

Transmission and System Integration of Wind Power in the Netherlands

W. L. Kling, *Member, IEEE*, B. C. Ummels, *Member, IEEE* and R. L. Hendriks, *Member, IEEE*

Abstract—In this paper, an overview of wind power transmission and system integration aspects is presented for the Netherlands. Particular aspects regarding the Netherlands, such as the market organisation with respect to wind power, the technical characteristics of conventional generation units and grid connection of offshore wind power, are discussed in detail. Power system integration of wind power typically comprises local impacts (distribution level), grid connection aspects (periphery of the network), system wide impacts (power balancing), grid codes and market designs, all of which are addressed in this paper.

Index Terms—wind power, grid integration, power systems, system operation, the Netherlands

I. INTRODUCTION

AS a renewable energy source, wind power has a number of specific characteristics that challenge its large-scale integration into power systems. Due to the availability of wind, wind turbines are often located at the periphery of the system and/or distant from load centers. As a result, specific system upgrades may be needed as well as grid connection requirements. The partial unpredictability and variability of wind furthermore complicate power system operation, as additional power fluctuations are introduced into the system. These characteristics of wind power also have impacts on the operation of electricity markets, since additional trading uncertainty is introduced. Possibly, adjustment of existing market designs may be required for the integration of large-scale wind power. Last but not least, the variability and limited predictability of wind power results in different power flow patterns, both during planning and operation. With the strong development of wind power in the past decade, grid connection, network security, market design and power balancing aspects of wind power have become important research topics.

In the Netherlands, about 1.6 GW of wind power is presently installed, mainly located onshore. Notably, the first offshore wind farm has been commissioned end 2006 and a second one is presently under construction. Often, the question is raised whether a reliable electricity supply is possible in the presence of a large amount of installed wind power. In the last couple of years, a number of network and system integration studies have been carried out, covering most of the relevant aspects. Some peculiarities of the Dutch case make the integration of large amounts of wind power particularly challenging, such as the high amount of combined

heat and power generation (CHP), high difference between day and night load, no storage facilities and the structure of the transmission network in combination with the narrow but vital coastline. Furthermore, the Netherlands is one of the very few countries where market forces are driving the everyday operation of wind power, because the Dutch market design treats wind power in the same way as other generation technologies.

The aim of this paper is to present an overview of system integration of wind power in the Netherlands. First, a brief history of the Netherlands as a wind energy nation is given. Then an overview of the electrical power system of the country is presented as well as the market design. In the next section the possible problems with grid integration of wind power are indicated. Local impacts, grid connection of offshore wind power, system wide impacts, grid codes and market design are all covered and illustrated using the Dutch case.

II. WIND POWER IN THE NETHERLANDS

The Netherlands is typically associated with windmills. The perception that windmills are typically Dutch can be traced back to the 17th century, in which the country flourished both economically and culturally. It was however not until the 1970s before wind energy became a part of the Dutch renewable energy policy. By that time, it became clear that fossil fuel reserves were finite and that depletion of resources should be prevented. Together with the oil crises of 1973 and 1979, energy policy became part of political debate and new energy policy goals were published by the Dutch Ministry of Economic Affairs. The development of new technologies was encouraged by funding new initiatives and coordinating further research. New technologies such as combined heat and power, wind power, and energy from waste were expected to contribute to the national energy supply from 1985 onwards.

Originally, the target for onshore wind power was 1000 MW installed by 2000. This capacity was reached in 2004, as can be seen in Fig. 1. Current installed capacity equals 1437 MW onshore and 127 MW offshore with capacity factors of 25% and 42%, respectively [1]. After the ratification of the Kyoto protocol and embracing the European Union targets for electricity production from renewable sources, national targets now include 1500 MW onshore and 700 MW offshore for 2010. Originally a target was also formulated of 6000 MW offshore for 2020. The past few years however were characterized by changes in governmental policy and accompanying subsidy schemes and this target was postponed. Nevertheless it caused an upsurge of activities and discussion, especially regarding

