Wind Turbine Monitoring for Control Versions Comparison

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Abstract
The wind is one of the most important sources of energy nowadays. Wind turbine generators
(WTGs) have undergone enormous change, with new components and new control strategies
being designed to improve their performance. WTG control is the most important component
although at the same time it is also the least-known system; it is considered a black box.
WTG control strategies are aimed at generating as much power as possible, while keeping
the loads in each component below certain limits. If these strategies perform poorly,
component life span could be reduced, decreased power production and even WTG collapse.
These control strategies are developed by the WTG suppliers who release them as new
control versions when a new strategy is implemented or when a failure has been detected in a
previous version. In order to understand more about these little-known strategies Iberdrola
Renewables has designed a monitoring system for control version comparison. The
monitoring system has been designed to collect more information from the WTG, and new
sensors have been placed in the blades, drive train and tower in order to compare different
control versions. With this new design, Iberdrola Renewables is able to detect any positive or
negative impacts on our fleet of these new control versions launched by the suppliers.

Keywords: Control strategies, wind turbine generator (WTG), monitoring system, real time
kinematic sensor (RTK), fast Fourier transform (FFT).

1. INTRODUCTION
The wind energy industry has grown quickly since the early 2000s. Global wind capacity
reached close to 433 GW by the end of 2015, 147 GW in EU [1]. Wind power met more than
20% of the electricity demand in several countries, including Denmark, Portugal, and Spain
[2], and, in certain moments in 2015, wind supplied up to 70% of Spain's demand coverage
[3]. EWEA’s new central scenario expects 320 GW of wind energy capacity to be installed in
the EU in 2030, [4]. Nowadays, WTG suppliers are involved in designing new machines to
favour wind energy expansion as well as increasing the efficiency and performance of
existing WTGs. With this desire to increase efficiency and performance, wind turbine
manufacturers are developing new control strategies to increase the yield of WTG. These
control strategies extract more power from the wind and are therefore able to reduce the cost
of wind energy, making the technology more cost competitive. In doing so it is a reasonable
hypothesis that WTGs could be overworked. In this study we are going to assess the impact
of these updates on the performance of the wind turbines in our fleet.
2. OBJECTIVE

To improve efficiency and performance, a new set of control strategies has been developed by suppliers. The information available on those new control strategies is only accessible to the WTG suppliers themselves. The objective of this project is to build and develop a monitoring system to understand how these strategies work and the impact they have on WTG. As the impact of control version strategies is incredibly complex to evaluate, the project will assess this by comparing different control strategies.

3. GENERAL DESCRIPTION

The monitoring system has been developed by Global Technical Services within Iberdrola Renewables together with Tecnalia, and has been implemented in a commercial wind turbine. The main purpose of the project is to analyse the differences between various control strategies with regard to WTG performance and structural impact. Both companies have designed the hardware and software necessary to meet the objectives. The hardware has been designed in a distributed topology with a central unit (HOST). The HOST is in charge of gathering all the information that comes from the PLC, Compass, Lidar, RTK and several sensors distributed over four systems, A,B,C and D, see Figure (1).

4. HOST DESCRIPTION

The HOST is a portable suitcase complying with IP standards located in the WTG nacelle. An industrial PC handles the data that comes from two different communications links, a cable and a wireless connection. The wireless connection is necessary to transmit measurements from the moving parts to the HOST. Built-in remote connectivity allows real-time data to be sent to an in-house management solution. This system has various advantages in term of noise immunity and ease of expansion. As shown in Figure (2), the system
monitors the different components, located mainly inside the nacelle, as well as on top of it (wind measurements), the blades and tower. All the systems are located inside the machine, as closely as possible to the measuring points.

Figure 2: Components placement.

5. NACELLE

Inside the nacelle various solutions have been installed, for data acquisition in the WTG main frame, low speed shaft, and nacelle.

5.1 WTG MAIN FRAME

Strain gauges have been installed in the main frame both right and left arm in a half-bridge configuration to measure the efforts transmitted through the gearbox to the main frame. It is crucial to locate the area that suffers the most deformation in order to locate the gauges in this position, as it is the area where dampers are located, even though is a difficult area to access.

Figure 3: Main frame monitoring System.
Isolating screens have been installed for all cables connected to the strain gauges in order to avoid noise in the measurements as much as possible. Amplifiers are used to ensure the data is transmitted well from the sensors to System-B and then to the HOST.

5.2 LOW SPEED SHAFT

Strain gauges and a wireless unit have been installed on the low speed shaft to measure the torque transmitted, bending and acceleration. These measurements are sent by System-B through a wireless connection to the HOST. See Figure (4). The cable connection is not possible since the shaft sensors are installed in a rotary part; on the contrary the HOST is installed in a fixed place in the Nacelle. Tecnalia has designed an “induction ring” to supply electrical power to the wireless unit and the strain gauges without losses.

