Market and regulatory aspects of trans-national offshore electricity networks for wind power interconnection

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Abstract

New connection schemes for offshore wind power are sought for to minimize the connection costs. Alternatives include the connection to multi-terminal interconnectors between countries or direct connection to another country than where the wind park is administered. Besides the technical constraints of this type of grid connection, market and regulatory aspects are important research topics. The paper gives an overview of these trans-national connection schemes for wind power, considers integration into electricity markets and discusses regulatory implications. The scope of the research is Western Europe.

1 Introduction

The demand for a more renewable electricity supply and the transition towards an open, competitive electricity market in Western Europe is gradually causing a paradigm shift in the organization of electrical power systems. Over the past hundred years power systems have been built in which generation and load were in the vicinity of each other and that were more or less balanced: local generation was most of the time adequate for supplying local loads and the exchange with neighbouring systems was small. Gradually these local systems have been interconnected to share responsibility for reserve and emergency power and to allow optimization of resources over a larger area. Power systems could have been organised in this way because generation has mainly consisted of fossil-fuelled or nuclear power stations. These primary energy sources are in a form that makes them excellent to transport to where the demand is high, resulting in a system with generation and loads within reasonable distances of each other. During last decades the disadvantages of fossil-fuel based generation – the contribution to the advanced greenhouse effect, the limitedness of Earth's natural reserves and the unequal distribution of fossil reserves among nations – became prominent and now the general tendency towards generation based on renewable energy sources can be observed. Large-scale renewable energy sources are often situated remotely and *in situ* generation is inevitable: the conversion to electricity should take place directly at the source, where resources are best and the highest energy yields can be accomplished. However, most of the time these wind power locations are far away from the main load centres: on plateaus, in the desert, at sea. This renewable power potential can only be opened up by long-distance electricity transports.

A second development that is going on is the shift towards open, competitive energy markets. Until fifteen years ago the production, transmission and distribution of electric energy was an affair of integrated (semi-)governmental bodies. Nowadays, in most countries in Europe and the USA markets have been deregulated. As a result higher exchanges of electrical energy between states and regions can be observed, demanding for higher transmission capacities among the systems participating in the market. Sharing reserve and emergency power is no longer the primary reason to interconnect power systems; international trade dictates the need for new transmission capacity.

Both of these developments lead to new philosophies for the extension of electrical power systems. The integration of large-scale renewable energy sources calls for long-distance transmission systems to bring the electricity to the load centres. Free, competitive markets demand more interconnection capacity for energy transactions between nations.

In Western Europe the environmental conditions are especially suitable for wind power production. The high population density in some regions, the stringent requirements of wind turbines placed close to the built environment and the availability of better wind conditions offshore, favours a long-term development for wind power at sea. Over the last five years the first offshore wind parks have arisen and the list of new projects is growing rapidly. Realized projects all lie within 25 km distance from the shore, but the future holds projects that are placed more remote. At these distances the costs for the electrical connection of the wind parks with the onshore power system start dominating the projects' budgets. Besides, technological boundaries of submarine cables operating at high-voltage alternating current (HVAC), the mainstream technology used nowadays, are reached at distances of about 100 km. New connection technologies based on high-voltage direct current (HVDC) promise a practically unlimited realizable distance, yet these alternatives are still more expensive for the connection of individual wind parks [1]. Synergies that increase the capacity utilization of the offshore infrastructure could offer interesting cost savings.

Besides the important question of technical feasibility, new offshore transmission-network concepts require full consideration of relevant market and regulatory aspects. This paper serves as an introduction to these complicated issues. The transition towards trans-national transmission structures can be divided into several 'development stages'. Development through these stages is mainly dictated by progress of technology development. In section 3 an overview is presented of the relevant properties of the transmission technologies, the mechanism of power system balancing and how the technical requirements are established in technical codes. Market aspects, such as balancing and energy program responsibilities are dealt with in section 4. Section 5 explores the regulatory aspects that are relevant to the development stages of wind power connection and illustrates the current situation in North Sea coastal states. The paper ends with some general observations about the current status and indicates the major barriers for the progression to trans-national offshore networks.

