

# Developing a transnational electricity infrastructure offshore: interdependence between technical and regulatory solutions

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# Developing a Transnational Electricity Infrastructure Offshore: Interdependence between Technical and Regulatory Solutions

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**Abstract**—This paper aims at identifying the options for designing an offshore electricity grid and the legal instruments to create such a grid. It will make a first attempt at presenting the technical and legal considerations which coastal states, EU and national legislators and policy makers should take into account in the coming years when planning and weighing their grid design options. By contrast to the onshore system where the current grid is the result of many decades of local, regional, national and international developments, the situation offshore is different in the sense that currently there is more or less no grid. Moreover, the legal basis for developing such a grid is different offshore than onshore.

Therefore designing a system which looks beyond national interests and concepts represents a major challenge. We will discuss whether such a new development as the construction of an offshore electricity grid should be a matter of national policy or should a multilateral or international approach be preferred.

**Index Terms**—offshore networks, long-term planning, legal aspects, wind integration

## I. INTRODUCTION

AN increasing interest can be observed in Europe towards the establishment of transnational electricity networks. This is driven by two developments. First, for reaching the European Union's targets on renewable energy generation, large-scale offshore wind power is a key generation technology. Second, due to the deregulation of the energy sector in Europe, there exists an increasing demand for cross-border exchange capacity. Until now the development of offshore power transmission infrastructure has mainly been governed on a local or national level. As such, major differences can be observed among the coastal states in how offshore power transmission infrastructure is treated in their policies, laws, and regulations. For instance, some states have

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assigned the responsibility of connecting offshore wind power to their national transmission system operators (TSO), whereas others leave the responsibility of connecting to the onshore network to the project developer.

For future expansion of the European transmission network, it is likely that a transnational offshore infrastructure will be developed, which facilitates the grid connection of large-scale offshore wind power, as well as cross-border trade, as well as other offshore applications (other offshore renewable energy sources, offshore consumers such as oil and gas platforms).

In this paper it will be argued that interdependence exists between technical and regulatory aspects when extending the transmission system offshore. The development of technical-economically optimal solutions may be hindered by the different national legal and regulatory frameworks in place. The paper will identify barriers in the creation of such offshore infrastructures.

## II. RELATED WORK

Greenpeace estimates the offshore wind energy potential of the North Sea region at 68.4 GW [1], which, assuming an average 41.2% capacity factor gives 240 TWh/year and would be sufficient to supply about 13% of the annual electricity demand recorded in 2006 for the seven neighboring coastal states. Recent estimates by the European Environmental Agency [2] are even more optimistic, assigning the economically competitive potential of offshore wind energy production in Europe by 2020 at 2600 TWh/year. This translates to a 60–70% share in the 2020 electricity demand, out of which about a quarter belongs to North Sea areas. The development of offshore wind energy therefore will not only meet the greenhouse gas and energy security objectives but also improve EU competitiveness in an international context. In order to meet these objectives and to fully exploit the offshore energy potential, several technical, policy and legal barriers must be overcome first. These barriers do not only involve the construction of offshore wind power plants but also the infrastructure necessary to transport electricity to shore, i.e. the construction of submarine cables. By contrast to the onshore system where the current grid is the result of many decades of local, regional, national and international developments, the situation offshore is different in the sense

that currently there is hardly any grid (except for some individual wind power plant to shore connections and a few two-terminal HVdc interconnectors). Moreover, the legal basis for developing such a grid is different offshore than onshore. Therefore, designing such a system which looks beyond national interests and concepts presents a major challenge. In this respect, an important role could be played by the recently formed North Sea and Baltic Sea Regional Working Groups, functioning under the umbrella of ENTSO-E, the European Network of Transmission System Operators for Electricity.

