. THE FUTURE INCREASED INTEREST AND NEW MARKETS

Today the interest for power from shore has increased in various other parts of the world and includes the extension to higher power levels and thereby higher voltages. Similar projects and development plans exists in Middle East, Asia and Australia.
Climate and enviromental issues like reduction of climate gases are important for these countries even if these projects are basically evaluated on economical considerations.
Experiences from other applications imply that transmissions for at least 1000 MW, +/-320 kV are feasible and can be used also for power from shore applications.

For larger petroleum fields, solutions with power hubs offshore, connected to the main grid with HVDC links, distributing the nearby platforms by AC cables are discussed.

Offshore Wind power is becoming more interesting as power supply for offshore oil fields, to reduce the carbon fingerprint as much as possible. Floating offshore wind mills are maturing fast (ref Hywind), and gives the potential to tap into the high wind energy density offshore. Some applications do not need constant power, like water injection (pushing oil to the production wells) where it's the average injection volume over time that counts.

All petroleum fields will enter into a depletion stage where the natural pressure in the reservoir is decreasing and it may be beneficial to use pressure support like pumping or gas compression, depending on the composition of the produced fluid. Such equipment needs a supply of electrical power to drive the electrical motor attached to the pump or compressor.

This has also led to development of subsea power distribution and power conversion solutions. For over 15 years, subsea transformers have been used with little or zero failures. Some major new developments are underway, where power equipment like; switchgear, power conversion (drives) are pressure compensated i.e. the same pressure inside the vessels as outside. It is a major R&D undertaking to realize major oil companies' vision of "the subsea factories" concept.

7. CONCLUSIONS

The Power from Shore concept using VSC HVDC converters was introduced in the early 2000s. It introduced the possibility to transmit power efficiently from more efficient and less polluting generation to the offshore installations.

This concept would be beneficial for changing from gas turbines to power from shore on existing platforms to secure supply of electric power for existing and increased needs on the platforms. The necessity to provide artificial pressure when the natural pressure in the field has been reduced after years in operation, can be achieved with a HVDC Power from shore transmission link, with the offshore converter placed on an existing platform.
The concept is presently used for medium and long distance transmission in the 100 MW range but there is no technology barrier to increase the ratings up to 1000 MW.

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