2 Development stages

In figure 1, different configurations for the grid connection of offshore wind parks are shown. Option I shows the most straightforward connection scheme in which the offshore wind park located in the exclusive economic zone (EEZ) of coastal state A is connected to the electrical power system of this state. The administration of the wind park is an internal affair of coastal state A. It may be the case that due to the geographical conditions and the current state of development of the grid, i.e. the availability of substations and sufficient transmission capacity, the connection distance to the power system in neighbouring coastal state B is significantly shorter. This option, labelled II in figure 1, may offer economic savings. This connection would lie in the EEZs of both states A and B, which means that two separate regulatory arrangements are applicable to the same cable.

The same applies to the configuration option III, which comprises an interconnector between coastal states A and C that includes the grid connection for the offshore wind park. This scheme not only allows the connection of wind power but also power transmission between states A and C, saving the costs of a separate connection for the wind park. The capacity utilization of the offshore electrical infrastructure is increased, leading to lower total transmission costs. Apart from the need for specific regulatory arrangements however, also a number of market aspects are applicable. For example, the transmission of wind power will interfere with power flows due to market transactions between the two countries.

The most sweeping alternative, option IV, is the construction of a trans-national offshore transmission network. Not only does such a grid cater for the interconnection of multiple wind parks in the EEZs of the participating coastal states and does it offer international interconnection capacity, it also enables offshore industries, such as the oil and gas industry, to purchase electricity. These industries are now dependent on their own generation, or have a dedicated connection to one of the onshore grids.

