EERA DTOC
THE EUROPEAN ENERGY RESEARCH ALLIANCE
DESIGN TOOLS FOR OFFSHORE WIND FARM CLUSTER

EERA DTOC far future scenario

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1 SUMMARY

This report describes the definition of the far future scenario (e.g post 2030), which will be investigated to demonstrate the value of the EERA-DTOC tool. Thereto it should be realized that the value of the EERA-DTOC tool could best be demonstrated by a comparison with measurements but the intended clusters for which the tool is developed are still mainly in the planning phase by which measurements to validate the tool are lacking.

As with the previously defined scenarios – the base scenario and the near future scenario – the present description is meant to be sufficiently open to leave room for the different users to calculate test cases in agreement with their needs. It is considered undesirable at this stage to provide a very detailed specification of the scenario and the different calculations to be made.

The scenarios as described in this document are denoted as the ‘far future scenario’, i.e. scenarios which include offshore wind farm clusters and grids that are not yet considered in current plans. Therefore this scenario has a more generic focus for use by strategic planners.

The approach will be the addition of new wind farms and grid infrastructure based on pre-existent installations (expansion planning). The basis for expansion could be the "near future scenario", which focuses on the Dogger Bank zone (UK).

The expansion of wind farms is considered nearby the Dogger Bank zone, with a new grid connection to Norway. Also a floating wind farm in the Norwegian waters, which is connected to this new grid, is being considered.

Main design considerations are the locations and capacities of the wind farms and grid extensions. For the Dogger Bank zone, the trade-off between wake losses of closely spaced wind farm clusters and costs of wider spacing are considered. Further, attention is given to the design aspects of the floating wind farm in the Norwegian zone, such as wind turbine sizing, floater type and layout. For the grid expansion additional or alternative connections are considered between the UK, Norway, Denmark, Germany or The Netherlands.

In this far-future scenario it is assumed that market conditions and grid codes that facilitate cross-border trading of both offshore and onshore-generated electricity are in place.

2 INTRODUCTION

2.1 Background

In WP5.3 of the EERA-DTOC project the integrated offshore wind farm design tool as delivered from WP4 is demonstrated for and by the industry on the basis of likely scenarios. The scenario described in this document is denoted the 'far future scenario', i.e. a scenario reflecting a likely future situation with a large number of existing offshore wind farms, a pre-existing offshore grid, new electrical transmission technologies and floating wind turbines. Two other scenarios, the 'base and the near future scenario' have been described previously in a separate document.

Requirements in the scenario definition are that industry itself plays an important role in them. Thereto industry partners have led the activity to define user stories [1], which complemented with the information from the present document forms the description of the scenario. Thereto the present report gives the input for the scenarios together with suggestions for calculations to be carried out.

2.2 Goal of the scenario and this document

It is important to realize that validation of the integrated design tool by means of measurements is still difficult to do on the scale of clusters because large wind farm clusters are in planning rather than in operation. Nevertheless the demonstration of the EERA-DTOC tool by means of likely scenarios enables a check on the industrial usefulness of the tool on the basis of the user requirements as defined in the start-up phase of the project and reported in D4.1 [1]. More specifically it should be shown that the tool is useful, easy to use, complete and robust. Moreover the 'steepness' of the learning curve will be determined and it will be checked which tutorials would have to be added (e.g. simple case, videos, etc.). Although a comparison with measurements cannot be made an expert view is carried out on the results in order to assess their degree of reality.

An important requirement for the scenario calculations is that all EERA-DTOC main modules (i.e. the wind module, the wake module, the grid module, the energy yield module and the cost module) are activated. The different scenarios are suitable to different degrees to test different models.

The present document should then be seen as a starting point and it describes the most important input data for the calculations and it gives suggestions for variations around this starting point in order to meet the user requirements and user stories. The input data in this document refer to the turbines, the location of the farms and the corresponding wind climate and the design of the electrical infrastructure. As such the goal of this document is to act as a time saver for users where it also provides a common basis for comparison of results but still leaving sufficient freedom to each user to calculate test cases in agreement with his/her needs. By using all the information from this document the requirement to activate each module in the tool is fulfilled. The wind climate data are used in the meso-scale modelling; the turbine data and the lay-out of the farm are used in the microscale wake modelling where the layout and the electrical infrastructure data are used in the grid modelling. This eventually leads to an energy yield production of the farm and cost estimates.

The user stories are summarized in [1] and they showed a strong interest into cluster design requirements and the determination of the optimum spacing and positions of turbines within a wind farm including the optimization of cable layout (i.e. determining optimum cable layout, electrical configuration and number of substations). It is believed that most of the user stories can be covered with the base and near future scenario but the cluster design requirements will mainly be covered in the far future scenario description.

2.3 Approach

The present report describes the far future scenario, which has been designed to demonstrate the usefulness of DTOC for long-term, strategic planning. This means planning by e.g. government, regulators, seabed owners, transmission grid owners and scientists concerned about making optimal recommendations and decisions. The scenario therefore addresses specifically the user stories related to "strategic planning". From a wind farm developer point of view this may be somewhat removed from their direct needs – however, also for such users it may be useful to study a far future scenario in order to provide input to their long term planning.

