TWENTIES project

Final report - short version

June 2013

Transmission system operation with a large penetration of wind and other renewable electricity sources in electricity networks using innovative tools and integrated energy solutions (TWENTIES)

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What is TWENTIES?

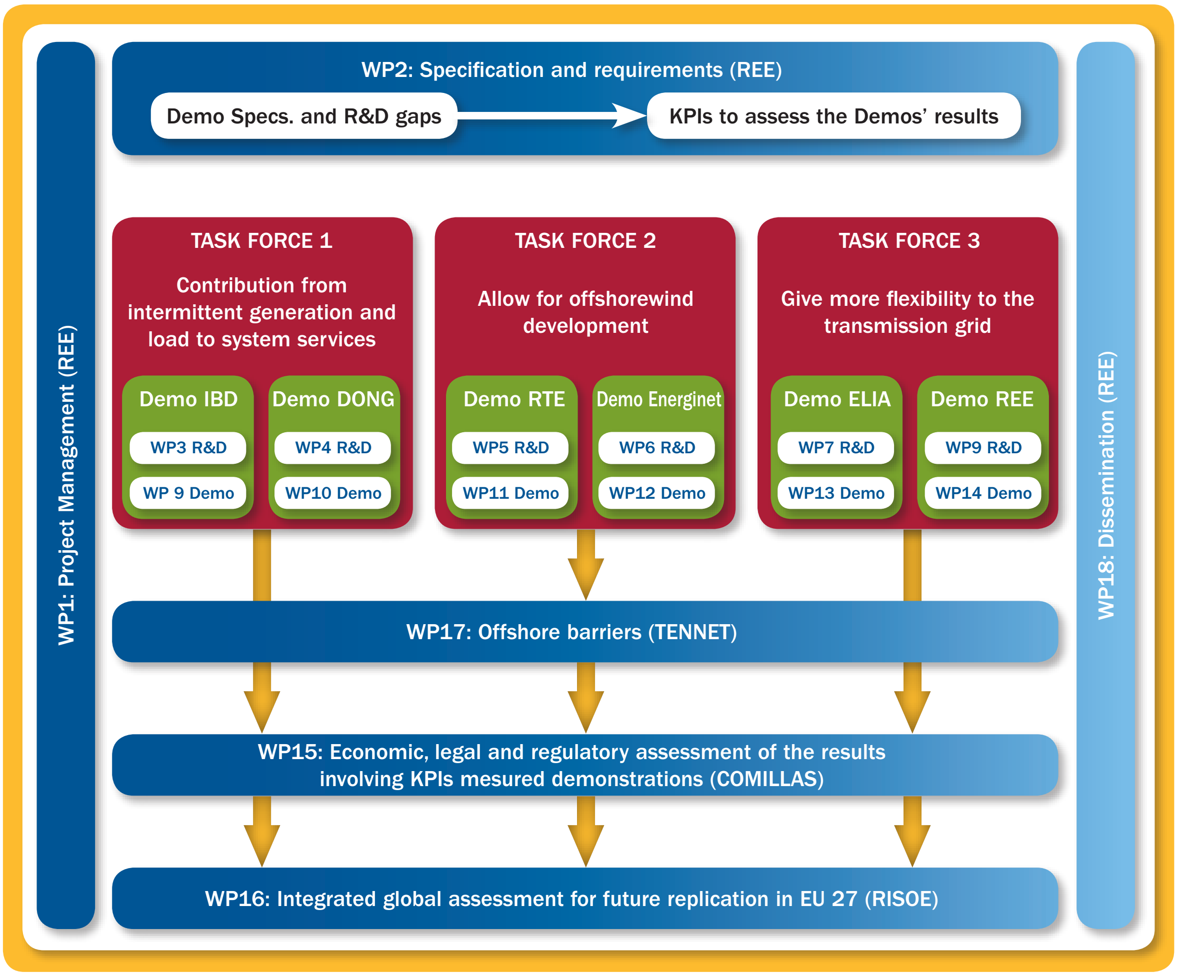
The EU-funded TWENTIES project - 'Transmission system operation with a large penetration of wind and other renewable electricity sources in electricity networks using innovative tools and integrated energy solutions' - coordinated by Spanish Transmission System Operator Red Eléctrica de España, was launched in April 2010.

The aim of the TWENTIES project is to advance the development and deployment of new technologies which facilitate the widespread integration of more onshore and offshore wind power into the European electricity system by 2020 and beyond.

TWENTIES is one of the largest renewable energy demonstration projects funded by the European Commission's Directorate-General for Energy under its seventh Framework Programme (FP7), with a total budget of over €56.8 million, and a European Commission contribution of close to €32 million. The TWENTIES project brings grid operators and wind energy operators together for the first time.

TWENTIES is organised around six large-scale demonstration projects grouped into three Task Forces, which aim to prove the benefits of new technologies. The six large-scale demonstrations are complemented by three work packages. One of the work packages focuses on the assessment of non-technology barriers to the development of a real offshore grid, and makes proposals for overcoming such barriers. The other two are related to the replicability and scalability at EU level of the results of the demonstration projects, based on their individual impact as well as the potential synergies between them.

FIGURE 1: TWENTIES PROJECT STRUCTURE



What did TWENTIES find out?

TWENTIES shows that Europe's energy infrastructure can be used a lot more efficiently than it currently is. The most significant findings include the following:

- Wind farms can provide wide area voltage control, and secondary frequency control services to the system.
- Virtual power plants enables reliable delivery of ancillary services, like voltage control and reserves, by intelligent control of distributed generation including wind farms and industrial consumption.
- A DC circuit breaker prototype was tested successfully.
- By applying 'high wind ride through control', reserve requirements are cut in half.
- By using Real Time Thermal Rating (RTTR) or Dynamic Line Rating (DLR) for measuring and forecasting overhead line capacity, 10% more flow in average can go through equipped overhead lines.
- By using the combined effect of DLR and power flow controlling devices to control the flows in the European grid, more wind in-feed can be integrated in the existing grid without jeopardizing the system security.
- By controlling flows by means of PSTs, HVDCs and FACTS, local congestions can be alleviated in a flexible manner. A smart control of a set of such devices enable getting even more out of the existing grids.

The key results:

Task Force 1: Contribution of variable generation and flexible load to system services

Demonstration project 1: System services provided by wind farms (SYSERWIND)

- Wind farms provided wide area voltage control, reducing voltage deviation from 9 kV to 0.7 kV.
- Wind farms can work in a coordinated way to provide secondary frequency control in the same way as conventional units.
- Secondary frequency control involves many challenges, including the need for very accurate wind forecasting in order to avoid curtailing large amounts of power.
- Wind farm voltage control leads to less wind curtailment and slightly lower overall system costs.

Demonstration project 2: Large-scale virtual power plant integration (DERINT)

- The virtual power plant - "Power Hub" - enables reliable delivery of ancillary services, like voltage control and reserves, by intelligent control of distributed generation including wind farms and industrial consumption.
- Power hub was able to optimise the output from the available resources in different units across different markets, deciding when most value would be generated.
- It is economically attractive to build virtual power plants. Power Hub can be replicated across Europe.
- Virtual power plants reduced marginal electricity prices by 0.25-0.4% and brought about lower total system costs in the day-ahead market in the Danish system.
- VPPs based on biomass and heat pumps could provide a 2.18% reduction in average electricity prices and a 3.46% reduction in CO_2 emissions in the German power system.