One of the earliest proposals for a transnational grid is the “Supergrid” concept [3], subsequently trademarked by Irish project developer Airtricity. This was imagined to connect offshore wind power plants to onshore transmission systems from the North and Baltic Sea regions to as far as the Atlantic coast and the Mediterranean sea, using what is widely accepted as the only technology of choice for such an enterprise, multi-terminal HVdc based on voltage-sourced converters (VSC-HVdc). As a first element of the Supergrid, Airtricity proposed the “10 GW Foundation Project,” a conglomerate of wind power plants to be situated in the North Sea and simultaneously connected with the UK, Germany and the Netherlands power systems. It is argued that due to synergies with international electricity markets, the offshore cables used in this project will experience an utilization factor of over 70%, compared to the typically low 40% for dedicated wind power plant connections.

Given the well-established fact that correlation among wind speeds decays exponentially with the distance between locations (see e.g. [4]), various initiatives funded by environmental agencies [1], TSOs (the European Wind Integration Study, EWIS [5]) and the European Commission [6]–[7], have stressed the importance of well-functioning international electricity markets and of an adequate pan-European transmission system. The existence of these two ingredients enables trading away imbalances (unscheduled surpluses or deficits of wind energy) and smoothing out the variability in wind power production when aggregated over large areas. More wind power can be integrated into the system without violating technical constraints since capacity credit for wind goes up [6] and minimum load problems are alleviated [8] as wind is traded over larger geographical areas. The Greenpeace study [1] starts by quantifying the variability in the aggregated wind power production envisaged for the North Sea region by 2020–2030, and goes on to discuss possibilities for connecting clusters of offshore wind farms via dedicated multi-terminal HVdc links or via existing HVdc interconnectors among countries. Both the EWIS and TradeWind studies use a combination of market and power flow models to determine congested corridors in the European high-voltage transmission system under various offshore/onshore wind energy development scenarios. However, for simplicity reasons the offshore wind in the TradeWind study is assumed to be directly connected to the nearest onshore grid point [9]. The EWIS study also started by

focusing on the onshore transmission system but is now examining the creation of North Sea electricity hubs, which should be gradually developed by expanding existing bilateral HVdc connections. Similarly, the Norwegian TSO Statnett has introduced the North Sea “Power Wheel” concept [10], where a coordinated offshore grid design among the North Sea states will complement existing HVdc interconnectors, resulting in the creation of a meshed grid, with several offshore hubs to be used as connection points for wind power. This design will enable the hydro power plants in Norway to act as a buffer for the variability in offshore wind. Recently, the OffshoreGrid project, funded under the framework of Intelligent Energy Europe has begun investigating the interactions between coordinated offshore trans-national networks and market design [11]. This project will deliver technical-economical analyses for various offshore grid blueprints, while taking into account possible market designs. It also aims at making recommendations for changes to the regulatory framework for cost recovery and operation of the grid. However, a legal component is not planned to be specifically included in this study.

The special report issued by European Coordinator Adamowitsch [7] investigates the possibilities for practical realization of a transnational offshore grid and is intended as advice to EU policy makers on subsidy programs for this advanced type of energy infrastructure. The North Sea and the Baltic Sea are identified as promising areas, with the Kriegers Flak area in the Baltic Sea recommended as a pilot location for large-scale wind power plants (totaling 1600 MW) and a three-way interconnector to Germany, Denmark and Sweden.

Most of these works, however, mainly focus on the technical and economical aspects related to transnational offshore electricity grids. They do not sufficiently address the equally important legal and regulatory aspects that are relevant to the development of such grids. It is the aim of this contribution to provide an overview of both fields of study and to demonstrate how they relate to each other.

### III. TECHNICAL-ECONOMICAL ASPECTS

#### *A. Reliability and Redundancy*

All offshore wind power plants that have been realized up till now employ a dedicated cable connection to the shore. Very little redundancy has been applied in the design of this type of connection infrastructure. The reliability of the connection critically relies on some of its main components, most importantly the export cable circuit connecting the whole power plant to the onshore grid. When failed, these components will take the complete installation out of service. In most of present projects, the grid connection is part of the wind power plant project itself and the limit of jurisdiction is the onshore grid connection point. As the total share of offshore wind power capacity in the national electricity supply systems is still very low and its impact on the operation of electricity networks is in most places rather negligible, transmission system operators do not require wind power

plant operators to meet defined availability figures. This is, of course, further complicated by the variable nature of the wind itself. As a result, for most of present designs, redundancy in the grid connection has been considered only in the light of technical-economical optimizations in the design phase. Put otherwise, redundancy in the grid connection will be considered only if the additional investments are at least covered by the revenues from the energy-not-supplied that it would prevent [12]. Looking at present designs, this has never been the case.

