Network of offshore wind farms connected by gas insulated transmission lines?

Anja Drews, ForWind, Carl von Ossietzky Universität Oldenburg, Institute of Physics, Carl-von-Ossietzky Str. 9-11, 29129 Oldenburg, Germany, Email anja.drews@uni-oldenburg.de, Tel. +49 441 7983929, Fax +49 441 7983326
Christian Rathke, ForWind, Leibniz Universität Hannover, Institute of Electric Power Systems, Appelstr. 9a, 30167 Hannover, Germany, Email rathke@iee.uni-hannover.de, Tel. +49 511 762-4412, Fax +49 511 7622369
Markus Siebert, ForWind, Leibniz Universität Hannover, Institute of Electric Power Systems, Appelstr. 9a, 30167 Hannover, Germany, Email siebert@iee.uni-hannover.de, Tel. +49 511 7622807, Fax +49 551
Detlev Heinemann, ForWind, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany
Lutz Hofmann, ForWind, Leibniz Universität Hannover, Hannover, Germany
Benjamin Hühnerbein, ForWind, Leibniz Universität Hannover, Hannover, Germany
Hermann Koch, Siemens AG, Power Transmission and Distribution, Erlangen, Germany
Dirk Kunze, Siemens AG, Power Transmission and Distribution, Erlangen, Germany
H.-J. Hoppensack, ILF Consulting Engineers, Munich, Germany
Harald Lohrenscheit, ILF Consulting Engineers, Munich, Germany
Theodor Roggenberg, ILF Consulting Engineers, Munich, Germany
Fred Wendt, ILF Consulting Engineers, Munich, Germany

Summary

The offshore wind power industry faces two major challenges: the connection of wind farms to the high voltage grid onshore and a smart grid integration of this offshore generated wind power. In terms of the first issue, concepts have to be developed that are efficient, economical, ecological practicable and supportive to the second matter.

Within the EU-funded project “North Sea Network using GIL technology” the technical, ecological, and economical feasibility of a network based on gas insulated transmission lines (GIL) is studied. It examines the possibilities for such an infrastructure for the North Sea bordering countries Denmark, Germany, the Netherlands, Belgium, France, and Great Britain.

Gas insulated transmission lines provide high transmission capacities with fewer losses than other cable technologies. These properties correspond with the needs of transmitting offshore generated power to the mainland. Furthermore, the high capacities of GIL as a bulk power transmission system allow a bundling of power lines from several wind farms in one line. Its superior electric behavior makes it applicable for long distance applications for wind farms far off the shore.

This contribution illustrates the idea of bundling transmission lines of multiple wind farms with GIL. The electrical characteristics of GIL are described.

1. Introduction

Power generation offshore faces the challenge of reliable, secure low-loss transmission to the grid onshore. This is not only a technical issue but also a planning job considering the growth of offshore wind power capacities. The unsteady energy production due to the highly variable resource wind requires first and foremost a grid that is able to transport offshore generated power and further on smart grid management. One way to deal with this task is linking North Sea wind farms to a network and bundling transmission lines. This supports balancing the grid in and between the neighboring countries without additional storage technologies. This network would support a reliable future energy supply employing decentralized energy systems and the electricity trade between European countries.

The project “North Sea Network using GIL technology” funded by the EU Commission in the subject area Trans European Energy Network (TEN-E) investigates the feasibility of a North Sea network connecting offshore wind farms by gas insulated transmission lines (GIL). The study, running from October 2006 to September 2009, is carried out by ForWind, Center for Wind Energy Research of the Universities Oldenburg and Hannover, Siemens Power Transmission, and ILF Consulting Engineers.

The project’s investigations examine the technical issues that need to be considered to employ GIL offshore, e.g. technical premises of the planned offshore wind farms, existing onshore power transmission lines, adapting GIL to an offshore environment, best routes for lines, logistics, installation, risks, and premises for secure operation and maintenance. Furthermore, the effects on the underwater environment, sociological factors as acceptance in public, formalities of energy trade of the neighboring countries, and finally cost calculations for various case scenarios are covered.