Task Force 2: Reliable offshore network and wind development

Demonstration project 3: Technical specifications towards offshore HVDC networks (DCGRID)

- Local voltage droop control was used in the operation of the DC/AC interconnected grid to accommodate wind generation and a large range of failures in the electrical system without any need for high-speed telecommunications.
- A DC circuit breaker prototype was tested successfully.
- New offshore network capacity allows local surpluses of wind power to be used elsewhere, reserve

power to be held, and potentially cheap, low carbon power to be used instead of more expensive higher-carbon fossil fuel plants.

Demonstration project 4: Management of offshore wind power in extreme high wind situations (STORM MANAGEMENT)

- Wind turbine energy output was increased in stormy conditions by using high wind ride through control, which took the cut-off point from wind speeds of 25 metres per second up to 32 metres per second.
- Use of high wind ride through control reduced the risk of power system instability and blackouts.

Task Force 3: Improvements in the flexibility of the transmission grid

Demonstration project 5: Network-enhanced flexibility (NETFLEX)

- By installing Ampacimon sensors that measure vibration to deduce the sag of the line, and forecasting capacities, TSOs can enjoy an average 10-15% more capacity out of overhead lines.
- By acting together, Power Flow Controlling devices (PFCs), like PSTs and HVDCs, can better distribute the flows over an entire area and unlock room for more wind power and exchanges.
- At the moment, the system damping is generally sufficient. Nevertheless, new means for controlling the damping must be identified to cope with high penetration of RES. Today, the damping of the system can be reliably predicted based on flows and injection.
- In order to achieve the same level of operational risk, the DLR forecaster can implement a more audacious policy because the smart controller enables compensating for over-estimations.
- The grid can be planned more boldly, i.e. higher capacities for the market and for wind, while delivering the same level of reliability.

Demonstration project 6: Improving the flexibility of the grid (FLEXGRID)

- Real-time monitoring of the temperature of the power cables allows over 10% more wind-generated power to be brought onto the transmission grid.
- Excess energy can be re-directed to lines with spare capacity in order to use the transmission capacity more efficiently, increasing the controllability and security of the grid and reducing the need for curtailments.

TWENTIES has held a number of dissemination events, some of them linked to the project General Assemblies and some in connection with other demonstration projects, and been present at several conferences and workshops in Europe.

The following pages present a brief summary of the most significant results obtained in each of the demonstrations, how the demonstration project worked, and an overview of the project work packages. A more detailed description of the work and the results achieved are available on the project site: www.twenties-project.eu.

Demonstration project 1

System services provided by wind farms (SYSERWIND)

Main findings

- Clustered wind farms provided wide area voltage control, reducing voltage deviation from 9 kV to 0.7 kV.
- Wind farms can work in a coordinated way to provide secondary frequency control in the same way as conventional units.
- Secondary frequency control involves many challenges, including the need for very accurate wind forecasting in order to avoid curtailing large amounts of power.
- A high amount of energy has to be curtailed for providing the upwards power reserve service, so it is not currently attractive from the economical point of view.

Project description

The first demonstration project in TWENTIES aimed to show that wind power facilities already in operation can be upgraded to provide services like wide area voltage control and secondary frequency regulation to the system, with limited changes in IT systems at wind turbine and wind farm level. The demonstration was carried out in 15 of Iberdrola's wind farms in the south of Spain arranged in three clusters: Arcos de la Frontera (111 MW), Tajo de la Encantada (122 MW) and Huéneja (248 MW), with a total capacity of 481 MW.

In order to meet the objective, new control regulators were developed and installed in the control centres and the wind farms, making 240 wind turbines work in a coordinated fashion in order to control the voltage in a 350 kilometre-long 400 kV AC corridor. It was also necessary to develop a very short-term wind forecasting algorithm due to the challenging requirements of providing a secondary frequency regulation band with the necessary precision. Most importantly, these tools were fully integrated into the system operation and the transmission system operator's (TSO) tools.

Results in detail

The wide-area voltage control test started with initial voltage differences of up to 9 kV and following the TSO's instruction the response provided by the 15 wind farms reduced the voltage deviation to 0.7 kV.

The main challenges that were faced during these tests were the fact that controlling the reactive power capabilities of the wind turbines meant taking into account the behaviour of the medium voltage grid of the wind farms as well as other installations that were not part of the demonstration but were connected to the same nodes, and the on-load tap changer of the transformers, which reacted to the modifications in the voltage profile.

Providing secondary frequency services with wind farms has proven to be even more challenging. The wind farms were integrated into the TSO's automatic generation control (AGC) system and, in this case, the main problem was the fact that, in order to provide a regulation band with sufficient reliability during the whole time span of the test, a very accurate and reliable forecast was needed. Other issues that made the demonstration difficult were the need to respond quickly to the set points that the TSO sends every four seconds and controlling the pitch in all the wind turbines in such a way that a reduction in power generation was achieved without stopping any machine, which would slow the overall response of the clusters.

Despite the challenges, the demonstration showed that voltage control and secondary frequency regulation can be successfully carried out by wind farms.

Demonstration project 2
Large-scale virtual power plant integration (DERINT)

Main findings

- The virtual power plant - "Power Hub" - enables reliable delivery of ancillary services, like voltage control and reserves, by intelligent control of distributed generation including wind farms and industrial consumption.
- Power Hub was able to optimise the output from the available resources in different units across different markets, deciding when most value would be generated.
- It is economically attractive for all stakeholders to participate in virtual power plants. Power Hub can be replicated across Europe, although challenges include attracting and integrating industrial units to participate in a virtual power plant.
- Another challenge was scaling up the virtual power plant on commercial terms in Denmark due to the Danish regulatory regime and market design. Similar challenges has been identified in Germany and Spain.

Project description

When an increasing share of energy is produced by renewable sources such as solar and wind, electricity production can fluctuate significantly. In the future there will be a need for services which can help balance power systems in excess of what conventional assets will be able to provide. Virtual power plants (VPPs) are one of the most promising new technologies that can deliver the necessary stabilising services. The goal of the second TWENTIES demonstration project was to show the full potential of the VPP technology.

The demonstration project involved the development of a virtual power plant, named "Power Hub". Power Hub is an IT system that can manage both small power generators (such as small hydro power plants, industrial combined heat and power plants (CHP) or emergency generation sets, etc.) and power consuming units (such as pumps in waste water treatment, grow light in greenhouses, cooling in cold storages, etc.).

The goal of Power Hub is to ensure that all units are used optimally for the benefit of both the electrical system and the unit owner. When the units are used optimally, they are able to provide the services that are needed in the future low carbon energy system. As an example, pumping water can be stopped or started in a matter of seconds if the power system needs it. Similarly a small hydroelectric plant could gain access through Power Hub to provide services which stabilise the frequency of the power system, which otherwise would be too complex to deliver.