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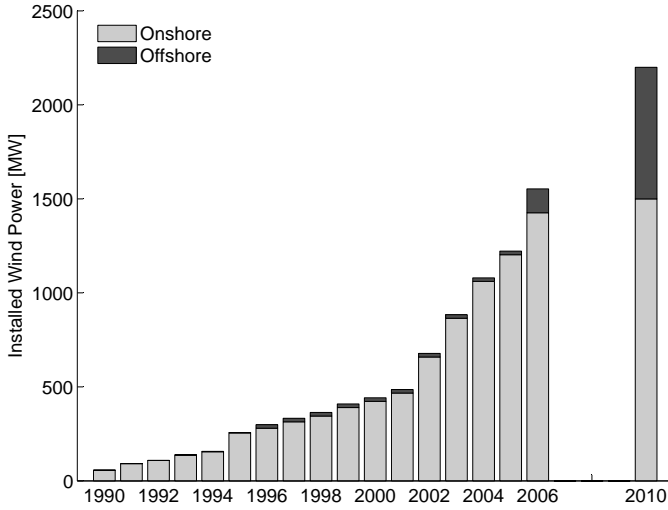


Fig. 1. Installed wind power in the Netherlands, both onshore and offshore. The bar for 2010 represents the target set by the Dutch government.

the issue of integration of large amounts of wind power in the Dutch electrical power system. At the moment, the first offshore project has been commissioned (108 MW, Egmond aan Zee Offshore Wind Park) [2] and a 120 MW one scheduled for medio 2007 [3].

III. THE DUTCH ELECTRICAL POWER SYSTEM

In this section, the specifics of the Dutch power system will be discussed. An overview of the Dutch transmission system will be given and the overall generation park will be briefly introduced. Then, some typical aspects of Dutch power system operation will be discussed.

A. Transmission System Overview

The Dutch transmission system consists of networks at 380, 220, 150 and 110 kV, the former two serving a transmission function while the latter two can be considered having more of a sub-transmission function. The main structure is a ring at the 380 kV voltage level with several radial branches, see Fig. 2. In the Northern part of the country a similar ring structure exists at 220 kV level. In the *Randstad*, the densely-populated area in the western part of the country, a second and third 380 kV ring structure are foreseen to keep up with demands while maintaining the desired level for security of supply [4]. The 380 and 220 kV grids are operated by the transmission system operator (TSO) *TenneT*, the shares of which are all held by the State of the Netherlands. The regional sub-transmission and distribution grids are operated by regional, distribution system operators (DSO).

The transmission grid is connected to the neighboring countries, Germany and Belgium, through five interconnectors at 380 kV. To have more control over cross-border flows, phase-shifting transformers have been installed recently at the Dutch-German border in Meeden. A high-voltage direct current (HVDC) interconnector with a rating of 700 MW (*NorNed*) is to be commissioned late 2007 that will connect the Dutch power system to Norway. This will make the advantageous

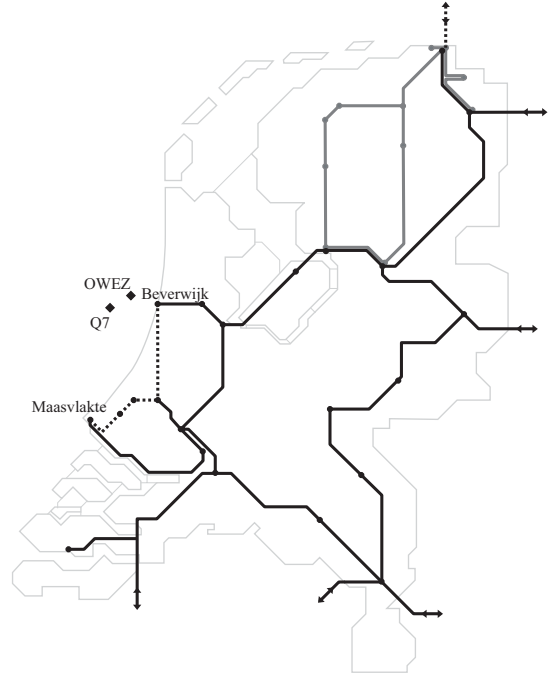


Fig. 2. Overview of the Dutch high-voltage network, showing grids at 380 kV (black) and 220 kV level (dark gray). The planned upgrades in the west of the country, as well as the interconnector to Norway (NorNed, to be commissioned end 2007) are shown in dashed lines. The locations of Egmond aan Zee Offshore Wind Farm (OWEZ, commissioned end 2006) and Windpark Q7 (to be commissioned medio 2007) are indicated. The substations of Beverwijk and Maasvlakte are the most likely locations for the grid connection of offshore wind farms planned at the North Sea west of the country.

differences in generation technology mix available to the market. Another HVDC link to England is in the study phase.

