APPLICATION NOTE

Wind Turbines

Wind power is a recent power source that exploded a few decades ago. The construction of windmills all around the world provides a promising future for sustainable energy. However, maintenance is critical to ensure a continuous yield and avoid any malfunction. In the worst case, a lack of maintenance could lead to a turbine shutdown and destruction, cutting off the production of power.

Figure 1: A 2 MW wind farm

Two types of applications are studied in this document:

- Turbine monitoring: measurements of vibrations on critical components
- Tower tilt inclination: angle calculation for proper tower positioning

Figure 2: A wind turbine accident in Germany
Source from www.tallbloke.files.wordpress.com

A 2MW turbine requires around US$2-3 million for its construction, and the maintenance of mechanical components cost between US$35'000 and US$60'000 per year. The use of accelerometers is very common for continuous condition monitoring, greatly reducing the number and frequency of unscheduled repairs. Moreover, a breakdown in a gearbox could necessitate a recovery period of up to six days before any restart is possible. The consequences of this problem are even greater offshore. Monitoring prevents any mechanical parts from failure by continual diagnosis.

Nowadays, the wind industry market has burgeoned with an anticipated growth rate of 10%, equivalent to 10'000 new wind turbines yearly. Siemens SA stated that over 2'000 Tower Control Monitoring (TCM) devices were installed in 2009, which includes one MEMS capacitive sensor on the main bearing, three sensors on the gearbox and two on the generator.

Another wind turbine application is the angular measurement of the sway in a tower. Building a wind turbine on a floating structure is a recent project involving offshore wind farms. It reduces the support weight by up to 50% and increases the power production from 10 to 30% (according to Sway AS). Lastly, it allows wind farms to be erected in deeper seas without investing in costly structures.

Explanation of the System

A wind turbine has a simple mechanism: three blades rotate about a horizontal axis at low frequencies, typically from 0 to 20 rpm depending on the external conditions. The rotation speed of the shaft is then amplified through a planetary and a gearbox. Lastly, the output shaft is connected to the generator that converts inertial to electrical energy. The entire system is suspended from the top of a tower to allow complete revolutions of each blade.

Vibration

Vibration sensors are installed in a 2-axis or 3-axis container. The sensors are fixed to a structure to measure its acceleration, created by gear shocks or displacements. An electronic unit applies FFT operations to the data in order to obtain a Frequency Response Function (FRF). At this stage, a vibration is easily noticeable due to its abnormality in amplitude and frequency. The TCM compares the current FRF with previous values. The SCADA unit alerts the maintenance team before any type of failure can occur.

Tilt

The tower's tilt angle measurements are possible thanks to the use of an inclinometer fixed either to a static or dynamic structure. The data will be treated exactly like monitoring data.