Compared to other technologies GIL have higher transmission capacities, fewer losses, and higher overload capacities. GIL technique allows the transfer of bulk power over long distances. It has proven a high reliability and operating safety already on land. In general, its qualities match the needs of transmitting offshore produced energy. However, as the distances are very long and the submarine laying of GIL is a new application for this technology, the addressed questions focus on the technically, economically, and ecologically feasibility of such a solution.
In this contribution GIL will be introduced as an option to connect North Sea wind farms with the high voltage grid on the mainland by bundling transmission lines. Motivation and project objectives are presented and the technical advantages of GIL compared to other cable technologies are described.

2. Future offshore wind power in the North Sea

2.1 Planned offshore wind capacities

The project is motivated by the planned expanding capacities of wind power on the North Sea, which require a new grid infrastructure offshore as well as an expansion and enhancement of the grid on land. In this project the countries Denmark, Germany, the Netherlands, Belgium, France, and Great Britain are considered.
It is a political goal in all North Sea neighboring countries to integrate offshore wind energy into the future energy supply for climate protection and conservation of fossil fuels. For example, in Germany offshore wind energy should be expanded to 25 GW till 2020, which will be a major contribution to the energy mix of tomorrow.

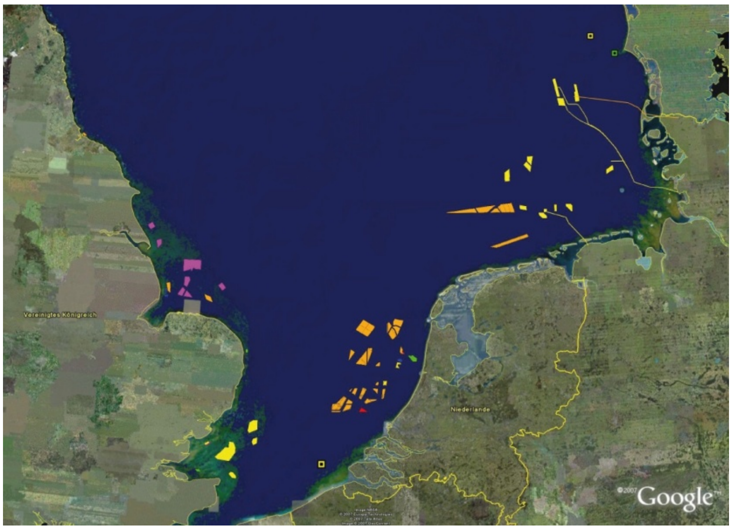

Figure 1 Offshore wind parks in different stages as displayed by colors. Green – in operation, blue under construction, yellow – approved, orange – applied for, red – application rejected, purple – unknown.

To gain information on the expected installed offshore capacities in the future, an inventory on the status of (all) European wind energy projects has been carried out. Around 200 offshore wind power projects were found with a total rated power of ~115 GW. Of course, not all of these projects will ever reach the status of operation. In the year 2007 a total of 23 wind farms of approximately 1 GW are in operation. Further eight projects are under construction intending to contribute another 700 MW of installed power. Without considering the 61 projects that are in an unknown planning status, the remaining 45 projects could contribute till 2020 with 45 GW assuming their realization. In any case, 37 projects are already approved by the authorities in charge. Figure 1 gives an overview on North Sea projects as far as information could be found. The map shows the intended offshore wind parks in their different planning status. Green areas are wind farms already in operation, blue displays parks under construction, yellow describes the farms that are approved, orange those with a proposal in progress, red are parks were the application has already been rejected, while at purple areas the status is ambiguous. All in all it can be summarized, that 45 GW of wind power are in work, while 70 GW are in an unknown status. Potentially 12.000 wind generators wait for their erection till 2020.

2.2 Network with gas insulated transmission lines

This amount of wind power needs a grid that transports the generated power secure and with low losses to the grid on the mainland. Since the terms and conditions to lay power lines to the shore are restrictive, especially for ecological sensitive areas as the Wadden Sea, the needed infrastructure for the connection of the wind farms is something where economic and ecologic interests, climate protection as well as landscape protection, need to be balanced. Due to ecological aspects concerning the Wadden Sea some wind parks are located up to 200 km away from the shore. Transmission lines, especially through the Wadden Sea, cannot be placed wherever they might be needed; they need to be bundled up to the points of delivery to connect to the onshore grid. The cable technology here needs to be capable of these distances with low transmission losses for a most efficient use of the wind energy supply. Therefore, we propose a network of transmission lines based on GIL.