B. Generation System Overview

In table I, an overview of the installed generation in the Dutch power system is shown, with installed wind power included as distributed generation. A total of 21.1 GW is installed, part of which is not available for operation due to scheduled maintenance, outages or mothballed capacity.

Notably, a large number of the Dutch generation units are CHP. Because operation of these units is heat-demand driven, power comes as a by-product of the production of heat or steam. The operational flexibility is therefore constrained to the power levels associated with specific demands for heat or steam for the area served. CHP units often have a must-run status (continuous demand while little storage for heat or steam), resulting in a significant amount of base-load power in the Netherlands during night-time. The generation connected at the distribution level of which the power output is generally not controlled (passive generation), also contributes to this high base-load. It can further be noted that in the Netherlands no significant hydro power is installed and therefore no possibilities for energy storage are present: power balancing is largely done using the larger, thermal generation units (coal, gas).

Even though installed capacity well exceeds annual peak load, which amounted on the transmission level to 15.2 GW in 2005 [5], the Netherlands import a substantial part of their

TABLE I
INSTALLED GENERATION CAPACITY IN THE NETHERLANDS

Generation Type	GW	%
Gas-Fired	10.3	49
Coal-Fired	4.1	19
Cokes Gas	1.0	5
Nuclear	0.4	2
Distributed Generation ^a	5.3	25
Total Installed	21.1	100

^aDistributed generation is defined the sum of all production units that are not included in the TSO's supervisory system, mostly units rated < 60 MVA.

energy from other countries, mainly France and Germany. Notably, annual consumption in the Netherlands was approximately 115 TWh, of which 18.3 TWh or 16% was imported. Of annual consumption, 7.1 TWh (6%) was produced by renewable energy sources, of which wind power produced 2.1 TWh, or 1.8% of annual consumption in 2005 [6].

C. Market Organization

With the liberalization of European energy markets, generation and supply have become decoupled from grid operation. Simultaneously, market parties have become free to make arrangements for trading electrical energy. Trading is done on different time-scales with different purposes: up to the day ahead large blocks for longer time periods (long-term supply contracts, reserve contracts), one day ahead on the spot market (matching of anticipated load for the following day) and intra-day (further optimization of operation taking into account unscheduled outages and updated load and wind power forecasts). In order to facilitate power system balancing in the liberalized market and to organize trading in an orderly fashion, the Dutch system of program responsibility has been set up. Program responsible parties (PRPs) have been assigned to maintain their energy balance (MWh/15 min.): generation is delivered to the power system only if there is a load to match it. At gate closure time, all trading for the physical delivery of electrical energy ends: the energy programs (e-programs) submitted by market participants become fixed. Real-time power imbalances are taken care of by the TSO, which uses regulating and reserve power made available by the market parties through a bidding process. Market parties pay the highest bid price (EUR/MWh for each 15 minute time interval separately) used for balancing e-program deviations to the TSO; the TSO pays the highest bid price for every bid used.

In the Netherlands, wind power receives a fixed subsidy for a maximum period of ten years, instead of a fixed feed-in tariff as applicable in many European countries [7]. The revenues from wind power therefore partly depend on market prices. Another notable difference to other countries is that wind power in the Netherlands is subject to program responsibility and treated just like conventional generation. The Dutch market design returns the responsibility for balancing the variability and limited predictability of wind power to the market [8]. Because deviations from the submitted e-programs

are priced through an imbalance pricing mechanism, PRPs are financially encouraged to limit their divergences, including those resulting from wind power.

As a result of the Dutch market design, wind power is not monitored by the TSO: no aggregated wind power output statistics are available for the Netherlands. The TSO only observes the area control error (ACE) of the Dutch control zone and applies regulating and reserve power to correct this. Furthermore, the Dutch market design implies that wind power balancing costs are not socialized through system tariffs imposed by the TSO, but instead are part of the overall operating costs incurred by Dutch market parties.

IV. SYSTEM INTEGRATION ASPECTS OF WIND POWER

The impacts of wind power on the power system can roughly be divided into local impacts and system-wide aspects. The local impacts of distributed wind power are mainly dependent on the turbine type and the local network characteristics, while system-wide impacts are a result of the nature of wind as the prime-mover [9]. Furthermore, concentrating wind power installations at remote sites, in particular offshore, challenges the planning and operation of the transmission grid. In a number of countries, grid codes have been formulated to restrain the possible impacts of wind power on the system. Last, the market design also has consequences for the integration of wind power. All of these aspects will be elaborated on below.