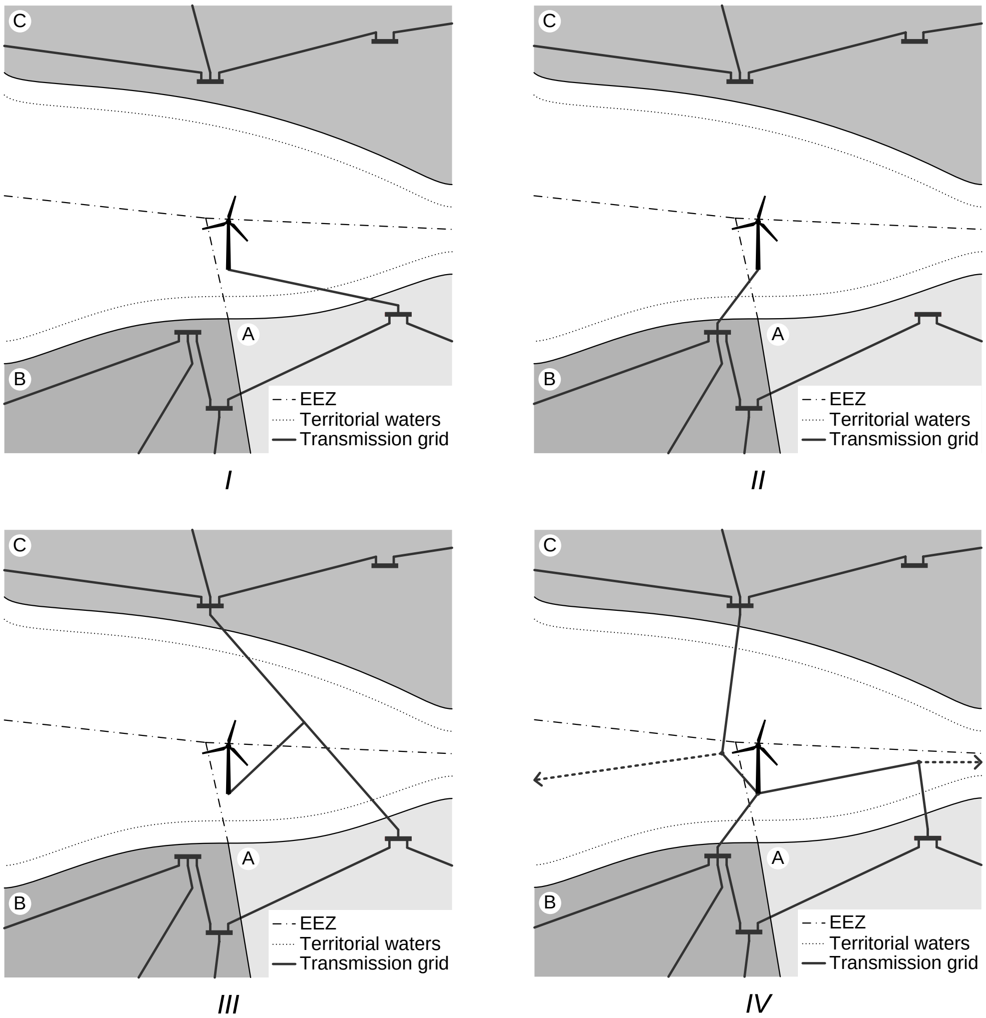

Figure 1 Connection options discussed in this paper: offshore wind park connected (I) to the transmission network of the same state, (II) to the transmission network of another state, (III) to an interconnector between two states, (IV) to a trans-national offshore transmission network.

3 Technical aspects

3.1 HVAC versus HVDC transmission

Over the last hundred years electrical power networks have been developed based on HVAC technology. Power flow in the grid is a function of the operating points of generation and loads; transmission line loadings cannot be controlled directly. Submarine interconnectors have been built, however only for short distances. The cables exhibit themselves as large capacitors that cause high charging currents. As these charging currents increase with the transmission distance, there is a critical length at which no cable capacity is left for transport of active power.

The alternative is the use of HVDC, where the charging phenomenon is absent. Theoretically the transmission distance for HVDC is only bounded by the losses in the cables, which are still acceptable even at distances of several hundreds of kilometres. To convert from HVAC to HVDC and vice versa large and expensive converter stations are required. Power electronic converters are versatile equipment that does not allow temporary overloading. However, power flow is fully controllable. A good overview of the integration of large-scale wind power into power systems is given in reference [2].

Almost all HVDC schemes that have been installed up to now are point-to-point links, where two converter stations are interconnected by a single dc-connection. Very few configurations with three or more terminals have been installed. Very complex control systems are required to ensure robust operation of multi-terminal HVDC schemes. The recent development of the voltage-sourced converter technology for transmission applications could simplify the realization of multi-terminal schemes [3]. Until now only a handful of point-to-point links has been realized based on this technology, but there seem to be no major technical barriers for the inclusion of more converters on the same link. It is expected that the structures III and IV in figure 1 will be based on this technology.

3.2 Power balancing and reserves for wind power

In power systems, a balance between the total generation, total load and transmission losses must be maintained at all times. As long as enough primary reserves are available the balance is kept automatically. To ensure enough reserves at each moment and to balance out unintentional exchanges between zones, transmission system operators (TSO) work together as being responsible for its respective control area. In order to maintain the power balance during system operation (in real-time) for its area, the TSO uses reserved capacity (power reserves) for continuous adjustments and preservation of the system balance. Primary reserves are shared between different interconnected control zones and held for frequency stabilization during the first seconds to minutes following an outage. Secondary reserves (available within 15 minutes) are held for each control area separately by the TSO responsible for the area.

Wind power introduces additional power variations into the system and is predictable only to a certain extent. The additional power reserves required for the system integration of wind power may be provided by the TSO or by the market parties themselves, dependent on the market design applicable to wind power, as further explained in section 4.2. In case (large-scale) offshore wind power is connected to trans-national grids, coordination of power reserves between different connected systems becomes an issue. Since power flows are fully controllable when using HVDC, coordinated efforts for power reserves must be made on beforehand by the TSOs responsible for the systems connected to this grid. Also, in real-time, the operation of the offshore grid itself must be done in a coordinated fashion.

