Unleashing the power of Condition Monitoring

A case study of the implementation of CM at the Smöjen wind park in Sweden

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Abstract

This case study deals with the technical solution and economical impact of machine condition monitoring implemented on wind turbines at the Smöjen wind park in Sweden. It presents an overview of the measuring techniques used to detect machine problems and very briefly describes Intellinova, an online condition monitoring system tailored to the special requirements of wind turbines.

Background

Ensuring machinery uptime is critical to maximize availability and production. The purpose of condition monitoring is to maximize the Life Time Profit of the plant. Implementing condition monitoring allows maintenance and repair activities to be scheduled, causing the shortest possible downtime. Minimizing production losses and avoiding secondary damage incurred through the failure of vital parts secures considerable economic benefits.

Annual savings of €34,000 per turbine

Since installation, the condition monitoring system has contributed to the detection of several damages at Smöjen. The early forewarning of developing machine faults has enabled planned repairs and replacements, significantly minimizing downtime and reducing repair costs. The annual saving represents €34,000 (340,000 SEK) per turbine.

Conclusions

The saving potential of condition monitoring in the wind power industry is dramatic. Based on the assumption there are 250 wind turbines (850 kW or larger) in Sweden, the potential is €5,000,000 annually in this market alone.

Our calculation is made from the experience in a small wind parks. In discussions with other owners, we found that this calculation is showing “low” figures. All should be aware of that all faults are not possible to detect (like broken teeth in a gear) and as well that damages in the planet gear cannot be repaired or replaced without replacing the whole gearbox. Anyway, to detect damages and give clear answers about the root cause of the problem, will save a lot of money in planning time, less secondary damages, less production losses etc.
Condition Monitoring defined

In the context of this paper, the term condition monitoring is defined as the use of advanced technologies in order to determine equipment condition, and potentially predict failure. It involves the frequent or continuous monitoring of various machine parameters, where a change in the readings may indicate a developing component failure.

The purpose of condition monitoring is to maximize the Life Time Profit of the plant. Implementing condition monitoring allows maintenance and repair activities to be scheduled, causing the shortest possible downtime. Minimizing production losses and avoiding secondary damage incurred through the failure of vital parts secures considerable economic benefits.

Typically, condition monitoring is applied on rotating machinery such as boilers, fans, pumps, gear boxes, electric motors, heat exchangers etc. Detectable problems include:

- Bearing damage
- Bearing lubrication
- Imbalance
- Misalignment
- Loose parts
- Planetary gears

In wind turbines, machine components of primary interest are main shaft and generator bearings and the rotating parts of the gearbox.

Smöjen wind park

Smöjen wind park, located on Gotland off the east coast of Sweden, consists of ten wind turbines:

- four Vestas V47-660 kW units
- four Vestas V66-1,65 MW (1,5 MW) units
- two Enercon 500 kW units

Production at Smöjen started in August 1999, at which time it was the biggest wind park in Sweden.

The wind park is owned and operated by one of Sweden’s oldest wind power companies Slitevind AB, established in 1992.

In addition to Smöjen, Slitevind also produces wind power at Näsudden on southern Gotland. This is Sweden’s most wind power dense area; about 100 wind turbines are found here, some of which are operated by Slitevind. Today, the company has operations also in Norway and Finland.

Since 2004, online condition monitoring systems are installed on the four V66 (1,5 MW) units at Smöjen. In 2008, systems were also installed on one Vestas V80 and one V66 turbine at Näsudden.
Technical solution

The wind power challenge

Wind turbines are particularly exposed when it comes to vibration and disturbances. Variable operating conditions, such as wind velocity, power generation, rpm and temperature etc. cause great natural variations in the readings measured in connection with condition monitoring. Thus, a condition monitoring system must work with dynamic alarm limits, automatically adjusted to avoid any false alarms due to an increase in signal strength, which is not indicative of condition deterioration. This is achieved by auxiliary measurements of load and rpm, which then control the automatic evaluation of the condition parameters.

Traditional vibration analyses used in industry alone will not give reliable condition information in the environment of a wind turbine. Detection and analyses of shock pulses can effectively complement vibration analyses. Shock pulses from rotating parts can be picked up by mechanically and electrically tuned sensors. These pulses are not affected by vibrations and through input of load conditions in the monitoring system, the external wind factors can be compensated for. Shock pulses from the planetary gearbox can be measured, and bearing wear, lubrication and gear problems can be detected at an early stage. In time domain and frequency domain, the source and severity of the shocks can be shown. The condition monitoring system used in this study can filter out irrelevant information and the impact of changing wind conditions. By setting up the system with bearing numbers, gear information and ISO class, as well as measuring rpm and load, the system will translate shocks and vibration data into operating condition in green, yellow and red for easy interpretation.

