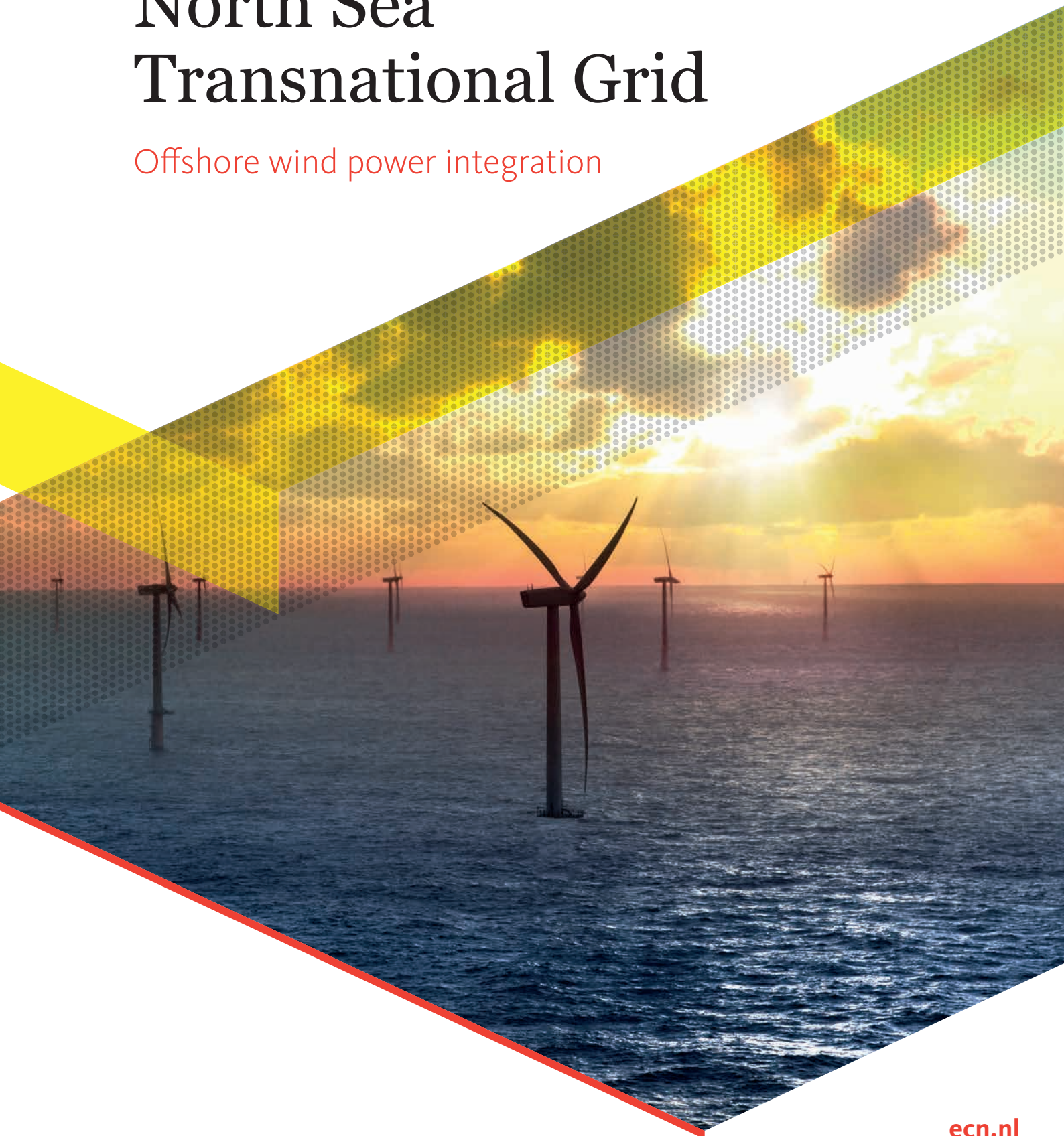


North Sea Transnational Grid

Offshore wind power integration



Overview

The European perspective

Renewable electricity generation is expected to make up a high proportion of the low-carbon European energy system of the future, with offshore wind power playing a major role. The plans for 2030 already anticipate 30-60 GW of offshore wind power in the northern part of the North Sea. To operate the electricity system reliably and efficiently, a substantial increase in international power exchange will be needed. In turn, this will require the flexible integration of national electricity markets and the strengthening of grid infrastructure. Achieving this will take many years and a huge amount of investment.

