Offshore Transnational Grids in Europe: The North Sea Transnational Grid Research Project in Relation to Other Research Initiatives

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Abstract— **The development of transnational offshore grids will play a major part in the grid integration of large-scale offshore wind power. Up to now, such an infrastructure has never been built and, when finished, it will probably consist of a combination of different transmission technologies. Therefore, the effects of these grids on the power system must be studied thoroughly**

The North Sea transnational grid research project intends to study technical and economic aspects regarding the development of an electrical network in the North Sea. It aims to provide a comprehensive technical reference for policy makers in the Netherlands.

This paper describes the objectives of the North Sea transnational grid research project and the approaches to be used. Moreover, an overview of other ongoing or recently finished research projects regarding transnational offshore grids in Europe will be provided. These are compared to the North Sea transnational grid project by assessing where the technical-economic focus lies, the time horizons and methods used.

Index Terms—**Large-scale offshore wind power, Transnational offshore grids.**

I. Introduction

WIND energy is generally considered to play a major role in Europe's Climate and Energy Package goals of reducing primary energy consumption and greenhouse gas emissions by 20% and having 20% of its primary energy coming from renewable sources by 2020. From the latter 20%, renewable electricity sources (e.g. hydro, solar, wind power) are expected to account for 1/3 of the total share. Inside the renewable electricity share, 1/3 is expected to come from wind power of which 1/3 is to come from offshore wind power [1]. Based on these expectations, the European Wind Energy Association targets 40 GW of installed offshore wind energy in Europe by 2020.

The majority of the planned offshore wind power plants (WPP) are foreseen to be built in the North Sea and the Baltic Sea. Beyond the time horizon of 2020, offshore WPPs are expected to have higher power ratings and will be situated further from the shore. This implies that the costs of the corresponding electrical infrastructure will constitute a higher share in the total investment costs. Therefore, methods to increase the utilization of the connection are attractive. Among these the combination with transnational interconnectors for trading purposes is the most prominent. This approach of better using infrastructures can be extended by interconnecting multiple WPPs, integrating national networks, and connecting offshore industries.

The development and design of such a transnational offshore network is a topic of several ongoing and recently completed research projects in which integration of offshore-located wind energy sources are examined. The North Sea Transnational Grid (NSTG) research project, which is specifically addressed in this paper, intends to study technical and economic aspects with respect to the development of an electrical network in the North Sea. It will provide a comprehensive technical reference for policy makers as well as a strategy for future grid expansion. The NSTG research project focuses on design, development and operation of offshore grids, as well as on the necessary adjustments to the mainland systems for implementing large-scale offshore wind power. Outcomes of related previous work on national (the Netherlands) and European level provide a starting point for the technical and economic analysis.

This paper aims to give an overview of the NSTG research project objectives and the approach to be used. In addition, a comparison will be made with other scientific work related to transnational offshore grids. As different projects have different objectives, the comparison will concentrate on duration, time horizon, research focus, initial assumptions, and technical-economic aspects treated.

The remainder of this paper is organized as follows. First, the scientific framework of the NSTG research project is explained by outlining the goals and structure of the research, including the contents of the relevant work packages. Second, a survey of ongoing and recently completed related work on the European level is given. In section IV the

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NSTG research project is placed in perspective through comparison of related efforts. The paper ends with conclusions.

II. The North Sea transnational grid research project

The NSTG research project aims to identify and study technical and economic aspects with regard to the development of a transnational electricity network in the North Sea for the connection of offshore wind power and trade between countries. It intends to determine a technical blueprint by taking the following design criteria into account: modularity, flexibility, and efficiency for the time horizon up to 2025. The project is jointly executed by the Energy Research Centre of the Netherlands and the Delft University of Technology; it started in October 2009 and will continue for a duration of 4 years. Results from recent studies on a national level (e.g. [2],[3]) as well as on the European level (e.g. [4],[5]) provide realistic initial conditions (inputs such as wind power development scenarios by country and suitable locations for offshore wind installations) for the technical-economic evaluation.

A. Project objectives

The NSTG research project has four main objectives:

1. Determination of the optimal offshore grid configuration: The development towards transnational grids is influenced by several factors. Because the initial investment costs are high compared to point-to-point WPP connections, there must be sufficient additional advantages to take steps towards extended networks. The fact that increasing the utilization of the grid connection can be improved by interconnecting WPPs is an important economic driving force that may lead to meshed offshore grids at a national level. The increased need for interconnection capacity between countries may support the transition to even larger offshore networks that transcend national borders. This project will identify the modularity and flexibility needed for these gradual developments and evaluates the related costs.

