ETIPWind Roadmap

Grid & system integration

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ETIP Wind

EUROPEAN TECHNOLOGY & INNOVATION PLATFORM ON **WIND ENERGY**

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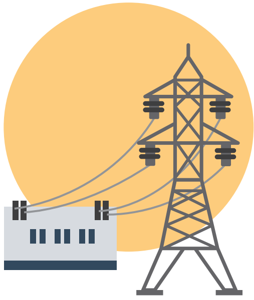

Grid & system integration

Wind energy has become a mainstream source of power generation, meeting 14% of Europe's power demand.[1] It will become the backbone of Europe's energy system, with estimations for the share of wind energy in the power mix ranging from 30% to 50% and more by 2050.[2] The International Energy Agency (IEA) estimates wind will become the largest power source in Europe by 2027.[3]

A renewables-based power system will be distinctly different from the current system. Research is needed to identify and quantify the stability needs of the future power system and innovative technologies will help establish a new grid architecture that values flexibility, efficiency and reliability.

Integrating these vast amounts of variable renewable energy in just a few decades will require a new range of technologies and solutions for system operators, as well as an updated market design. In particular innovation is needed to facilitate communication between wind power plants and system operators, to develop more robust technologies for grid integration and for transferring wind power quickly, efficiently and safely from the site of production to wherever it is needed.

Apart from including more variable renewable energy sources, the future electricity system will also be much larger than the current one. As shown earlier the electricity demand is set to at least double by 2050. Development of enabling technologies for direct and indirect electrification in other sectors will maximise the decarbonisation potential of green renewable power. Short- and long-term storage solutions will help overcome periods of low natural resources without relying on polluting fossil fuels.

Challenge 1

Preparing the system for 100% of renewables

As more and more Member States will increasingly rely on variable renewables to decarbonise their economies, the power system will undergo a transformation. Currently renewable power operators are asked to emulate conventional power plants. This is an ineffective use of the resources and often leads to additional costs. There will be a shift from demanding renewables to adapt to the existing system to demanding the existing system adapts to renewables.

This shifting notion of how the power system works will raise some significant challenges. As more distributed generation will enter the grid, it is essential to enhance and accelerate communication and coordination between all actors including plant operators, system operators (TSOs/DSOs) and consumers. With increased digital communication, data management and cybersecurity becomes paramount. In a converter-based grid, optimising the use of existing grid infrastructure and developing High Voltage Direct Current (HVDC) technology and grid-forming capabilities will be essential. In addition, hybrid projects and virtual power plants need to be demonstrated at larger scale and across Europe.

Challenge 2

Flexibility at the heart of a 100% renewable system

To decarbonise the EU economy more variable renewable energy power plants will be installed in Europe and wind is set to become the largest source of electricity in Europe. In the short term this will require grid operators to add more flexibility to the grid. A lack of flexibility in hardware and software at system level would lead to unnecessary and unsustainable costs. The need for flexibility is present at various time intervals. Real-time flexibility is needed to stabilise the system, short-term solutions to balance the system and sustaining system adequacy will require solutions operable on the long term.[4]

Wind farm operators can also be expected to take on more and different responsibilities towards grid management by providing ancillary services, and to develop new solutions to decouple energy production from energy harvesting, so that power can be provided to the system when resources are low. This requires innovation in short-term and seasonal storage, multi-cultured wind farms (wind farms with more than 1 type of turbine installed) and hybrid systems. At the same time, more accurate and precise forecasting of both power production and demand well help to better link demand and production and ensure optimal use of available resources.

Wider regulatory requirements

Whilst new technologies will help manage an energy system with high shares of renewables, the capabilities to absorb high shares of wind energy are more determined by economics and market design. Technical constraints exist, but market barriers and existing operating paradigms and principles are often more restrictive. To ensure optimal integration of wind energy in the system policymakers should tackle following regulatory issues for a sound implementation of the Clean Energy Package:

- Increase flexibility in the electricity market design so that it can integrate new technologies and adapt to their characteristics (e.g. by updating the market, operation and connection codes), in line with article 59§2 and article 60 of the recently adopted Electricity Regulation;[5]
- Establish effective intraday markets so that electricity can be traded as close to the moment of production as possible, in line with article 6§4 of the Electricity regulation;[6]
- Enable daily procurement of balancing reserves to allow variable resources to participate and products should be short to reflect real-time variability as stated in Annex 1 of the Electricity Regulation;[7] and
- Promote virtual aggregation of different power generation technologies as a standard practice, rather than an exception.

