IMPROVE THE WIND ENERGY EFFICIENCY THROUGH THE USE OF SMART ROTORS: FRENCH NATIONAL PROJECT SMARTEOLE

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1. Introduction

One major challenge for the wind energy development is the reduction of the power production costs. Using more advanced control system is one lever to improve the wind turbine performance and so, to reduce the costs of producing energy.
The present consortium, composed of four complementary research labs and two industrial partners, has teamed-up to evaluate innovative control strategies at different scales of the wind farm: 1. the turbine blades aerodynamics, 2. the turbine pitch and yaw control system and 3. the wind farm global production. The project is called SMARTEOLE and will contribute to develop the concept of "smart rotor" in order to improve the operating conditions of wind turbines. It will consist in integrating new sensors (as Lidar technology) in order to detect in advance the wind speed and direction at the very-short term timescale of the seconds. This anticipated wind measurement enables to implement real-time control strategies to drive the nacelle and blade orientation of turbines in an optimal way. This will dramatically mitigate load fluctuations (on mast and blades), reducing then the maintenance costs, increasing the wind turbine life duration, and improving the global energy production.
Additional flow control strategies acting at shorter time scales and directly on the blades are also studied in the SMARTEOLE project.

2. Approach

The control technologies developed in the present project are applied at three different scales (blade, rotor and farm scales) and are tested from the lab to the full scale for the most mature ones.
Two types of experiments are performed:
- Testing at full scale in a wind farm owned by Maia Eolis on the basis of control strategies developed by IFPEN and Maia Eolis with the use of Lidar sensors manufactured by Avent Lidar technology.
- Wind tunnel testing in LHEEA and PRISME facilities, on active flow control on blades with control strategies developed by LAAS-CNRS and PRISME.

These developments are based on the partners' expertise on wind energy, Lidar technology, metrology, control sciences and fluid mechanics.

3. Main body of abstract

Wind energy is one of the most dynamic industries worldwide with an annual increase rate of activity of 20%. It is expected that it contributes also for France to reach its energy, economic and environment objectives by being a modern, reliable and cost competitive source of energy.

The wind power is a growing market in France since the current installations supply 8.3 GW, with 631 MW installed in 2013.The national objectives plan to reach 25 GW of wind power installed in 2020 (19 GW onshore and 6 GW offshore). This ambitious challenge implies to dramatically increase the installed capacity with an average rate of 2 GW per year. The technology involved in the wind energy sector is wrongly considered as mature whereas the real-time wind turbine (WT) efficiency is strongly deteriorated by the relative unpredictability of the short-term wind conditions. In order to reduce the Levelized Cost of Energy (LCoE), the robustness and the life duration of the WT's must be improved to ensure operation availability and an optimal energy production during periods longer than 15 to 20 years. Indeed, WT's operate in a very hostile environment regarding their durability, since the wind conditions they encounter in the Atmospheric Boundary Layer are strongly inhomogeneous and unsteady. They are then subject to unsteady wind loads, responsible of combinations of unsteady mechanical loads with characteristic time scales from seconds to minutes. The wind conditions can become even more hostile when WT's are arranged in parks, since the WT wakes, which are characterized by a velocity deficit and production of turbulence, can impact other WT's. When not properly managed, this could lead in real life to blade damage after only 5 years of operation. Alleviating the impact of these upstream wind fluctuations would lead to more sustainable life conditions for the rotors, and consequently, improved economics and reduced LCoE. This can be achieved by controlling in real-time the aerodynamic performance of the WT rotors in order to immediately compensate the overloads. The standard way to reduce load fluctuations on current WT's is based on the mechanical pitch control, modifying the overall blade pitch. This strategy contributes to mitigate loads but it has been observed that it cannot be optimal since it is characterized by a global modification of the pitch whereas it would be more optimal to combine this action with a more local one, directly on blade areas that contribute at the most to the torque generation. Furthermore, the action cannot be anticipated since the wind upstream of the blade is not measured, leading to a curative strategy instead of a preventive one. The project SMARTEOLE aims at optimizing the wind energy efficiency by developing innovative control concepts of WT's (gathered within the term of "smart rotor") - based on the real time measurement of the incoming flow conditions.

