End of project popular science description

Introduction

Turkey is one of the fastest-growing energy markets in the world, with an annual 8% increase in energy demand. Nowadays, more than 70% of all electricity production is supplied by fossil resources, and almost 30% of all electricity production comes from renewables, mainly hydro, while wind constitutes only 6.6 % of the total electricity mix. The wind and solar energy rate in total consumption are planned to be increased by at least 30% in the coming five years according to the 2023 vision plan of Turkey. However, due to the intermittent nature of wind energy, large-scale wind power integration may pose some serious challenges to Turkey's power system. Therefore, planning analysis and designing efforts are required to ensure the smooth, secure, and reliable operation of Turkey's power system and electricity markets considering large-scale wind power integration. In this way, the WindFlag project aims at solving relevant challenges of large-scale offshore wind power plants (OWPP) deployment and integration into the Turkish grid while ensuring system stability, performance, and coordination. For this purpose, the project objectives are as follows:

- Specifying which are the potential OWPPs sites in Turkey and assess their power production capabilities considering grid connection.
- Identifying the short-term and the long-term impact of the potential large-scale OWPPs on the power system stability and proposing control solutions.
- Identifying potential harmonics, resonances and instability conditions caused by the integration of OWPPs into the power system, and to investigate control strategies to mitigate them.
- Developing control strategies to maximize the power generation capability from the large-scale OWPPs considering coordination with current power plants and energy storage systems (ESS).

Results

The WindFlag project main research findings covered the following aspects,

- **Optimal offshore wind power plants (OWPP) siting and sizing**: a quantitative methodology for offshore wind power plant site selection in Northwest Turkey using Geographical Information Systems (GIS) and Analytical Hierarchy Process was performed. As the result of this comprehensive analysis, Bozcaada is found to be the best suitable site for an OWPP in Northwest Turkey, at the same time, Kiyiköy emerged as a strong candidate for the first time, with this study as the second-best alternative. Using this result, an OWPP sizing and electrical design was performed for the Kiyiköy site, including preliminary analysis considering the main Turkish grid equivalent given by TEİAŞ (Turkish TSO).
- **OWPP integration analysis considering grid-forming and plant controllers**: the grid integration analysis of Kiyiköy OWPPs to the Turkish power system was performed, furthermore, the effects of grid forming and grid following controllers on the Turkish power system performance have been investigated. A grid compliance study and voltage and frequency stability studies for Kiyiköy OWPPs were addressed, finding that the grid connection of Kiyiköy OWPPs does not lead to any voltage or frequency stability problem. The investigated case studies were determined by TEİAŞ.
- **Harmonic analysis and mitigation**: in this study, the Kiyiköy OWPP site was modeled considering frequency-dependent models and connection analyses are performed to evaluate the harmonic effects on the Turkish grid. Further, to mitigate the harmonic content, a hierarchical harmonic control architecture has been developed for the OWPP. The harmonic primary controller mitigates the harmonics of the terminal voltage and currents of the wind turbines units. The harmonic secondary controller reduces the harmonic distortion of the point of common coupling (PCC) voltage and grid current.

- **Coordination controllers among the OWPP and other existing plants in Turkey, considering energy storage systems integration**: a techno-economic framework was established to analyze the feasibility and economics of coordinating OWPPs with a conventional thermal plant, and a techno-economic framework was constructed to optimally select ratings of a BESS for OWPPs. Case study simulations showed that coordination of the proposed Kiyiköy OWPP with a nearby thermal plant can successfully address future limitations on the active power introduced into the grid code. Furthermore, it was found that investing in an optimally selected BESS is a better solution for the Kiyiköy OWPP case.

A full publication list with the project outputs in detail can be found in the project website www.windflag.energy.aau.dk.

Conclusions

Several barriers and opportunities were found throughout the project, which point out to the need of detailed planning, technical preparation, and international partnering-up for continuing the OWPP path in Turkey:

Barriers	Opportunities and findings
Experience under development in system operation & market design for renewables.	A significant potential for offshore wind power.
No official long-term planning.	Basis for grid code development on voltage ride through, reactive power control and active power control.
Limited wind data available making WTG-selection and business case estimations difficult.	No voltage or frequency stability problem in the event of critical fault and outage conditions during OWPP case study analysis.
Lack of WTG harmonic emission data.	OWPP harmonics does not create considerable effect on Turkish grid, nor resonance problems.
Relaxed Turkish grid code requirements for renewables and storage.	Integration of coordinated solutions is an effective approach for the technically stable and economically efficient operation of OWPP.
	Investing in an optimally selected BESS is more profitable for the OWPP than coordinating with thermal plants.

Recommendations

From the project results and discussions with partners, and stakeholders, the following recommendations are suggested:

- **Plan**
  - Renewables long-term, ambitiously, and follow-through.
  - Specifically, the significant potential for floating and fixed bottom offshore wind should be considered.
- **Prepare**
  - Select sites, prepare grid codes, and ensure suitable regulation.
  - Specifically, the grid code should be prepared for significant amounts of offshore wind, as well as for integration with other renewables & storage.
- **Partner-up**
  - Collaborate internationally and mature national competences & supply chain.
  - Experienced international developers will probably be interested, provided suitable market conditions.