A. Local Impacts

Local impacts of wind turbines connected to the distribution system mainly depend on local grid conditions and connected wind turbine type, and the effects become less noticeable when the (electrical) distance from the origin increases. The observed phenomena include changed branch flows, altered voltage levels, increased fault currents, and the risk of electrical islanding, which all complicate system protection, and power quality problems, such as voltage levels, harmonics and flicker.

In the early days of wind power in the Netherlands (1970–1990) mainly small projects of one or several wind turbines have been constructed, connected to the local distribution grid, usually at 10 kV. The turbines in those days chiefly comprised fixed-speed designs with synchronous generators or squirrel-cage induction generators, with a rigid grid connection. In the case of asynchronous generators, capacitor banks have often been applied to achieve a power factor close to unity.

Nowadays wind turbines are equipped with versatile power electronics that, if controlled correctly, can mitigate most power quality problems [10]. This is a result of both increasingly strict grid connection requirements for wind power worldwide and continuing research and development efforts by wind turbine manufacturers, research institutes and academia.

B. Grid Connection of Large-Scale Wind Power

Although from a technology point of view offshore wind power is not fundamentally different from onshore, the foreseen large amounts of concentrated wind power introduce

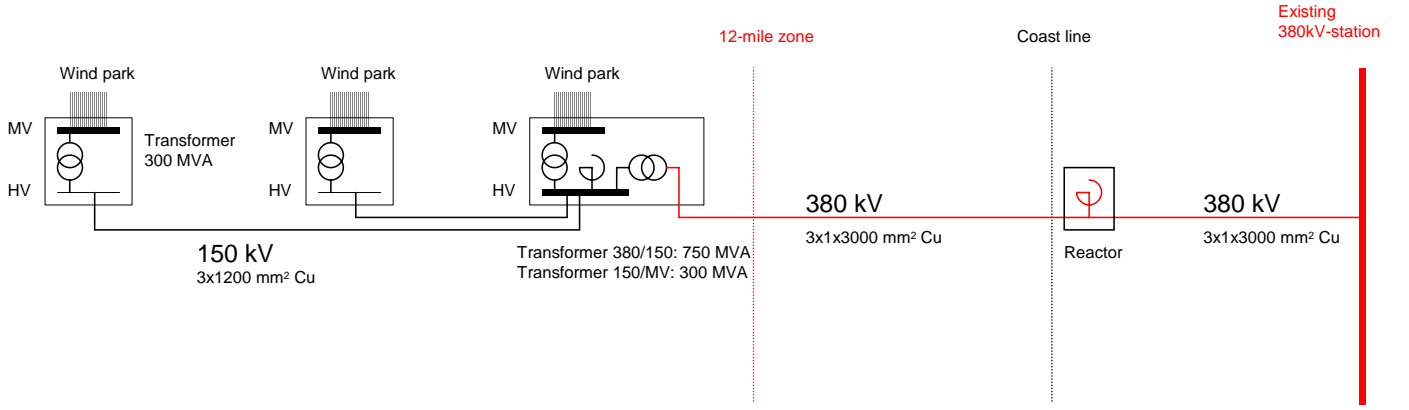


Fig. 4. Combined wind farm connections.

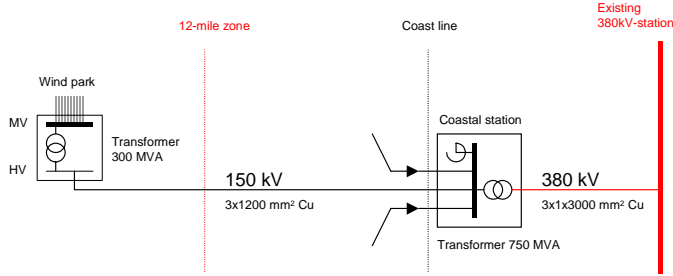


Fig. 3. Individual wind farm connections

new challenges in the area of planning and operation of the high voltage grid. The aforementioned amount of 6000 MW offshore wind power production capacity would require the construction of an offshore grid infrastructure to accommodate about 25% of the total generation capacity installed in the Netherlands, which would feed into the existing grid at a small number of points.