Furthermore, a complete offshore network could support the balancing of the grid of the neighboring countries. In case of low wind situations, power flows from other wind-rich parts of the North Sea maintain balancing without any additional storage technologies and therefore, support the energy trade throughout Europe.

Considering the amounts of expected power production, GIL matches exactly the need of offshore produced energy in terms of high voltage bulk transmission. Study area to investigate the technical requirements for such a GIL-based system is the transmission line crossing the German island of Norderney. This line is already approved for eight wind parks that are supposed to feed into the grid at the mainland by one power line each. We are studying the advantages of bundling these power lines to one GIL line. Figure 2 shows the area and a simplified straight course, which does not meet the real conditions.

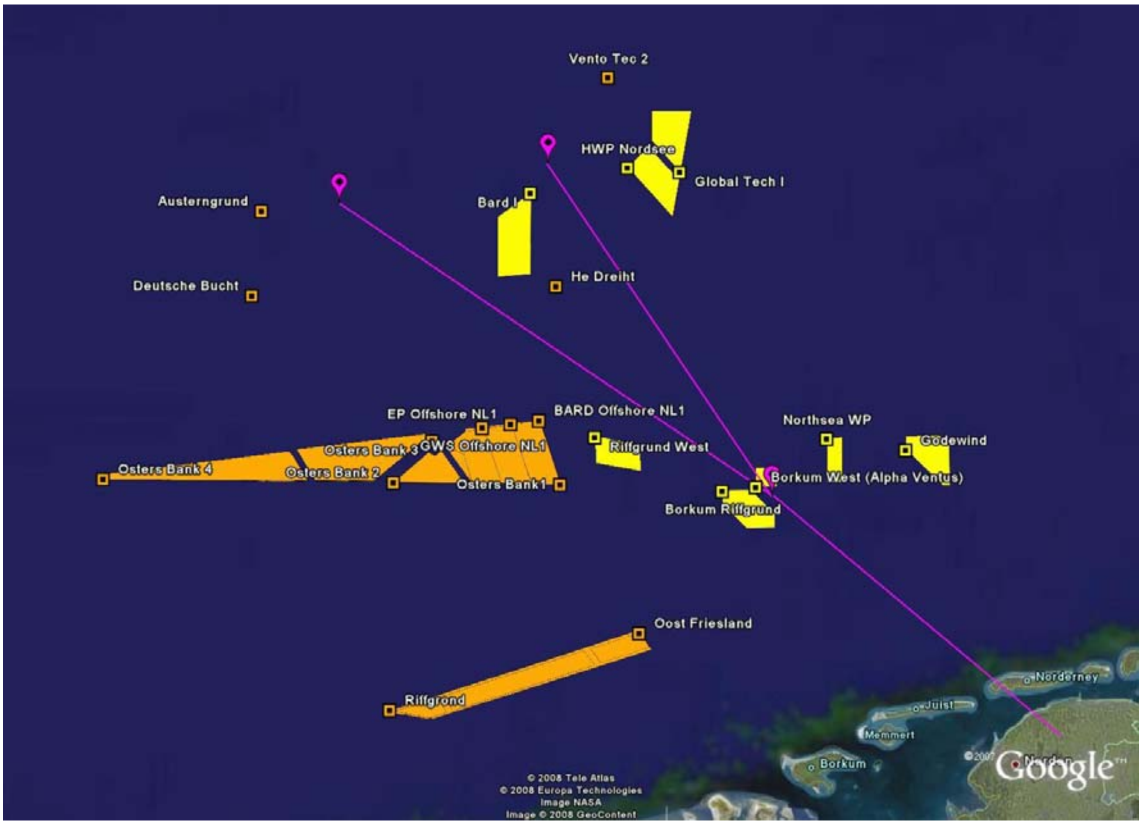

Figure 2 Study area bundling power lines of offshore wind farms over the German island of Norderney.