3.3 Grid codes

Grid codes are appendices to electricity regulation that specify technical requirements for the connected generation units during different states of operation of the power system. Some countries included special requirements in these codes for wind power installations [4]. However, the current tendency is to consider wind parks as ordinary generation stations and subject them to the same technical regulations.

For wind turbines the most demanding parts of grid codes are the required reactive power range, both in normal operation and during system faults, the ride-through of periods of low system voltage, and participation in frequency control. These requirements have stimulated technical developments and now most modern wind turbines are compliant even the most demanding grid codes. The cost however is more expensive turbines, e.g. larger power electronics or more complex control systems.

Grid codes are formulated to ensure a quality standard of the grid connection in a technical sense. Onshore generation and consumption are connected to the same grid. For offshore wind farms connected through HVDC-transmission systems, the transmission link forms a technical barrier for most of these quality aspects. It can be argued that less demanding grid codes could be formulated for these isolated parts of the grid in which only generation is present, to enable the installation of simpler equipment.

4 Market aspects

4.1 Energy trade

Electric energy trade is organized in such a way as to allow electricity to be treated as much as possible like any other commodity [5]. In liberalized markets, participants are free to make arrangements for trading power on a bilateral basis and to choose from a number of market platforms, including forward and futures markets (long-term contracts up to years ahead), day-ahead spot markets (fine tuning of market position) and intra-day adjustment markets (adjustments up to one hour ahead of operation). Furthermore, the possibility may exist to bid for reserves to the TSO in an imbalance market. After market closure, the intended energy exchanges become fixed in so-called energy programs: scheduled exchanges which are submitted to the TSO. The responsibility for maintaining the power balance in real-time then lies with the TSO. During operation, the TSO monitors the actual energy exchanges with neighbouring systems and applies power reserves in order to balance unplanned exchanges of market parties, resulting in energy program deviations. The imbalance settlement process makes sure that the costs of the TSO for power balancing are fully targeted back to the market parties causing the imbalance, thereby providing economic incentives for their energy programs execution as scheduled.

4.2 Market design for wind power

Due to its inherent variability and partial unpredictability, wind power complicates the task of power balancing in real-time. Market designs may except wind power from program responsibility (priority dispatch, Germany), which is the most common arrangement, or wind power may be subject to program responsibility just like other generation technologies (Netherlands, UK). With priority dispatch for wind power, market parties are not penalized for energy program deviations as a result of wind power variations and prediction errors: it is the TSO who forecasts wind power and makes arrangements for power reserves. In case wind power is subject to program responsibility, the market parties are responsible for keeping their scheduled energy programs, including wind power. Each market party will therefore forecast the wind power associated with it and balance unscheduled output in order to minimize energy program deviations [6].

Since market designs for wind power vary between countries, a number of aspects must be considered when considering trans-national offshore grids for wind power connection. These include the integration of wind power into power markets (availability of spot market/adjustment market, market closure time, selling location) and arrangements for balancing wind power (TSO or market party, wind power forecasts, coordination of reserves, physical balancing of wind power variations, imbalance settlement processes). As with the continued efforts of market coupling in Western-Europe, which may reduce the hurdles for the interconnection of offshore wind power, it seems likely that coordination and harmonization of market designs and arrangements will be needed in order to create market conditions necessary for the implementation of offshore grids for wind power connection.