The VPP demonstration was set up in Denmark on fully commercial terms. This means that the VPP delivers services to the Danish power system based on the controlled units on a daily basis. It also means that the VPP only pays the unit owners a share of what can be earned from the portfolio of units in the existing markets.

Building a VPP consists of a range of tasks, which fall into three main groups: 1) Building the conceptual solution, including the IT platform 2) Reaching an agreement with the unit owner and installing unit controls 3) Running the daily operation, trading energy and flexibility in the markets and delivering services by optimising the units.

Results in detail

The project integrated 47 units into the VPP representing 15 different unit types. One of the conclusions from the project is that it is a challenging task to mobilise industrial units to participate in a virtual power plant; the task involves complex unit flexibility assessment and unit owner education in the complex issues of VPPs, power markets and future energy system.

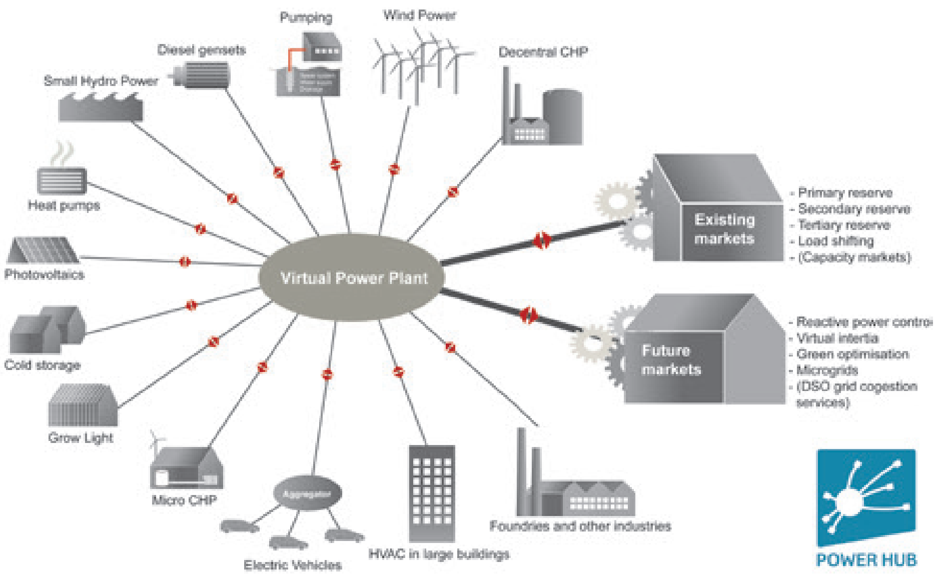
Every day, Power Hub delivers services to the Danish TSO, Energinet.dk and to the Faroese power company, SEV. Power Hub is also trading daily on the Nordic power exchange NordPool. Power hub is able to deliver a wide variety of services. These include primary, secondary and tertiary reserves, dynamic reactive power control, fast frequency demand response and load shifting, where a unit's power consumption is moved from one hour to another and traded on the power markets. Load shifting can be done either to optimise costs or in order to optimise the integration of renewables.

Power Hub is able to transform the flexibility in a portfolio of units with stochastic behaviour, e.g. wind turbines and some industrial consumption units, into reliable services while still fulfilling the primary purpose of the industrial units. The demonstration project showed that wind energy is not only a challenge to the future energy system, but also an integral part of the solution. Power Hub showed how modern wind turbines can be used to deliver ancillary services and how wind turbines and batteries can work together.

The project has also shown how a VPP is able to combine a portfolio of both production and consumption units and how several units can be bundled to deliver a service. Another key feature of VPP technology that has been demonstrated, is how Power Hub is able to optimise across different markets and how it can decide, whether the flexibility generates most value today or tomorrow.

Power Hub has proven that VPP technology can deliver a wide range of services needed in the future low carbon power system, something that is not only relevant in Denmark, but which could be replicated in many countries across Europe. Power Hub has proven that it is economically attractive to build virtual power plants, however at the same time it was challenging to scale up the VPP on commercial terms in Denmark due to the Danish regulatory regime and market design.

FIGURE 2: THE DEMONSTRATION PROJECT 2'S VIRTUAL POWER PLANT - POWER HUB.



It is technically possible and economical attractive to build virtual power plants that controls a wide variety of producing and consuming distributed energy resources. Virtual power plants can deliver a wide range of services, that will all be needed from new sources when the future low carbon power system has to be balanced.

Demonstration project 3

Technical specifications towards offshore HVDC networks (DCGRID)

Main finding

- CO_2 emission and new DC technology costs have been detected as influent economic parameters in the economic drivers analysis.
- Simple structures (such as backbones) are feasible from both technical and regulatory standpoints and can provide ancillary services (voltage support, frequency control, PSS) and Fault Ride-Through capability to the AC network.
- The technical feasibility of an innovative DCCB was proven through successful medium-voltage power tests (at the time of writing, the assembly of the high-voltage DCCB demonstrator is nearly completed).
- In addition to the control of the converters, a DC fault detection and selection algorithm was designed and successfully tested on the low-scale DC grid mock-up.

Project description

In order to integrate large amounts of offshore wind generation into the European power system from 2020 to 2030 and beyond, wind farms will need to be developed, connected to the existing grid, and operated at the required security level for the new grid facilities of the whole power system. This will probably happen first in the North Sea area where wind generation zones have been determined, some of them far from the shore.

Traditionally, the integration of wind power is managed nationally or between two neighbouring countries. This results in radial connections for existing wind farms, mostly in AC, but also through DC submarine cables in case of a long distance to shore. Over the next 10 years and beyond, larger amounts of wind power throughout Europe, generated by wind farms far out to sea, will probably require regional approaches, based on one or several multi-terminal networks, meshed or not. This will not only bring wind power to shore at the right place, but also help smooth out any variations, offer new interconnection capacities to the electricity market, and to provide ancillary services, compensating decommissioned conventional generation.

To tackle the complex task of designing, developing and operating new trans-national grid facilities, based on existing and future technologies, the third TWENTIES demonstration project, DCGRID, examined the most suitable DC technology (Voltage Source Converter - VSC) roughly split into three time scales:

1. Short-term technical feasibility analysis (up to 2020).
2. Medium-term technical feasibility analysis (2020-2030).
3. Long-term economic analysis (2030 and beyond).

Results in detail

For the long-term analysis, a probabilistic methodology was developed to compare several possible future network topologies in the North Sea area, based on specific economic and reliability criteria. According to its actual assumptions, the study has shown that none of the topologies under concern can be definitely sorted out, meaning that refining assumptions and criteria has to be pursued, stressing at the same time that the risk level in developing and financing future offshore grids remains high.

The medium-term analysis had two goals:

I. The development by ALSTOM Grid of a DC circuit breaker prototype which passed successful breaking tests witnessed by an independent observer.
II. The design and development of a low-scale real time mock-up to illustrate the control and protection algorithms of a DC grid, as well as the interconnection of the physical DC grid to a simulated AC grid.