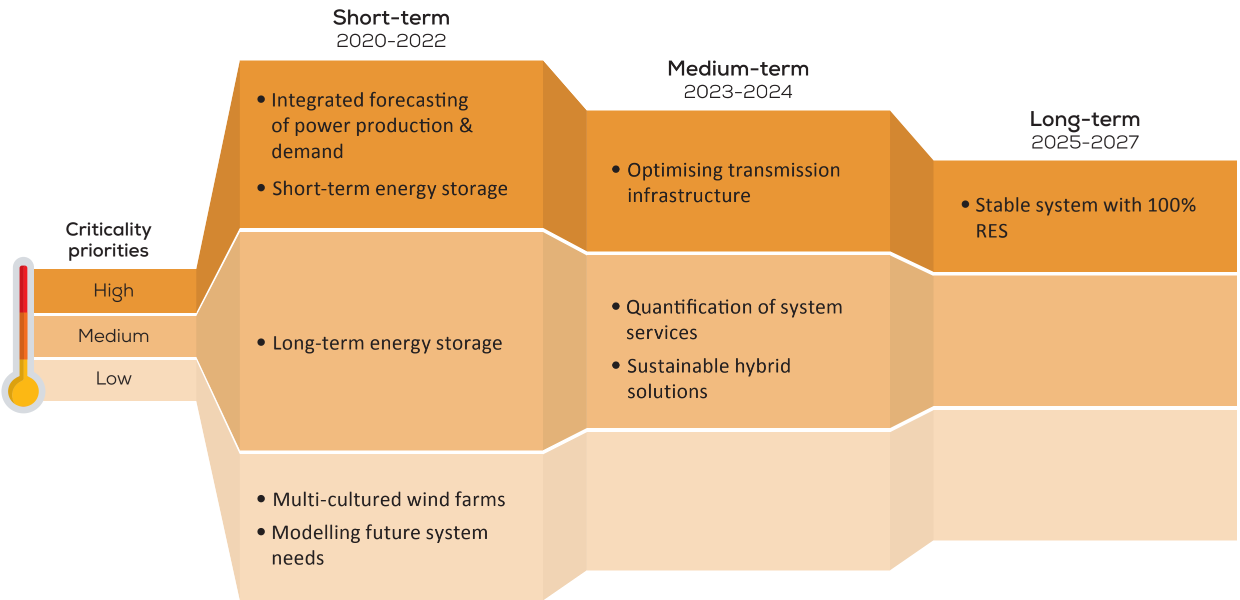

Figure 6 Research & Innovation action areas for grid & system integration

Challenge 1.1

Towards a system fit for 100% of renewables

Integrated forecasting of power production and demand	Sort-term	High priority

Description and scope

There is a need for more accurate and disaggregated forecasting of both power production and power demand to further optimise wind power operations, both in terms of power production and fleet maintenance. To maximise the use of available renewable power, better predictions of local demand should be shared with local power producers such as wind farm operators.

A clearer understanding of the demand profile from off-takers and/or other production/consumption technologies will help development of Virtual Power Plants and ultimately better inform consumers to sign renewable Power Purchase Agreements suited to their needs. Understanding the effects of new loading profiles from e-mobility or electrification of other sectors such as heating and industry on distribution systems will be essential to ensure clean renewable e-mobility has the lowest possible impact on the grid.

Recommended research actions

- Develop harmonised and standardised data models to be used for new data sets.
- Create, aggregate and integrate various data sets to be used across all of the above use cases.
- Adaptat and integrate existing forecasting methods to the new data sets and demand profiles.

Milestones

- EU-wide study on power demand profiles in various energy-intensive industries and their potential for demand-side flexibility.
- Funding for 1-2 research and/or demonstration projects on matching production and demand by 2021.
- Investigate the possibility to charge electric vehicles during high wind conditions on a national and EU level.
- Investigate the potential of charging electric vehicles to help control system-wide power demand.

Challenge 1.2

Towards a system fit for 100% of renewables

Modelling future system needs	Short-term	Low priority

Description and scope

With the increase of renewable power generators (and associated power electronics) linked to the system, new challenges and interactions, such as low wave quality, harmonic instabilities and instabilities related to the Phase-Locked-Loop might arise. This will prompt the need for developing new operational conditions in the system to ensure power quality. In order to evaluate the extent and likelihood of these changes, new simulation models and software and/or hardware packages are needed to perform simulations at all levels (wind turbine generator, wind farm, wind farm cluster and ultimately the entire system).

