Editorial on Special Issue "Wind Turbine Power Optimization Technology"

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Abstract: This Special Issue collects innovative contributions in the field of wind turbine optimization technology. The general motivation of the present Special Issue is given by the fact that there has recently been a considerable boost of the quest for wind turbine efficiency optimization in the academia and in the wind energy practitioners communities. The optimization can be focused on technology and operation of single turbine or a group of machines within a wind farm. This perspective is evidently multi-faced and the seven papers composing this Special Issue provide a representative picture of the most ground-breaking state of the art about the subject. Wind turbine power optimization means scientific research about the design of innovative aerodynamic solutions for wind turbine blades and of wind turbine single or collective control, especially for increasing rotor size and exploitation in offshore environment. It should be noticed that some recently developed aerodynamic and control solutions have become available in the industry practice and therefore an interesting line of development is the assessment of the actual impact of optimization technology for wind turbines operating in field: this calls for non-trivial data analysis and statistical methods. The optimization approach must be 360 degrees; for this reason also offshore resource should be addressed with the most up to date technologies such as floating wind turbines, in particular as regards support structures and platforms to be employed in ocean environment. Finally, wind turbine power optimization means as well improving wind farm efficiency through innovative uses of pre-existent control techniques: this is employed, for example, for active control of wake interactions in order to maximize the energy yield and minimize the fatigue loads.

Keywords: wind energy; wind turbines; control and optimization; aerodynamics; structures

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Wind turbines are widely recognized as one of the most efficient technologies for electrical energy production from a renewable source and the expectation is that the efficiency is going to further grow, primarily because of the increasing rotor size and secondarily because of the technology optimization.

Wind turbine technology optimization has therefore become in the latest years a core topic in wind energy research. The purpose of this Special Issue is collecting innovative contributions to the multi-faced issue of wind turbine power optimization technology.

The power output of a wind turbine has a complex dependence on ambient conditions and operation parameters; nevertheless it can fairly be stated that the most important aspect for power extraction optimization is the aerodynamic efficiency. For this reason, a remarkable line of research deals with optimization of wind turbine blades technology. For wind farms already operating, a typical intervention is blades retrofitting through the installation of active (like Air Jet Vortex Generators) or passive (Vortex Generators, Gurney Flaps and so on) flow control devices. For new installations, in the context of wind turbine design, it is important to optimize the blade design and the flow control

devices for increasing rotor size and efficiency also in particular in the context of floating wind turbines, whose technology should be appropriate for exploitation in ocean environment.

Two contributions about the above aspects are featured in the present Special Issue. The study in [1] is devoted to the optimization of the Gurney Flaps for a DU91W(2)250 airfoil: Reynolds-Averaged Navier–Stokes simulations are performed with Gurney Flaps from 0.25% to 3% of the chord length at angles of attack from $-6°$ to $8°$, assuming a Reynolds number Re $= 2 \times 10^6$. The highest increase of lift-to-drag ratio is obtained when the Gurney Flaps length is 0.5% of the chord length and the angle of attack is $2°$; the influence of the Gurney Flaps is shown to decrease when the angle of attack exceeds $5°$. The main lesson from the study in [1] is that a fixed Gurney Flaps length would not reach the optimal lift-to-drag ratio for all the values of the angle of attack: this suggests that Gurney Flaps could more profitably be employed as active flow control devices (differently from their typical use), adapting their size on the working conditions. For this reason, in [1] an Artificial Neural Network has been trained and employed for predicting the aerodynamic efficiency of the airfoil in terms of the lift-to-drag ratio.

The objective of the study in [2] is the optimization of the blades of the NREL 5MW wind turbine: this model has been analyzed in several studies and it stands as a scientific prototype for large offshore wind turbines. The methods proposed in [2] are remarkably innovative: a Particle Swarm Optimization algorithm combined with the FAST (Fatigue, Aerodynamics, Structures and Turbulence) software (developed at the NREL) is employed for blade design optimization and the results are compared against traditional blade design methods (like the Glauert method). Furthermore, the aerodynamic performance of the blades is optimized for application to floating wind turbines, taking into account the motion of the platform caused by the sea waves; a meaningful site is selected as test operation site and the main result is that the proposed optimized blade design can provide a 3.8% improvement of the maximum power of the wind turbine.