3. Project objectives

The project “North Sea Network using GIL” consists of different work packages covering all aspects of an infrastructural planning project. But it has a special focus on technical development. Since the GIL technology so far has proven its reliability only on land and no experience with offshore applications is on hand, making this technology applicable offshore and finding solutions for laying techniques is stressed due to the fact that GIL behaves more like a pipeline than a cable (compare Chap. 4).

Shortly described, the following issues, among others, are examined in this project:
The general investigations cover an inventory on the planned offshore wind parks (compare Chap. 2.1) and their intended connections, conditions on land considering the connection points with the available grid infrastructure behind, the framework for electricity trade and simulations of electricity flows giving answers on limits and critical system conditions.
A second part is the submarine laying of GIL, which deals with assessing the most appropriate routes for lines, investigation of laying techniques and needed vessels. Furthermore, the adoptions that might be necessary to lay GIL offshore are inspected.
As already mentioned the experience with GIL is restricted to a few hundred laid kilometers onshore. Therefore, all technical aspects of offshore GIL systems need to be considered. The required capacities need to be determined; the connections between wind farms and the high voltage grid onshore. Furthermore, concepts of operation and maintenance need to be developed.
Next to the issues that affect the GIL network itself, several accompanying studies belong to the project. Hereby, the environmental aspects as effects on the marine environment during construction and operation are described. Public opinion is accounted for as well.
Furthermore, the economical aspects are addressed. Life cycle costs and economic comparison to conventional concepts with sea cables are covered.

4. Gas Insulated Transmission Lines

4.1 Characteristics of GIL

Figure 3 Cross-section of a GIL (one of three phases). Source: Siemens AG.

GIL is an AC transmission system for high and extra high voltage. Figure 3 shows a cross-section of a GIL. It is based on coaxial pipes of aluminum alloy, with the inner conductor (see Fig.4, element 2) at high voltage centered by solid insulators within an outer earthed enclosure (see Fig.4, element 1). The space between the enclosure and the conductor is filled with a pressurized insulating gas mixture (80%/20% nitrogen (N_2)/ sulfur hexafluoride (SF_6) at 0.7 MPa). Due to its very high conductor cross-section the domain of GIL is high power transmission with currents exceeding 2000 A at 380 kV.

The assembly of GIL is similar to the laying of pipelines. Highly standardized elements are used to install a GIL in every spatial direction, even vertical. All in all four different elements exist: straight elements, elbows, disconnection units for smaller gas compartments and for sectional commissioning tests, and compensator modules for cases of thermal expansion of the enclosure. These elements are assembled adaptive to the environment. The straight elements are preassembled to a length of 12-18 m and then are automatically welded on site. The bending radius of the GIL is 400 m. Following the natural landscape is usually possible, but in case of sharp curves, elbow elements are needed, which can be applied for angles between 4 and 90 degrees. Figure 4 shows the outline of a straight element.

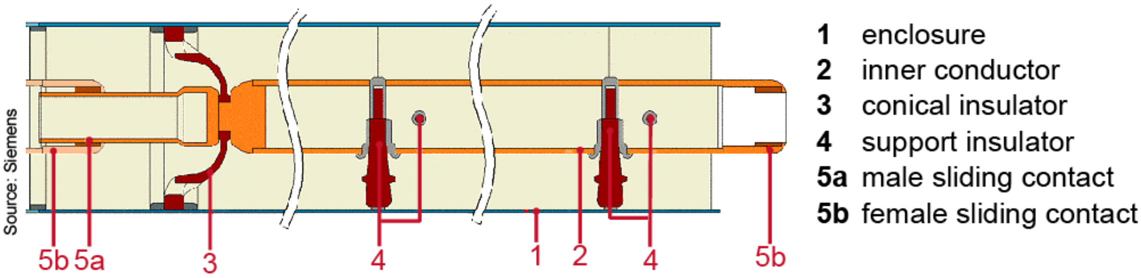

Figure 4 Design of a straight GIL element. Source: Siemens AG

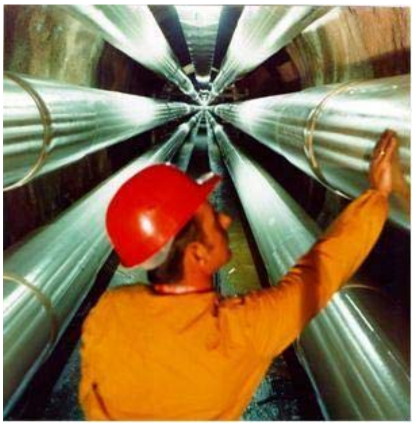

Figure 5 Example for tunnel laid GIL. Source: Siemens AG

The conductor tube (Fig. 4, orange element) is fixed by a conical insulator (see Fig. 4, element 3). Support insulators (see Fig. 4, element 4) guarantee the coaxial design and allow a thermal expansion of the conductor tube in longitudinal direction sliding on the enclosure.

