WIND ENERGY update

Wind Power in Canada Part 1

Wind Turbine Blades, Gearboxes and Generators

Produced in association with:

Wind Turbine Optimization, Maintenance and Repair Summit

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With a recent explosion in new wind project developments and constructions throughout the provinces, Canada is rising up the ranks in terms of the contributors to the global wind power mix.

In a recent survey with wind power experts working in the Canadian provinces, key concerns regarding power production loss were highlighted alongside views on the opportunities to reclaim some of that lost power.

In response, Wind Energy Update has published the following whitepaper looking at the three most capital-intensive components of a wind turbine: the technologies involved, causes for their failure, their reliability and failure rates.

This extract has been taken and edited from the WEU Onshore Wind O&M Strategies Report 2014.

In conjunction with the Wind Turbine Optimization, Maintenance and Repair Summit, Canada (8th – 9th December, Toronto) this whitepaper will help you to master strategies to minimize power production losses and optimize turbine performance in harsh climatic conditions.

If you find this report interesting, please let me know – I'd be delighted to hear your feedback.

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Rotor Blades

Blade reliability is crucial. Being directly responsible for harvesting the mechanical energy contained by the wind, they are completely exposed to its stochastic effect and turbulences. These challenging conditions determine a highly dynamic loading regime, which already becomes a headache at design stage, when blades have to achieve an extraordinarily delicate balance between structural resistance, aerodynamic properties and noise-related performance.

Data collected by NREL on US wind turbines (Sheng S., 2013) assessed the reliability of turbine components over a period of ten years from commissioning. With regard to rotor blades, initial failure rates were high due to defects occurring at the manufacturing stage, or damage caused during transport to or assembly at the wind farm site. During the ten-year assessment period, approximately 2% of turbine blades needed replacement each year, most commonly as a result of damage caused by lightning strikes.

Another component associated with the reliability of rotor blades is the rotor system (which determines blade position). A study by Delft University in the Netherlands (Echavarria, 2008) looked in more detail at the reliability of the major components over time on a number of German wind projects. Rotor systems (excluding the blades) were analyzed over the course of 10 years, and the findings revealed a stark difference between the reliability of turbines with pitch control and those with stall control. Pitch-controlled rotors suffered many more failures throughout the course of the monitoring period, averaging around one failure every four years.

Causes of rotor blade failure

Among the various causes of damage to rotor blades, the most common are:

- Embedded issues related to non-optimal design or manufacturing defects
- Preliminary damage occurring during transportation or installation
- Environmental factors (e.g. erosive materials transported on the air, lightning strikes or ice build-up where relevant)
- Wind turbulence and operative conditions (high dynamic loads)
- Lightning damage, partially mitigated by the implementation of lightning rods, but a frequent cause of accidents given the increasing tip height of modern generators.

The main types of damage that wind turbine blades can suffer are:

- Debonding, undermining the structural integrity of the component through the deterioration of the bonding agents used at the interface between the various structural elements of a blade

- Delamination, sometimes associated with poor design and resulting in air traps between the piles of a blade or poor infusion of resin in a given area that causes poor or no bonding
- Leading-edge erosion, caused by the prohibitive operational environment (high rotational speed) and a variety of erosive agents like sand, rain or hail
- Bolted joint failure, essentially due to the accumulated fatigue associated with the extreme dynamic loads
- Matrix cracking, sometimes developed at the manufacturing stage
- Surface wear
- Multiple cracking, with random and scattered damaging pattern
- Fractures

Routes to cutting rotor blade failure rates and driving up reliability

Rotors are the most exposed of all the components, being open to the elements and experiencing continual dynamic load changes. At the beginning of their lives, manufacturing defects can condemn blades to failure before they even leave the factory. During transportation to the site and at the construction phase physical damage may occur, which will require repair before the turbines are commissioned. In these scenarios, there may be opportunities to improve operator procedures and introduce checks, firstly to reduce the risk of defects and damage occurring, and secondly to detect any problems which have arisen before installation.

Once in operation, environmental problems such as lightning strikes and the gradual accumulation of debris on the blade surface can lead to damage and a significant fall-off in efficiency over time. The risk of damage from force majeure can never be eliminated; however, careful design (through appropriately specified lightning conductors, for example) can reduce the risk of costly and time-consuming catastrophic failures.

Regular maintenance checks can also ensure blade integrity is sound and operating performance is maintained.

Downtime due to blade pitch mechanism failures

A survey by VTT Technical Research Centre of Finland (Stenberg and Holttinen, 2010) assessed the downtime of each of the major components for 72 wind turbines between 1996 and 2008 to ascertain the impact of failures over a turbine's lifespan.