2. NSTG operation and control strategy: It is most probable that power electronic converters will be present in a considerable number inside a large multi-terminal offshore grid due to the large distances to shore and the superior controllability awarded by these devices. For instance, their presence introduces additional possibilities to control power flows with a high degree of independency on network topology, a feature which is not easily realizable with ac transmission technology. Given that a potential transnational grid may consist of a combination of different power converter technologies, their electrical and operational compatibility must be evaluated a priori, in order to assess the technical feasibility of such a transnational grid. The NSTG research project aims at studying these different technology combinations (e.g high-voltage direct-current transmission base on voltage sourced converter technology (VSC-HVdc) and HVdc based on line-commutated converters (LCC-HVdc)) and how to control power flows on a converter level as well as on a system basis, for normal and emergency (faulted) conditions.

3. Coordinated grid expansion plan: The introduction of large-scale offshore wind energy into the total generation mix will lead to a relative decrease in conventional generation. The transition towards this new system layout is considered a major challenge: connection points of generator units change from a rather dispersed situation to a configuration in which large-scale in-feed from offshore wind occurs at only a few connection points along the coastline. This leads to certain power flows inside the transmission network which may lead to congestion. Moreover the grid connection interface of the NSTG is largely dominated by power electronics, which results in different dynamic behavior of the onshore ac system. On the other hand these power electronics introduce a high degree of flexibility/controllability into the operation and control of power systems, onshore as well as offshore. The influence on the overall ac system stability of the transnational grid in combination with gradual substitution by wind of the onshore conventional power plants will be evaluated via modeling and dynamic simulations. In addition, an optimized transition towards the integration of large-scale offshore wind power is to be determined by a coordinated grid expansion plan that avoids structural congestion both offshore and onshore.

4. Socio-economic evaluation: The costs and benefits related to a transnational offshore grid depend on the organizational structure, the availability of suitable technology, and expected revenues from cross-border energy trade as well as wind generation. These issues are closely related to the offshore system topology, the market environment in which the transnational grid is to be operated as well as the interconnection capacity between countries onshore and offshore. The NSTG research project aims to develop a number of realistic scenarios and to study these scenarios with respect to the investment costs, benefits, and security of the power system.

To achieve these four objectives, the project is subdivided in the following specific subtasks (or work packages):

- Inventory of available technologies
- Technical and economic evaluation of different topology alternatives
- Operation and control of a multi-terminal grid with different kinds of technologies
- Real-time multi-terminal converter simulation and testing
- Optimization of NSTG solutions
- Grid planning, congestion management, and stability evaluation
- Costs, benefits, regulations, and market aspects of the NSTG and connection alternatives
- International collaboration (e.g. within IEA Wind Task 25)

B. Project organization

The NSTG research project is coordinated by the Energy Research Centre of the Netherlands.

The objectives of the NSTG research project are laid down in work packages (WP) as mentioned before. These WPs are shown in Fig. 1 together with their interdependency and projected duration. WP1 and WP2 assess the available technologies by literature study and by performing an initial technical-economic evaluation of different transnational grid configurations respectively. The most promising results will be used as an input for subsequent WPs. WP3 focuses on control and operation of multi-terminal converter topologies and the results will be simulated and tested by scaled experiments on a real-time simulator in WP4. Grid integration aspects of a NSTG are addressed in WP6, which is together with WP3 and WP4 used as input for a detailed multi-objective optimization of the NSTG configurations proposed by WP2 according to the progressive design method[6] (WP5). Market, policy, and regulatory/organizational aspects are treated in WP7, which uses the most promising results and scenarios of previous WPs.