4. Conclusion

One year after the project launch, first outcomes are very promising regarding the efficiency of pulsed-jets and plasma actuators located at the rounded trailing edge of an airfoil to modulate the lift coefficient of a wind turbine blade tested in wind tunnel (Figs. 1 and 2) (PRISME and LHEEA). The development of more efficient actuators, as well as the appropriate closed-loop control tools are under process (LAAS, LHEEA and PRISME).

A 6-month measurement campaign has been set-up in the north of France (November 2015-May 2016) to study the wake behavior of 2 wind turbines, with an original set-up using one scanning Lidar, 2 nacelle-mounted Lidars and a nacelle-embedded 2-axis inclinometer (Fig. 3 and 4) (Maia Eolis and Avent Lidar Technology). The great challenge of this part of the study is to perform correlation analysis between the wind turbine wake behavior and the wind turbine monitoring sensors, characterized by signals having different dynamic responses and being polluted by variable meteorological conditions, by the broadband turbulent scales and by the wind turbine structural response.

The connection between the nacelle-mounted Lidar, enabling the anticipative incoming wind measurement, and the control toolbox developed by IFPEN is now operational. It is based on an innovative real-time processing to anticipate the incoming wind and based on the signal coming from the nacelle-mounted Lidar, which is integrated into control strategies with the objective to mitigate loads and optimize the power (Fig. 5).

5. Learning objectives/ Future works

The project develops some technologies with different levels of maturity and then, their application in finalized demonstrators appears at variate time scales. The active flow control on blades will reach the proof of concept at lab scale within the present project but will need to be validated at the full scale in a future project.
The Lidar-assisted pitch control should be validated on a full scale wind turbine within the present project. The benefit of the anticipative, rather than reactive feedback control should be quantified. Reducing the aerodynamic load fluctuations through Lidar-assisted pitch control will be a reality to exploit.
Some wind farm control scenarii will be tested at full scale in order to improve the overall power production of the farm and to reduce the structural fatigue due to wind turbine wake interactions. Then, they will have to be validated and implemented in wind farm management strategies