5 Regulatory aspects

5.1 Offshore jurisdiction

According to international law coastal states have sovereignty on their territory, including the territorial sea. Most coastal states have extended their territorial sea to 12 nautical miles from the coastline. Outside this 12-nautical-miles zone coastal states have a limited or functional jurisdiction. On the basis of the UN Law of the Sea Convention 1982 (UNCLOS) all coastal states have a continental shelf and possibly also an exclusive economic zone (EEZ). By contrast to a continental shelf, which applies automatically, the EEZ has to be established explicitly. According to UNCLOS coastal States have territorial jurisdiction on land and in the territorial sea and functional jurisdiction on the EEZ 7. Whereas the functional jurisdiction on the continental shelf is limited to the exploration and exploitation of natural resources,[1] coastal states have more powers in an EEZ, viz.:

> *"(i) sovereign rights for the purpose […] of the production of energy from the water, currents and winds, and (ii) jurisdiction […] with regard to the establishment and use of artificial islands, installations and structures"*[2]

[1] Article 2 Conventional of the Continental Shelf 1958 and article 77 UNCLOS provide that "the coastal state exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources".

[2] Article 56 UNCLOS

For the purpose of these activities, coastal states also have the exclusive right to construct installations and structures for the purpose of i.a. the production of wind energy. The coastal state shall have exclusive jurisdiction over such installations and structures and may thus issue laws and regulations, including customs, fiscal, health, safety and immigration.[3]

All North Sea states are party to and have ratified UNCLOS[4] and have established an EEZ or similar (i.e. Renewable Energy Zone or REZ in the UK). These coastal states have therefore the exclusive right to produce wind energy within the territorial sea and the EEZ. Whereas all territorial laws apply in the territorial sea, an express decision needs to be made as to the laws applying to the EEZ. Hence, coastal states may decide to extend (parts of) national laws to the EEZ or issue new legislation to regulate specific activities on the EEZ. Whichever option is chosen, the regulatory regime has to take into account the principles of the law of the sea: freedom of navigation, fishing, overflight and the laying of submarine pipelines and cables.[5]

As to the construction and exploitation of electricity cables, two sets of principles apply. First is the exclusive right to lay – and thus regulate – the cables necessary for the development of wind energy in the EEZ of the coastal state. Second is the freedom to lay cables. Hence, a coastal state cannot impede the general freedom of laying cables, i.e. oppose to the laying of (transit) cables on its EEZ.

When examining the legal regimes of the North Sea states, one can notice two different approaches. One is the coastal state considering the production of offshore wind energy as an activity involving the construction of an establishment which may hamper the freedom of the high seas. Thus, regulation is required to limit the negative consequences for the other users of the high seas as well as the environment. Two is possibility that a coastal state considers the establishment of wind parks as an activity generating (green) electricity. Therefore, wind energy falls within the framework of the Electricity Act. Consequently, the application of the Electricity Act is extended (entirely or partly) to the EEZ. An overview of the choices made by EU member states can be found in [8].

From the above, it follows that a coastal state has the right to regulate in the EEZ the construction and the exploitation of wind turbine installations and the electricity cables connected to it. In doing so the coastal state has several options. It may consider the wind turbines and the cables as one installation or as two different installations, i.e. the wind turbines as one installation or a combination of several installations and the cable bringing the electricity to shore as a separate structure or installation. Moreover, the construction and exploitation of the turbines and cables can be governed on the basis of (parts of) the electricity legislation or some sort of building act that has been extended offshore or specifically designed for the offshore. The extent to which coastal states have jurisdiction with regard to electricity cables in the EEZ and the territorial waters is investigated in more detail below, using the offshore grid design options introduced in section 2 as a guideline.

5.2 Legal regime governing electricity cables in the EEZ

Regarding the different states around the North Sea, it can first be noted that different solutions have been chosen by the individual legislators. Germany and the Netherlands have chosen not to extend the Electricity Act to the EEZ (with some minor exemptions). Also, the construction of offshore wind turbines and cables has in principle been made dependent on a building or construction permit. Other North Sea states, such as Denmark, UK, France and Belgium, have opted to extend their Electricity Act to the EEZ so that the construction and exploitation of wind turbines and cables to transport electricity to shore is subject to the general (or specific) principles of the Electricity Act. Returning to the connection options depicted in figure 1, the current jurisdiction has different implications.