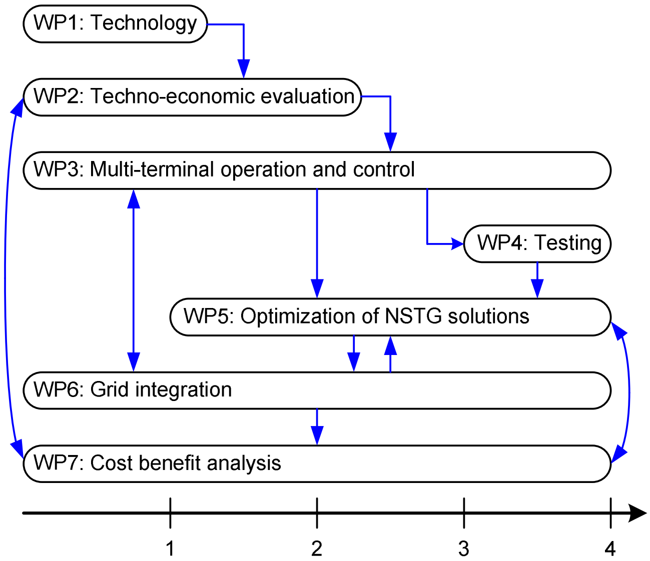

Fig. 1. NSTG research project work packages: duration and interdependency

International collaboration is achieved in two ways. First, the methods, planning, and results are being discussed with the project's stakeholder advisory board on a yearly basis. This board consists of participants from industries, transmission system operators (TSO) and governmental organizations. Second, used methods and results will be discussed within the International Energy Agency (IEA) Wind Task 25 platform, which includes a number of international industry and academia experts in the field of grid integration and operation of electricity markets for systems with large amounts of wind energy.

III. Related work

The need for coordinated planning of the energy infrastructure in Europe was already recognized as early as 2006. On September of that year, the European Energy Commission laid down the course of action towards a trans-European network for electricity (TEN-E) [7]. A revision of the TEN-E guidelines, including a list of priority transmission corridors, mainly onshore but also some offshore interconnectors, is expected by the end of 2010. In this respect, the planning, development, and realization of transnational offshore grids is currently being examined under responsibility of European Coordinator Adamowitsch, who issued two annual reports up to now aiming to support the European Union policy makers on decision making on subsidy programs regarding the development of these grids [8].

On the Baltic Sea, the planned deployment of large-scale offshore WPPs in Kriegers Flak area is considered as a possible pilot project for the feasibility of transnational offshore grids. A joint pre-feasibility study has been performed by the TSOs of the countries which were initially involved (Denmark, Germany, Sweden) [9]. It has assigned concrete numbers to the costs and benefits of various interconnection options, which was repeated by a study using other methods [10]. In the final feasibility study, the Swedish TSO has decided to abstain from a combined solution (i.e. WPPs of all three countries interconnected), as the WPPs on the Swedish part of the Kriegers Flak area are not expected to be constructed in the near future. The participants have decided that the technical solution must be constructed in such a way that future Swedish participation can be achieved [11].

On 7 December 2009, at the EU Energy Council in Brussels, with a view of fostering the integration of clean and renewable energy into their energy production portfolio, nine European countries – Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Sweden and the United Kingdom – signed a political declaration for joint cooperation on the development of a transnational electricity infrastructure in the North Sea. The document recognizes the importance of offshore wind energy in order to help Europe to meet its energy targets for 2020 and welcomes the related work and research initiatives for the effective coordination and planning of the offshore grid infrastructure between the signatory countries [12].

This political declaration is a consequence of the underlying thoughts previously elaborated by pioneer projects on the establishment of an offshore grid in the North Sea. Therefore, it is of importance to be aware and acquainted with the results and conclusions already drawn by earlier projects on this subject.

For the sake of concision, only a selection of all the relevant study projects can be reviewed here. These are TradeWind, EWIS, Energy [R]evolution, and OffshoreGrid.

A. *TradeWind*

The TradeWind project, financed under the EU's Intelligent Energy-Europe (IEE) Programme, was a European project which dealt with issues regarding reliable integration of large amounts of wind and the impacts of such integration in the trans-European power markets.

The project lasted from November 2006 until February 2009 and had as research focus the analysis of cross-border power flows derived from increasing wind power penetration scenarios in Europe [5].

The TradeWind project spanned 8 different European countries working as partners in 8 work packages distributed over 3 phases: preparatory phase (WP2-4), simulations and analysis (WP5-7) and recommendations (WP8). The study time horizon, which included short, medium and long term scenarios, was targeted until the year 2030. The medium term scenarios chosen were 2008, 2010, 2015 and 2020, while the 2015 scenario was willingly chosen in order to allow for comparison with the EWIS study [13].

The emphasis of the TradeWind study was on institutional, market, and regulatory aspects. Therefore, even though the modeling included technical aspects of wind integration, it did not have as a primary objective the aspiration of making a detailed grid design for offshore WPPs.