3 SCENARIO DESCRIPTION

The context of the scenario is a post 2030 situation where many offshore wind farms have already been installed and an offshore grid infrastructure is in place, which connects the countries around the North Sea. In this far future scenario, three new wind farm clusters are considered, as illustrated in Figure 1. The red dots and lines represent potential new wind farm clusters and connections. One particular wind farm cluster (A) is singled out for more detailed analyses (shown in cyan in the figure). Another one (B) has a location, which is not precisely given, and instead left as part of the scenario analyses to determine.

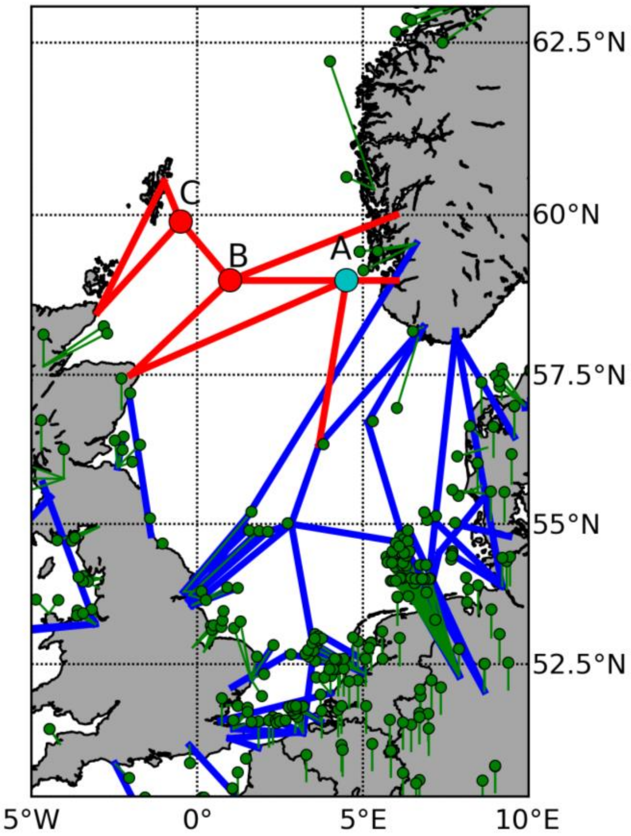


Figure 1: Possible starting point, showing assumed existing wind farms and grid in green and blue, and new wind farms and potential grid connection options in red. The cyan dot represents a wind farm cluster to be studied in more detail.

3.1 Development Area Location and Description

The far future scenario includes three wind farm clusters located in the northern parts of the North Sea as shown in Figure 1. Wind farm cluster C is placed in relatively deep sea (about 200m) off the coast of South East Norway, suitable for deployment of floating wind turbines. The two other wind farm clusters, B and C, are located in medium water depths (about 100m) on the British seabed. The precise location of the middle wind farm can be one of several options, and it is left for the analyses using the DTOC tool to determine the best alternative.

Wind farm cluster A:	latitude=59.276,	longitude=4.54
Wind farm cluster B:	latitude=59.5,	longitude=1.0 (plus variations)
Wind farm cluster C:	latitude=59.884,	longitude=-0.826

3.2 Wind turbines

The far future scenario considers wind farms, which consist of hundreds of floating wind turbines, based on the HyWind design. The floating wind turbine is based on the benchmark model developed by the Offshore Code Comparison Collaboration (OC3) [2]. OC3 is an international collaboration established to verify the accuracy and correctness of aero-hydro-servo-elastic codes used for offshore wind turbine simulations. The main activities in OC3 include developing benchmark models and simulations and comparing simulation results. The model used here is a wind turbine installed on a floating spar-buoy support structure, which is an adapted version of the Hywind demo. Hywind is a full-scale deep-water floating wind turbine that has been in operation since 2009 [3][4].

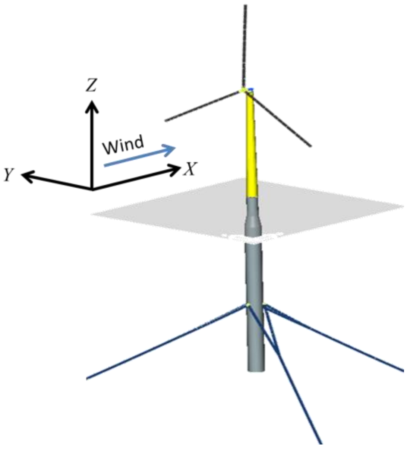


Figure 2. Spar-buoy floating wind turbine [4].

