Emergency stops are typically the most severe torsional events to occur in wind turbines. There is growing evidence that E-stops, and other infrequent but severe torsional events, may be a major cause of drivetrain-component problems. This article provides insights into transient-torsional-reversal events that have been poorly understood, until recently, as a source of damage to gearboxes and other drive components.

We’ll use a diagnostic method called “Five Whys”, which asks “Why?” about five times, to identify the root cause of the gearbox problem. It’s a well-proven process used in lean enterprises. There is no magic to the number five. In this article, we ask enough “whys” to the wind-turbine-gearbox life issue to yield a surprisingly simple, low-cost solution that can be easily retrofitted in wind turbines worldwide.

Premature gearbox failures have plagued the wind turbine industry for decades, and only recently have the real culprits been identified. That information has led to a solution not as complex as imagined.
The five whys

1. Why do bearings and gears in wind turbine gearboxes fail to survive to their intended 20 year design life?

The NREL Gearbox Reliability Collaborative has answered some of the key “whys” to this question. “Most gearbox failures do not begin as gear failures or gear-tooth design deficiencies. The observed failures appear to initiate at several specific bearing locations under certain conditions, which may later advance into the gear teeth as bearing debris and excess clearances cause surface wear and misalignments.”

The inspection of numerous wind turbine gearboxes in operation and those returned for repair have shown the general progression of events that lead to the need for gearbox replacement.

The bottoms two “whys” in Gearbox life problems – several known “whys” deserve further explanation. Bearing experts agree that the pitting of rollers starts with micropitting, also called grey staining or frosting. This consists of microscopic cracks only a few microns deep (about 0.0001 in.). Individually, these cracks are too small to be visible, but as they accumulate, they appear as grey stains on the roller surface. Eventually the bearing roller starts to shed its cracked and weakened surface losing a small bit of its precision tolerance. Furthermore, this contaminates the oil with microscopic, super-hard steel particles most of which are too small to be filtered out.

Why does grey staining begin? The primary cause is typically a breakdown of the oil film that separates the rollers from the races. But this is not the root cause, so this leads us to the next “Why”.

2. Why do rolling elements in bearings break through the oil film and contact the races, even though gearbox designers take great care to prevent this?

Bearing and gear experts understand that even in a properly designed and lubricated gearbox, oil-film breakdown can occur during transient events with concentrated loading and skidding bearing rollers.

The recent and extraordinary instrumentation of a wind-turbine gearbox in actual operation by JR Dynamics Ltd.2, measured the movement of gears, shafts, and even the rollers of the bearings to find the root cause. The data clearly showed that the gears and shafts shifted rapidly, and the bearing rollers skewed during transient-torsional reversals in the drive system. The load zone of the bearing shifts almost 180°, as shown in the illustration During torque reversals, bearing load directions change. Concentrated edge loading on the skewed rollers can break through the oil film. Slower unloaded rollers must accelerate rapidly as they suddenly become loaded, causing skidding that magnifies the surface stress on the skewed rollers. But this is still not the root cause.

3. Why are wind turbine drive systems subject to torsional reversals?

The torsional load in a wind-turbine drivetrain is constantly fluctuating. There are many potential transient load events in their operation that can cause the drive system to rapidly go through a torsional reversal. Such events can include:

- Grid loss
- Emergency stops
- Grid faults
- Generator short circuits
- Crowbar events
- Resonant vibration
- Wind gusts
- Control malfunctions
- Curtailments
- High wind shutdowns
During torque reversals bearing load directions change

Bearing load zones shift 180° radially during torsion reversals. In some bearing locations, load zones may simultaneously shift axially 180°, adding axial skidding and impact loading to overstressed rollers.

All wind turbines are subject to most of the listed torsional-reversal events. Although these torsional reversals are infrequent, they can be severe and damaging. Older, stall controlled, two-speed wind turbines with blade-tip braking are potentially subject to these same infrequent severe torque reversals in addition to reversals during normal blade tip braking, contactor engagements, and downshifting that are frequent but generally less severe. The later even occurs when controls shift load from one generator to the other.

4. Why can’t controls protect the gearbox from torsional reversals?

Improvements in controls have lessened the frequency and magnitude of some events that cause torsional reversals. However, a wind turbine is a complex machine with large rotating masses in the blades and generator that are subject to a wide variety of transient loads. It would be difficult and expensive to use controls alone to ensure against all the potential causes of torsional reversals. (For example, see GE Hybrid Braking System Patent #8,080, 891 which attempts to address severe transient loads from an E-stop with a complex monitoring and control system.) Control malfunctions would still put the gearbox at risk of damage. Torque reversals from shutting down in high wind graphs the torque during such an event for a 2.0 MW, pitch-controlled wind turbine.

Severe torsional reversals were recorded with the PT Tech Wind Torque Monitor during a high-wind shut down on a 2.0 MW, pitch-controlled turbine. Every time the torque trace goes through zero (a torque reversal) the gearbox bearing rollers are potentially skewed and skidding.

Actual torsional reversals (solid red plot) were recorded with the PT Tech WindTM torque monitor during a grid-disconnect event. These torsional reversals are significant. The solid black line marks zero torque, the blue broken line marks rated torque, and dashed reds are the slip torque settings. Bearings continue to see torsional reversals across the zero torque line, despite the slip of a conventional torque limiter.
Why can't conventional torque limiters, typically mounted on the generator shaft, absorb the torque spikes and prevent damage during torsional reversals?