In the Netherlands, all offshore wind farms have been foreseen in the North Sea, west of the country. Only the 380 kV substations of Beverwijk and Maasvlakte are located close enough to the coastline at a reasonable distance from the wind farm locations; the lower voltage levels do not offer enough capacity. Moreover, the sand dunes play an important role in the collection of drinking-water and therefore it was argued that the impact of construction works had to be kept to a bare minimum. A key issue regarding the offshore grid is whether the grid connection for offshore wind farms should be coordinated or left to the responsibility of the market parties.

A number of studies were initiated by the Dutch Ministry of Economic Affairs [11],[12]. For the grid connection alternatives investigated it was concluded that individual connections at a voltage level of about 150 kV are the most cost-effective (Fig. 3), but it might be attractive to combine some wind farms on one 380 kV cable to the shore (Fig. 4). Interestingly, these options also offer the most flexibility with regard to a phased development of offshore wind power and corresponding investments, as is highly desired by the government. Furthermore it was found that from an economic efficiency point of view, line redundancy for improved availability (commonly applied

for transmission grids in the Netherlands) is not viable. Ring-shaped network structures would be very costly, but could become more attractive if the offshore network could help mitigating problems in the mainland network. In that case an HVDC or hybrid (DC+AC) ring is expected to be a better option than an AC ring with FACTS equipment [13].

The infeed of 6 GW of offshore wind energy on only two substations will have noticeable effects on the power flows in the transmission grid. The already planned grid reinforcements in the Randstad region will accommodate most of foreseen power transmission. Besides that, increased transmission capacity will be required on West to East lines [4].

The future integration of large amounts of offshore wind power into power systems may also be considered in combination for the increasing need for international interconnection capacity. Possibly, submarine interconnector cables provide synergies for accommodating international power exchange and connecting offshore wind farms along the cable route. Due to physical limitations for the cable, direct current (DC) transmission technology is preferable. Research at Delft University of Technology is currently investigating the behavior and control of a DC-grid offshore with three or more AC-to-DC converter stations (Figure 5, [14]). Such a transmission scheme could be regarded as a first step towards an international approach to the grid integration of offshore wind farms.

C. System-Wide Impacts

System-wide impacts are largely a result of the variability and limited predictability of the wind and mainly depend on

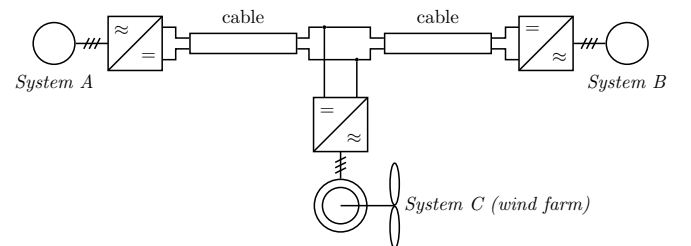


Fig. 5. Multi-terminal HVDC transmission scheme including an offshore wind farm connected to DC-bus in the middle.

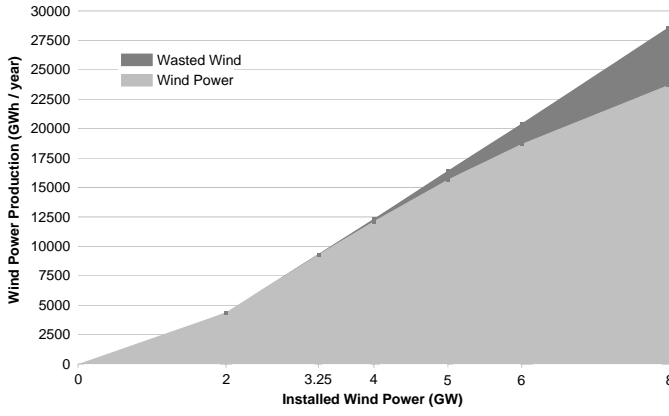


Fig. 6. Simulated wind power production and wasted wind in the Netherlands, assuming fixed import levels.

the wind power penetration level, geographical dispersion of wind power and the size of the system. Most importantly, wind power has impacts on power system dynamics, secondary (load-frequency) control and on the operation of other units in the system (unit commitment and dispatch).

Recently, the technical possibilities of generation units in the Dutch system for the integration of large-scale wind power were studied [15]. The study uses load data, technical data of generation units and wind data as an input for the simulation of the commitment and dispatch of Dutch thermal units for different wind power penetration levels. Based on the simulation results it can be concluded that about 4000 MW of wind power (half of which offshore) can be integrated (Fig. 6). From 2000 MW, some additional integration measures are needed at times of low load and high wind (minimum load problems), ultimately shedding available wind energy. Ramping problems as a result of large variations in wind power and load on a 15-minute basis seem to be absent, indicating that sufficient regulating and reserve power are present within the Dutch system.