Offshore wind transmission requires particular attention as these wind farms are far away from the main grid connected to the latter through a long cable. The cable impedance is relatively large and this can lead to significant interactions (harmonics or resonances) between wind power converters of different turbines. Several accidents related to harmonics have already occurred in offshore wind farms.

Recommended research actions

- Create new software/hardware packages allowing quicker and less resource consumption simulations.
- Develop new simulation models representing accurate behaviour of wind turbines, wind farms and wind farm clusters.
- Develop new models to simulate the power system and to pre-emptively detect new stability phenomena (e.g., harmonic instability).
- Develop solutions and controls to mitigate grid instabilities related to harmonics and Phase-Locked Loop.
- Develop models for power quality assessments at level of wind farm cluster.
- Validate numerical models through power quality meters installed at wind farm clusters.
- Economic assessment of potentially new grid requirements for renewable feed-in technology and storage technology.

Milestones

- Development of new simulation software/hardware package by 2022.
- Development of new system level models by 2024.
- Development of new controls and solutions for stable grids with high shares of variable renewables by 2027.
- Development of new models for power quality assessments at system level.
- Validation of models using site-specific information.
- Development of analytical models regarding harmonics and resonance in wind farms.
- Development and testing of control strategies to mitigate harmonics and resonance.
- Formulation of grid code requirements for low harmonics and resonance in offshore wind farms.

Challenge 1.3

Towards a system fit for 100% of renewables

Quantification of future system services	Medium-term	Medium priority

Description and scope

To increase and ensure successful large-scale integration of renewable power technologies, they need to be able to provide the services that grid operators will ask from them. Currently many system services are provided by synchronous generators as the whole system is modelled on their characteristics. The intermittent character of some renewable energy sources at times excludes them from easily providing certain grid services. However, the future energy system will be centred on variable renewables. As such, grid requirements should be redefined in light of the emerging system needs.

In addition, the regulatory framework needs to be updated so that all the identified future system services are available at all location at any given moment. The ancillary services market should offer a level playing field to all power technologies linked to the grid. Services should be procured on a free market basis. Services could be categorised on the requested technical capabilities of grid-connected assets. These can be essential capabilities “must have – must provide”, mandatory capabilities “must have – can provide” or optional capabilities “can have – can provide”.

Recommended research actions

- Definition and characterisation (mandatory or operation capability) of system service requirements and updates to the grid codes or market rules where relevant.
- Design and testing of new converters/systems for provision of system services in the absence of large synchronous generators. Including (but not limited to):
    - Synthetic or virtual inertia;
    - Black start;
    - Frequency control (Fast Frequency Response, Frequency Containment reserves and Frequency Replacement Reserves);
    - Fault-Ride-Through current contribution; and
    - Voltage control.
- Economic and technical assessment of the capabilities of power generation technologies to provide grid services.
- Analysis of interdependencies between power system developments and increased system services requirements.
- Demonstration of live coordination of controls provided by different sources of power generation.

Milestones

- Description of physical and electrical system phenomena and potential mitigation measures to be taken by power generators and/or consumers.
- Design of converter/systems for provision of system stability services.
- Lab test validations of service provision.
- Demonstration in “on line” sites under operational conditions.

Challenge 1.4

Towards a system fit for 100% of renewables

Stable system with 100% RES	Long-term	High priority

Description and scope

Today's grids are designed for the characteristics of conventional power plants, yet at times variable renewables make up the majority of power. The further development of renewables to decarbonise the EU's power system necessitates new solutions to take over system responsibility from conventional power plants and to prevent technical limitations to the integration of renewables.

The challenge could split in three phases:

1. Integration of additional renewable generation (e.g. with storage solutions, see chapter 1.3 and 1.5).
2. Stabilisation of the electrical grid.
3. Maintain the grid operator's ability to act in an almost 100% renewable-based power system.

Recommended research actions

- Research study of relevant effects in an inverter-based grid.
- Impact assessment of load-characteristic and grid equipment to system stability (including possible system service out of loads).
- Research into and demonstration of alternative technologies for system stabilisation (e.g. synchronous condenser).
- Impact assessment of the topological distribution of stabilising sources on system stability.
- Development of new system models for grids with weak voltage and frequency control.
- Research study on additional and necessary system services for phases with high renewable penetration (including necessary inertia).
- Research study on system interactions in grids with high shares of variable renewables.
- Development and demonstration of cost-minimal-solutions, products and requirements to ensure a 100% renewables-based energy system post-2050.