Two live demonstrations were carried out on 21 March 2013 in Villeurbanne and on 3 April 2013 in Lille.

The short-term analysis was backed up with simulations verifying that a step by step development starting from several radial connections was feasible. The control of the H-shaped topology (see Figure 3) was analysed in detail, and extended to the 'backbone' (either tree-like or meshed versions) and 'meshed five terminal' topologies (Figure 4). It was concluded that methods of local voltage droop control are efficient in operating the AC/DC interconnected grids, enabling to accommodate for intermittent wind generation as well as for a large range of disturbances without any need for high-speed telecommunication (so far such communication is required for DC fault detection only).

This was illustrated, along with DC grid protection algorithms, by the small-scale demonstration in Lille on 3 April 2013.

FIGURE 3: EXAMPLE OF AN 'H' TOPOLOGY

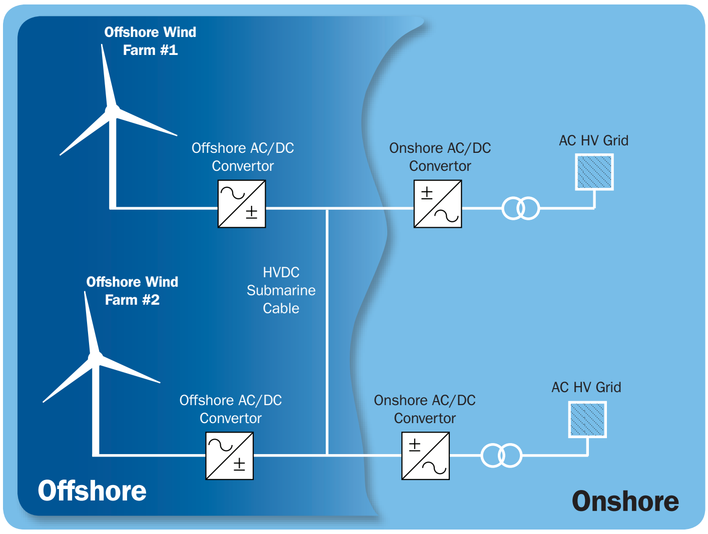
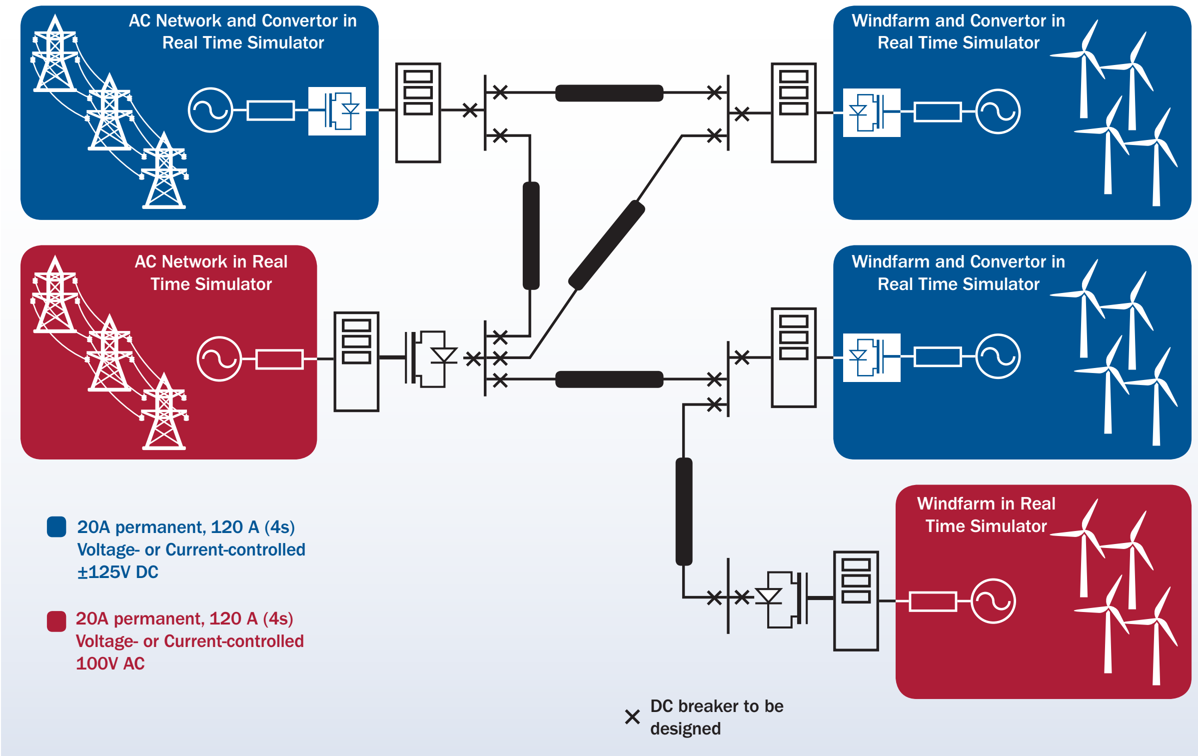


FIGURE 4: LAY-OUT OF THE MESHED FIVE-TERMINALS



Demonstration project 4
Management of offshore wind power in extreme high wind situations (STORM MANAGEMENT)

Main findings

- Wind turbine energy output was increased in stormy conditions by using high wind ride through control, which took the cut-off point from wind speeds of 25 metres per second up to 32 metres per second (m/s).
- Using of high wind ride through control reduced the risk of power system instability and blackouts.

Project description

Experience from very tough weather conditions in western Denmark during autumn 2012 demonstrated that if offshore wind turbines are equipped with new high wind ride through control, it is possible to run them for longer during periods with high wind speeds, which means there is less risk of turbine shut-down and less risk to the stability of the power system.

In addition, total output during these periods is higher from turbines equipped with the new high wind ride through control than in those with old control algorithm, which would abruptly shut down the wind farm when the wind speed went over 25 m/s. Measurements from Horns Rev II during stormy weather proved that the wind turbines equipped with the new high wind ride through control software could stay in operation in wind speeds of up to 32 m/s. The new high wind ride through controllers, developed by Siemens (installed on 91 wind turbines at Horns Rev II) leads to less abrupt changes in production for the wind farm as a whole. Wind farms with the new high wind ride through control options will in extreme weather situations experience gradual reductions in production and the mechanical parts of the individual turbine are, generally, less exposed.

In the autumn of 2012, several storms hit western Denmark. During these storms, power production at Horns Rev II hardly went down at all. Simulations show that if the old control algorithm had been in operation, the wind farm would have shut down completely (see figures opposite).

During the autumn 2012 and winter 2012/2013 storms, the extra power production with the new system was considerable. Moreover, if wind speeds are high enough to cause the power produced to decrease, the drop in output happens much more gradually than would have been the case with the old system. This was the case for the big storm on 30-31 January 2013. This is a huge advantage for balancing the electricity system.