Survey data for pitching mechanisms on turbine rotors were, however, skewed by problems at one particular site where a specific modification to deal with cold environments did not work as intended. Filtering these results out revealed a trend in failures that peaked at around year five before settling down again in later years. Average downtime per year is about 0.1% of total availability time.

With all these figures it is worth bearing in mind that the overall long-term trend in reliability is improving, as well as being a factor of individual turbine age, therefore figures which may be representative of 10-15 year old turbines may not hold true for models with reasonably mature technologies installed today.

Gearboxes

Gearboxes tend to provide the greatest headaches for operators. In a recent Wind Energy Update survey, they were said to be the most problematic component in reliability terms, with an average downtime of 25 days for each failure.

Looking at gearbox replacements, results from the aforementioned study by Sheng at the NREL (Sheng, 2013) showed that, in contrast to rotor blades, early gearbox reliability was very good, but replacement rates climbed sharply with peaks in gearbox failures noted in years four, five and eight of the assessment period.

Causes of gearbox failure

The high intensity of static and dynamic loads and the vibrations placed on the many rotating parts of a gearbox during the generation process determine wear and tear and eventually failures.

Among the factors causing deterioration of a gearbox are:

- Higher loads than those estimated at design stage
- Contact patterns deviation due to mis-assembly or misalignment
- Poor lubrication conditions that could increase metal-to-metal contact
- Reduced material strength due to thermal stress or corrosion
- Vibrations
- Deviation from optimal operating temperatures
- Presence of water or metal content in the oil.

Among the type of issues that can evolve in a failure of the gearbox there are:

- Bearing deterioration
- Abrasive and corrosive wear
- Plastic flow, occurring when metal surfaces yield under heavy loads
- Scoring, consisting of removal of metal due to severe adhesion between surfaces
- Surface fatigue, due to repeated stress
- Tooth cracking, resulting from surface deterioration of the gears.

A 2011 NREL study (Sheng et al, 2011) assessed the top failure modes of gearboxes and their causes, based on data obtained from gearbox rebuilds. Gearbox failures can be categorized into bearing and gear failures. On the bearing side, the following were the most common failure modes:

- Radial roller/bearing cracking as a result of manufacturing anomalies
- Abrasion resulting from oil contamination (sand, rust, machining chips, grinding dust, weld splatter, and wear debris) or embedded particles in meshing surfaces
- Scuffing as a result of a micro-welding and tearing process during sliding contact between two meshing surfaces

Gears tended to fail for the following reasons:

- Vibration-generated deterioration of gear teeth, known as fretting corrosion. The vibratory action tends to force out lubricant and increase the rate of wear
- Cyclical fatigue, starting with the formation of microcracks at stress points which can then spread unnoticed and eventually lead to sudden fracture

Downtime due to gearbox failures

The survey by VTT Technical Research Centre of Finland (Stenberg and Holttinen, 2010) revealed that gearbox reliability was dented in the first four years due to manufacturing defects (Figure 35). Other faults increasingly developed over the following years, peaking in year 11, although it should be noted that the number of turbines being assessed at this stage in their lifespan was relatively low. Although figures are not published, the average annual downtime per turbine due to gearbox failures appears to be a little under 1% of maximum available hours (8,760 hours per year). This is, however, the highest proportion of downtime of any component.

Routes to cutting gearbox failure rates and driving up reliability

The gearbox is one of the most expensive components in a wind turbine system, and although failure rates are low compared with some other components, the downtime associated with each failure is significant, as are the repair costs. According to recent research (Keller et al, 2012), gearbox failures happen more frequently as a result of failures in the bearings – and in particular on the high speed side of gearboxes – rather than in the gears themselves. Gear faults and failures tend to be concentrated in the planetary gears, where corrosion and fatigue are the main root causes (Sheng et al, 2011)

More recent research has found that, in gearboxes with one planetary stage and two parallel stages, axial cracks on bearings on parallel stages are the dominant cause of failure (Sheng, S. 2013).

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The NREL study (Sheng et al, 2011) cited previously in this report concluded that: "operation and maintenance improvements are necessary to minimize the possibility of oil loss" and pointed out that more care should be taken at the assembly stage to minimize the risk of damage to components which may ultimately lead to catastrophic failure.

Generators

Wind turbines typically have an AC generator that converts the mechanical rotational energy into electrical energy. This component is different from other industrial generators because it works with a significantly fluctuating power source. The natural variability of wind conditions causes continual change in the speed of the rotor blades, which in turn causes fluctuations in the mechanical energy transmitted to the generator.