Wind turbine specification

Similarly to the near future scenario a 10 MW turbine is selected. Such turbines are not on the market yet. Therefore the INNWIND.EU reference turbine is proposed since the data of this turbine are already made publicly available by DTU. The main characteristics of this turbine are:

- Rated power: 10 MW
- Rotor diameter: 178.3 m
- Hub height: 119 m
- Wind class: IEC class Ia
- Regulation: Variable speed, collective pitch
- Orientation of rotor: Upwind, overhang 7.1 meter
- Cut in wind speed: 4 m/s
- Rated wind speed 11.4 m/s
- Cut-out wind speed 25 m/s
- Minimum rotor speed 6 rpm
- Maximum rotor speed: 9.6 rpm (maximum tip speed: 90 m/s)
- Gearbox: Medium speed, Multiple stage generator

A detailed description on the turbine including a power curve and C_{Dax} curve as needed in many wake models can be found at: http://dtu-10mw-rwt.vindenergi.dtu.dk/

Floating Spar specification

The floating spar platform is based on the description found in [5]. The equilibrium stick-up position above mean sea-level should be 10 m. To achieve this, the spar mass has been slightly modified, as the mass of the mooring lines will pull it slightly down. This occurs due to the fact that in [5] the mooring lines are modelled as massless springs. The platform has a slimmer section at the top where the wave loads are largest, and a larger diameter cross section at the lower part. The two are connected using a tapered section. The platform is regarded as a rigid body. The mass and inertia are modelled in one point by a point mass and their respective inertias. The buoyancy of the structure is based on the displaced water volume of the submerged part of the platform. The water density is 1025kg/m3. Parameters used for the floating substructure are listed in Table 1 [4].

Table 1. Key parameters for the floating substructure [4].

Parameter	Value
Total length of platform	130 m
Elevation of platform above SWL	10 m
Draft below SWL	120 m
Platform diameter above taper	6.5 m
Platform diameter below taper	9.4 m
Top of taper (nominal position below SWL)	4.0 m
Bottom of taper (nominal position below SWL)	12.0 m
CM of spar buoy (nominal position below SWL)	89.9 m
Elevation of mooring line connection (below SWL)	70 m
Mass or spar buoy	7326 t
Platform roll inertia about CM	4.23e9 kg m^2
Platform pitch inertia about CM	4.23e9 kg m^2
Platform yaw inertia about centerline	1.64e8 kg m^2

* t = metric tonne, CM = center of mass, SWL = sea water level

Mooring lines

The mooring lines are modelled as structural beam elements with very low bending stiffness and realistic axial stiffness according to data received from Statoil. Each mooring line consists of 106 beam elements, which are subjected to wave loads and drag forces based on the structural response. The specifications of the mooring line data will not be presented due to confidentiality issues. The mooring lines have a clump weight of about 35 tons attached about 300 m from the spar buoy. This ensures that the mooring lines are always subject to tension and keeps the lower part of the mooring lines from touching the seabed. The mooring line mass and hydrodynamic properties influence on the dynamic behaviour of the spar platform. They represent the actual physics of the system as close as possible with the model data available at the time of the work. Figure 3(a) shows the complete floating wind turbine with spar buoy and mooring lines, and Figure 3(b) shows the delta connections of the mooring lines to the spar buoy.

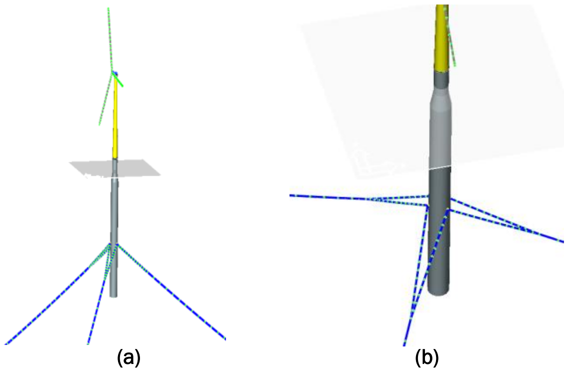
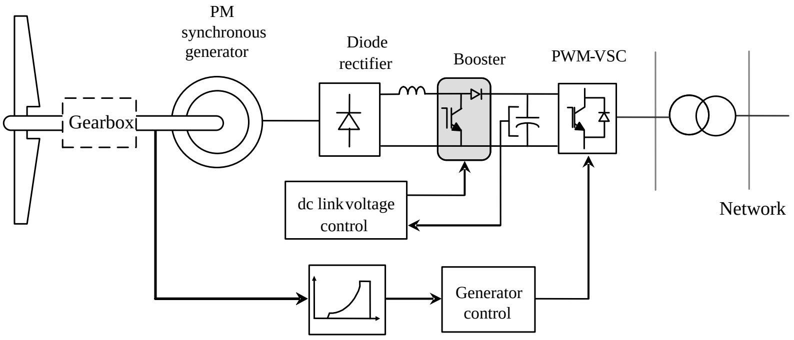


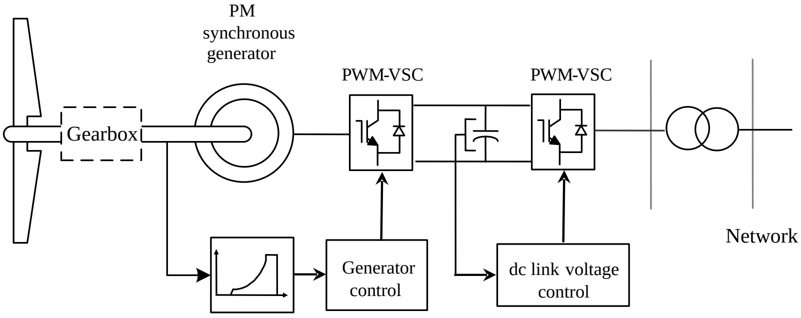
Figure 3. (a) Complete wind turbine with spar buoy and mooring lines, with delta connection and clump weight, (b) Mooring lines shown with delta connection to spar buoy (zoomed in view).