![Figure 4: Low speed shaft monitoring system and induction ring.](image)

The operation of the induction ring is shown in Figure (4). It consists of two coils located on the rotary ring (one on each half in order to facilitate the installation) and a small inductive coil located in a head fixed to the structure with a bracket as shown Figure (4). The induced voltage is rectified to meet the supply requirements of the equipment. It can supply up to 100 mA.

The strain gauges are placed a certain distance from the gearbox, see Figure (5). There are two pairs of gauges, for both bending and torsion measurements. Torque has been measured in the low speed shaft in order to relate the electrical power generated to the mechanical power.

![Figure 5: Low speed shaft strain gauges system.](image)
5.3 NACELLE DISPLACEMENT

The nacelle displacement along two axes is measured by an inclinometer located inside the nacelle close to the WTG vibration sensor Figure (6). This variable can be used to determine whether changing a control strategy influences the increased nacelle displacement.

![Figure 6: Nacelle displacement real configuration.](image)

6. TOWER

The measurement System-C installed in the tower measures the bending along two axes, as well as a 3-axis accelerometer. The system is located a certain distance from the nacelle. The X axis is always longitudinal to the nacelle facing the most likely direction of wind flow while the Y axis is perpendicular to this. With these measurements, the tower effort sustains can be monitored. The following configuration, shown in Figure (7), has been installed in the tower: there are 4 double strain gauges in each position both north-south and east-west to measure positive and negative micro-deformations with respect to the reference system already mentioned.

![Figure 7: Tower measurement system.](image)

All the measurements are sent to the main HOST through System-C which is a built-in wireless connectivity unit. The system is powered by an auxiliary socket inside the tower. As mentioned for the WTG frame, the system should be well shielded against EM radiation.
Therefore, the best option is to place it away from power cables, lights and other sources of EM radiation.

Figure 8: Tower real configuration.

7. BLADES

In order to measure the stress on the blades, strain gauges and a wireless acquisition unit have been installed in each one. Figure (9) shows an overview of the system with the previously mentioned elements. A power source for the different systems has been placed inside the distributed electrical panel of the hub.

Figure 9: Blade monitoring.

Each blade has a wireless module containing the electronics and two strain gauges, one active and another to compensate, mounted in a half-bridge configuration perpendicular to the central axis of the blade, close to the root. Acceleration is also measured using a 3-axis accelerometer - axes X, Y, Z (local reference axes for each blade) - included in the acquisition unit for each blade.
8. WIND MEASUREMENTS

8.1 LIDAR

WTG orientation is an important aspect with regard to the performance of the machine. In order to assess the impact that the various control strategies could have on the nacelle orientation algorithm; wind speed and direction have been monitored using Lidar technology. This system allows us to benchmark the results against the WTG’s own orientation system. Lidar relies on the Doppler Effect – a slight change in frequency of the backscattered light – caused by moving particles passing through the laser beam. The Lidar is mounted on the nacelle and has two beams with an opening angle of 30 degrees east and west from the nacelle.

8.2 RTK

A real time kinematic sensor has been installed in the nacelle that gives us the orientation in relation to magnetic north. The system is based on 2 antennas placed respectively on the rear and front parts of the nacelle hood, as can be seen in Figure (10). Both are vertically mounted with respect to gravity and at the same height with respect to sea level.

![Figure 10: RTK antennas real configuration](image)

9. FIRST RESULTS

Apart from the hardware described above, a software tool has been developed within the project to be able to analyse the data collected by the HOST. With this software it is possible to produce graphs in order to compare different control strategies. In this case two different control strategies has been compared, strategy A is the current control strategies installed in the WTG (in blue) whereas strategy B (in green) is a new strategy that is able to produce more power. See Figure 11.
According to Figure 12 the strategy B, apart from generating more power, is able to reduce the WTG misalignment.

As example of the data collected from the strain gauges, Figure 13 shows the efforts measured in the main frame for each control version.
The software tool is able to produce Fourier analysis, Figure 14 shows the FFT for efforts measured in the main frame.

![FFT Right arm and FFT Left arm](image)

Figure 14: FFT strain gauges main frame measurements.

10. Conclusions

This paper describes the hardware design that Iberdrola Renewables and Tecnalia have developed in order to meet the objective of the project. The monitoring system used to compare control strategies allows us to understand and be aware of the impact that the new control strategies generate in a WTG. The monitoring system described in this paper provides the data necessary to be able to relate the WTG performance and the control strategies. Further studies will be necessary to analyse all the data collected in order to improve the control strategies knowledge.

REFERENCES