Nevertheless, the study concludes that an offshore grid can be a solution and could be economically beneficial when considered at a European level and recommends that further studies should focus on more thorough planning and optimization of offshore grid solutions in the North and Baltic Seas.

B. EWIS

The European Wind Integration Study (EWIS) is, along with TradeWind, one of the first studies on integrating large amounts of wind energy, onshore and offshore, at a pan-European level, analyzing all synchronous areas within Europe. The study, which lasted for almost 3 years, was initiated by the European Network of Transmission System Operators for electricity (ENTSO-e) in association with its stakeholders in June 2007. In total 13 different European countries were involved in the project.

The technical part of the study was finalized in October 2009 and its final report published at the end of March 2010 [4]. On a technical level the project was split in 6 work packages: Present Situation and Market Aspects, Scenarios and Exchange Schedules, Power System Analysis, Operational Aspects, Cost Analysis and Legal Aspects, and Communications.

The main research focus of EWIS was on how to efficiently accommodate wind generation from a market and TSO point of view, ensuring electrical energy supply remains safe given wind unpredictability. The study aims to demonstrate that the necessary costs for network reinforcement are to be overcome by the benefits of wind energy generation, even though, in absolute terms, these costs are expected to be significant. The time horizon of EWIS was until 2015, for which the study provided detailed analysis of power flows inside the ENTSO-e network as well as dynamic system behavior, for the different wind penetration scenarios.

EWIS results can be a valuable starting point beyond the 2015 time horizon for future detailed investigations of offshore WPP clusters and suitable offshore grid infrastructure concepts.

C. Energy [R]evolution

The Energy [R]evolution study is an initiative led by Greenpeace. The initial report of Energy [R]evolution, published in 2007, provided feasible solutions to cut by half the CO_2 emissions worldwide by 2050 (compared to 1990). The Energy [R]evolution study, now in its third version [14] and developed from this initial concept of cutting carbon emissions, has become a worldwide energy outlook on different sustainable energy forms.

It is as a follow up of the Energy [R]evolution initiative that, on September 2008, Greenpeace launched a study focused on the development of an offshore electrical infrastructure on the North Sea [15]. This particular study was performed in partnership with the Belgium consulting agency 3E. The study had the intention of showing that offshore wind power can also be used to supply base electricity demand in the North Sea region by taking advantage of the reduced variability resulting from aggregating over a wide geographic area.

According to the report, for a timeframe somewhere between 2020 and 2030, it is expected that 68 GW of wind power will come from more than 100 installed offshore WPP locations in the North Sea. Given the envisioned amount of aggregated power, the Electricity [R]evolution study recognizes that HVdc interconnectors will play a key role in the development of the North Sea transnational grid. For the forecasted scenario of 2030, the study provides a visual sketch of a possible offshore grid topology, using the HVdc technology.

D. OffshoreGrid

The OffshoreGrid project [16], funded similarly to TradeWind via the IEE programme, is among the most recently started research projects with respect to offshore electricity infrastructures. It aims to provide recommendations for policy makers as well as TSOs concerning technical, policy, and economic aspects related to building a transnational offshore grid. In particular, the project targets to be used as input for fulfilling the European Unions electrical infrastructure objectives stated in the Second Strategic Energy Review [17], which includes the development of a Baltic interconnection plan, a blueprint of a transnational electricity grid in the North Sea, and the completion of the Mediterranean ring.

The initial focus will be on Northern Europe while the obtained results will be used to include the Mediterranean area into the study at a later stage. The OffshoreGrid project has started in May 2009 and is foreseen to finish by end 2011. It is executed by a consortium of European research centers, universities and consultancy partners [18].

The project is set up by preparatory work packages and technical-economic work packages. First, the current state of the regional electricity markets is being assessed by comparing market integration and coupling, fuel costs, CO_2-price scenarios, and installed conventional generator capacities. Second, realistic wind generation scenarios are developed for the Baltic Sea and North Sea countries for 2020 and 2030, containing high-resolution wind power generation time series. This is the stage of the project at the time of writing this paper.

Subsequently, prototype networks of fundamentally different topologies are provided to illustrate the connection arrangement of future transnational offshore interconnectors: shore-to-shore, meshed, cluster with multi-way interconnector (similar to the Kriegers Flak study) and a combination of interconnectors and meshed grids. These prototype grids form initial conditions for the technical-economic analysis, which consists of design optimization by considering technical constraints such as bottlenecks in the transmission grid and availability of technology as well as the corresponding investments costs, and economic issues such as (offshore) market consequences [19].