5.2.1 Option I: Current standard situation

Option I involves the construction of a wind park in the EEZ and a cable transporting electricity via the territorial sea to shore. In those countries where the Electricity Act has been extended to

[3] Article 60 UNCLOS
[4] Whereas the EU ratified UNCLOS in 1998, the following coastal States around the North Sea have ratified the treaty separately: Germany (1994), France (1996), Sweden (1996), the Netherlands (1996), United Kingdom (1997), Belgium (1998) and Denmark (2004).
[5] Article 87 UNCLOS

the EEZ the same legal regime may apply to the construction and exploitation of the entire cable. In countries like the Netherlands and Germany where the Electricity Act has not been extended to the EEZ, two different regimes may apply. One regime applies to the EEZ and one regime to the territorial sea and the part onshore. The latter situation may be complicated by the fact that in practice the application of the Electricity Act may be hampered, as is the case in the Netherlands. There the operation of the grids is based on a territorial demarcation which is linked to territorial scope of municipalities and which not has been extended to the entire territorial sea.

5.2.2 Option II: Connection to a neighbouring power system

Option II involves the construction of a wind park in the EEZ of country A and the connection of the wind park to the power system of country B. In this case the construction and exploitation of the wind park is subject to the laws and regulations which have been made applicable to the EEZ of country A. The same applies to the part of the cable on the EEZ of country A. The cable part situated on the EEZ of country B is not connected to any installation in the EEZ of country B and is therefore not subject to the functional jurisdiction of country B in the EEZ. It may be considered as a *transit cable* as this cable part merely crosses the EEZ of country B. Consequently, it falls within the regime of the high seas, i.e. the freedom of laying cables. In this case, country B cannot object to the laying of this cable and has a very limited jurisdiction with regard to this part of the cable. This means that any regulation regarding the construction and exploitation of this part of the cable (i.e. the transit part) is limited to legislation concerning environmental and safety protection. The cable part situated in the territorial waters of country B would in principle be regulated by the national Electricity Act, which may have an impact on the regulation applicable to the cable part situated in the EEZ of country B.

5.2.3 Option III: Connection to an interconnector

Option III involves an interconnector between countries A en C and the connection of an offshore wind park to this connector. Basically an interconnector is a cable connecting two onshore grids: there is no direct relationship with the production of electricity. The cable parts of the interconnector on the EEZ of countries A and C can both be considered as transit cables, since they cross the EEZs of these countries. Hence the principle of the high seas, the freedom of laying offshore cables, applies. Countries A and C can make the construction (and operations) of the cable on the EEZ subject to provisions governing the protection of safety and environment. In principle, they cannot object to the construction of the cable. A different regime may apply to the parts of the interconnector in both territorial seas: here all national laws apply. In case of the construction of an interconnector it may also be of importance whether the coastal states have decided to extend their electricity legislation to the EEZ. If so, it is likely that the Electricity Act will include provisions with regard to the construction and operation of interconnectors similar to the provisions in the EU Electricity Directive (Directive 2003/54/EC) and Regulation 1228/2003.

The connection of a wind park to an existing interconnector is another case. First, it should be noted that EU legislation does not require the appointment of an interconnector system operator. In other words, if parties (countries A and C) do not agree otherwise, the interconnector will be subject to the regimes of both country A and country C applicable to their respective EEZ/territorial waters. Consequently, possibilities to connect the offshore wind park to the existing interconnector will depend on the content of the individual national regimes. The construction and operation of the wind park is subject to the laws and regulations of the country whose EEZ it concerns. As to the construction of the cable connecting the wind park with the interconnector again different situations may apply. Some countries may consider this cable as part of the production facilities and others may again consider it as a separate cable requiring separate permits. When the wind park is situated on the EEZ of A and is connected to the interconnector part in the EEZ of C, as shown in figure 1, option III, part of the cable is a transit cable which cannot be objected to. In case this cable part would have been connected to the interconnector part in the EEZ of A, then this cable part could be regarded entirely as a part of the wind park facilities or as a separate cable. In either case, however, the operator of the interconnector must agree with the connection. Depending on the applicable laws and regulations, this operator may or may not be required to do so. In case the Electricity Act applies the normal access and connection rules have to be followed. If not, each wind park developer has to negotiate interconnector access and possibly submit a complaint with the national competition authorities in case access is denied.