The power system in western Denmark is operated as one area that needs to be in balance. Problems occur only rarely thanks to advanced operating systems. Everyone responsible for balancing in the power system in Denmark is obliged to update their detailed production and consumption schedules every five minutes. The detailed schedules provide Energinet.dk (the Danish TSO) with the opportunity to avoid larger imbalances by manually activating regulating power. Manual regulating power has an activation time of 15 minutes. This means that the automatic balancing system needs to be ready to handle the system imbalance that can arise within around 15 minutes. The potential of a more gradual decrease of production from a single offshore wind farm during 15 minutes allows the integration of more wind farms into the system.

Almost all power production is balanced through well-functioning Nordic power markets (both in the day-ahead and regulating power markets). Thanks to the Norwegian hydropower system, and the HVDC connection to Norway, a very high share of the wind power variability in western Denmark is balanced, today. With the new high wind ride through controller installed in offshore wind parks it is possible to integrate more offshore wind into the system without jeopardising system security at times of high winds.

The goal of doubling the share of wind power in final electricity consumption in Denmark (from approximately 25% to 50%) within seven years, along with increased growth in wind power capacity across Europe will significantly challenge the power system. Advanced controllers have been considered to effectively balance power variations between the Nordic Region and western Denmark so that power system balance restoration is possible in case of unforeseen large variations in (offshore) wind power generation.

Results in detail

This demonstration project concludes that it is possible to find a solution to future challenges with large amounts of offshore wind power production. At the Horns Rev II wind farm, the new high wind ride through control installed makes a big difference compared to old control algorithms. Not only does energy output increase, but the implications for the overall power system, such as instability or risk of blackouts.

More advanced control options will reduce the difficulties and maintain the balance in the system in high wind speed situations and keep system security at high levels as today.

The new high-wind ride through control installed at Horns Rev II wind farm increases the total wind power production. Figures 4 and 5 show the difference between power production at Horns Rev II during stormy weather conditions on 24 September 2012 (Figure 5) and 30/31 January 2013 (Figure 6), for wind turbines with the new high wind ride through control (actual measurements). The red line shows what the turbine would have produced if the old control algorithm was still installed (simulations), while the blue line shows what it produced with the new technology. The wind speed (grey line) is shown as the average wind speed over the 91 turbines.

FIGURE 5

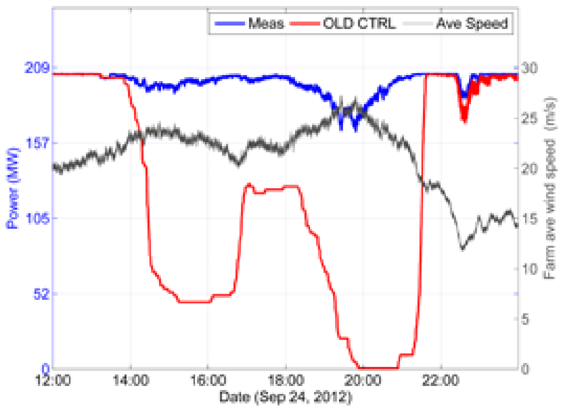
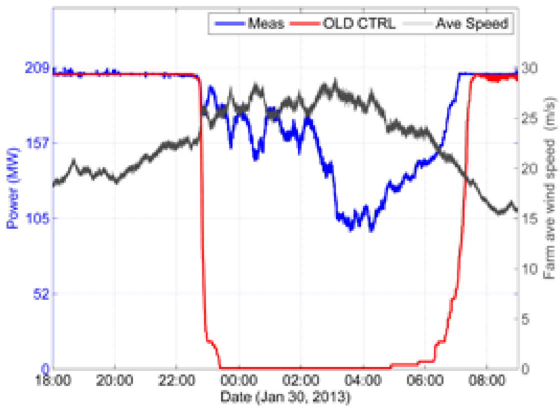


FIGURE 6



Demonstration project 5
Network-enhanced flexibility (NETFLEX)

Main findings

TSOs can plan the network more boldly by monitoring it more accurately and by controlling it more tightly while delivering the same level of reliability:

- The Dynamic Line Rating (DLR) forecaster enables to plan in average 10-15% higher transmission capacities thanks to an accurate monitoring of overhead line sag and local wind forecast.
- The Smart Controller enables to coordinate multiple Phase-Shifting Transformers and HVDC links to impact on the flows on some critical branches and to route electricity when it is needed and where capacity is left.
- In order to achieve the same level of reliability, the DLR forecaster can use a more ambitious policy as the Smart Controller enables compensating for over-estimations.
- The Smart Controller also enables to enhance wind penetration thanks to more coordinated actions on multiple Power Flow Controlling devices (PFCs).
- Damping can be reliably forecasted based on flows and injections.

Project description

The variability of wind generation creates quicker and more significant changes in the flows of electricity through the transmission network than conventional fuels. Grid reinforcements are needed to connect and integrate more wind by managing variations from wind output while keeping the same level of security of supply. Furthermore the upgrading and installation of new overhead lines and underground cables takes time. More flexible solutions are needed to cope with these variations in a timely and cost-effective way.

The goal of NETFLEX is to demonstrate that network flexibility enables more power to be transported to where it is needed without compromising operational security. It shows how a more accurate monitoring and enhancement of grid control allows TSOs to plan and operate the networks more boldly.

Dynamic Line Rating (DLR) devices like Ampacimons (www.ampacimon.com) can be installed quickly on overhead lines to provide accurate measurements of the capacity of the transmission system in real time as well as forecast up to two days ahead with a warranty of no clearance violation. Real time measurements from Ampacimon enable defining the confidence interval and choosing the appropriate level of risk. This capacity depends on wind conditions and is very sensitive at low wind speeds (0-5 m/s). Integrating this capacity into network operations requires reliable weather-based forecasts.

Power Flow Controlling devices (PFCs) like Phase-Shifting Transformers (PST) and High Voltage Direct Current (HVDC) links provide the means for changing and distributing flows locally, through ‘corridors’. But several PFCs together would influence flows over a broader area and free up more system capacity. To do so, a more sophisticated and coordinated controller was developed: a smart controller.

Phasor Measurement Units (PMU) and Wide Area Monitoring Systems (WAMS) provide real time information about system dynamics. Because these dynamics are closely related to the intrinsic features of power plants, loads and dispersed generations – and not only the transmission grid - it becomes more and more complicated to simulate them. As a consequence, planning more accurately and possibly closer to stability limits, involved finding a solution for accurately forecasting stability, which was a real challenge.

Results in detail

The demo team successfully developed a reliable

DLR-forecaster which forecasts one and two days ahead and delivers an average gain of 10-15% over the seasonal ratings (with 98% confidence). Ampacimons measurements and weather forecasts were integrated using a risk-based approach.

The project team developed a smart controller to optimise the use of PFCs for directing flows to lines which still have capacity. The controller takes conventional security criteria (N-1) into consideration and smooth the operation of PFCs while alleviating congestions. It also assesses wind deviations the system can cope with. By comparing wind deviations and the uncertainties on wind forecasts, operators can estimate which part of the remaining margin can be allocated to the market and which part must be preserved for security purposes. Tests showed that it could enable the integration of more wind power into the existing system.