Electrical System.

From the electrical point of view, for the purpose of AC grid stability simulations, wind turbine models are described by wind conversion technology according to the new IEC standard, the IEC 61400-27-1, in four categories: type 1, 2, 3 and 4, were types 3 and 4 are the most relevant including (DFIG, SCIG, WRSG and PMSG). The Fully-Rated Converter Wind Turbine topology (type 4) is proposed in line with the Hywind Scotland Pilot Park Project EIA Scoping Report [13].



(a) Permanent Magnet synchronous generator with diode rectifier



(b) Permanent magnets synchronous generator with two back-to-back voltage source converters

Figure 4. Fully-Rated Converter wind turbine technologies [6].

3.3 Offshore wind farm clusters

It is assumed that each offshore wind farm cluster identified in this future scenario (A, B, C) has a wind energy potential of at least 3GW, with individual wind farms reaching up to 1.2GW. The wind farm inter-array design will be based on the descriptions provided in D2.2, "Design procedure for inter-array electric design". Two basic designs are proposed as shown in Figure 5 based on electrical collectors currently used in existing offshore wind farms [6].

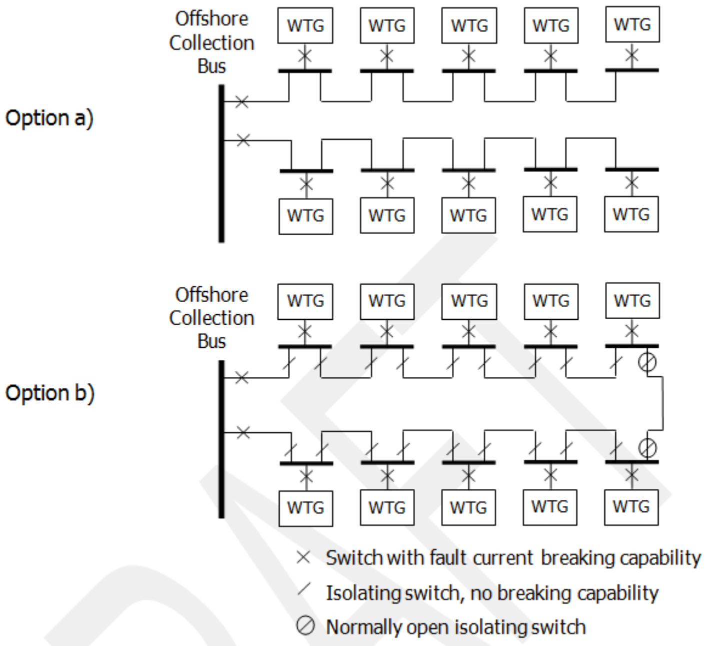


Figure 5. Wind farm electrical collector basic designs.

Option a - Simple radial strings.

This grid has no redundancy and a fault on any section of a string would take out the entire string for as long as the fault occurs. There are no means to isolate the fault remotely, which is a great disadvantage as an offshore repair can take a considerable amount of time. No part of the power generated along a string can be exported for the duration of the outage. Moreover, supply to the wind turbine generators (WTGs) auxiliary demand would be lost, therefore diesel generators would be needed on each of the WTGs to provide supply to the essential demands. It could take three months to repair a cable, during which time fuel supplies for the emergency generators would have to be maintained to the WTGs affected and this could be very difficult during winter sea conditions.

Option b - Fully flexible strings.

This array configuration allows the faulted section to be isolated for repair and get the normally open link closed between the two feeders remotely to restore an electrical link with most if not all of the WTGs. The great benefit of this arrangement is that supply to the essential demands of all WTGs can be maintained after a fault on a cable string. In this way, at least a proportion of the generation capacity can also still be exported, depending on the fault location, the selected cable ratings and whether their sizes are tapered (lower rated cables are used for the sections near the end of a string). This is much better than not being able to export any power specially when considering that the load factor of wind generation is often less than 35%.

In practice, the WTG layout is normally given as an input to the collection network design and the cables are routed for connection to the WTGs such that cable costs and conductor losses are minimised. This is achieved by minimising the total cable length and applying a similar utilisation (peak power/rated power) to all cable strings as much as possible.

3.4 Offshore grid infrastructure

It is assumed that a meshed grid infrastructure with some offshore substations already exists, and that this is identical to the *Split Design* alternative described by the OffshoreGrid project [7]. This pre-existing offshore grid is shown in blue colour in Figure 1.