E. Other ongoing efforts

1) IEA Wind Task 25

The (IEA) Wind Task 25: *Power Systems with Large Amounts of Wind Power* is an international forum for the exchange of best practices regarding the integration of large-scale wind energy into power systems. The main focus is on technical-economic feasibility (inclusion into electricity markets, grid expansion costs, reliability, capacity credit), the assessment of technical constraints (grid stability, reserve requirements) [20], and sharing information on used methods.

The first phase of IEA Task 25 started in 2006 and in 2008 it has been decided to continue with a second phase until 2011. In the final report of Phase 1 [21] the IEA Wind Task 25 recommends the transition towards a more flexible electricity grid, which includes management of generation and demand, larger balancing areas, more interconnection capacity, better integration of markets, and utilizing the improved controllability of future wind power plants.

2) The TWENTIES project

More recently, the EU-funded TWENTIES project has started, which intends to research the large-scale integration of wind power into the European power system. TWENTIES involves 26 companies and research institutions from 10 EU countries. The particular focus is on demonstration projects which improve this integration. In this respect, the French TSO RTE will study the technical feasibility of offshore HVdc grids, with particular focus on the operation and control of these grids during normal and faulted operating modes. The investigation of these include, among other matters, the development and testing of dc circuit breakers [22]. The project started in 2010 and will last 3 years.

IV. The NSTG Research Project in Perspective

After having described the relevant projects to which the NSTG research project is related, it is then relevant to establish the comparison between them on a regulatory, economic and technical basis, together with the durations of the research efforts characterized in Section III. The project durations are shown in Fig. 2.

Compared to onshore, the amount of offshore wind power is still comparatively small. In Europe the onshore wind energy market has grown in the past decade at an average pace of 33% [1] while worldwide the growth rate was of around 25% with the total installed power reaching 159 GW in the end of 2009 [23],[24]. It is expected that the total amount of offshore wind energy in Europe will grow with similar rates and will therefore reach a total capacity of circa 65 GW by 2025. This development is anticipated on by all the surveyed research projects, which approximate time horizons are shown in Fig. 3.

A. Approaches and assumptions

Not all mentioned projects particularly include transnational offshore grids in their assessment. EWIS for instance, has a time horizon between 2015 and 2020 which is considered to be a stage at which offshore WPPs will be connected through point-to-point connections only. The TradeWind project analyses the operating costs of radial and meshed transnational grids for the 2030 high-wind scenario by comparing bottleneck costs, which are the additional system operating costs due to transmission constraints. The transnational grid part of TradeWind did not take start-up costs of conventional generators, dc-grid congestion, balancing costs/benefits, and the costs of added and/or avoided ac reinforcements into account. This makes the comparison between topologies conservative in the sense that the difference in operating costs between meshed and radial structures would have been larger when these assumptions would have been taken into consideration.

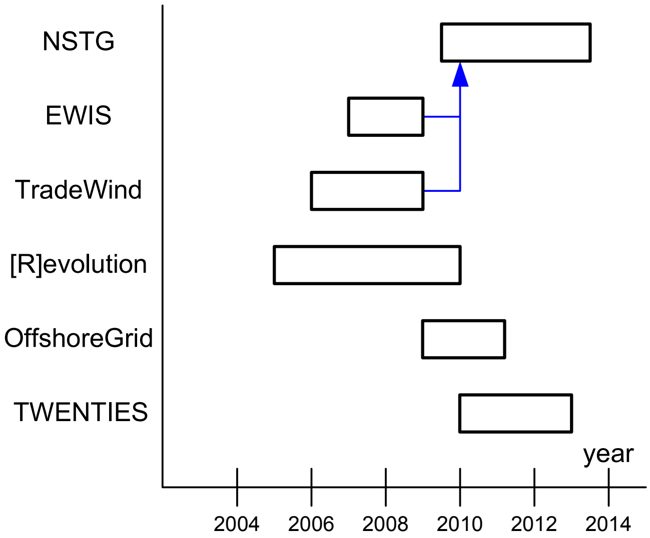

Fig. 2. Durations of the research projects described in Section III in relation to the NSTG research project. The arrow indicates the (European) projects which are currently being used as inputs to the NSTG research project.