Milestones

- Completed system study showing different scenarios with varying shares of power generation and storage technologies.
- Identification of the impacts of different loads to system stability.
- Formulation of system requirements for loads, storages and renewable sources.
- Description of relevant electrical effects in grids with high shares of variable renewables.
- Completed model environment development based on relevant system effects.
- A final economic assessment of different solutions to integration of renewables and establish a variable renewables-based power system.

Challenge 2.1

Enhancing decarbonisation through wind energy development

Short-term energy storage	Short-term	High priority

Description and scope

With further installation of renewables into the grid, the pressure grows for them to support grid and system stability. A combination of wind and battery storage can offer short-term solutions and has already shown promising results.

However, only a few projects are realised in real grids and their impact on grid support and their cost-effectiveness are still open important questions for the renewable energy system of the future. Whilst this is mostly a matter of market design and grid operating principles, research should further investigate the different battery technology and wind combinations to determine the potential use and business cases in various regions across Europe.

The approach would be to first identify and assess (both in terms of technology and economics) the grid and system services a wind + battery storage facility could offer. Second, to optimise design and dimensions of storage units in line with the size of the wind farm and the requested provision of grid services. Third, to assess the impact of providing grid services on the wind turbine control system and farm controller. Finally, to assess the business cases of wind + battery systems against wind systems without battery.

Recommended research actions

- Economic and technical assessment of selected battery storage technologies (li-ion, flow, high temperature) with regard to their suitability in providing different requirements of grid and system services.
- Model simulation and comparison of ideal versus real windfarm conditions in combination with technologies and services including variations in design and dimensioning of wind farm controller and storage system.
- Implementation of measurements in combination with selected best case storage systems and analysis of the results.

Milestones

- Economic assessment in the form of a matrix which shows the different storage system in regard to grid and system service under consideration of cost and revenue (development of cost of today and future).
- Demonstration of optimisation potential based on simulation and measurement results.
- Formulate guidelines which show an optimised storage system in dependence of the wind farm size and in regard to the respective grid and system service.

Challenge 2.2

Enhancing decarbonisation through wind energy development

Long-term energy storage	Short-term	Medium priority

Description and scope

An 85-90% decarbonisation of the energy system will require a large roll-out of variable renewables. As a consequence, there is an increasing need to balance the seasonal production patterns of the variable renewable energy sources. This calls for long-term energy storage solutions.

Power-to-x (where x could be gas, liquid or thermal energy) would allow renewable energy producers to store excess renewable energy at times of abundance and re-use it at times of scarcity. Power-to-x could also help reduce the impact of abundant renewable energy on the grid and help abate emissions in the most fossil-fuel-dependent sectors.

Developing cost-effective seasonal storage solutions will take time. It is highly dependent on market incentives and regulation, but further research is advisable. In the first phase, the focus lies on requirements studies, concept development and demonstration of early prototypes. In parallel to the technical development, the political and economic circumstances of long-term energy storage must be adapted. In the second phase the industrial prototypes should be transferred into a certified product in order to facilitate large scale deployment.

Recommended research actions

- Study requirements for long-term energy storage in the future energy system.
- Research study to identify and verify the potential business cases in various regions of Europe.
- Comparative concept study: integration of various seasonal storage facilities in wind farms or turbines.
- Development of control algorithms of new system services provided by flexible storage (e.g. electrolysers) including prototype testing, validation and verification.

Milestones

- EU-wide study on various business cases for wind and storage.
- Definition of system services that could be provided by flexible seasonal storage solutions.
- Development of new prototype wind farms with integrated storage facilities.
- Models are available for simulation studies.
- New prototypes (e.g. ammonia electrolysers) are certified products and can be serially produced.

Challenge 2.3

Enhancing decarbonisation through wind energy development

Multi-cultured wind farms	Short-term	Low priority

Description and scope

Mono-cultured windfarms that feature wind turbines with the same hub height and rotor diameter are more vulnerable to climatic and meteorological changes. They suffer from significant wake losses under specific wind directions and atmospheric conditions and, when wind is weaker than predicted, the whole farm yield lowers dramatically.