Conventional torque limiters set at 150% to 180% of the wind turbine’s rated torque do provide some protection against forward torque spikes (where the bearing rollers are in position to take a 150% load). However, that same slip torque level in reverse is high enough to damage the skewed and skidding rollers during sudden torque reversals. The illustration Reversing torque despite a conventional torque limiter shows reversing torque and the torsional vibration present even when a standard torque limiter has clipped the maximum reverse torque at 150% of the wind turbine rated torque. A final “why” yields a simple retrofittable solution.

Why can't a torque limiter have different reverse and forward-torque settings?

If the torque limiter mounted on the generator shaft could be set at a much lower reverse slip-torque setting than the forward setting, it could significantly reduce loads on the skewed and skidding rollers, minimizing and perhaps eliminating the start of micro-pitting.

To do this, PT Tech has developed the WindTC Torsional Control product. Just as an electrical snubber circuit can selectively suppress positive or negative voltage spikes, a wind turbine can benefit from the snubbing of the reverse torque spikes. Torque reversals with and without a reverse-torque setting shows a partial power grid disconnect in two turbines. The red line shows an unprotected standard drivetrain, while the blue line shows a nearby turbine equipped with WindTC Torsional Control. By clipping off the first torque reversal it dampens the magnitude and has eliminated further torque reversals. This significantly reduces the stresses and potential damage to bearing rollers.

Enhancing fatigue life in the entire wind-turbine drivetrain

Fitting the torsion-control product described onto the generator shaft can prolong gearbox life and benefit the entire drive system, from rotor blades to generator. Controlling the levels of reverse-torque stress extends the fatigue life of all the driveline components.

Even in modern pitch-controlled turbines there is growing awareness of a link between the frequency of emergency stops and the life of gearboxes and blades. What a torque limiter should really do compares the loads that must be accommodated by a wind turbine depending on the type of torque protection it has. The WindTC,
The torque traces show maximum forward and reverse-torque loads to which a turbine drive system can be subject.

The transceiver for WindTM, a torque sensor and battery pack, has been mounted to the main shaft of a 1.5-MW turbine. The unit provided torque traces that appear in this article.

with a unique feature that allows setting a reverse torque lower than the forward torque, provides a simple, cost effective, retrofittable lean solution to transient torsional reversals. It has a potential to significantly improve the ROI of todays and tomorrows wind farms.

The torque controller has benefits for:

• Wind-farm operators, by lowering operating costs. Furthermore, retrofits are made easy by simply replacing the coupling hub on the generator shaft.

• Wind-turbine designers and OEMs, as a low-cost method for ensuring predictable reverse-torque levels throughout the drive system. The device also reduces need to oversize bearings, gears, and numerous other components.

• Gearing and bearing designers, by reducing loads that compromise the oil film during torsional reversals. WPE

The WindTC (blue unit behind the coupling) is a torque limiter that allows setting different torque values for forward and reverse. It’s mounted on a generator where the device can minimize the transmission of reversing torque loads from the gearbox, as well as from generator to gearbox. Patents are pending in countries with significant wind turbine installations, or manufacturing, or both.
AeroTorque now offers a system to accurately monitor the torque on your turbine’s drive train. The WindTM™ Torque Monitoring System mounts to your main shaft via high powered magnets, allowing for quick mounting of hardware, with less downtime.

The system has the capability of measuring and storing the 100 largest events both forward and reverse torque values measured at the main shaft, throughout the logging period.

A second channel is utilized for shaft speed as well, to allow for an accurate gauge of ambient conditions at the turbine at time of an event.

Data is retrieved over a wireless Bluetooth connection and is accessed remotely over cellular networks or by removable data card.

This system, when combined with the WindTC™ torque limiter, allows for a before and after view of the effectiveness of our torque control.

Don’t take our word for it, test it on YOUR turbine!

Installation of strain gauges - installs quickly
Completed mounting - ready for startup
Shown with optional extra battery pack
Control your gearbox loads to control your gearbox life!

Extend the life of your gearbox! The WindTC™ is an innovative torsional control for wind turbines. The torque limiter offers standard forward torque limiting but has a reverse torque limiter that is significantly lower. This unique mechanical control reduces damaging loading in your drive train.

With the WindTC™ in your turbine, you get reduced magnitude spikes, shorter duration events, improved bearing alignment and increased gearbox life!

In all turbines, very large transient events occur in the drive train. These events include:

- Grid loss
- Grid fault
- Pause events
- Braking
- Control malfunctions
- Wind gusts

Despite much progress by gearbox manufacturers and bearing suppliers, bearings and gearing continue to fail, costing up to $250,000 to repair or replace the gearbox. All of the incremental improvements have not been able to address the dynamic loads that a wind turbine gearbox and its bearings will encounter.

Axial cracks and other damage in bearing raceways have become the major cause of premature gearbox failures in the latest generation of wind turbines, shortening life to as little as 1-2 years once it is initiated. Research and field application have shown that the torque reversals and impact loads are a leading cause of this damage. Only the WindTC addresses those loads.