The concept

One option is to combine the individual connections between offshore wind power plants and the shore with the grid reinforcements between North Sea countries in a North Sea Transnational Grid. Such a grid would provide a flexible, reliable and cost-efficient solution for the export and cross-border trade of wind power. Several visions have already been presented in line with this concept, such as the European Supergrid and Zeekracht.

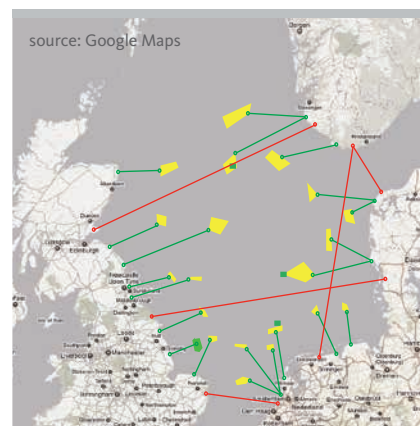
The project

In the North Sea Transnational Grid project, we not only analysed the feasibility of several grid scenarios, but we also studied the impact on social welfare on a regional scale, along with the implications for the planning and operation of the connected onshore grids. Moreover, we investigated various technical solutions to the problem of how to build modular meshed DC-grids, and how the operation of these complex grids might be controlled and optimized.

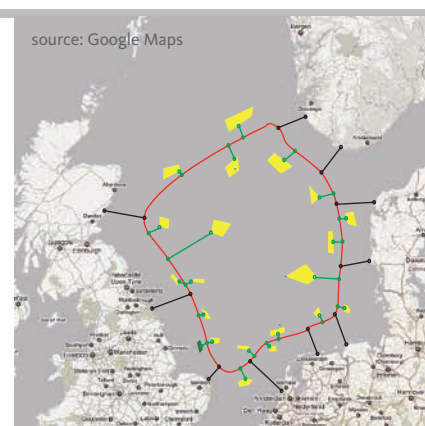
Objective

Providing modular, flexible and cost-effective solutions for a North Sea Transnational Grid, connecting future wind power plants in the northern part of the North Sea.

Individual wind power connections and bilateral connections



The North Sea Transnational Grid



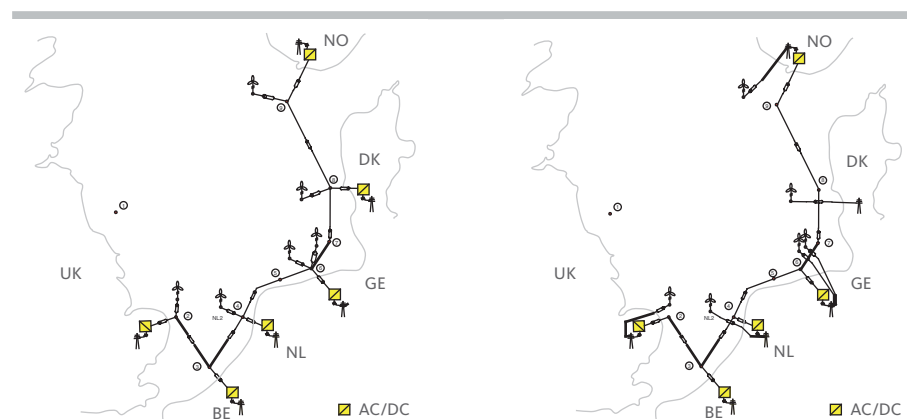
Assessing the Costs of Energy Transport

Two scenarios compared

We evaluated two scenarios for the development of a North Sea Transnational Grid for the trade and connection of 52.8GW of wind energy. In scenario 1, the transport of wind power and traded power are integrated in an interconnected DC grid. In scenario 2, wind power and traded power are separated: wind is AC-connected to the onshore grid, whereas a DC grid interconnects the North Sea countries. Both scenarios were developed in ten stages or phases, with an approximately equal increase in wind power at each stage.