Acknowledgements
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Figures

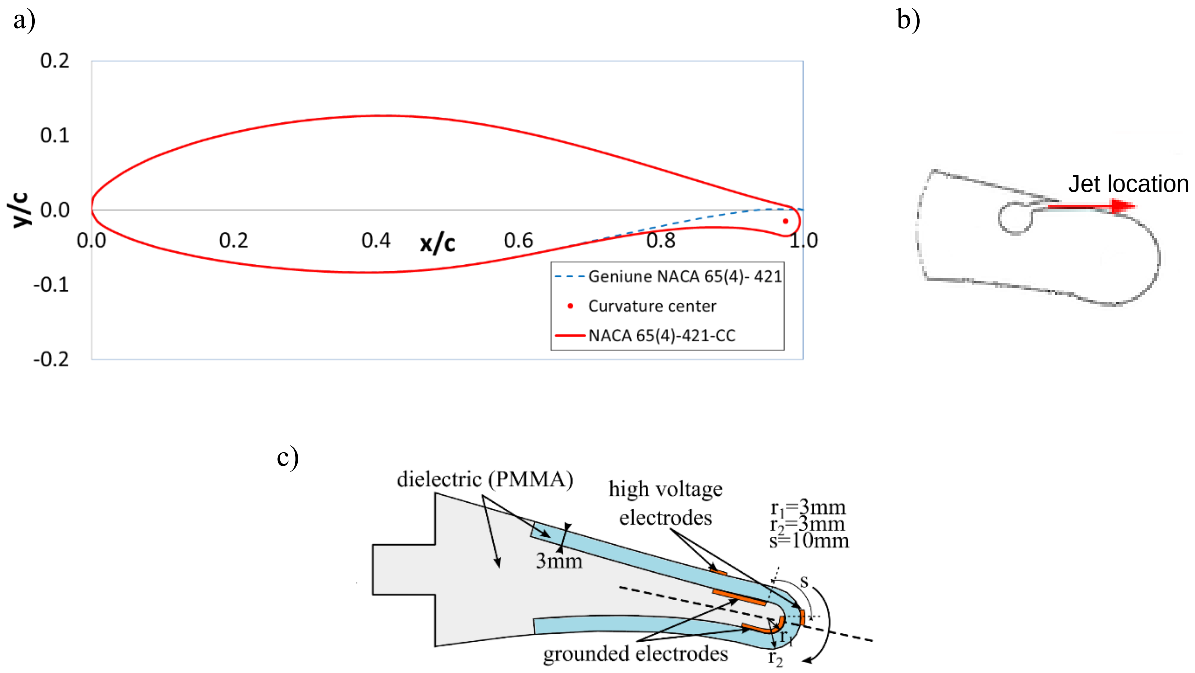

Figure 1. Section view of the control circulation oriented NACA65$_4$-421-CC (a) and of both trailing edges equipped with b) the fluidic jet actuator and c) the plasma actuator.

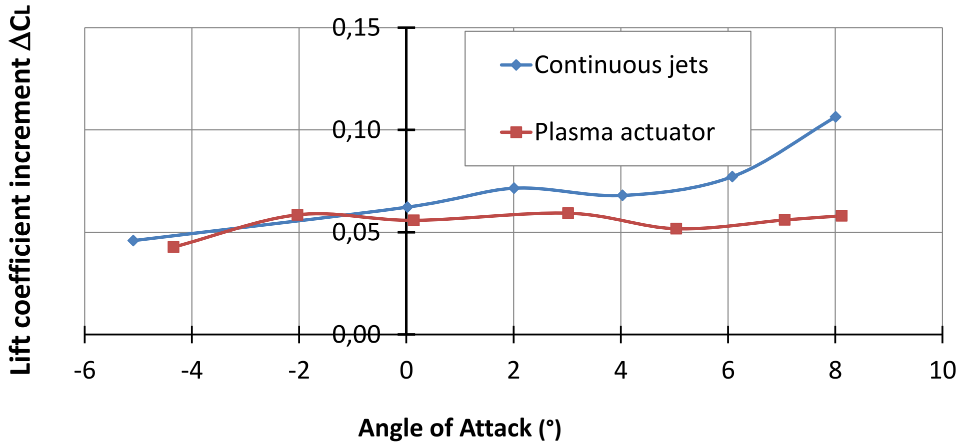

Figure 2. Increment of lift coefficient due to the actuation versus angle of attack with both actuations.