The DTOC tool, via the Net-Op module, may be used to determine an economically sound offshore grid expansion that takes into account the existing grid and to some extent future market conditions. For this, price levels and price variations at potential onshore connection points have to be assumed, i.e. provided by the user.

The existing grid is also relevant for grid code and grid stability analyses applying the relevant EERA-DTOC procedures [8][9].

3.5 Wind power markets

In the current electricity markets in Northwest Europe the electricity prices show considerable differences, which can partly be explained by different incentive schemes, generation mix and limited international trade. In countries with relatively high penetration of intermittent generation like wind energy prices already tend to decrease in periods of higher production, in particular during the night hours.

For the future scenarios it is assumed that cross-border trade will be much further developed, both in terms of grid reinforcements, such as interconnectors, and market reforms and harmonization, as the simplified model considered in the OffshoreGrid project.

The likely effect of the future higher penetration levels of renewables is a stronger decrease of the prices during hours of high wind production.

This increased price volatility will affect both the design of the wind farms, for instance the specific power density of the turbines, and the sizing of the electricity infrastructure, relative to the capacity of the connected wind farms. Also the flexibility to sell wind power to neighbouring countries and the geographic distribution of the wind farms are aspects to consider in the design.

As future markets are very difficult to predict, only a fictitious example can be presented in the scenarios without any quantitative significance.

Another aspect of the far future scenarios is the provision of ancillary services. Currently the European TSOs and DSOs are in the process of defining a market framework for ancillary services and future European grid codes will include requirements for ancillary services [10].

The design of the far future offshore wind farm clusters and offshore electricity infrastructure has to include the provision of the likely mandatory ancillary services. Also the design should value ancillary services provision as well as produced electricity.

3.6 Grid connection technologies

The complexity and bulk of wind generators and offshore wind farm structures continuously increase. Under this context the wind system integration and the operation of the electrical grid with dispersed wind farms is becoming multifaceted. As technology advances and integration challenges grow, novel and more ingenious solutions for the operation, control and protection of both OWFs and the power grid are expected in the far future scenarios. Due to the long connection distances involved it is assumed that offshore connections will be based on HVDC transmission in both point-to-point and multi-terminal arrangements. It is believed that the core technology will be the same as the currently existing one but incorporating different features which make it more efficient, reliable and cost-wise feasible. It is also assumed that submarine cable technology will developed at a steady pace to make practical the transmission of large amounts of offshore wind power with losses and with lower requirements for introducing compensation equipment. Therefore it is considered safe to assume that studies on future scenarios may be conducted using current technology bearing in mind that sensible adjustment would be required in terms of efficiencies and costs.

Particular enabling technologies that may have a significant impact on offshore developments include subsea substations. More details on this are provide as per reference [6]. Platform-based substations are used at present for the connection of offshore wind farms. As deep waters (>40 metres) are explored for the deployment of WTGs and non-fixed devices for the capture of wave and tidal energy, then subsea substations may become a competitive alternative to platform-based substations. The technologies for subsea substations have so far been developed for offshore oil and gas industrial installations. The electricity generation industry is only recently becoming involved especially for tidal and wave energy generation. The major obstacle to using subsea technologies so far are the (i) high costs; (ii) health and safety risks associated with installation and maintenance; and (iii) most subsea technologies are still limited in voltage levels. The essential components required for a subsea substation are briefly reviewed next.

- The largest voltage rating of a constructed and tested subsea transformer to date is 50 kV. Higher voltage levels will be needed for longer transmission links.
- Subsea connectors can be split into two categories; ‘wet mate’ where the physical connection can be made whilst submerged, and ‘dry mate’ where the connection must be made above the surface before submerging the connector. This would require a ship, platform or similar. A ‘wet mate’ connection cannot be made whilst the line is energised; however, cables can be connected without regard for water ingress as the connectors contain a system for ejecting the water from the connection area.
- Wet mate connector designs are far more complicated than dry mate versions and therefore are more expensive. However, costs may be offset against the simpler cable design and installation, which does not need to include making the connection to the item of plant above the surface before lowering both the cable and plant to their subsea positions. Dry mate and wet mate connectors have been demonstrated up to 33 kV. Future designs are in place for dry mate connectors at 145 kV however no such plans are in place for wet mate connectors.
- The oil and gas industries have operational subsea switchgear at 24 kV, which utilise a magnetic actuator system. The significant benefit of this system is that it is largely maintenance free. There are proposed designs for 33 kV subsea circuit breakers, but early indication is that a motorised spring charge actuator system will be used. Such a system requires periodic maintenance and is therefore not ideal.

3.7 Available Meteorological and Reanalysis Data

The wind conditions for the various locations will be provided by DTU WRF runs.

Data provided by CorWind model is used to create long-term correlated time series used during the variability and predictability analysis and the optimization of the grid layout.

3.8 Grid Optimization and Constraints

The optimization of the grid layout in the far future scenario in EERA-DTOC is implemented in two different stages inasmuch as two different potential users are addressed in this scenario: the Strategic Planner and the Developer.