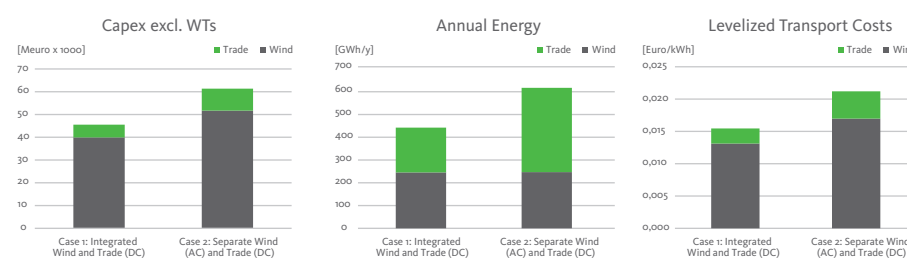
Scenario 1: Interconnected, phase 1 of 10

Scenario 2: Separate, phase 1 of 10



The investment needed for scenario 2 is higher than that for scenario 1 in all phases, because additional DC connections are needed to connect the ring to shore. Combining wind and trade in a single connection to shore, however, reduces the available transport capacity in the case of high wind production levels, resulting in a lower amount of traded energy. It should be noted, though, that the lower investment in combined scenario 1 outweighs the reduction in traded energy, leading to lower average Levelized Transport Costs compared to the separate scenario 2.

Results



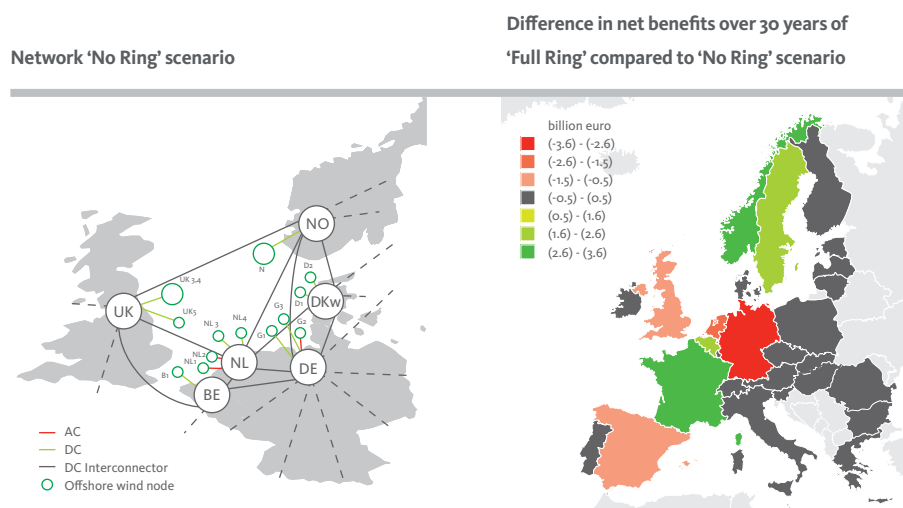
Conclusion

Based on the price estimates that are currently available, the most cost-efficient solution would be the integrated scenario 1 based on DC connections.

Main findings of the socio-economic analysis

From a European perspective, an offshore ring is preferable to a mainly onshore ring with the same transmission capacity.

If all of the offshore ring costs were to be borne solely by the six NSTG countries that border the North Sea, adding an offshore ring structure to the wind farm connections would not be beneficial for these countries. A possible solution to this would be to expand the scope of the existing 'Inter-TSO Compensation' (ITC) scheme.



Difference in net benefits over 30 years of the Full Ring scenario, as compared to the No Ring scenario:

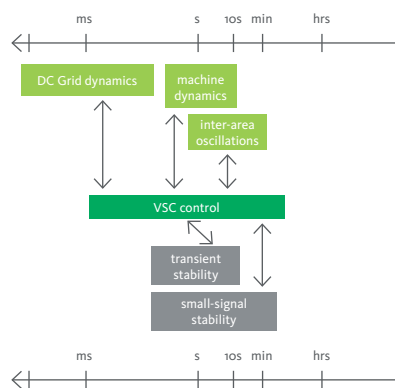
NSTG scenarios	NSTG countries	Other countries	EU28 + 7 countries
Full Ring	-1.76	3.46	1.69
Full Ring Equivalent	-2.29	3.61	1.33

Grid Integration of a North Sea Transnational Grid: Planning, Operation and Stability Impacts

Integrating large amounts of offshore wind power through a North-Sea Transnational Grid (NSTG) into a future transmission system presents a significant challenge. Therefore we investigated the consequences of such a grid for the planning, operation and electro-mechanical interactions (i.e. stability) of the combined North-West European onshore and offshore transmission system. Our main finding was that the topology of a future NSTG would greatly influence the transnational power flows and the integral power system dynamics.