Turbine generator designs are now dominated by models with induction generators, as opposed to synchronous generators. At the start of the monitoring period, induction generators were in their infancy and demonstrated a relatively high failure rate of around three failures per turbine per annum, settling down to two failures per year later in their lifespan. Synchronous generators proved to be more unreliable at around 3.5-4 failures per turbine per year, although reliability appeared to be on an upward trend towards the end of the period.

Adding direct-drive turbines into the analysis, it seems clear that this newly-introduced technology was suffering from some teething problems in the early years. Reliability improved markedly through the second half of the period; however, overall reliability is significantly poorer than for induction generators.

Causes of generator failure

According to a report presented to NREL in 2011 (Shermco, 2011), generator failure modes can usually be traced back to a number of root causes, grouped into four categories:

- Design and manufacturing issues – Including problems resulting from the incorrect specification of component parts, or inadequate performance of those which have been fitted, rather than fundamental engineering design problems. The report cited the example of electrical insulation that does not offer sufficient physical protection to the conductor material in the context of its installation.
- Operations issues – Such as failures to correctly install components, components failing as they are being forced to operate outside of their parameters (over-voltage or over-speed conditions) and – as with rotor blades – damage caused in transit.
- Environmental conditions – Lubricant contamination with moisture or dust and extreme heat or cold are all factors that can play havoc with moving parts. Finally, environmental factors can all play a role in generator problems – excessive

heat, cold and thermal cycling can all play havoc with various systems; likewise, turbulence and lightning strikes are well-documented causes of damage and component failures.

- Maintenance procedures – A class of failure particularly pertinent to this report is those that result from maintenance practices. Oil cooling system failures (perhaps as a result of a missed filter change) can result in problems with various components overheating. Likewise, inadequate monitoring or maintenance of bearings can lead to failure. Over-packing of bearing grease, for example, can lead to excess grease spilling out and contaminating other parts of the generator or blocking essential ventilation ports. This can cause overheating, leading to a chain reaction affecting other components - for example, rotor leads. Downtime due to generator failures

Downtime due to generator failures is significantly lower than that for gearboxes. These components do not seem to suffer the initial teething problems of gearboxes, although reliability tends to deteriorate with time due to wear and tear. Average downtime per year over a turbine's lifespan is around 20 hours, or around 0.25% of the potential availability.

Routes to cutting generator failure rates and driving up reliability

The NREL report (Shermco, 2011) reached a number of conclusions from its investigations, in particular stressing the importance of proper and timely maintenance in relation to prolonging the life of generator components.

It also highlighted the benefits of monitoring components for deterioration, stating that planning maintenance and repairs was a more effective strategy than simply reacting to failures as and when they occurred.

1st Annual

Wind Turbine Optimization, Maintenance and Repair Summit, Canada

8th-9th December, 2014 // Westin Prince Toronto

The Wind Energy Operations and Maintenance Series is now recognized as the Americas most reputable and rewarding commercial business forum. Since 2009 over 2000 delegates, 400 companies, 90 exhibitors and sponsors, from 28 different countries have come together to develop winning O&M strategies, conduct important business and to cement their company's name in the growing industry.

The Wind Turbine OMR Summit 2014 will unite investors and owners of wind power projects with the biggest operators, service providers and suppliers making this a must-attend event at a tipping point for the industry.

Topics at a glace:

NAVIGATING COLD WEATHER CHALLENGES: Ensure maximized power production for turbines operating during periods of extreme cold and snow using highly valued equipment and strategies to ensure maximized profits

BLADE PROTECTION & REPAIR: Explore the latest advances on how to mitigate production losses resulting from icing, lightening and leading edge erosion so that turbines are operating to their full potential

OPTIMIZATION: THE KEY TO POWER PRODUCTION INCREASES: Evaluate the different optimization strategies and technologies that will provide a real increase in power levels

WORKFORCE MANAGEMENT: Find, recruit and retain a competent team to perform only the best service for your organization

BUILD A STRONGER SUPPLY CHAIN: Devise a new supply chain plan to source parts at a reduced price without compromising on quality or longevity

GEARBOX, GENERATOR AND CONDITION MONITORING: Recognize ways to see premature wear, cracks and issues in your drivetrain and methods for fast repair so that the turbine stays operational for as long as possible

I found the event well organized and the individual presentations very informative

TransAlta

For turbine owners and especially operators, the conference was the best balanced and most informative sharing event I have participated in.

Kruger Energy