Chapter 1
Applications of Submarine Power Cables

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Submarine power cables have been around for more than a century and the major use has shifted through the decades. In the early times, submarine power cables were used to supply isolated offshore facilities such as lighthouses, infirmary ships, etc. Later, the power supply of near-shore islands was the main objective of submarine power cables. The connection of autonomous power grids for the sake of better stability and resource utilisation has been pursued since the sixties of the last century. In modern days, the connection of offshore facilities is again in the focus. Oil and gas production units ask for shore-generated power, while offshore wind parks (OWP) need to bring their precious green power to the onshore grids.

1.1 Power Supply to Islands

Islands located closely to the mainland can be connected to the mainland grid by submarine power cables. This is normally done with medium-voltage a.c. cables ($\leq$52 kV) and a transmission power of 10–30 MW per cable. The submarine power cables replace island-stationed, often-inefficient power generation such as diesel generators. The maximum economic length of these cables is 10–30 km. In response to increased power demand of the island, additional cables are often laid in different routes to reduce risks and increase the power availability on the island. The island supply can be secured by other cables even in the case of a cable failure. The archipelago of the North Frisian Islands in Northern Germany was connected to

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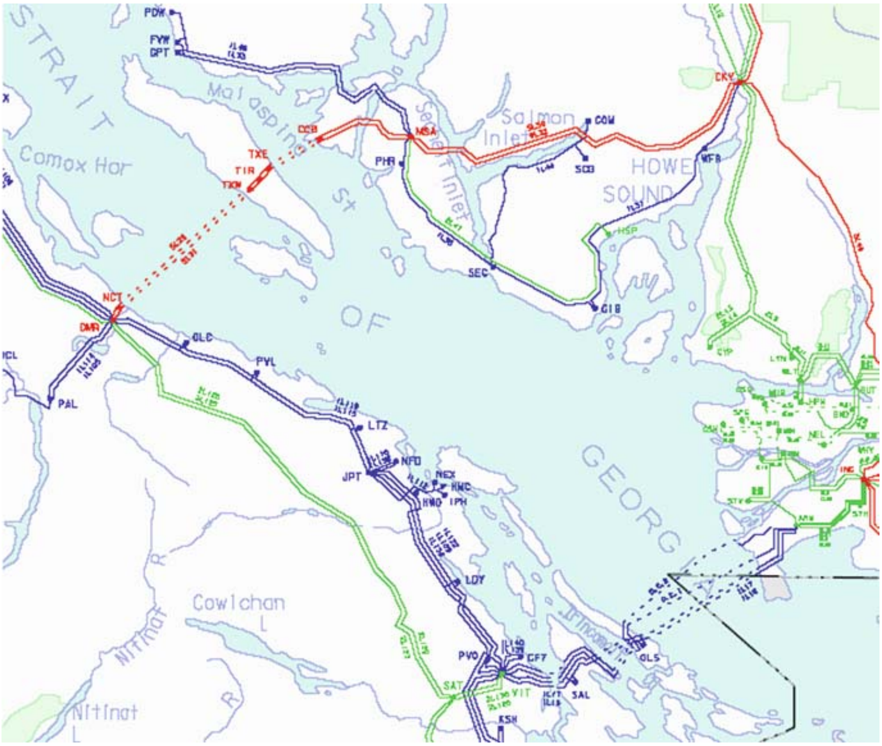

Fig. 1.1 Submarine power cables supplying Vancouver Island, Canada. The island (*down left*) was first connected to the mainland (*upper right*) with a 138 kV system (*down right*). Increasing power demand necessitated more cable systems, both a.c. and d.c. [2]

the mainland by a grid of 20 kV submarine cables starting in 1944 [1]. Other islands like Vancouver Island, Canada, and Long Island, NY, USA, have a large population and massive power demands requiring a number of extra high voltage submarine power cables circuits (Fig. 1.1).