Our approach was to represent a future NSTG using existing commercial simulation tools, and to employ existing grid models that had been made available by the project partners. For the planning and operation part of the work package, a detailed time series of available wind and solar power was fed into a market simulation tool to perform a year-round security analysis. For the power system dynamics part of the work package, we needed to develop both dedicated converter and HVDC-system modelling and sophisticated simulation algorithms, on the grounds that VSC-HVDC inherently couples DC system dynamics to those present in AC systems.

VSC-control couples AC and DC system dynamics



Transnational loop flows during high-wind conditions



Both studies integrated large amounts of offshore wind power, taking the main grid extensions for their respective time horizons into account. In the stability part of the work package, one specific worst-case snapshot was adapted from the planning and operation part, in which lots of wind infeed from Germany and the North Sea flows through the Dutch power system.

The results show that the topology of such a grid significantly influences the power flows and dynamics of the entire system. Our conclusion is thus that onshore and offshore network extensions must be planned together in order to be able to exploit the operational benefits of an NSTG to the full (e.g. fewer CO₂ emissions, transnational power exchange and advanced control during power system disturbances). In this respect, our main recommendation is that the NSTG and its surrounding synchronous areas should be included explicitly in both the market and the stability grid integration analyses.

Controlling the Power Flow in the Meshed DC Offshore Grid

Objectives

A key objective of the project was to control the power flow in meshed DC offshore grids. It was therefore necessary to develop the modular dynamic models, so that we could understand how the system would operate once all of its components were connected together. The next goal was to build a scaled-down version of the North Sea Transnational Grid in the laboratory. This would allow us to validate the models that had been developed and to test the Distributed Voltage Control strategy (the algorithm developed in the North Sea Transnational Grid Project to control the power flow in meshed DC offshore grids).

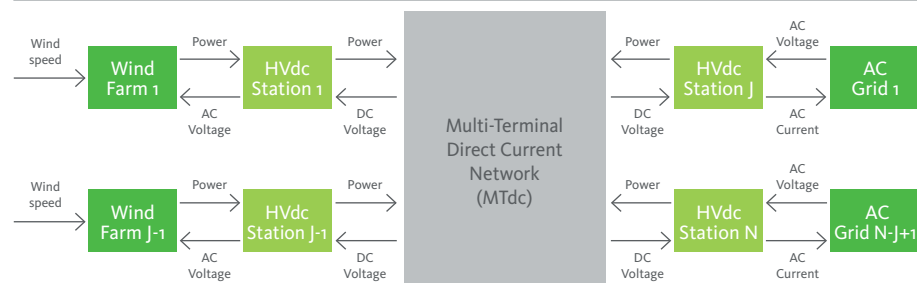
Challenges

The main challenge was to build a three-terminal DC network to test the models and the Distributed Voltage Control strategy in real-time. The offshore wind farms were emulated using a real-time digital simulator (OPAL-RT), and the power electronic converters were controlled in real time via Matlab/Simulink.