With the expected increase of the share of offshore wind power capacity in the future, this situation is likely to change. TSOs may start putting requirements on the availability of the connection. Only then, the loss of production due to an offshore transmission outage will become a manageable risk. In some North Sea states (notably in Germany) the national TSO is now already made responsible for the grid connection of offshore wind power plants and the further development of the offshore grid. It will depend on the extent to which the electricity legislation is applicable to offshore, whether requirements such as  $N-1$  safe connections also hold for the interconnection of wind power.

Transnational offshore electricity networks are expected to improve reliability. As they will have at least several connection points to the onshore power systems, there will be always an alternative path along which (part of) the power can be evacuated. However, a timely coordination among the participating states will be crucial in this respect. If there are large differences in the requirements for infrastructure reliability between the coastal states, this might well make the investment in transnational infrastructures less attractive.

### *B. Flexibility, Standardization, and Modularity*

As the development of offshore wind power and offshore electricity transmission will probably span decades, it will be hardly possible to determine a detailed blueprint of such infrastructure in the present. As with onshore networks in the past, the evolution of offshore infrastructure is a gradual process that constantly needs to adapt to new developments in the industry and society as a whole. However, since the nodes in this offshore network, i.e. high-voltage substations located on offshore platforms, are almost impossible to modify or extend once installed, it is essential for the success of such a network to consider future network expansion plans right from the beginning. For optimal results, such offshore grid expansion plans should be the result of coordinated efforts among the responsible authorities in the various North Sea countries.

Two aspects are of specific relevance in this respect: standardization and modularity. Looking at the development of onshore transmission systems, a lesson can be learned with regard to the selection of key technical parameters. An early agreement on voltage levels, frequency, short-circuit levels, etc., prevents the development of systems based on multiple standards. Proper standardization ensures interoperability right from the beginning and allows all involved stakeholders to

operate on an equal basis. Taking the idea of standardization one step further, one could think of an offshore grid consisting of many equally dimensioned subunits. The TSO transpower that is responsible for the network development in the German part of the North Sea has launched plans in this direction [13]. They envisage a network of multiple identical clusters of offshore wind power plants centered around offshore substations connected to the mainland, which could in turn be interconnected. Not only does modularization ease the process of planning an offshore network, but also leads to easier maintenance during the operation phase (due to e.g. better availability of spare parts). As far as standardization and modularization have impact on the intrinsic structure and functioning of the grid, they will probably be enforced through technical regulation such as grid codes (see below). Therefore, again, an interdependence between technical and regulatory aspects exists.

### *C. Controllability of Power Flows*

As an offshore transnational grid is likely to be based to a large extent on HVdc technology, it will have higher controllability of power flows than onshore ac grids. In the latter the distribution of power flows mainly results from the dispatch of generators and the impedance of the transmission lines, and can therefore only be influenced indirectly e.g. via additional equipment such as phase-shifting transformers. HVdc inherently enables forcing a predefined power flow along a certain line. This will for certain have impact on the rules for congestion management for this offshore grid. Most notably, at present there exist different rules among the European electricity markets for the priority dispatch of renewables, including on- and offshore wind. Some markets, such as in Germany, always give precedence to generation from renewable sources, whereas others, such as in the Netherlands, give renewables an equal status to any other generation source. The creation of a transnational offshore grid would create an (implicit or explicit) coupling of these markets and, hence, a harmonization of market and operation rules will be necessary. This results of such a harmonization process needs to be embedded in a proper regulatory framework.