Measuring techniques

Shock pulse measurement is a patented signal processing technique used to measure signals caused by metal impact and noise in rolling element bearings and gears. It is the most efficient method for condition monitoring of machines and is widely used throughout the world as a basis for predictive maintenance.

For the slowly rotating bearings in wind turbines, the appropriate measuring techniques are the SPM Method® and SPM Spectrum™ for analysis of the running condition and lubrication status.

To identify symptoms related to rotational forces in the machine, EVAM® (Evaluated Vibration Analysis Method) can be implemented. With enveloping technique, it can determine faults caused by acceleration forces, such as gear mesh problems.

Bearing monitoring with the SPM Method

The primary targets for measurement are rolling bearings (damage and lubrication condition). In many applications, these are the only machine elements which need monitoring. The method also reacts to gear mesh, shaft misalignment, cavitations, and other faults. It requires little input data (rpm and shaft diameter) and is fast and easy to apply.

Bearing analysis with SPM Spectrum

The purpose of SPM Spectrum is to verify the source of high shock pulse readings. Shocks generated by damaged bearings will typically have an occurrence pattern matching the ball pass frequency over the rotating race. Shocks from e. g. damaged gears have different patterns, while random shocks from disturbance sources have none. From a wind power point of view, the SPM Method is unique in that it is capable of handling the low rpm of the main bearings and in the planetary stage of the turbine gearbox.
Vibration analysis with EVAM

EVAM has been developed to allow large scale, cost-efficient vibration monitoring of industrial machinery. The method combines a number of established vibration analysis techniques with a machine specific statistical evaluation to supply easy to understand machine condition data. With access to machine specific data and information on the vibration behavior of the machine under normal operating condition, EVAM is a sophisticated analysis tool for verifying the root cause of vibration problems.

Online condition monitoring system Intellinova®

Intellinova is an online condition monitoring system featuring functionality such as conditional measurements, filtering and flexible alarm handling and condition evaluation, all developed with the special demands of the wind power industry in mind. Intellinova handles the variable operating conditions of wind turbines with great precision. The system is very sensitive and provides an early warning of deteriorating operating condition.

The condition of vital parts of Slitevind’s selected wind turbines at Smögen and Näsudden is continuously monitored with Intellinova, using a combination of the measuring techniques mentioned above. The system communicates with Condmaster Nova, powerful diagnostic software, in a wireless or cable network.

Monitored parameters are shock pulses and vibration, the most reliable and specific condition indicators, at preset intervals. The system measures signal amplitudes and provide shock and vibration spectra and, most importantly, it presents individual values on specific fault symptoms showing the state of a bearing inner ring, a gear wheel, etc.

Intellinova system communication
Condition monitoring results

Case 1, Bearing damage

In 2004, an online condition monitoring system was installed in one of the V66 Vestas turbines at Smöjen. During the winter and spring 2005, increased measuring results indicated a symptom on an outgoing shaft bearing (BPFI) in the gearbox.

Trend diagram from the symptom BPFI (Bearing inner race)

In August 2005, the bearing was replaced in a planned maintenance action.
Case 2, Broken part

The turbines at Smöjen are equipped with a main generator and one auxiliary generator for power generation up to 300 kW. It is connected with the gearbox via a cardan shaft. One night in 2006, the online system showed a dramatic increase in the shock pulse values on all measuring points located around the smaller generator. An SPM Spectrum analysis showed clear indications at the rotational speed of the cardan shaft. The turbine was stopped and inspection the next day showed a broken part in the cardan shaft. The shaft was dismounted and the turbine could start production again after a short stop.

The time frame from the first high reading to the stop of the turbine was only seven hours.
Case 3, Planetary gear damage

During 2009, measurements on a planetary gear on one turbine were running into bad condition.

Right: The graph shows a limited time span from the shock pulse readings in the form of a trend diagram. The general trend is increasing. The alarm level has been adjusted to the upper level of the measuring values. The symptom is “Gear Mesh 28 teeth”.

The graph shows the output power from the generator. Typically the measured value follows the output power. In this case the measured value is increasing, even when the power generation is stable.