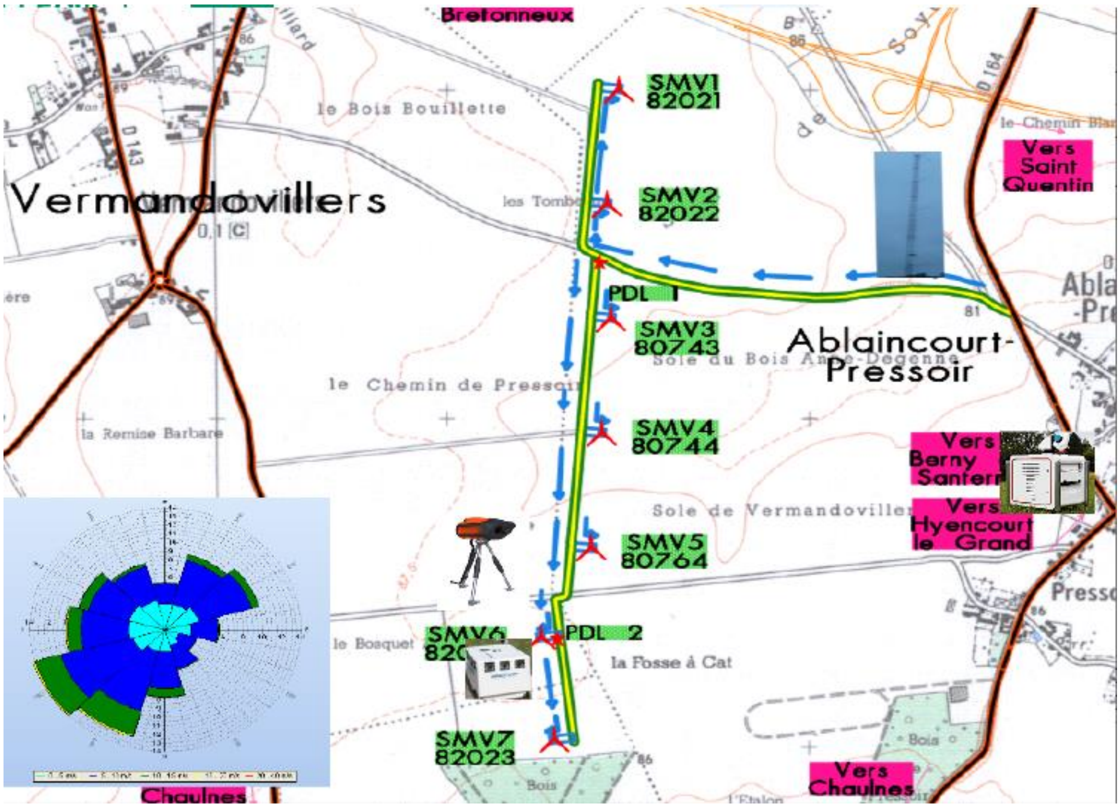

Figure 3: Field site. Wind turbines of interest are SMV5 and SMV6.