## IV. REGULATORY ASPECTS

### *A. Offshore Jurisdiction*

According to international law, coastal states have sovereignty over their territory, including the territorial sea. Most coastal states have extended their territorial sea to 12 nautical miles (22.2 km) from the coastline. Outside this 12-nautical-miles zone, coastal states have a limited or functional jurisdiction. On the basis of the UN Convention on the Law of the Sea (UNCLOS, 1982), all coastal states have a continental shelf, defined as the stretch of seabed adjacent to the territorial sea. Each coastal state automatically has a continental shelf. In contrast, coastal states could opt to explicitly establish an exclusive economic zone (EEZ), which stretches from the seaward edge of the territorial sea to at maximum 200 nautical

miles from the coast. According to UNCLOS, coastal states have territorial jurisdiction on land and on the territorial sea, and functional jurisdiction outside. On the continental shelf this functional jurisdiction is limited to the exploration and exploitation of natural resources. In the EEZ, however, coastal states have more powers and the functional jurisdiction also governs “the production of energy from water, currents, and winds,” and “the establishment and use of artificial islands, installations, and structures.” [14]

All North Sea coastal states have ratified and are party to UNCLOS, and have established an EEZ or similar (e.g. Renewable Energy Zone, REZ, in the UK). Thus, these coastal states have the exclusive right to produce wind energy within the territorial sea and the EEZ. Whereas all territorial laws apply to the territorial sea, an explicit decision is required as to the laws applying to the EEZ. Coastal states have several options here: existing national laws may (partly) be extended to the EEZ, or specific legislation may be established. However, the regime regulating the EEZ has to consider the principles of the high seas at all times, including freedom of navigation, fishing, flight transit, and the laying of submarine pipelines or cables.

Concerning the laying of cables that are necessary for offshore wind energy installations, a coastal state has several alternatives as well. It may treat the wind turbines and the cables as a single installation for the production of electrical energy, or it may consider the wind power plant and the export circuit connecting the plant to the onshore network as two separate installations, for which separate regulations apply. For example, a coastal state may opt to (partly) extend its electricity legislation to offshore, or to establish a new regulation specifically governing offshore cables and installations, e.g. in the form some sort of building act. These choices will to a great extent influence how the offshore electricity infrastructure in these coastal states will further develop. For instance, based on the legislation different stakeholders may be made responsible for the development of offshore grids (for example the TSO versus the project developer). In this respect it must be stressed here that other stakeholders other than the TSO could also participate in the development of (parts of) the offshore grid.

As a result, regulation for offshore electricity infrastructure is likely to continue developing mainly on a national level, unless the EU Commission (EC) decides to play a more active role.

### *B. Bilateral versus Multilateral Regulation*

For the development of offshore electricity infrastructure, possibly a lesson can be learned from the oil and gas industry. All offshore cross-border oil and gas pipelines in the North Sea have been developed and operated on the basis of a bilateral agreement between the coastal states involved. In such bilateral agreements the involved authorities involved agree on the general principles that should apply to the pipeline. This same principle of bilateral agreements could also be applied for the case of submarine electricity cables.

Coastal states can begin to agree beforehand on the type of cooperation necessary to operate the cable, such as an operator on each side of the border or a joint operator, the requirements for connection to the grid, safety and environmental provisions, etc. Such agreements could also include the extent to which the national feed-in regimes apply to offshore wind projects. Consequently, such an agreement would enable the feed-in of electricity into offshore interconnectors and the supply of electricity into the system of another (member) state. Bilateral or multilateral agreements can be promoted by a variety of organizations such as the North Sea Minister Conference, or the national regulators promoting the development of regional electricity markets [15].

Although the EC supports the development of offshore wind power, as expressed in the Egmond Declaration of 2004 and the Berlin Declaration of 2007, until now this has not resulted in any major initiatives. Recently, the EC has included the development of offshore wind energy in its policy on Trans-European Energy Networks [16]. The impact of this policy remains to be seen as in practice the Trans-European Networks policy has only resulted in some degree of funding of specific projects and not in any harmonization of legislation. At the end of 2008, the EC published a further recommendation on offshore wind energy [17]. However, as this is a recommendation, it does not present any concrete legal obligations for the promotion of offshore wind energy and the development of an offshore grid facilitating the transport of offshore generated electricity. Several other initiatives have been listed in the introduction of this paper, most importantly the work of European Coordinator Adamowitsch [7]. However, it will still take considerable time before the conclusions of these activities will find their way into binding obligations. Coastal states therefore still need to rely on the above mentioned legal instruments if they wish to establish a legal basis for building and operating transnational electricity grids.