Left: The symptom “Gear mesh 28 teeth” (the planet) is defined (with side bands).

Right: The time signal shows clear indication of one shock event for every three rotations of the planets. As three planets are rotating in the gear ring, it indicates damage in one planet in the gear.

The time signal from the shock pulse measurements verifies the spectrum pattern. Note that the speed is only 19 rpm.
**Case 4, Oil pump damage**

The shock pulse readings were suddenly increasing dramatically on the HSS shaft in the gearbox:

![Spectrum analysis of SPM signal](image)

A spectrum analysis of the SPM signal indicated $9 \times \text{rpm}$ with side bands on rotational speed, the signal from the oil pump on the same shaft. The spectrum below shows the frequencies in orders (one order = 19.12 \text{ rpm})

![Graphical evaluation](image)

The pump was replaced and the problem was solved in a few hours.
Economical impact

Over a six year period, the implementation of condition monitoring has enabled the detection of one major damage per year in gears or bearings on the six wind turbines at Slitevind AB (with continuous online systems and handheld condition monitoring). Planned repairs and replacements have minimized turbine downtime. The estimated value in production uptime and reduced repair costs represents €34,000 (340,000 SEK) annually per turbine. The investment, depreciated over five years and considering the operating costs, gives an annual contribution of €5,000 (50,000 SEK) per turbine.

Summary

As can be concluded from this case study, the potential of condition monitoring in the wind power industry is dramatic.

The SPM online solution above contributed to an annual saving of €34,000 (340,000 SEK) per wind turbine over a six year period (1.5 MW turbines).

It can be estimated that, for 850 kW wind turbines or larger, the system can potentially increase profitability by €20,000 (200,000 SEK) per annum, minimum. Assuming there are 250 such wind turbines in Sweden only, the saving potential for the Swedish market is

€20,000 * 250 wind turbines = €5,000,000

SPM Instrument AB

SPM Instrument has 40 years of experience in machine condition monitoring in all fields of industry. Our equipment detects fault conditions well in time for planned maintenance and repairs, causing none or minimal interruption of the production process. The head office, R&D department, production and educational centre of SPM is located in Strängnäs, Sweden. The SPM Group employs about 230 people, 75 of which are based at the facilities in Sweden.

For further information please visit our website www.spminstrument.com or contact Jan Hoflin, jan.hoflin@spminstrument.se.
Condition Monitoring defined

- Determine equipment condition, and potentially predict failure.
- Maximize the Life Time Profit of the plant.
- Avoiding production losses and secondary damage
- Condition monitoring is applied on rotating machinery
- In wind turbines, machine components of primary interest are the generator bearings, the gearbox and the main bearings.

Online condition monitoring system Intellinova

- Features developed with the wind power industry in mind
  - Conditional measurements
  - Filtering and flexible alarm handling
  - Condition evaluation
  - Provides an early warning of deteriorating operating condition
  - Communicates through wireless network with Condmaster Nova, a powerful diagnostic software

System communication via 3G

SPM installations in wind parks

- Online Condition Monitoring:
  - 4x V66 – Smöjen, 1x V80 – Näsudden, 1x V66 – Näsudden, 1x V39 – Näsudden
  - 3x NM52 – Klimpfjäll
  - 1x V90 – Kvarkenvinden, Umeå
  - 1x WW600 – Mellbystrand
  - 5x WW550 – Bockstigen
  - 1x V42 – Utterås

Technical solution

The Wind power challenge

- Demands dynamic alarm limits, automatically adjusted to avoid any false alarms due to an increase in signal strength, which is not indicative of condition deterioration
- Achieved by auxiliary measurements of load and rpm, controlling the automatic evaluation of the condition parameters
- Detection and analyses of shock pulses can effectively complement vibration analyses
- Shock pulses from rotating parts can be picked up by mechanically and electrically tuned sensors and are not affected by vibrations

Measuring techniques

- SPM Method® for bearing condition and lubrication
- SPM Spectrum™ for bearing analysis
- Patented signal processing technique used to measure signals caused by metal impact and noise in rolling element bearings and gears
- Widely used throughout the world as a basis for predictive maintenance. Great for the slowly rotating bearings in wind turbines

Economical impact

- One breakdown per year in average during study
  - Cost, gearbox replacements: € 220 000
  - Cost, gearbox overhaul: € 17 000
  - Calculated savings per turbine and year: € 34 000

![Wind turbine diagram]

![Graphs showing condition monitoring results]

![Cost vs Yearly savings chart]