The supply of distant islands is difficult as losses in a.c. cables increase dramatically with distance. Islands located more than 50 km from the mainland have not been connected for a long time. The German tourist island of Heligoland will be connected to the mainland only later this year (2009). The Swedish island of Gotland is some 100 km off the Swedish mainland and had to rely on inefficient diesel power generation for a long time. The island wasn't connected to the mainland grid until 1954, when the first submarine HVDC cable was installed. The canal islands of Jersey and Guernsey were connected to the French mainland in 1987 and again 2000, and the Italian islands of Sicily and Sardinia were connected to the Italian mainland by submarine power cables.

Islands with an autonomous power supply are sometimes connected to the mainland or neighbour islands in order to increase the power availability. The submarine cable has the function of a spare power plant providing emergency power in case of a local generator outage.

Owing to the geographical character, some countries, such as Norway, the Philippines, Japan, and other countries, have a long tradition of installing submarine power cables between their numerous islands.

1.2 Connection of Autonomous Grids

Since the advent of powerful submarine cables many grids have been interconnected, using different techniques. Submarine cables connect grids of different countries (To name a few: UK – France, Sweden – Germany, Denmark – Sweden, Morocco – Spain, Greece – Italy). Using HVDC techniques, regions with different frequency control can be linked (Store Belt in Denmark, Sweden – Germany, Norway – the Netherlands). In the mentioned cases, both sides have a 50 Hz grid but the frequency is controlled in different ways, rendering asynchronous grids. The interconnection of national grids is a prime objective of the European Community.

The connection of autonomous grids can have various purposes and objectives:

- The load peaks of the connected countries/grids occur at different times of the day due to different time zones or due to different habits of electricity use. With the submarine cable transmission it is possible to share generation capacities to meet the power demand.
- The connected countries/grids may have different electricity generation mixes with differences in availability and pricing patterns. Many HVDC cables connect the NordEl grid system with its abundant hydropower to the European continental power grid (UCTE), which mostly relies on fossil and nuclear power. "Green power" can be traded across borders.
- Each power grid needs a certain amount of "spinning reserve", that is generation capacity that can be switched to the grid within minutes. Traditionally, generators (hydro or thermal) provide spinning reserve while running idly. It is obvious that a submarine power cable making a connection to another grid is a more efficient and maintenance-free spinning reserve, which can be used to dispatch power flow in either direction within minutes.
- Since the deregulation of the power markets, the pricing pattern is highly volatile. Power traders can use submarine power cables to earn money by exploiting the price difference in the connected countries/grids. Sometimes they change the direction of power flow several times a day responding to the price fluctuations [3].

Submarine HVDC power cables of extreme length have been used to connect distant autonomous grids: The longest existing HVDC submarine cable system is a pair of 580 km cables (NorNed), and a number of 200+ km systems are in successful operation (Baltic Cable, Swepol, Bass Link) or under construction (BritNed, SAPEI).

1.3 Offshore Wind Farms

Offshore wind farms (OWP) consists of a number of wind turbine generators (WTG). The distance between the WTGs is 300–800 m. A grid of submarine cables interconnects the WTG and bring the power to shore. The in-field cables are three-phase medium-voltage cables (10–36 kV) with polymeric insulation. The connection to shore can be achieved with medium-voltage cables for distances up to about 10 km.

For OWP with many turbines, large output power, or large distance to the shore, the losses in a medium voltage transmission to land would be quite high and a high-voltage connection to land would be more economic. In larger offshore parks the WTG are connected to an offshore platform that carries a step-up transformer. From the transformer platform, a submarine power cable (export cable) sends the power to shore. Three-phase cables with >100 kV operating voltage serve most often as export cables for distances exceeding 30 km (Fig. 1.2).

Export cables may also operate with HVDC, which requires converter stations both offshore and onshore. The erection of an offshore converter station on a platform is expensive and can be motivated only when large amounts of power must be transmitted over a long distance.

The use of a.c. frequencies lower than 50 Hz for WTG has been considered, in order to reduce capacitive losses in the cables, and mechanical requirements for the WTGs.