To monitor and improve system stability, a damping forecaster was developed. Based on the forecasted flows and injections from some large power plants, the damping ratio of the system's dominant inter-area modes is forecast in a reliable way. The analyses have shown that the existing PFCs do not have a significant impact on the damping ratio. Hence, their use for improving damping is rather limited. On the other hand, increasing capacities through PFCs does not come at the expense of a decreased damping.

Together, the Ampacimons, the PFCs, the PMUs, the WAMS, the DLR-forecaster, the damping-forecaster and the smart controller will allow more audacious forecasting thanks to a more accurate monitoring of capacities and stability, and a tighter control over the flows. Further investigations are underway in order to identify how to increase damping both in real time and in operational planning.

A full deployment of Ampacimons and their integration into SCADAs and EMS, and the full implementation of a smart controller of existing PFCs in Central Western Europe would generate substantial economic benefits (up to 250 million EUR per year) by lowering overall generation costs for the region.

Enhancing network flexibility means the grid can be used to transport more power. It is a better way to use existing assets. It does not create permanent physical capacity as such. It allows network operators to close the gap between grid congestion and the effective commissioning of new transmission assets that takes between five and 10 years, thus effectively allowing the integration of more variable generation, in particular wind power (correlation with the cooling), with existing network assets.

Demonstration project 6

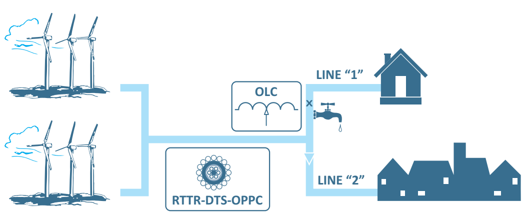
Improving the flexibility of the grid (FLEXGRID)

Main findings

- Real-time monitoring of the temperature of the power cables allows over 10% more wind-generated power to be brought onto the transmission grid.
- Excess energy can be re-directed to lines with spare capacity in order to use the transmission capacity more efficiently, increasing the controllability and security of the grid and reducing the need for curtailments.

Project description

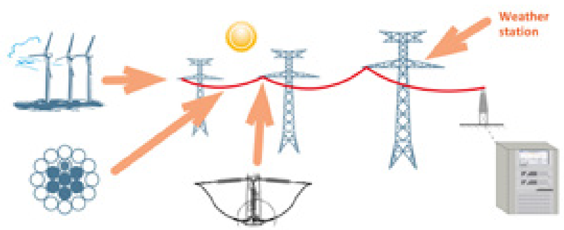
The integration of renewable energy has had a significant impact on the flow of energy through the power grid, making it necessary to increase network development while maximising the utilisation of the existing facilities. Even when the grid has been adapted to the changes, not all wind power can always be integrated, leading to curtailments. These curtailments sometimes happen when the nominal static ratings (the maximum power that can be transmitted) of the lines are exceeded, making the operation of the line unsafe. However FLEXGRID demonstrates alternatives to help optimise infrastructure and avoid curtailment of renewable generation.



Firstly the power line conditions were monitored in order to assess their maximum capacity in real time based on the real conditions rather than using static seasonal ratings: so-called 'dynamic line rating'.

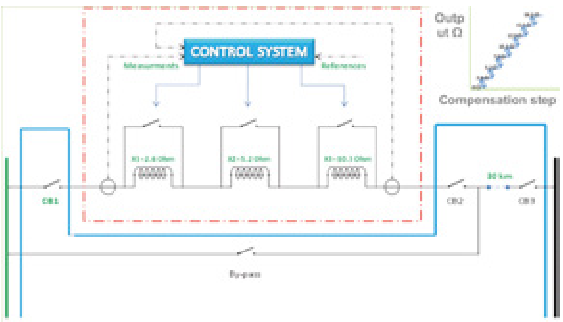
The use of dynamic line rating is closely related to wind power integration because when the wind blows harder, wind power production increases and the load factor is higher. More transmission capacity is needed in these situations. However, there is more transmission capacity because of the higher cooling effect of the wind over the lines allowing for more power to flow through them.

The temperature along the line is recorded in real time, allowing operators to obtain the transmission capacity rating. In order to assess the temperature, a special kind of conductor called an 'Optical Phase Conductor' (OPPC) is used. OPPC is a conventional conductor in which one of the wires has been replaced by a stainless steel tube in which a beam of fibre optics is integrated. Through a DTS (Distributed Temperature Sensor) system located in the substation, a laser pulse is sent through the fibre optics. By processing this signal it is possible to monitor the temperature to a 2ºC accuracy along the entire line. Alongside this technology, two hour and four hour forecast algorithms will be developed which can be integrated into any other operation tool.



Secondly, grid operators should be able to dynamically control the power that flows through the line to avoid surpassing the limit by implementing power flow control devices. These devices allow excess energy to be re-directed from one line to another with spare capacity in order to use the transmission capacity more efficiently, thus increasing the controllability and security of the grid. The use of power flow control devices is closely related to wind power integration because it is an energy source with higher variability requiring an instantaneous power flow control. The so-called 'Overload Line Controller' is characterised by the integration of traditional power solutions (reactors and switches) and an advanced control system typically implemented in Flexible AC Transmission System (FACTS) solutions based on power electronics.

This solution offers an attractive alternative in terms of functionality and cost, in comparison with other solutions. It is composed of nine reactors mechanically arranged in series, driven via individual switches and in parallel with each of the reactors. Through the optimum and controlled action of these reactors, it is possible to achieve staggered limitation of the desired power flux, allowing the overload control of the affected line in a steady and a contingency state.



Results in detail

The results of the demonstration are striking.

Dynamic Line rating:

- Acquisition of the maximum transmission capacity in real time. Most days the dynamic ratio, throughout the day, is more than 10% higher than the seasonal rating. In days with more wind, it could be more than 25% higher over the day.
- Monitoring along the entire line without having to make estimations or extrapolations. The demo records temperature every 2 metres and every 10 minutes. This provides the operator with complete certainty.
- 'Hot Spots' – areas which need maintenance - can easily be detected with this technology.
- Possibility of studying the correlation between wind production and the increase of transmission capacity in lines affected by local weather conditions.

Overload line controller:

- Control of power flows in steady state and contingency state. Control strategies based on real-time measurements and set points from dispatching centre.
- Lower cost device and maintenance compared with other power electronics solutions.
- Easily transferable to another location if necessary. Easily scalable solution in terms of size and the number of steps.

Both developments have been validated by simulations, lab testing and finally infield demonstrations. A sensible application of these new technologies would provide extra capacity for the integration of renewables, as well as an increase in operational safety. With the same level of safety, these developments will allow a more efficient management of the electrical grid:
- Increasing the availability of infrastructure.
- Optimising the management of the networks.
- Balancing the loads on the lines.
- Setting out immediate corrective actions.

Work package 15
Economic impacts of the demonstration projects, barriers to scaling up and solutions

Main findings

Taskforce 1 (Demonstration projects 1 and 2): 'Contribution from variable generation and load to system services'

- Twenties has overcome a major technical barrier preventing better use of wind generation. The capability of providing frequency and voltage control by wind farms makes it possible to reduce system operation costs and carbon emissions. However, such impact would be limited under certain system conditions, as shown in the performed analysis (Demonstration 1).
- Virtual power plants reduced marginal electricity prices by 0.25-0.4% and brought about lower total system costs in the day-ahead market (Demonstration 2).