Developing mixed wind farms would improve the business case for operators and enhance the system value of the wind because the farm would be operational under a wider range of meteorological conditions, more base-load wind power could be generated. A mixed wind farm with turbines varying in hub height, diameter, nominal power and wind class could match the Annual Energy Production (AEP) of a mono-cultured wind farm, but spread over more days.

Recommended research actions

- Improve models for farm layout and optimise tools for park planning of mixed wind farms with regard to multiple objectives like yields and costs.
- Develop new control strategies for optimal operation of the mixed farms, taking into account interaction effects, grid stability and energy exchange price.
- Research of specific turbine technologies for cost-effective turbines optimised to perform under specific wind speed regimes.

Milestones

- Availability of new innovative and computationally effective tool chain.
- Development and testing of new control strategies for mixed wind farms.
- Operational validation of new control strategies proven in the field.
- Establishment of a business case benchmark.
- Formulation of new wind speed specific wind turbines.

Challenge 2.4

Enhancing decarbonisation through wind energy development

Optimising transmission infrastructure	Medium-term	High priority

Description and scope

Wind energy systems can provide flexibility to the system, but improvements could be required in the future. So, to maximise the share of renewable energies in the system, the energy harvesting and evacuation capacity of grids need to be enhanced.

On the one hand, this can be done by an appropriated hybridisation of different renewable energy technologies by making use of the Virtual Power Plant concept (see sustainable hybrid solutions). On the other operation of available grid assets can be optimised too. Better and more real-time information exchange and more accurate storing of big data could foster further integration and help to improve the "modus operandi" of TSO/DSOs. Testing and implementation of innovative solutions and technologies to improve grid management connections should be allowed in live grids and under conditions that are easily replicated.

As offshore wind power in Europe has great potential, additional grid technology developments are necessary to decrease the cost of offshore wind power production. A holistic offshore grid development, considering larger areas and developing transformative maritime grid infrastructure, possibly combining High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC) technologies, will be needed. Moving away from point-to-point gird connections towards multiple offshore grid connection points will also reduce unwanted effects of electrical failures.

Recommended research actions

- Development of quicker and more powerful communication systems between grid operators and wind farm operators.
- Establish a big data information exchange platform.
- Further development of HVDC technology.
- Feasibility study on offshore direct current collector grids.
- Optimal design and operations concepts of hybrid grids (HVDC & HVAC).
- Develop, test and validate cable protection concepts for direct current and hybrid grids.
- Technology development for floating platforms and suitable cabling connection concepts.

Milestones

- 2 proposed projects to define the design and concepts for operating hybrid grids.
- 2 projects on the topic of floating infrastructure, addressing the electric cabling issues in particular.
- 2 proposed projects on Direct Current collector grids.
- Formulate recommendations for the optimal design and operation of hybrid grid concepts (combining high voltage direct current and alternate current technology).

Challenge 2.5

Enhancing decarbonisation through wind energy development

Sustainable hybrid solutions	Medium-term	Medium priority

Description and scope

With the increase of wind power plants linked to the European grids, wind farm operators will need to provide more and different system services to the grid. More variable renewables will require grids to become more flexible. Wind farm operators may be required to be more flexible when feeding power to the system. Flexibility could be provided by wind turbines themselves, but most will come from aggregating different generation profiles. Wind farm operators could preempt flexibility needs by coupling wind energy with different technologies such as solar photovoltaic cells, batteries, hydrogen electrolysers etc. into a single concept. These hybrid solutions could offer additional value to be monetised in a future merchant environment. Moreover, such hybrid solutions would result in more efficient use of the electrical infrastructure, providing higher capacity factor for the plants and more stable revenues for the operators.

Recommended research actions

- Technology development of new concepts for the electrical infrastructure of hybrid plants (e.g. dc-connections).
- New tools and methods for optimal sizing and design of the hybrid plants.
- Development of next generation plant control logics to optimise system operation and fulfil grid integration requirements.
- Research studies into the possible future technical requirements in different regions across Europe.
- Economic assessment of the system value of hybrid plants.

Milestones

- Development of 2 hybrid projects.
- Development of new design tools suited to model hybrid power plants.
- In-field demonstrations of newly developed control strategies.

References

1 WindEurope Annual Statistics (2019)
2 See figure 1.
3 IEA, *World Energy Outlook*, 2018
4 Immediate is defined as shorter than a minute, short-term is identified as a range from minutes to daily and long-term as a range from months to seasons.
5 Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, accessed online at https://eur-lex.europa.eu/.
6 Ibid.
7 Ibid.

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