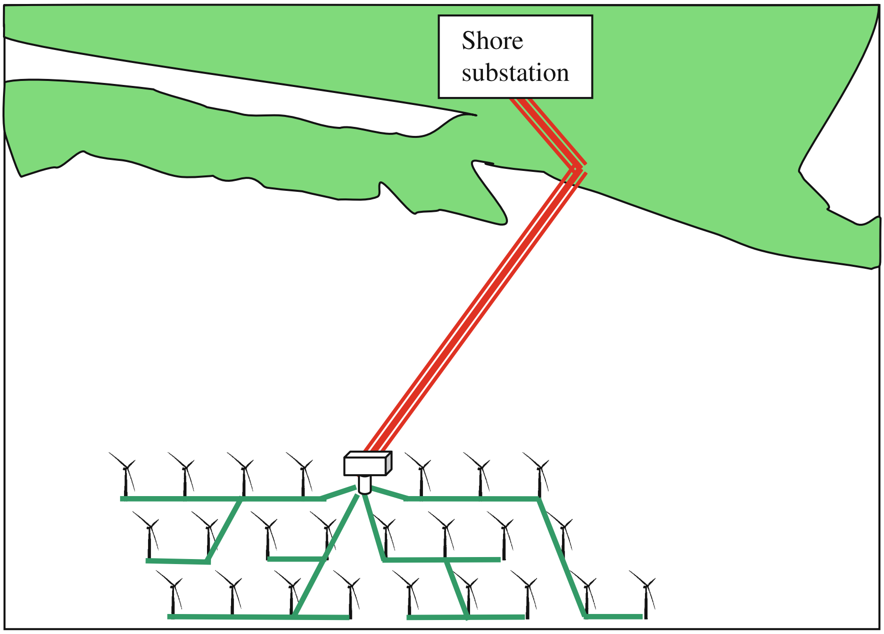

Fig. 1.2 Layout of an offshore wind farm with 34.5 kV in-field cables and 138 kV export cable between the OWP and the shore line

1.4 Supply of Marine Platforms

Production platforms in the offshore oil and gas business have a large power demand to extract hydrocarbons from wells. Energy use covers a range of activities including driving pumps to extract hydrocarbons and to re-inject water for enhanced oil recovery, heating the output stream to allow separation of the oil, gas and water, powering compressors and pumps for transporting oil and gas through pipelines to processing plants or to shore, and supply of the electricity needed for on-site operations and living quarters.

Energy needs vary widely according to local circumstances and operational conditions. The electric power for many platforms is generated from locally produced gas in steam plants or gas turbines at rather low efficiency. The power plants require precious space while their operation and maintenance staff needs additional accommodation and transport. All this makes the onboard power production expensive. As the power need increases, it becomes viable to connect the platform to onshore grids by submarine power cables.

In Norway, the offshore industry produced a quarter of the country's total CO_2 emission in 2006. As Norway has vast resources of hydropower, there is a large potential to reduce the country's CO_2 emission by connecting platforms to the onshore grid (Fig. 1.3).

Fig. 1.3 The Norwegian gas platform "Troll A" receives its electric power supply from a pair of HVDC cables (Courtesy of ABB, Sweden)

For these reasons, an increasing number of platform operators invest in submarine power cables for the power supply of offshore platforms. The supply of floating platforms is a special challenge as the repeated movements, induced by wind and waves, require certain design considerations.

1.5 Short-Haul Crossings

Hundreds of submarine power cables have been installed to transport power across rivers, channels, straits, fjords, or bays. Though overhead lines can be used for crossings up to 3 km (e.g. Messina Strait, Italy) in many cases submarine cables have been chosen instead of overhead lines. The invisibility of cables is important in tourist resorts and natural resources. Allegedly, for the crossing of a 500 kV d.c. power transmission over the St. Lawrence River, Canada, a 5.1 km submarine cable system was used to avoid optical impact. Cables do not restrict the height of ships passing the river or strait. The overhead lines over the Ems River in Germany have to be shut down each time when an upstream shipyard transports its new mega-size cruising ships to the North Sea. When the lines were switched off the grid in 2006 for the passage of the "M/S Norwegian Star" a galloping instability blacked out millions of households in Europe. Sub-river cables have been discussed for this river crossing but were not yet realized.