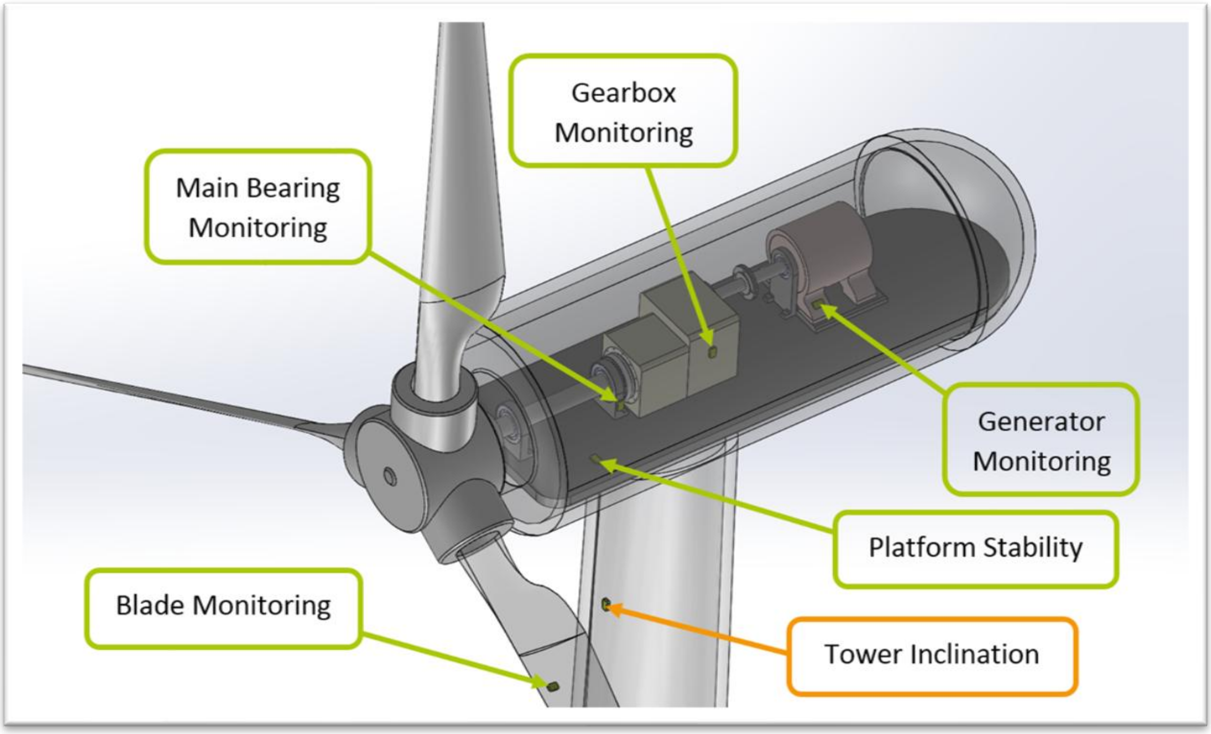

Figure 3: The different roles of MEMS and piezo sensors on a wind turbine

Environment Analysis

The sensors will be exposed to a temperature between -40°C and 55°C, at atmospheric pressure. Humidity level can vary from 3% to 100%, whether the wind turbine is working in a desert or under rainy conditions.

Good vibration analysis requires both a broad bandwidth and excellent precision. The range of the bandwidth allows low or high frequencies to be distinguished, and the precision describes how quickly a defect is detected.

Critical Technical Properties

Vibration

Continuous vibration monitoring on external structures such as the blades of a wind turbine demands vibration sensors with a bandwidth between DC 0 Hz and 1000 Hz, considering the various vibration modes. The nominal rotating frequency of a functioning tower is typically around 0.5 Hz. The maximum amplitude of the vibrations should not exceed 250 mg. In practice, the use of 2-axis sensors fixed along the structure is sufficient to obtain adequate information.

The monitoring of components, such as the gearbox, bearings and generator is also possible. The output shaft rotates from 1000 to 3000 rpm. In this case, the vibration frequency range varies from 50 to 10’000 Hz. An accelerometer with 3-axis detectors fixed on the component is a good configuration for vibration monitoring.

Tilt

Tilting an entire wind turbine offshore is a process that needs to be controlled very carefully. The maximum value of tilt is 5-8° depending on its size, meaning that the inclinometer must have very good precision. A resolution of 0.01° is required for this type of application. The degrees of freedom of the floating structure directly determines the number of sensors.

Figure 4: WindIT Tower Inclination Study

Green: 0-0.015g, Yellow: 0.015-0.05g, Red: 0.05-0.06g (collapse)

Furthermore, thermal drift is a point that needs to be carefully considered. For example, a wind turbine placed in an arid environment constantly endures important temperature variations. This induces an amplification of the bias that inevitably reduces the accuracy of the sensors, if they are not compensated for electronically.

The MEMS Technology

MEMS accelerometers measure a change of capacitance between two electrodes and convert it into an electronic signal proportional to the acceleration's variation. These sensors are identified by their weight and size. The MEMS technology offers high durability, a solid resistance to fatigue, and accurate measurements. They also have excellent stability within a wide temperature range.

Two other types of sensors could be used for the two applications:

- Accelerometers based on the piezoresistive effect (PR) provide acceleration through a variation of resistance. However, the deterioration of the piezo crystals makes it hard to deliver proper diagnosis over a long period of time. In addition, these sensors are strongly affected by bias drift compared to the MEMS capacitive accelerometers.
- The piezoelectric sensors (PE) can resist very high temperatures (700°C) and have a large frequency bandwidth, but they cannot measure low frequencies down to DC 0 Hz.

About Safran

Safran produces various MEMS sensors, all capable of working in any type of environment. The usual range would be ±2g for external diagnosis, and around ±10g for internal monitoring. Sensors can measure frequencies from DC 0 Hz up to 7000 Hz (typically, at ±3dB), and have a functioning temperature range from -55°C to +125°C.

Vibration monitoring can be successfully achieved with the VS1000 sensors. Available in many ranges[1], these sensors have a very low noise density (lowest at 7 µg/√Hz), anon-linearity below 0.1% FS and excellent accuracy.

Figure 5: The VS1000 vibration sensor

[1] ±2g, ±5g, ±10g, ±30g, ±50g, ±100g, ±200g.

With over 40 years of experience, and an industry located in Switzerland, Safran uses the bulk micro-machining technology to achieve state of the art precision. Furthermore, the MEMS sensors are guaranteed to function effectively for many years, and a self-test function is even integrated into every MEMS sensor. The sensors are delivered with hermetic ceramic packaging and can still function underwater.

Glossary:

- dB: Decibel
- DC: Direct current
- DOF: Degree of freedom
- FFT: Fast Fourier transform
- FRF: Frequency response function
- FS: Full scale
- Hz: Hertz
- MEMS: Microelectromechanical systems
- PE: Piezoelectric
- PR: Piezoresistive
- RPM: Rotation per minute
- SCADA: Supervisory control and data acquisition
- TCM: Tower control monitoring