Taskforce 2 (Demonstration projects 3 and 4): 'Allow for offshore wind development'

- New offshore network capacity that interconnects national networks allows local surpluses of wind power to be used elsewhere, reserve power to be held, and potentially cheap, zero carbon power to be used instead of more expensive higher-carbon fossil fuel plants (Demonstration 3).
- 'High Wind Ride Through' controllers can help lower reserve requirements by 50% (Demonstration 4).

Taskforce 3 (Demonstration projects 5 and 6): 'Give more flexibility to the transmission grid'

- Overhead Line Controllers (OLC) and Dynamic Line Rating (DLR) technologies have many benefits. They:
  - Enable the system to be operated more efficiently (Demonstrations 5 and 6).
  - Bring down the costs of electricity supply by reducing the need for 'out-of-merit generation' (Demonstrations 5 and 6).
  - Avoid or reduce wind curtailment, contributing to a better and more efficient integration of wind power (Demonstrations 5 and 6).

Work package in detail

The goals of WP15 are to assess the local economic impact of each demonstration project, to perform an analysis of the joint impact of all the demonstrations in each task-force, to identify the barriers to scaling up the results, to propose solutions to overcome those barriers, and to see how the different project results could impact on each other.

In Task-Force 1, 'Contribution from variable generation and load to system services', which is made up of Demonstration projects 1 and 2, the economic impact assessment performed for Demonstration project 1 shows that if wind generators in Spain used active power control, there would be less need to commit extra conventional generation to comply with reserve requirements. This would avoid wind curtailment and slightly reduce system operation costs. Based on a sensibility analysis (one result varies when you modify any variable of the model), the economic impact may be higher on systems with a high share of wind power capacity, a low share of flexible pumping-storage facilities, and where the reserve's constraints highly influence the resulting generation scheduling.

The study demonstrated that in most cases wind penetration will not be limited by the provision of voltage control by wind generators. This voltage control by wind farms causes a slight increase of active power losses in the wind farm grid that could be reduced by developing an optimised voltage control strategy.

The economic impact assessment for Demonstration project 2 showed that the implementation of the

Virtual Power Plant (VPP) concept in the Danish system is expected to reduce marginal electricity prices by 0.25-0.4% and total system costs in the day-ahead market. However, the expected reduction of CO_2 emissions is highly dependent on system configuration.

Offshore wind power development is at an early stage today. However, it will contribute massively to future European energy supply. The results of Task Force 2, 'Allow for offshore wind development', which is made up of Demonstration projects 3 and 4, suggest that new offshore network capacity which allows an increase in the exchange of power between different countries will be important for realising the full potential of new wind power developments. This new network capacity allows local surpluses of wind power to be used elsewhere, and allows reserve power to be held remote from a particular area. However, it might also allow cheap generation with zero carbon emissions in remote areas to be used instead of more expensive higher-carbon fossil fuel plants in a local area.

As offshore wind power is concentrated in relatively small geographical areas, extreme weather conditions can lead to large variations in offshore wind power production. WP15 shows that the new 'High Wind Ride Through' controllers explored in Demonstration Project 4 can help lower reserve requirements, reducing the maximum reserve to approximately 50% of the level needed previously.

In Task Force 3, 'Give more flexibility to the transmission grid', which is made up of Demonstration projects 5 and 6, the most significant economic benefit of Overhead Line Controllers (OLC) and Dynamic Line Rating (DLR) technologies tested in Demonstration projects 5 and 6 is relieving transmission congestions, which enables the system to be operated more efficiently. While Demonstration project 5 focused on the increase in net transfer capacities provided by the tested devices, Demonstration project 6 focused on local network effects. The economic impact assessment performed for each demonstration showed that OLC and DLR devices reduce the need for dispatching 'out-of-merit generation' (conventional generators which are run above what is economically optimal) in both cases, decreasing electricity supply costs. In areas with high wind potential these technologies avoid or reduce wind curtailment, contributing to a better and more efficient integration of wind power.

Despite the benefits of innovative system management approaches and the novel technologies demonstrated in the Twenties Project, some regulatory barriers still exist. One important barrier concerns the current design of day-ahead, intraday and balancing services market designs - their rules are not designed to integrate high shares of variable renewable generation. In general, three market aspects should be improved in order to favour a higher penetration of renewable generation: liquidity, flexibility and integration with other power systems' markets.

A major barrier to the development of offshore grids is related to the high investment need and cost allocation. To overcome this barrier the enhancement of the existing inter-TSO compensation mechanisms will be required as well the development of joint support instruments and targeted EU funding.

The adoption of grid technologies such as the ones tested in Task Force 3 include the establishment of economic (as well as environmental) criteria for assessing alternative solutions and the definition of standards for the use and control of these technologies. The latter is especially relevant when different TSO jurisdictions are affected, which will require the agreement of the TSOs involved.

Work Package 16
EU-wide assessment of the demonstration projects' replication potential

Main findings

Taskforce 1 (Demonstration projects 1 and 2): 'Contribution from variable generation and load to system services'

- It is socio-economically feasible to have wind power contribute to system frequency control in limited periods.
- Wind power could generate cost reductions in the secondary control reserve market by up to 24% with 99.99% reliability in Germany (Demonstration 1).
- VPPs based on biomass and heat pumps provide a 2.18% reduction in average electricity prices and a 3.46% reduction in CO_2 emissions from the German power system (Demonstration 2).

Taskforce 2 (Demonstration projects 3 and 4): 'Allow for offshore wind development'

- When offshore grids are used for hydro-wind power balancing, CO_2 prices have a major impact because they can change the merit order e.g. of gas and coal fired thermal plants (Demonstrations 3 and 4).
- Wind power forecast errors can be significantly reduced in storm periods, especially on a national level in Denmark, by high wind ride through controls. At European level, the impact is less significant, but can reduce the volume of frequency containment reserves needed to ensure secure system operation (Demonstration 4).

Taskforce 3 (Demonstration projects 5 and 6): 'Increase grid flexibility'

- Demonstration 5 showed the decrease of total generation cost by providing additional flexibility at system level thanks to DLRs and a smart controller of PFCs. Local benefits in terms of reduced congestion management costs and improved operation have been assessed by demonstration 6. Additional grid flexibility will deliver both.
- The experience gained through demonstrations 5 and 6 enables to identify where to install RTTRs or DLRs to capture the cooling benefits from wind and new PFCs for both alleviating local congestions and creating a greater effect at pan-European level.

Work package in detail

This work package aimed to analyse the technical and economic potential for the replication of the projects in large areas of the EU.

The potential for using wind power in frequency control in Germany and France was assessed, as was the economic impact of using wind power in secondary frequency control in Spain (Demonstration project 1). In general, the results show that it is socio-economically feasible to have wind power contribute to system frequency control in limited periods, although this implies that wind power production will be less than it could have been in those periods.