Also the lifetime costs of a maintenance-free cable can be lower than that of an overhead line threatened by storms, salt and ice deposition, etc.

In short-haul applications, submarine cables with very high voltage can be used when no joints are required. Often cables are available at higher voltages than the corresponding joints.

Crossings of some 1400–1800 m can be realized with trenchless horizontal directional drilling methods from the shoreline. The bore is lined with pipes and the cables would simply be pulled through the pipes. Longer crossings would require ordinary submarine cable laying techniques.

1.6 Other Applications of Submarine Power Cables

There are many niche applications of submarine power cables that cannot be covered in this book. The submarine cables used here are in the medium-voltage or low-voltage range. Here are mentioned a few:

Oil and gas production cables. As production wells are established in ever larger depths of water, more sophisticated equipment such as submersible pumps and compressors of all kind is placed on the seafloor. Figure 1.4 illustrates different oil and gas installations all requiring submarine power cables.

Umbilicals are armoured flexible assemblies containing anything from power cable cores, signal cables, fluid conduits, hydraulic lines etc in the same

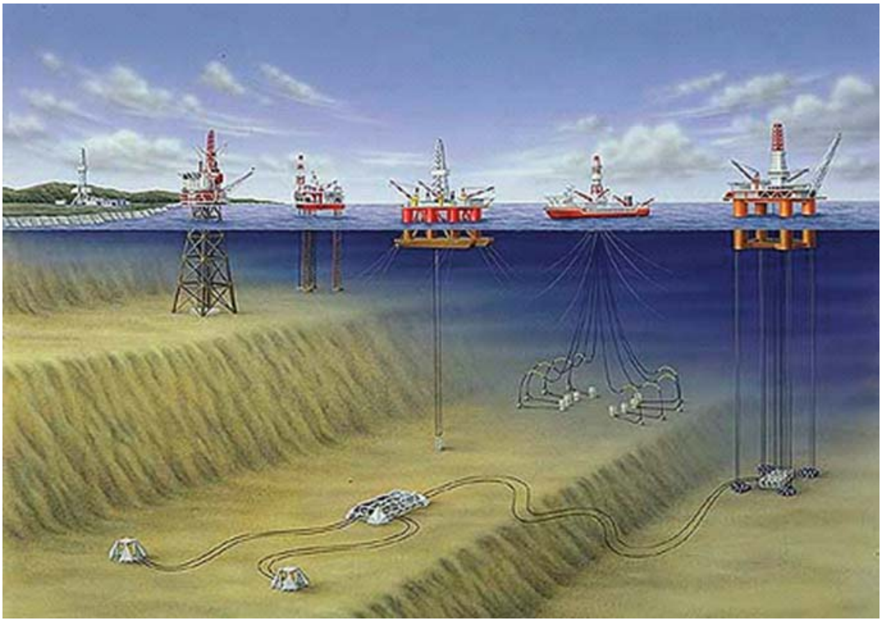

Fig. 1.4 Various oil and gas installations requiring submarine power cables. (Courtesy of Minerals Management Service, US Department of the Interior, www.mms.gov)

cable. They serve oil and gas equipment on the seafloor and remotely operated subsea vehicles (ROV).

Pipeline heating cables. Submarine pipelines sometimes need electric heating to prevent the formation of wax and hydrate deposits. The pipe itself is used as the heating element, and the power supply is accomplished by XLPE-insulated power cables with large conductor size and without metallic water barrier [4].

Subsea observatories. Tsunami pre-warning systems and military reconnaissance arrays require underwater power. The increasing focus on oceanographic research has triggered the installation of subsea automatic research stations to collect data. All these must have reliable submarine power supply [5].

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