5.2.4 Option IV: Offshore wind park connected to major trans-national offshore transmission grid

Option IV could in principle be regarded as a variation on option III, concerning a cable connecting country A and C but crossing the EEZ of B (or in the same sense connecting country B and C crossing the EEZ of country A). In this case, the same aspects would apply as described above for option III. The cable parts crossing the EEZ of A, B and C would then be considered as some sort of transit cables and would then only subject to laws and regulations governing safety and environmental protection. The cable parts located in the territorial waters of A, B and C and onshore would be subject to the national laws of A, B and C. However, option IV could also be regarded as a variation on option I, to which two additional cables are connected. The parts of these two cables located in the EEZ of countries B and C would then again be regarded as transit cables and therefore be subject to limited environmental and safety jurisdiction of these countries; the parts crossing the territorial waters of countries B and C are then subject to full jurisdiction of these countries.

5.3 Licensing issues

Following their limited jurisdiction in the EEZ, coastal states have the right to decide which laws and regulations they wish to apply to their EEZ. In practice the choices made differ between countries and coastal states not always have opted for extending their Electricity Act to the EEZ. As most grid codes usually are part of the Electricity Act, these codes do not apply to the EEZ if the Electricity Act is not extended to the EEZ. However, as these codes usually are applicable to the territorial sea it seems most likely that in practice they will de facto apply to the EEZ as well. Moreover, each coastal state has the right to change the content of their Electricity Act as long as this law takes into account the general principles of EU law (EU treaty, Electricity Directive and Electricity Regulation).

Consequently, coastal states can decide whether a tendering, a ‘first come, first served’ or other principle applies to the establishment of offshore wind parks. Furthermore, states decide whether connection cables are to be considered as part of the production installation, as a separate structure or whether the cable should be treated as a specific line dedicated to a certain installation or not. Finally, it is up to the coastal state to decide whether or not the authority of the national TSO is extended to the territorial sea and/or EEZ. In case the TSO is indeed awarded the sole responsibility to construct offshore cables, cables constructed by wind park developers can be considered only as part of the installation or as a direct line, and no longer as a separate structure.

Clearly, any developer interested in constructing trans-national cables for electricity transmission will be confronted with a diverse choice of national legal options which have to be taken into account. As the regimes of coastal states differ, possibilities to realise such cables will depend on the possibility to obtain probably a wide range and number of licenses and permits. It may even be so that the actual route of a trans-national cable(s) will be dependent on the legal regime of the coastal states involved.

5.4 Financial instruments

5.4.1 Policy trends

Wind power is commonly regarded as an important renewable energy technology. The EU recognises that the realisation of the renewable targets requires financial support schemes, which are organised on the national level. Any application of public support in favour of renewable energy sources must however be in line with the state aid provisions of the EU Treaty. In general, wind energy support schemes will be recognised in the Community guidelines for state aid for environmental protection. The EU Directive 2001/77/EC (renewables directive) provides that member states may operate different support mechanisms for renewable energy sources, including green certificates, investment aid, tax exemptions/reductions, tax refunds and direct price support schemes. It appears that member states either apply a fixed-feed-in tariff or a market-based system involving trade in green certificates. The first option has so far been used most commonly and has been successful in providing regulatory certainty for developing wind power. Other instruments can be used as well, such as requiring the TSO to extend its grid to the offshore in specific designated areas and to pay for the connection costs (Denmark, Germany), providing wind power with subsidies based on an 'unprofitable top' (Netherlands) or priority grid access for renewable energy sources (Germany).