In Stage I, for the Strategic Planner, the aim is to expand an existing offshore infrastructure considering the location of new wind farms, the required expansion capacity and technology to connect the new wind farms and the analysis of reserve and balancing power provision capabilities.

The main tool to implement is the NET-OP model, which will use the existing grid infrastructure description and the location of the new development areas for new wind farms to create an optimized expansion grid layout based on the required transmission capacities and the energy prices in the connected countries.

The DTOC-WCMS is used to calculate the possible capabilities to provide power reserve and balancing power at the connection point (POI) of the new wind turbines based on historical data.

The CorWind model will provide the correlated time series of power in-feed generated by the old and new wind farms on the analyzed area.

This constitutes Stage I in the far future scenario.

In the case of the Developer the investigation will be focussed in one of the new developed wind farms, creating and analyzing the inter-array design which will be based on the descriptions provided in D2.2, "Design procedure for inter-array electric design".

The main analysis tool is the EEFARM II module, used to create the inter-array infrastructure needed for the new wind farm as long as the related transmission infrastructure to connect this wind farm to the shore exists. The outcome of NET-OP in the previous stage gives EEFARM II the main constrains related with minimum and maximum required capacities and the implemented technology (AC or DC), to further investigate the characteristics of the inter-array, the electrical losses, the availability and the provision of active and reactive power. EEFARM II provides also a well-described grid layout for further analysis, namely Ancillary Services provision and the analysis of grid code compliance of the new infrastructure.

In this stage, the DTOC-WCMS will use the wind farm description and the electrical grid infrastructure to analyse in detail the historical availability of power reserve as well as balancing power based on forecast (and depending on its quality). Also the capabilities of reactive power contribution to the onshore nodes will be thoroughly analyzed.

Finally, the procedures described in D2.5 "Procedure for Verification of Grid Code Compliance" are used to determine if and to which extent the new grid layout is in compliance with the most advanced grid codes.

This constitutes the second analysis stage in the far future scenario.

4 SCENARIO ANALYSES

This section outlines some relevant analyses that can be performed with the DTOC software and associated procedures.

4.1 Offshore grid optimisation

The DTOC module Net-Op is to be applied to perform an automated high-level grid connection design process for the indicated wind power clusters and connection points. Required input data for the process are

- wind power time series for the wind clusters (A, B, C) as well as for other wind power in-feed in the relevant regions, obtained e.g. from the DTOC CorWind module
- power demand variations (scaled versions of current profiles)
- generation capacity and costs per generator type (based on scenarios, e.g. as assumed in the OffshoreGrid project)
- grid infrastructure cost parameters

The analysis takes into account wind variability and power demand, and different assumptions regarding cost parameter assumptions, and location of wind cluster B will be investigated.

The outcome is a specification of those offshore nodes and connections to be realised, the number of cables and their total capacities, and the annual cost – benefit estimates associated with the solution.

In addition to determining economically sound offshore grid alternatives, this analysis can be used to investigate the impact of high wind power penetration on the offshore grid design.

4.2 Wind farm lay-out and electrical infrastructure

The electrical cabling will be installed on top of the sea bottom, partly free hanging. Input for installation costs, failure rates as well as repair times and costs are not known and need to be provided by industry parties.

In case of severe maintenance of the turbine (structure) or failing cable connections a ring structure might increase the availability and therefore be cost effective. In order to limit the costs for platforms and cabling the location of the floating will be chosen such that the array cables either connect directly to an onshore substation or to a nearby offshore substation in shallow waters.

Future electricity markets are likely to show higher volatility in prices, i.e. lower prices at high wind speeds. For offshore wind farms this may influence the design, such as enlarged rotors, wider inter-turbine spacing and cluster spacing, leading to a higher number of full-load hours per year.

Higher market penetration of renewables and future market harmonisation will lead to higher demands of electricity trade, both for offshore and onshore generated power. This will encourage investments in offshore electrical infrastructure for cross-border trade, eventually also integrating offshore wind farms.

Another effect of high penetration levels of renewables is the need for system services, such as balancing reserve and voltage support. The far future scenario will describe several solutions to provide these ancillary services with their design requirements. The value of ancillary services is difficult to estimate as there is no market mechanism for these services and their need is highly dependent on the location and grid operating conditions.

The far future scenario includes large offshore wind farm clusters, which require careful choice of the wind farm location. The DTOC tool is designed to facilitate optimization with respect to wind farm location and layout in relation to neighbouring wind farms and other sea users, and minimizing investments and operational costs for the electrical infrastructure.

The scenario is designed as a stepwise expansion of existing infrastructure. Splitting up the development in steps helps to compare different expansion options and shows planning issues that may arise.