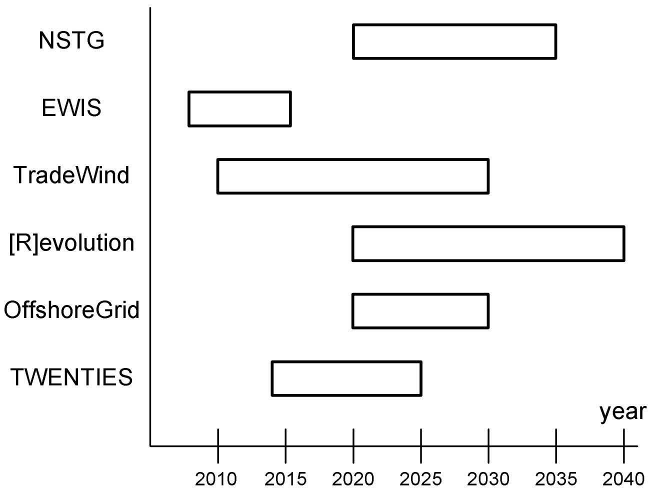

Fig. 3. Approximate time horizons of the surveyed research projects.

According to available wind speed time series, the [R]evolution study calculates hourly wind power productions for the envisioned offshore WPP locations, at a resolution of 9x9 km^2. A total installed capacity of 68 GW has been assumed, based on national targets and the scenarios developed in the TadeWind study. No particular emphasis has been laid on different kinds of topologies. In addition, VSC-HVDC has been considered as the transmission technology to be applied and congestion within the offshore network is not considered in the study.

OffshoreGrid applies an iterative approach to implement the design of a transnational grid, by optimization the market and infrastructure design. As a starting point, four topologies varying from point-to-point to meshed networks have been selected, based on wind-connection and/or trade design drivers. Notable boundary conditions for this evaluation are planned WPP capacities, (regional) fuel costs, CO_2 price scenarios, and high resolution time series of WPP generation.

In the NSTG-project the location and capacity of offshore WPPs will be adopted from outcomes of the previously described related work at European level as well as from [1], which currently provides the most up-to-date list on offshore wind energy installations up to 2030. Available wind speed distributions will be used for market analysis as well as for steady-state grid integration evaluation. It is assumed that different types of transmission technologies may be implemented into the NSTG. For the evaluation of operation and control of these technologies, it is expected that dc circuit breakers will be available by that time, which considerably improves the operation flexibility and reliability.

B. Technical-economic aspects treated

As the initiatives regarding the development of WPPs and electrical infrastructure offshore advance with time, they tend to depart from a mere economical assessment toward a more thorough technical analysis of the topic. Fig. 4 represents an effort to situate the projects discussed in this paper with regard to the technical and economical aspects treated.

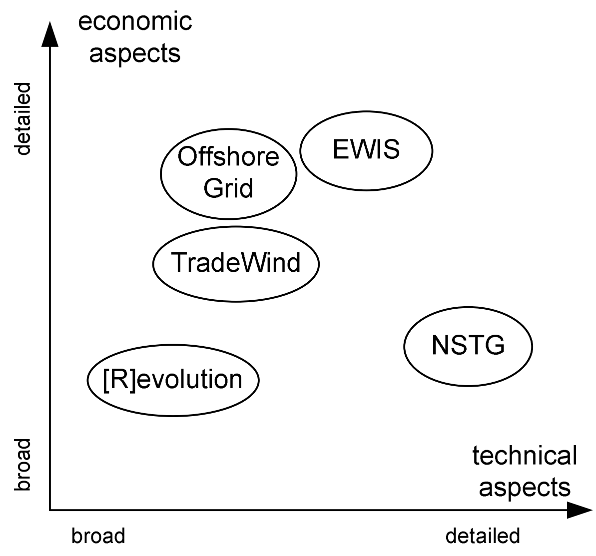

Fig. 4. Technical an economic aspects treated by each of the initiatives analyzed with respect to the NSTG research project.

TradeWind puts emphasis on the economic cost-benefit evaluation of wind integration, which is performed by assessing cross-border power flows for future wind power capacity scenarios. First, already planned grid reinforcements and HVdc interconnectors were included. Then, three offshore topologies have been studied (1 radial and 2 meshed). The operating costs (particularly bottleneck costs) of these networks were studied by a flow-based power market simulator developed by SINTEF. HVdc links were assumed to be fully controllable and only constrained by their transmission capacity.