D. Grid Codes

With increasing wind power penetration levels, several countries adapted their grid connection requirements to the specific characteristics of wind turbines. Examples of codes with specific regulations for wind power are the Danish grid code [16] and the German E.ON Netz grid code [17]. Important issues include the desired behavior in case of a voltage dip (the so-called *fault ride-through* behavior), the contribution to the primary response and the supply of reactive power.

In the Netherlands, generation based on intermittent sources of energy (i.e. wind and solar power) are exempted from the obligation to supply primary reserves. Neither do they have to offer any capacity as reserve power or regulating power to the Dutch TSO nor provide reactive power compensation (Dutch Grid Code 2.5.1.4, [18] and Dutch System Code 2.4.1.7, [19]). There are no specific regulations for the fault ride-through behavior of wind turbine generators. Formally, all production units, including renewables, are required to remain

connected to the grid for the first 300 ms independent of the dip depth or shorter if the calculated critical clearing time dictates otherwise. For voltage dips with a post-fault voltage > 0.8 pu, production units should remain connected at all times (Dutch System Code 2.1.16). In practice, the grid operator and the wind power developer agree on this in the design stage according to the technical possibilities and local circumstances.

E. Market Aspects

As was discussed above, wind power challenges real-time balancing of supply and demand in electric power systems. Although the variability and limited predictability of wind power can be dealt with by the TSO and/or market parties, the market design also to a large extent determines the actual impacts of wind power on system operation. A number of aspects are of importance here, among which market closure times, the design of the balancing market and the geographical spread of wind power.

Nowadays, different markets for trading are in place, such as the spot-market, the intra-day adjustment market and the regulating power market of the TSO, each with different closing times (section III-C). Because the forecast errors for wind power decrease as the hour of operation draws nearer, the closing times of these markets are important when investigating the market integration of wind power. Typically, a day-ahead spot market closes 12–36 hours ahead of operation time, resulting in significant prediction errors ($\sim 30\%$ of predicted value on average [20]). At the closing times of adjustment markets (1–2 hours ahead), the forecast error has decreased to about 15%. Therefore, additional opportunities for optimization of unit dispatch exist for market parties, taking into account updated wind power forecasts. The shorter the market closure time to the hour of operation, the more efficient the integration of wind power will be. Interestingly, the Amsterdam Power Exchange has as of September 2006 reinstalled an adjustment market for the Netherlands, extending the possibilities for intra-day trading.

In the UCTE¹ interconnected system, the responsibility for power system balancing is assigned to the respective TSO for each control zone (most control zones coincide with country borders). Energy transactions between control zones are not used for balancing. Therefore, the physical size of the balancing market is constrained to the control zone. For wind power, organization of the interconnected system in larger zones would be beneficial, since the amount of regulating capacity available for balancing would increase.

The geographical size of the control zone also impacts the wind power output variations. A larger geographical spread decreases the correlation between wind speeds at the sites located inside the control zone. Hence, wind power output variations are less correlated as well, smoothing the overall power variation introduced to the control zone by wind power.

¹Union for the Co-ordination of Transmission of Electricity, <http://www.ucte.org/>

V. OUTLOOK

This paper gave an overview of the power and transmission system integration of wind power in the Netherlands. Current research in this field is mainly done in a broader, European framework. All European TSOs are cooperating in a European Wind Integration Study (EWIS), started in 2006. The scope of work covers all the technical, operational and market/regulatory aspects related to the integration of wind power in Europe at a large scale. The overarching goal of the project, particularly relevant to European TSOs and authorities, is to address the network issues related to large-scale wind power plants and to make proposals for a generic and harmonized European-wide approach towards wind energy issues. The final objective is to set up a model for the integration of the capacities of sources of renewable energy, and more specifically wind power within Europe, as forecast in different scenarios to be covered by the study. The EWIS study therefore is expected to accumulate most of the issues presented above.

Recently, the Dutch government has decided to incorporate a Transitional Platform for Offshore Wind Energy in order to work out the full range of relevant policy criteria in consultation with grid operators and market players. This approach would enable the adoption of preferences for locations, cable routes etc to be used in any future government-organized tendering process for offshore wind power development in the Netherlands.

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