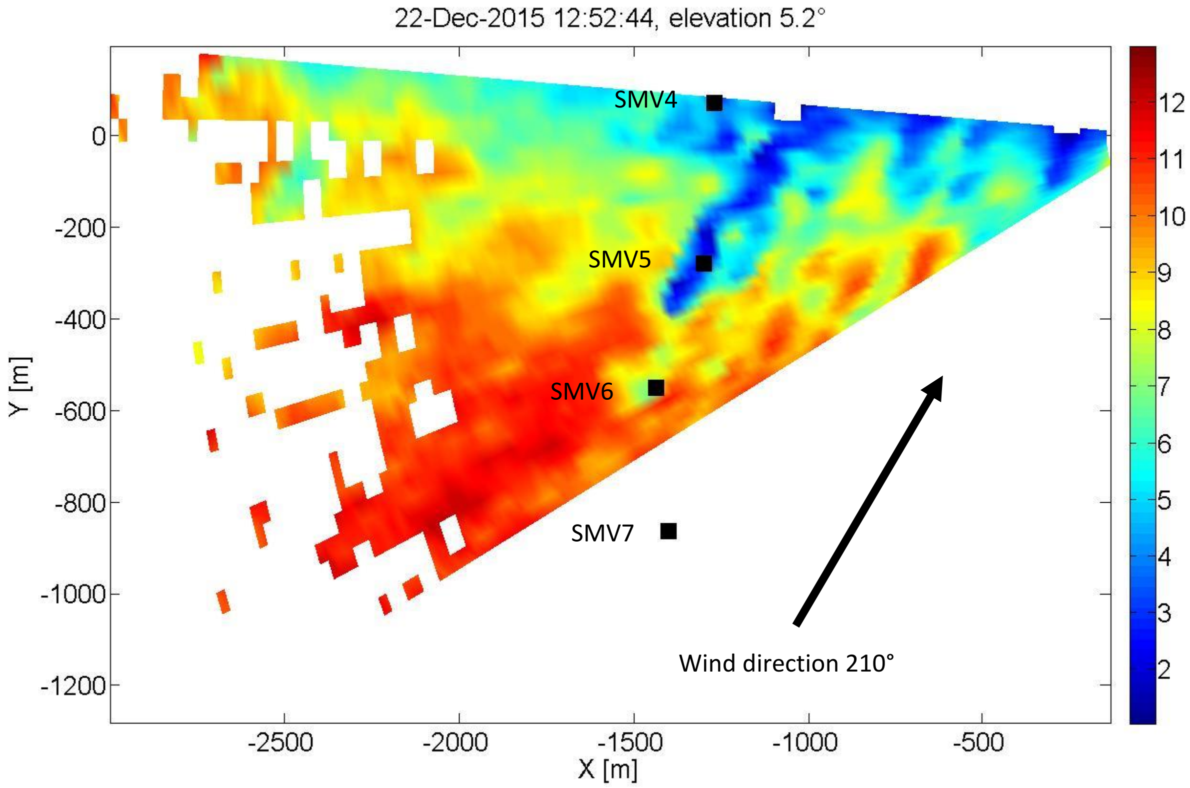

Figure 4: One velocity magnitude field measured with a scanning lidar during a period with a wind direction of 210°.

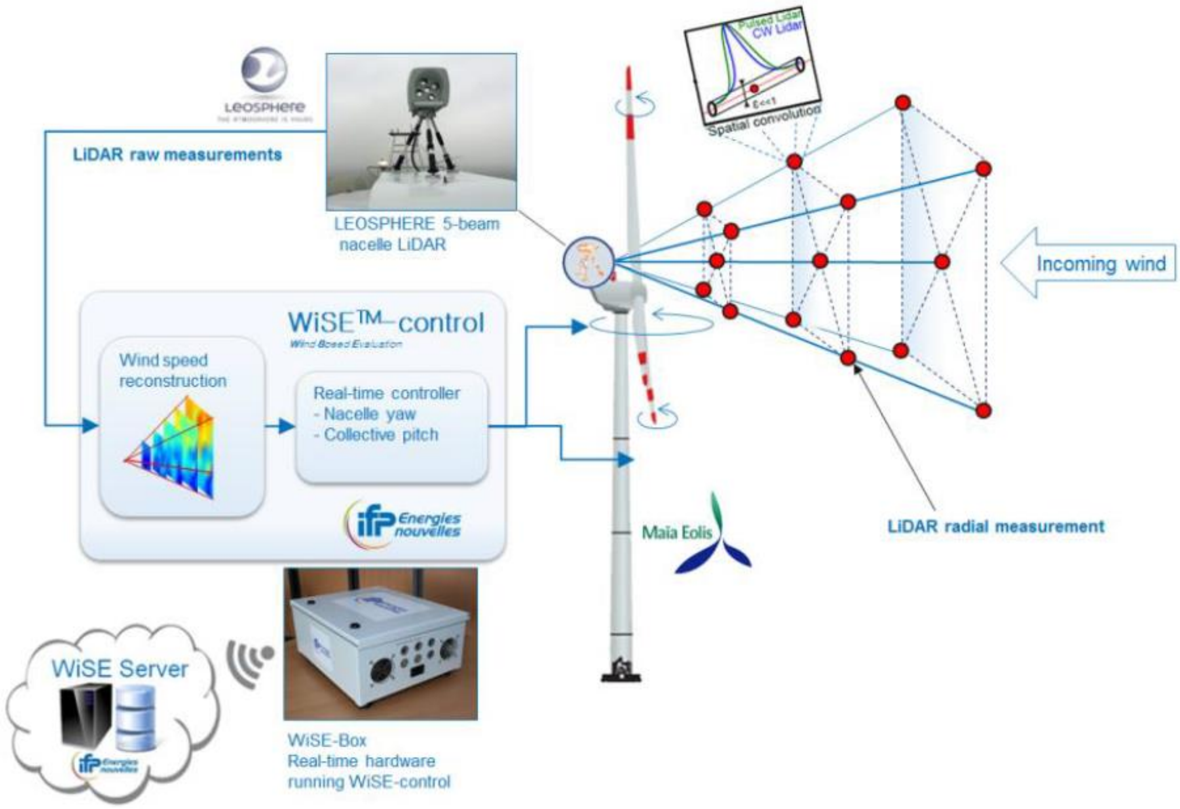

Figure 5: SMARTEOLE set-up to perform lidar-assisted control strategies