During the installation the GIL is filled under pressure by the insulating gas mixture. Before filling and to avoid any dirt and humidity in the tube, the enclosure is evacuated. This is done in gas sections of 1200 -1500m; length is limited by the capability of vacuum pumps. This is necessary because any contaminants might cause a dielectric breakdown. Therefore, the assembly has to take place under very clean working conditions. Inner particle traps are installed in periodic intervals.

The final construction and laying of a GIL is quite similar to a pipeline. All elements of the line are produced separately and assembled on site with the four standard elements. These single pipes are welded together by an automatic orbital welding machine. Three single pipes are combined to a three-phase system.

GIL can be laid above ground, directly buried or can be installed in tunnels. Fig. 5 gives an example for tunnel laid GIL.

GIL has a superior electric behavior, which enables to collect the generated power of several wind farms for transmission to the grid onshore:

- Highest ampacity - up to 4000 A at 500kV.
- Low capacities - no compensation for long lengths.
- Electrical behavior similar to overhead lines (OHL) - auto re-closure capable.
- Highest personal and operational safety – no burn through of the enclosure.
- Low radiation - no external electric field and very low electromagnetic radiation.
- Well known three phase AC technique – easily applicable in existing structures.
- Very robust and simple design – benefit for the offshore environment.
- Long lifetime – more than 50 years.

4.2 Comparison to other transmission systems

Basic requirement for power transmissions are high power capacities combined with long distance application. The possible length of high voltage alternating current (HVAC) cables is strongly limited due to their high capacitance and low thermal permissible power. GIL does not have this disadvantage because its capacitance is significantly lower and its permissible power is much higher. Therefore, from a technical point of view it is the best high HVAC transmission line for long distance applications. Fig. 6 shows the AC transmission capability of overhead lines (OHL), cross linked polyethylene insulated power cables (XLPE), and GIL in comparison. Despite of their good electrical behavior OHL are not applicable in the offshore environment, which reduces the options to sea cables and GIL. In case of low power transmission of up to 200 MVA and short distances of less than 100 km, the sea cables with a voltage of 110-170 kV are the most economic option. But for higher transmission capacities only GIL or high voltage direct current (HVDC) systems are appropriate for transmission. For usage under offshore conditions three-phase alternating current has some benefits to HVDC solutions, like robust and well known behavior, simple configuration, and easier encapsulation because of smaller platforms.

Furthermore, compared to HVDC systems, the benefits of GIL are the higher power capacity and the robust three-phase technique, which does not demand huge converter stations. That reduces the size of offshore needed platforms.

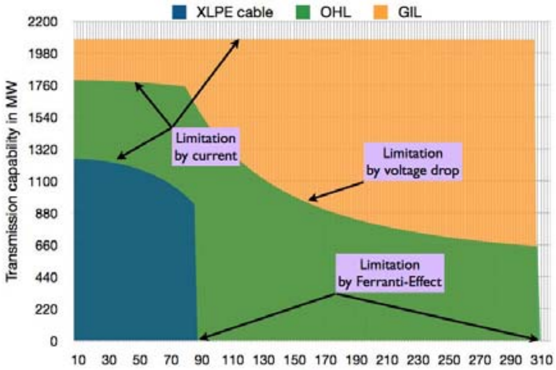

Figure 6 AC transmission capabilities of OHL, GIL, and XLPE cables depending on transmission line length.

5. Conclusions

Compared to other transmission technologies, the characteristics of GIL show a very high potential to contribute significantly to the needed infrastructure, which is mandatory for the effective use of the offshore produced wind power.

Acknowledgements

The Project is funded by the European Commission in the Trans European Energy Networks (TEN-E).