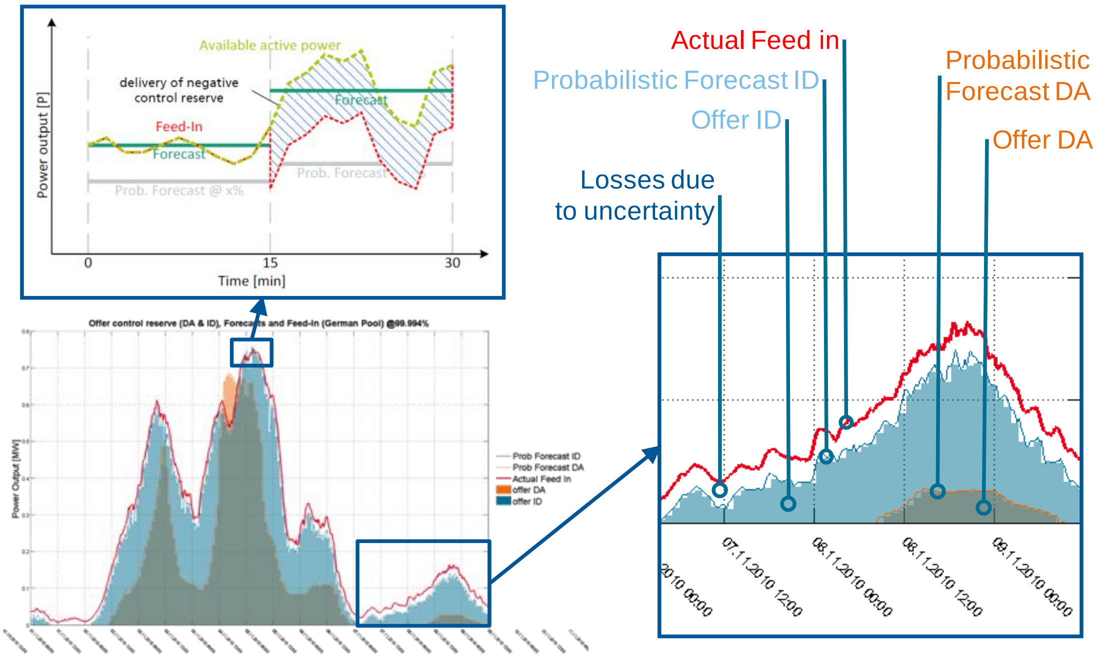
4.2.1.1 Ancillary Services provision analysis

At this stage, the provision of system services is investigated. The system services considered are:

- Reserve and balancing power provision:
- Voltage Support: reactive power contribution at onshore nodes;

The detailed description of those analyses is commented in [12]. For reserve and balancing power provision, Figure 6 provides a graphical representation. This is the main analysis performed in Stage I of the far future scenario.

Based on the day-ahead forecast the amount of available power for the next day is calculated. This amount of power (minus a safety margin) is possibly available as reserve. Based on the hourly intra-day forecast, the WCMS estimates the available power for the next hour. This value is available to be traded on the intra-day market.



Source: Malte Jansen – Fraunhofer IWES

Figure 6. Graphical representation of the data analysis performed by the DTOC-WCMS: based on forecasts, the day-ahead power is calculated to estimate the available reserve.

When a complete electrical description of the grid is available, like in stage II of the far future scenario investigation, estimates the DTOC-WCMS for all calculations the status of the grid and - for lower and upper values of possible power output- estimates the status and informs if any measured value (active/ reactive power output, currents, voltages, etc) could be out of range.

The difference between the real power output (given by CorWind time series) and the addition of offered power (as reserve, active power and balancing power as a function of forecasted values) are the losses due to forecast uncertainties (Figure 6).

An analysis regarding the voltage support capabilities is also performed in stage II. The preferred investigation (or scenario to be investigated) regarding the voltage support with wind farm clusters is represented in Figure 7, as an example.

Controlling the assets of this portfolio in a coordinated way, a specific response in one or more nodes into the grid can be achieved.

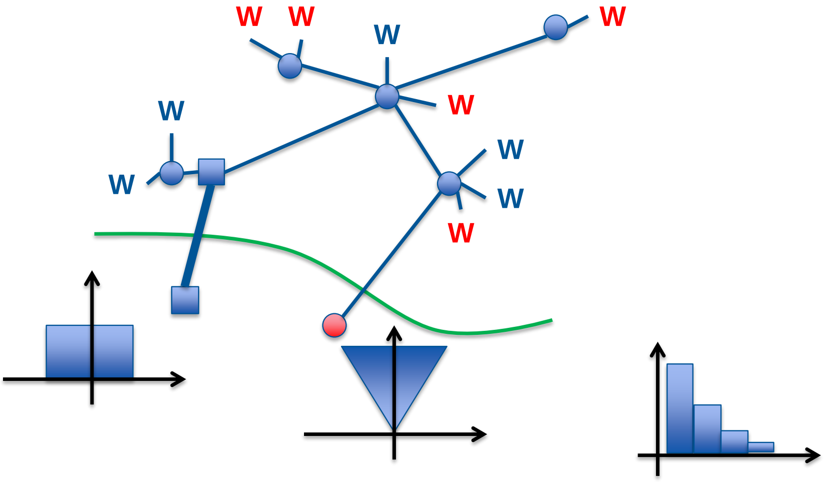


Figure 7. Graphical representation of the scenario for voltage support investigated by the EERA-DTOC WCMS: possible reactive power (Q) contribution calculated at onshore connection nodes. Different clusters are investigated based on the ownership of the Wind Farms (denoted by "W"). Wind farms belonging to the same owner are represented with the same colour.