5.4.2 Support schemes and trans-national grids

So far the application of fixed-feed-in tariffs has been a successful instrument to promote the production of renewable energy sources. However, such a system can be a show-stopper for the development of trans-national grids for offshore wind power, since it requires renewable energy to be produced and fed into the grid of one and the same member state. This may also apply to other subsidy schemes, such as fixed EUR/kWh subsidies based on the unprofitable top. Clearly a market-based system involving more harmonized support mechanisms between states would open up the possibility for a wider group of market parties to participate in the development of trans-national grids for the connection of offshore wind power. Simultaneously, it would promote additional cross-border trade for wind power.

Although the EU commission supports the development of offshore wind power, as expressed in the Egmond Declaration of 2004 and the Berlin Declaration of 2007, up until now this has not resulted in major initiatives. Recently, it has included the development of offshore wind energy in its policy on Trans-European Energy Networks, but in practice recognition of a project as being part of a scheme of Trans-European Networks has only resulted in some degree of funding and not in any harmonization of laws. Although the EU Commission is considering publishing a recommendation on offshore wind energy at the end of 2008, it is too ambitious to expect that concrete legal instruments will be presented. Coastal states therefore have to turn to other legal instruments if they wish to establish and operate trans-national electricity grids.

5.5 Realization

From the above it can be concluded that following the principles of UNCLOS and lacking of harmonising measures on EU level, the construction and operation of trans-national cables will depend on the support given by the coastal states involved. Recent offshore interconnector projects all involve a cooperation of two national TSOs operating on each side of the border, i.e. in the EEZ and territorial sea of the respective coastal states. These cross-border cables are constructed as interconnectors without the express idea that wind parks can be connected to it in a later stage.

In order to develop offshore electricity cables and facilitating the connection of offshore wind parks to such cables, possibly a lesson can be learned from the oil and gas industry. All offshore cross-border oil/gas pipelines are established and operated on the basis of a bilateral agreement between the coastal states involved. In such bilateral agreements the authorities involved agree on the general principles which should apply to the pipeline. In the case of submarine cross-border electricity cables, coastal states can begin to agree on beforehand 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 can be promoted by the North Sea Minister Conference or the national regulators promoting the development of regional electricity markets [9].

A specific problem concerns the difference in national incentive regimes. The application of feed-in tariffs or other national arrangements for wind power support does not promote the realisation of synergy infrastructure (mainly grid configurations III and IV presented in this paper). Although a harmonization on EU level would be preferable, coastal states may include in a bilateral or multilateral agreement that in the national feed-in regimes an exception is included for electricity produced offshore and fed-in to an offshore interconnector.

6 Conclusions

For the minimization of connection costs for offshore wind power, new connection schemes are sought for. HVDC technology may be used to realise multi-terminal interconnectors between countries. Besides existing technical challenges of this type of grid connection, market and regulatory aspects are important topics. This paper has explored different connection schemes for wind power for coastal states in Western Europe and has considered the integration into electricity markets and regulatory regimes.

The operation of trans-national offshore grids for offshore wind power requires coordination between all involved TSOs in order to cater for wind power reserves and reliability. Also, the simultaneous integration of wind power into different electricity markets requires considerable efforts. Aspects to consider include the availability of market types, market closure times and arrangements for balancing wind power by the TSO or market parties. Furthermore, integration of wind power may interfere with power transmission associated with market trading, which is especially relevant in case wind power is prioritized. Coordination and likely harmonization of market designs are a first enabler for trans-national offshore grids for wind power interconnection.

Harmonization is also important when considering the regulatory aspects. At the moment, the construction and operation of trans-national cables depends solely on the support of individual (coastal) states and the cooperation of TSOs on both sides. Bilateral agreements between states should be regarded as an essential first step and should cover arrangements regarding cooperation, grid operation, safety provisions, market operation, and more. In particular, differences in national incentive regimes for (offshore) wind power must be addressed. Present country-based feed-in tariffs or subsidies do not promote the realisation of synergy infrastructures.

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