The design of innovative wind turbine controls is a keystone of technology optimization. Several solutions have recently become available also in the industry and deal, for example, with the optimization of the yaw control (in order to maximize the operation time with zero or almost zero yaw angle) and of the pitch control (especially near the cut-in and rated speeds). The present Special Issue features a contribution about innovation design of wind turbine control and the investigation object is once again the NREL 5MW: in [3], the proposed approach is a nonlinear economic model predictive control which considers the tower and gearbox dynamics. The optimization of this control considers all the actuator constraints (pitch angle, and torque constraints with their rate of change constraints) and the hard constraints (rotor speed, generator speed, and electrical power): the objective is achieving the maximum generated power against the competing penalties constituted substantially by the fatigue loads. Several sample configurations are analyzed through FAST simulations, in order to support the practical application of the proposed control.

Another meaningful contribution dealing with the NREL 5MW wind turbine is included in this Special Issue: in the context of floating wind turbines technology, the object of [4] is the design optimization of a tension leg platform through the addition of further mooring lines with respect to a traditional system. The rationale for this choice is increasing the horizontal stiffness of the system and thereby reducing the dominant motion of the platform. An experimental analysis is performed by applying Froude scaling: the experiment set up is a lab-scale wave flume generating regular periodic waves by means of a piston-type wave generator. Two main results are achieved: it is shown that the optimized design in general improves the stability of the platform and reduces the overall motion of the system; furthermore an extreme wave conditions analysis is conducted and it results that the optimized design reduces the wave loads.

It should be noticed that some innovative aerodynamic and control design solutions have recently become available in the wind energy practitioners community and this has stimulated a further line of research, thanks to the availability of large amounts of Supervisory Control And Data Acquisition (SCADA) data from operating wind farms: the objective is the on-site assessment of wind turbine

optimization technology through operation data analysis. This task is challenging because practically it translates in the necessity of comparing the measured power against a reliable estimate of how much the power would have been if the upgrade had not taken place. Therefore, a precise data-driven model for the power of the wind turbines of interest must be constructed and trained with pre-upgrade data sets and this is complex because the power of a wind turbine has a multivariate dependence on ambient conditions and working parameters and because there commonly is a wind field data quality issue as regards cup anemometers mounted behind the wind turbine rotors. These critical points are circumvented in an innovative manner in the study [5], included in the present Special Issue. The underlying idea is based on the fact that power optimization technologies are typically tested on pilot wind turbines and therefore the remainder wind turbines from a given wind farm can be employed as reference. In [5], it is shown that a multivariate linear model is adequate for the task of interest: the power of the upgraded wind turbines is modelled as linear function of the operation variables of the nearby wind turbines. Several test cases have been addressed in [5] and the main result is that aerodynamic optimization technologies can improve the energy up to the order of 2% of the Annual Energy Production, while control optimization typically weights for the order of 1%.

One of the most timely topics in wind energy literature is wind farm control: the general idea is upstream wind turbine wakes active control, in order to maximize energy yield and minimize loads. At this aim, it is of fundamental importance to develop computationally affordable techniques for wakes modelling. The present Special Issue features a contribution about the topic of wake modelling: in particular, the object of [6] is the modelling of multiple upwind wakes. The peculiarity of this situation is that the higher turbulence level and shear stress profile generated by upwind turbines in the superposed area leads to faster wake recovery: this implies that it is not appropriate to model the multiple wakes as a simple superposition of wakes. In [6], a mixing coefficient is introduced in the energy balance wake superposition model. The correction coefficient depends on the average distance, in units of rotor diameters, among the sequence of downstream wind turbines. The proposed model is evaluated using data from the Lillgrund and the Horns Rev I offshore wind farms, which are two typical test cases for wake models validation in wind energy literature.

Finally, the present Special Issue features a contribution about the optimization of Vertical-Axis Wind Turbines (VAWT). The object of the study in [7] is dynamic stall control of VAWTs through plasma actuation. Unsteady Reynolds-Averaged Navier-Stokes (URANS) simulations are used to study the dynamic stall phenomenon of VAWT at different tip speed ratios, and the azimuthal position corresponding to the start and end of dynamic stall is found. The main result of [7] is that pulsed plasma actuation can be profitable for enhancing the power extraction efficienct of VAWTs and the actuation from $60°$ to $120°$ is optimal.

In summary, this Special Issue presents remarkable research activities in the timely subject of wind turbine power optimization technology, covering various aspects on single turbine technology as well as wind farm and site optimal exploitation. The collection of seven research papers is believed to benefit readers and contribute meaningfully to the wind power industry.

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