In the context of this scenario, the software calculates the possible maximum contribution of reactive power at onshore nodes and creates a PQ diagram based on wind turbines/ wind farm capabilities. At the same time creates a histogram depicting how many hours per year the contribution could be 10%, 20%, until 100% of the wind turbine installation.

4.3 Dynamic stability and grid code compliance

Assessment of dynamic stability in future power systems may still be valid using current approaches, as onshore AC networks will still be dominated by conventional plant based on synchronous machines. Hence, the concept of power system stability as we know it right now may still prevail. However, with offshore power networks being dominated by power electronic converters, it may be necessary to make adaptation in the analyses due to the fact that converter-connected generation behaves differently from conventional plant. Nevertheless it can be assumed that current practices to assess power system dynamic performance as those indicated in [8] can still be applicable to future networks with the proper caveats.

Regarding grid code compliance in future power system it is important to note that traditionally, wind power has not been required to provide ancillary services like conventional plant. However this is set to change in the future as now grid codes are requiring these services in emerging documents and particular performance is being requested from high voltage direct current connections and DC-connected wind farms [10][11]. A change in the procedure to test grid code compliance of future networks is the introduction of additional requirements brought about by the need to provide these ancillary services. However, the procedure recommended in [9] will still be applicable.

4.4 Wake effects and Energy yield estimation

Wake modelling will be included in the present scenario but it is not expected to yield much additional insight compared to the insights gained from the base and near future scenario in which micro-scale wake models and meso scale wake models have already been applied to analyse internal wake effects and farm-farm wake effects. The 3 wind farms A, B and C are most likely sufficiently far away from each other to expect farm-farm wake effects. For the calculation of internal wake effects the end users are left free on which model to use. Obviously their choice should be documented in the output document so that it can be taken into account in the final evaluation of the results. Floating versus fixed mounted wind turbines has a meteorological impact (movements of the turbines leading to more wake dynamics) but this is an aspect that is not taken into account in EERA-DTOC.

5 GLOSSARY

Ancillary services: are all grid support services required by the transmission or distribution system operator (TSO/DSO) to maintain the integrity and stability of the transmission or distribution system as well as the power quality[1].

Cluster: see Wind Farm Cluster.

Connection Point: The interface point at which the Power Generating Module, Demand Facility, Distribution Network or HVDC System is connected to a Transmission Network, offshore Network, Distribution Network, or HVDC System, as identified in the Connection Agreement.

Intra array design: Covers the design aspects **between** the wind farm

Inter array design: Covers design aspects **within** several wind farms

Point of Interconnection (POI) or Point of Connection (POC): is the point at which the Wind Farm's electrical system is connected to the public electricity system.

Wind Farm (WF): defines the aggregation of a number of WTs connected to the same substation (or collector system station), and controlled by only one autonomous WFC. WF have one only POI and one WFC.

Wind Power Plant (WPP): set of independent WF controlled by a unique WFC which operates and manages the entire set of WF as a power plant. A WPP could implement one or more than one POI but only one WFC.

Wind Farm Cluster (Cluster): set of independent WF/WPP controlled by their own WFC that are jointly managed by an special control system operating each single WF/ WPP in a coordinated manner through their own WFC. The pooling of several large wind farms to clusters up to the GW range facilitates the integration of large amounts of variable generation into electricity supply systems. Cluster management includes the aggregation of geographically dispersed wind farms according to various criteria, for the purpose of an optimized network management and optimized generation scheduling. The scope and size of a Cluster is mainly limited by the services provided, namely: in case of frequency control, the WF/WPP integrating the Cluster could be disperse and far away one from the others; providing voltage control, due to the locality of the phenomena, integrating WF/WPP must either connected to the same POI or located nearby to provide effectively the intended service.

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[1] Refer to (EURELECTRIC, 2004)

6 LIST OF ACRONYMS

DFIG	Doubly-fed Induction Generator
DTOC	Design Tool for Offshore wind farm Clusters
DTU	Danmarks Tekniske Universitet (Technical University of Denmark)
ECN	Energieonderzoek Centrum Nederland (Energy Research Centre of the Netherlands)
EERA	European Energy Research Alliance
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
FRC	Fully-Rated Converter Generator
GW	Giga Watt
HVAC	High Voltage Alternate Current
HVDC	High Voltage Direct Current
kV	kilo Volts
KVT	Kjeller Vindteknikk AS
MW	Mega Watt
NC RfG	ENTSO-E Network Code for Requirements for Grid Connection Applicable to all Generators
O&M	Operation and Maintenance
PMSG	Permanent Magnet Synchronous Generator
SO	System Operator (indistinctly TSO or DSO)
TSO	Transmission System Operator
TYPE 3	Variable speed, double-fed asynchronous generators with rotor-side converter
TYPE 4	Variable speed generators with full converter interface
UK	United Kingdom
WP	Work Package
WRSG	Wound Rotor Synchronous Generator
WTG	Wind turbine generator

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