As OffshoreGrid uses an iterative approach to determine the interaction between market operation, offshore grid design, and the corresponding operation costs, the main focus is more on topology and cost optimization than on the technical characteristics of the grid connection. OffshoreGrid focuses on steady-state operation, in which the same market simulator as during the TradeWind study is being used.

Among the economic aspects treated within the EWIS project were the costs related to the integration of WPPs and a benefit analysis of integrating wind power in the European power system. EWIS created a market model of the ENTSO-E grid showing where potential onshore transmission bottlenecks could arise, given selected landing points for offshore wind. The study pointed out the most critical grid reinforcements that should take place inside Europe to accommodate the trade from the predicted WPPs. Contrary to related projects, EWIS also studied the consequences of higher wind penetration levels for the dynamic behavior of the system as well. However, since transnational offshore grids were not in the scope of the research, the effect of these grids remain still unknown to a large extent.

For the economic analysis of offshore transnational grids, the [R]evolution study looked into straight-forward cost considerations related to the capital costs of HVdc transmission systems. Other related costs, such as operation and maintenance costs were not included. For the dc network, the study used a copper plate assumption.

TABLE I
RESEARCH FOCUS OF PROJECTS AND STUDIES CONSIDERING TRANSNATIONAL OFFSHORE GRIDS

	[R]evolution	Trade Wind	EWIS	Offshore Grid	NSTG	TWENTIES
Market & Load Flow Models	✓	✓	✓	✓✓	✓	--
Offshore Grid Design	✓	✓	--	✓✓	✓	✓
Dynamic Stability	--	--	✓	--	✓	✓
MTDC Control	--	--	--	--	✓✓	✓✓

By considering simple, but fundamentally different topologies, the costs and benefits of each grid solution are examined in the NSTG research project according to wind power generation data, investment cost figures as well as offshore transmission capacity. The market aspects of each scenario will be studied according to an idealized market model in combination with a round the year load flow tool similar to [25]. As the main intention of the NSTG research project is to provide a technical blueprint, the focus will be on design, operation and control of a transnational grid. This includes steady-state behavior as well as detailed dynamic modeling of the main components expected to be part of such a grid. Table I summarizes to what extent the surveyed projects treat different aspects regarding transnational offshore grids and how these relate to each other.

V. Conclusions

Offshore wind power plants (WPP) will play an important role in the transition towards a more sustainable energy society. The connection of these WPPs is costly, especially when they are located far offshore. At the same time, an increased need for interconnection capacity between European countries is induced by market coupling and balancing of the variable output of renewables. Offshore WPP connections can be combined with interconnectors between countries to increase the utilization of the electrical infrastructure and hence to reduce costs. This concept may be exploited further by interconnecting several countries and WPPs, which gives rise to the development of transnational offshore grids.

On a European level, several recently finished or ongoing efforts are focusing on enabling the integration of onshore as well as offshore wind power into power systems. This paper reviewed the approaches of several research projects to evaluate the effectiveness of transnational offshore grids as well as the need to increase cross-border connection capacities. The North Sea transnational grid (NSTG) research project is a research programme jointly executed by the Energy Research Centre of the Netherlands and Delft University of Technology and intends to contribute to similar efforts in this emerging field. It was shown that although the NSTG research project contains a detailed technical-economic evaluation as well, related projects treat this aspect more elaborately. On the other hand, the NSTG research project addresses some technical elements in more detail, like multi-terminal control, secure grid operation both onshore and offshore, and optimization of different transnational offshore grid solutions. In these areas, the NSTG research project aims to be an important contributor nationally (the Netherlands and its environment) and internationally (Europe-wide and abroad).

Most of the reviewed projects that deal with transnational offshore grids have a time horizon between 2020 and 2030. One of their main conclusions is that onshore grid connections must be reinforced to avoid congestion due to the variability of wind and hence to achieve optimal electricity market coupling. Besides, planning of future WPPs requires rethinking the way these are connected to the shore since future investment costs can be saved when the transition towards meshed offshore grids is anticipated already during the early development stage.