### *C. Technical Regulations and Grid Codes*

A specific part of national electricity regulation deals with technical requirements for connected equipment. Such requirements are often detailed in grid codes, which are secondary regulations that are referenced in the Electricity Act. As with the onshore transmission networks, these grid codes have gradually developed over the years and are in many aspects specific to a national power system. Wind turbine manufacturers have recently faced the challenge of making their product compliant to a wide range of grid code requirements. However, the many different grid codes in place may form a major barrier towards the development of transnational offshore electricity grids.

Many surveys, including more recently [18], have shown the need for a unified regulatory framework of national/regional grid codes, comprising technical requirements for grid connection of wind power plants and also grid connection charging methods. Such grid code harmonization will support the development of a true pan-

European transmission system. Typical technical grid code requirements for wind power plants include low-voltage ride-through, voltage and reactive power support, and active power and frequency control. This fragmentation issue has already been recognized by major wind industry stakeholders. As a result, the EWEA Working Group on Grid Code Requirements has proposed a two step harmonization approach [19]: a structural harmonization providing a grid code template [20], and a technical harmonization exercise that has to adapt the existing grid code parameters of each country to the new grid code template. This harmonization will benefit not only wind turbine manufacturers, but also project developers and system operators alike. Such a grid code template may also prove useful in case the North Sea countries will decide to further extend and interconnect their grids offshore. However it should be kept in mind that grid codes were conceived with an implicit assumption that wind turbines are connected to an ac grid. Since the offshore grid is expected to be HVdc to a large extent, one could reasonably argue for a separate offshore grid code, where certain requirements for wind power plants are relaxed, and instead passed on to the onshore HVdc terminals which, enabled with proper control algorithms, can also provide support for the onshore ac network.

Until technical regulation is harmonized and binding on a European level, governments and system operators only have the abovementioned bilateral or multilateral agreements at their disposal, under which they can also regulate the technical aspects concerning the interconnection of offshore grids. However, having yet another set of technical rules in force does not make the access to the European electricity grid necessarily more transparent.

## V. CONCLUSION AND OUTLOOK

This contribution discussed the development of an offshore transnational electricity grid that would provide interconnection capacity between coastal states as well as better opportunities for the connection of large-scale offshore wind power. Various related research works and ongoing initiatives have been reviewed. Those works concentrate mainly on specific issues of such a transnational grid, mainly technical or economic. In this paper it has been argued that it is important to consider the dependence between technical and regulatory aspects right from the beginning. The paper focused on the North Sea region. The perfect conditions for large-scale offshore wind power production together with the fact that different coastal states, each with their own legislation, power systems, and electricity markets are involved, makes this area a very interesting topic of study.

It has been explained that even though national legislation must take into account the general principles laid down in UNCLOS, there is a degree of freedom for coastal states to implement legislation for their EEZs. This leads to different implementations that make it difficult to establish a common ground for the development of a pan-European transnational offshore grid. Although a number of research initiatives are

currently being undertaken at a European level, it may take considerable time until the results find their way into practical regulation. It is argued that until that time, coastal states wishing to engage in the development of such an offshore grid should focus on the possibilities offered by bilateral or multilateral agreements, as are common for oil and gas pipelines. It has furthermore been shown that especially with regard to technical-economical aspects that relate to the design and operation of transnational offshore grids (such as the need for redundancy and standardization), an interaction with the regulatory framework should be taken into account.

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## VII. BIOGRAPHIES

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Since 2005 he is a Ph.D. researcher at the Electrical Sustainable Energy Department at Delft University of Technology, the Netherlands. His main research topic is grid integration of offshore wind power plants through high-voltage direct-current transmission, with a special focus on synergies with interconnectors. From 2007 he is also a consultant with Siemens AG, Energy Sector, Erlangen, Germany.

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