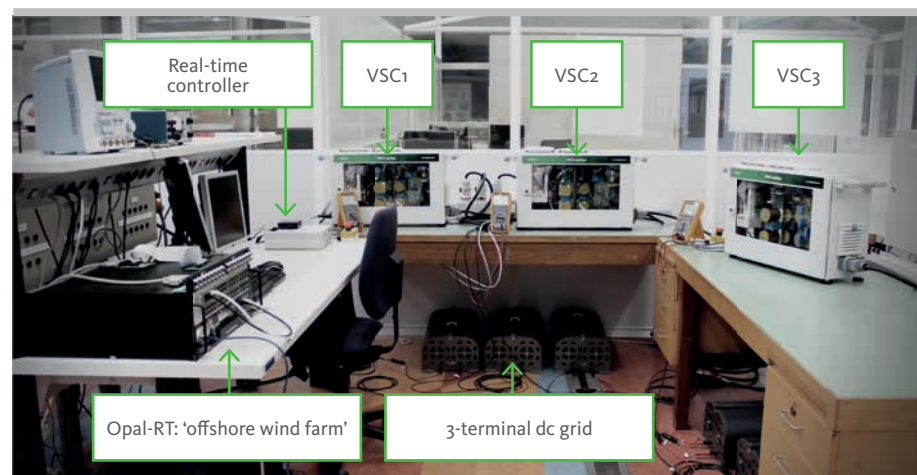
Conclusions

- The NSTG project developed non-linear and linear models of the key elements of a future HVDC offshore grid: DC cables, wind turbines, a wind farm and voltage-source converters models;
- A new power flow control algorithm for meshed DC offshore grids was developed: the Distributed Voltage Control strategy;
- A hardware-in-the loop platform using a real-time digital simulator and three power electronic converters was built to emulate the NSTG;
- The results obtained from the scaled-down platform show that the power flow strategy that was developed is well suited to controlling large meshed multi-terminal DC networks.

Multi-Terminal DC grid interconnecting offshore wind farms and onshore grids



Offshore wind farm 3-terminal DC grid

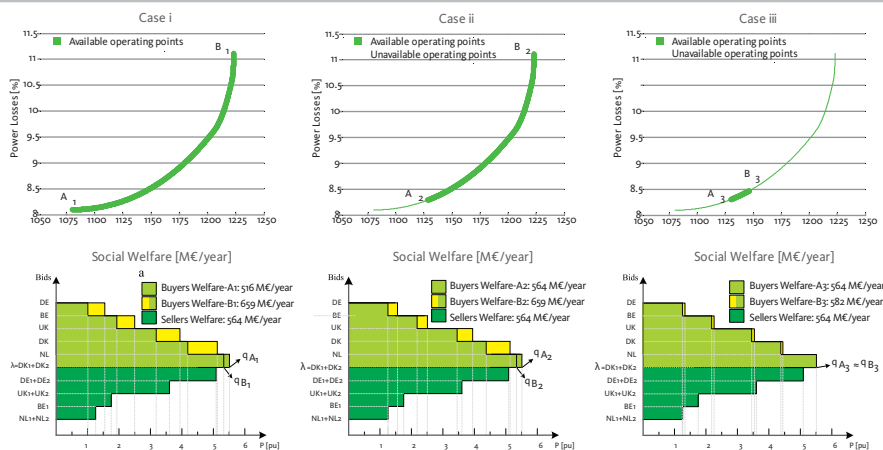


Optimal grid operation

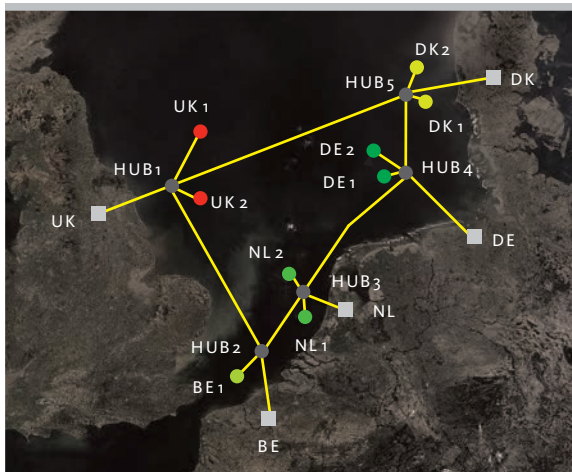
Achieving optimal power flow control in MTDC networks continues to present a challenge. We proposed using an independent system operator (ISO), to control the MTDC network (as shown below) via a market pool structure. The ISO is responsible for receiving the pool market participants' bids and, after determining optimal DC power flow before sending the DC voltage references for the onshore converters so that the optimal flow can be realised. A multi-objective genetic algorithm was used to optimise the power flow of the MTDC network. This was set to optimise the network transmission losses and social welfare.

The resulting Pareto fronts (see upper three graphs) indicate that maximum social welfare is achieved when more power is transmitted to countries with higher bids. However, this leads to an increase in transmission losses. Additional constraints to the power flow prohibits the operation in some of the Pareto front regions, meaning that it may not be possible for the ISO to operate the MTDC network where the best possible cases are found. In this event, the ISO must decide which is the best operating point for the offshore grid.