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VII. BIOGRAPHIES

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Rodrigo Teixeira Pinto was born in *São Paulo*, Brazil, on November 3rd 1983. In 2003 he joined the *Escola Politécnica da Universidade de São Paulo* for a bachelor in Electrical Engineering at the Electrical Energy and Automation (PEA) department. In 2006 he started his MSc. in Electrical Engineering at the *Politecnico di Torino*, in Turin, Italy. From May to November 2008 he was with Siemens PTI, in Erlangen, Germany, working towards his MSc. as a *Diplomand* on the Network Dynamics Studies department. On December 2008 he received his MSc. (cum laude) from the *Politecnico di Torino*. Since December 2009 he is working as a PhD researcher on the North Sea Transnational Grid research project at the Electrical Power Processing group (EPP) of TU Delft.

Madeleine Gibescu received her Dipl.Eng. in Power Engineering from the University Politehnica, Bucharest, Romania in 1993 and her MSEE and Ph.D. degrees from the University of Washington, Seattle, WA, U.S. in 1995 and 2003, respectively. She has worked as a Research Engineer for ClearSight Systems, and as a Power Systems Engineer for the AREVA T&D Corp., U.S. She is currently an Assistant Professor with the Electrical Power Engineering department, Delft University of Technology, the Netherlands. Her research interests include operations and planning for power systems with significant renewable energy penetration, with an emphasis on wind power.

Pavol Bauer received his Masters in Electrical Engineering at the Technical University of Kosice ('85), Ph.D. from Delft University of Technology ('95) and title prof. from the president of Czech Republic at the Brno University of Technology (2008). Since 1990 he is with Delft University of Technology, teaching Power electronics and Electrical Drives. From 2002 to 2003 he was working partially at KEMA (Arnhem) on different projects related to power electronics applications in power systems. P. Bauer published over 50 journal and 200 conference papers in his field, he is an author or co-author of 6 books, he holds international patent and organized several tutorials at the international conferences. He has worked on many projects for industry concerning wind power, power electronic applications for power systems such as Smarttrafo etc. and participated in several Leonardo da Vinci EU projects as project partner (ELINA, INETELE) and coordinator (PEMCWebLab.com). He is a Senior Member of the IEEE, Chairman of Benelux IEEE Joint Industry Applications Society, Power Electronics and Power Engineering Society chapter, member of the EPE-PEMC council, EPE member and also member of international steering committee at numerous conferences.

Jan Pierik was born in The Netherlands in 1954. He received his M.Sc. degree in Chemical Engineering from the Technical University Twente in 1978. Since 1980 he has been employed at the Energy Research Centre of the Netherlands ECN in Petten, presently as a Senior Research Scientist. His main technical interest is modeling and control of electrical systems for wind turbines and wind farms.

Frans Nieuwenhout was born in the Netherlands in 1957. He obtained his M.Sc. degree in physics from Utrecht University in 1985. Since 1990 he works for the Energy research Centre of the Netherlands ECN. His main research interests are integration of renewable energy in electricity networks, smart grids, electricity storage, and energy markets.

Ralph Hendriks received the B.Sc. and M.Sc. degrees in electrical engineering from Delft University of Technology in 2003 and 2005 respectively.

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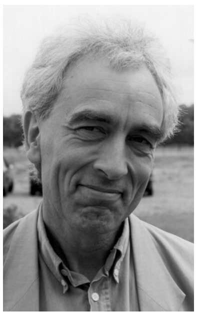
Wil Kling received his M.Sc. degree in Electrical Engineering from the Eindhoven University of Technology, Eindhoven, the Netherlands, in 1978.

Since 1993, he has been a part-time Professor with the Delft University of Technology, the Netherlands in the field of Electrical Power Systems. Up till the end of 2008 he was also with TenneT, the Dutch Transmission System Operator, as senior engineer for network planning and strategy. Since Dec. 2008, he has been appointed Chair of the Electrical Power Systems group, Eindhoven University of Technology, the Netherlands. He is leading research programs on distributed generation, integration of wind power, network concepts and reliability issues.



Gijs van Kuik received his M.Sc. in theoretical aerodynamics in 1976 from Delft University of Technology and his Ph.D. on aerodynamics of wind energy at Eindhoven University of Technology in 1991. From 1988 to 1998, he was employed at Stork Product Engineering and worked on the development of wind energy technology for Dutch and foreign turbine and blade manufacturers. He became a full professor in wind energy at Delft University in 1998 and the scientific director of the Delft University Wind Energy Institute in 2000. Prof. Van Kuik is a regular speaker at many European and US conferences on wind power. Furthermore, he is editor of the journal *Wind Energy*, chairman of the We@Sea knowledge consortium. He was founding member and president of the European Academy for Wind Energy.