The German study concludes that in the right conditions, wind power could generate cost reductions in the secondary control reserve market by up to 24% with 99.99% reliability. The full potential will be deployed if wind turbines decided to bid for negative reserve products (that is, only to reduce power output) only, while bidding for positive reserve products under the current cost structure is not beneficial for wind farms.

Using a supply and demand model, the French 2020 case study concludes that less than 2% of the total required frequency control volume will be provided by wind power.

The potential for using wind power in voltage control was assessed in three wind power plants in Willich, Germany (Demonstration project 1). The cost of using wind power in voltage control varies between 0.022 € per kiloVolt amps reactive hour (or kVarh, which is the unused percentage of electricity which still has to be generated) and 0.0393 €/kVarh, depending on the different wind power plant grid layouts.

The potential for using wind power in frequency control in Germany was assessed by Demonstration project 2, which looked at the economic impact assessment of the Virtual Power Plant (VPP) in Denmark. It is concluded that the potential for VPPs based on biomass and heat pumps provides a 2.18% reduction in average electricity prices and a 3.46% reduction in CO_2 emissions from the German power system.

The potential for using offshore grids to support the use of Nordic hydro power to balance wind power generation in North Europe has been assessed in studies supplementing the general studies of HVDC networks in Demonstration 3 and the balancing of wind power variability in storm conditions in Demonstration 4. These studies have confirmed that the assumptions of the CO_2 prices can be very critical to the findings, because CO_2 prices can change the merit order e.g. of gas and coal fired thermal plants.

A survey of the plans for offshore wind power development in North Europe – including the North and Baltic Seas has estimated that there could be 40 GW by 2020 and 114 GW by 2030. This spatial concentration of large-scale wind power will increase the variability of wind power significantly in the European power systems.

Preliminary analysis of the impact of the high-wind-ride-through control capability (see Demonstration 4 for more information) has shown that the new control will reduce wind power forecast errors significantly in storm periods, especially on a national level, because the impact of the storm on power production from offshore wind power plants e.g. in Denmark is highly correlated. At European level, the impact of storm control is less significant. However, the preliminary results confirm that the new high-wind ride through controllers seen in Demonstration project 4 can reduce the volume of frequency containment reserves needed to ensure secure system operation.

A survey of the potential for increasing hydro power generation and pumped storage capacity in Nordic countries has concluded that the existing 29.6 GW hydro power generation capacity in Norway can potentially be increased by 16.5 GW, and that there is a potential for 10-25 GW pumped hydro.

This work also assesses the value of increased Nordic hydropower production flexibility and the corresponding need for transmission capacity investments. Studies of the internal grid in the Norwegian power system recommend expanding the corridor connecting the hydro plants to the Norwegian interconnectors to other European countries to be able to utilise the potential for increased hydro generation capacity and pumped storage capacity in Norway. This expansion is in line with existing plans published by the Norwegian TSO Statnett.

Preliminary results from studies of utilising hydro power in the Alps to balance offshore wind power generation in north Europe confirms that this will require grid reinforcement of the central European network to connect hydro generation in the Alps and wind power generation in the north.

Modelling grid flexibility in long-term simulation tools is very complex as it requires to integrate multiple operational strategies at once. What is more, a vast majority of today's long-term planning tools use probabilistic approaches to identify bottlenecks and grid reinforcements needed to best serve market needs. Hourly situations are treated as independent from each other in a Monte-Carlo simulation. Modelling grid flexibility requires to analyse sequences of situations to integrate decisions over one day or more. Instead, guidelines have been drafted based on the experience gained through the 2 demonstrations to plan where to install RTTR, DLR, PST, HVDC link and OLC.

Work package 17
Reframing licensing and permitting for offshore interconnectors

Offshore interconnectors play a crucial role in the EU energy system. Offshore interconnectors are transnational high voltage DC cable connections between national grid systems and are the basis for European market integration, security of supply, and integration of renewable energy sources. In the near future offshore wind farms may tee-in to offshore interconnectors, and this will enhance grid access for renewable energy from offshore wind farms.

The aim of WP17 is to make the procedure for obtaining an authority permit for offshore interconnectors more efficient and more robust by defining best practices for planning and permitting focusing on the North Sea and Baltic Sea regions. Applicable conclusions have been drawn up concerning common licensing barriers together with a proposal for concrete measures for anticipating licensing problems. WP17 looks into options for harmonising the national permitting process and for sharing standards for studying and evaluating project impacts. It results in practical approaches for making the transnational consenting processes more efficient and more effective.

Planning and permitting

We distinguish the European Commission, regional (e.g. North Sea) and national levels as the main actor levels for optimising the planning and permitting process for offshore interconnectors.

European Commission

The European Commission is a key player in promoting offshore interconnectors. The Commission is responsible for EU regulations, such as those governing nature protection, which have a major impact on marine spatial planning in general. The European Commission also plays a vital role in promoting future infrastructures with financial support schemes and its support of Projects of Common Interest (PCIs). The interests at an EU level may sometimes supersede the interest of a single member state or individual project case. In practice this means that individual member states in cross-border cable projects may not benefit equally from the project. In such project cases, the European Commission may support more coordination on the overall cable route and compensation schemes between member states in order to balance the interests of the EU and the individual member states. Additionally, the European Commission may strive for legislation concerning the harmonisation of planning processes between Member States, similar to its support of PCIs.

Regional and national levels

The coordination of routing is a key factor in the successful planning of offshore interconnectors. For national and transnational routing, the regional and national authorities play a crucial role in balancing the benefits and drawbacks between Member States and stakeholders. In practice, individual Member States and stakeholders will experience a different sense of urgency when it comes to supporting the project. Compensation schemes may be needed to overcome these imbalances between stakeholders. When it comes to Member States' legislation and policy, most current interconnector projects will have already been identified and registered in planning strategy documents. These documents identify, at an early stage and on a global scale, the possible routing, landing points and time horizon of identified projects. For the further strategic development of interconnectors, Member States should also develop a comprehensive offshore master plan covering time planning, routing and connections for interconnectors in combination with wind farm connectors. The technical requirements for combining interconnectors and wind farm connectors need further consideration.

Stakeholder management

It is essential to cooperate with policy-makers at EU and national level to encourage the development of interconnector projects.

Twenties
Transmitting wind

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TWENTIES project

The TWENTIES Project (Transmission system operation with a large penetration of wind and other renewable electricity sources in electricity networks using innovative tools and integrated energy solutions) was coordinated by Red Eléctrica de España, the Spanish Transmission System Operator, and ran from 2010 to 2013. Its aim was to advance the development and deployment of new technologies facilitating the widespread integration of more onshore and offshore wind power into the European electricity system by 2020 and beyond.

TWENTIES is one of the largest renewable energy demonstration projects ever funded by the European Commission under its seventh Framework Programme (FP7), with a total budget of over €56.8 million and an EU contribution of close to €32 million.

TWENTIES was organised around six large-scale demonstration projects grouped into three Task Forces. The demonstration projects were complemented by three work packages focusing on the replicability and scalability of the project results across the EU, and on the non-technological barriers to the development of an offshore grid.