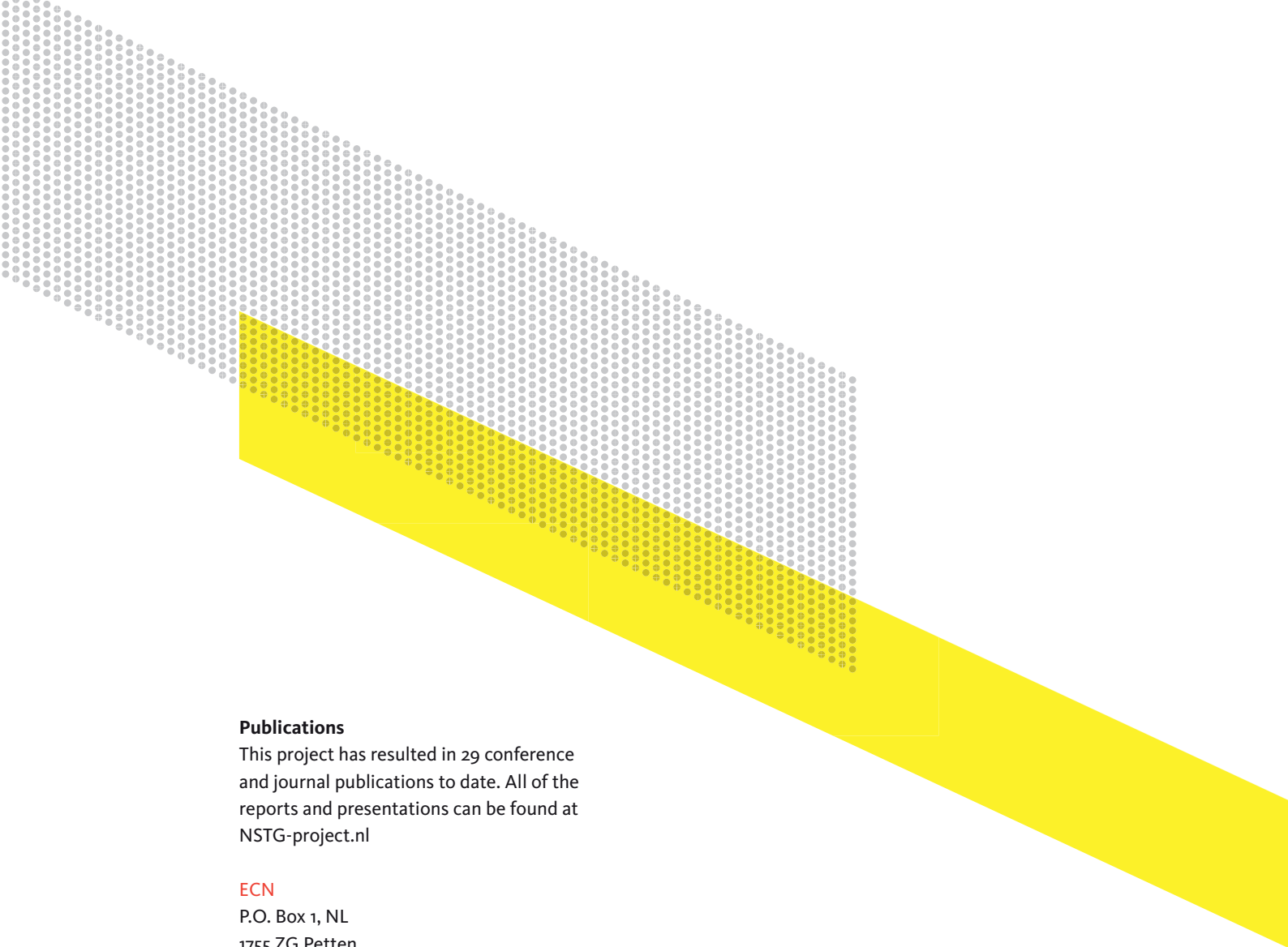
Optimal solutions for unconstrained (Case i) and constrained (Cases ii and iii) power flows



MtDc grid for which the power flow optimization has been applied



The proposed approach to controlling the MTDC network offers the ISO a high degree of flexibility in achieving optimal trade-offs.



Publications

This project has resulted in 29 conference and journal publications to date. All of the reports and presentations can be found at NSTG-project.nl

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