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Abstract: this paper describes a new Friction Drive (FD) wind turbine technology aimed at managing torque excursions. Torque excursions are identified as the main cause of damage to current wind turbine drive trains, mainly related to failure in gearboxes. The friction drive technology introduces a wind turbine 'drive' that manages the torque transmitted through the mechanism, such that torques and rates of torque change above design levels do not occur. The new wind turbine technology also increases the part load efficiency, improves reliability and provides ease of maintenance. In addition, the friction drive addresses issues that conventional wind turbine technology has in respect to scaling up to higher rated powers and size limitations.

History has shown a large number of problems and failures related to gearboxes in conventional wind turbines. These problems affect the reliability, availability and economics of such turbines, especially those operating in areas with high annual average wind speeds and turbulence intensity. Additional contributors to these failures in wind turbines that are equipped with a gearbox include:

- Wind gusts at low speed, can cause load reversal in the drive train. This may lead to undesired axial load cycles on the high speed bearings in a helical gear stage.
- Rapid speed variations at low load levels are problematic for large spherical roller bearings.
- An insufficient rigidity of the bedplate can result in the misalignment of the gearbox and generator shafts and consequently lead to unwanted vibrations.
- Lack of well dimensioned oil filtration systems can lead to accelerated gearbox failure.
- Transmission error, the difference between the actual and ideal position of the driver gear can result in load variations.
- Lack of insight in the drive train behavior during various transient phenomena, current unknowns.

Direct drive wind turbines that do not use a gearbox have scale-up limitations due to the nacelle size and weight, which result in higher costs. Limited data is available for direct drive wind turbines operating in high turbulence intensity. Direct drive turbines also face challenges related to cooling requirements in offshore applications.

Wind farm economics are directly related to the performance of the wind turbines. In European lands most of the first grade wind sites that are characterized by good wind speed, low to moderate turbulence intensity and ease of access, have already been developed. In other places around the globe, setback regulations often prevent developers from using first grade sites . Wind farm developers are forced to move into second grade sites that are characterized by high turbulence intensity, remoteness and challenging environmental conditions like in offshore cases. Wind turbines will be required to cope within second grade site conditions, while maintaining high availability and reliability.

The CWind friction drive replaces the expensive and failure-prone gearbox in existing designs and overcomes this specific limitation allowing the utilization of the useful energy available in high turbulence winds.

The friction drive features a steel drivewheel connected directly to the wind turbine main shaft. The drivewheel drives multiple permanent magnet electrical generators via tires. The tires are directly coupled by friction to the drivewheel. The drivewheel has a larger diameter than the tires; hence it provides a speed increase ratio of about ten to one. The distinguishing feature used to achieve torque management is short lived slippage. The friction coupled drive allows torque peaks to be avoided by slippage between the friction components when torque exceeds a prescribed level. The friction drive will filter undesirable torques and rate of torque change and only allow the pre-set torque to be transmitted to the power generation components. Small amount of the mechanical power is dissipated as friction heat during slippage (due to the minute time associated with the slip event) and most of the power is stored as inertia in the rotor blades as the blades are momentarily allowed to speed up during the wind gust. This protection feature is instantaneous but does not take place unless a large torque overload occurs, and the inertia stored in the blades during the wind gust is ultimately recovered as useful energy once the gust has passed.

Pitch control of the wind turbine blades allows reduction of the power collection capability of the rotor as wind speed increases. Pitch control is relatively rapid; however, gusts can occur faster than the pitch control can respond or be capable of detecting. During a gust interval when wind speed is changing faster than the response of the pitch control, other controls of the friction drive manage the torque to maintain design levels. Wind turbines using gearboxes often utilize their pitch drive in order to control the torque excursions and protect their drive train; this methodology of operation reduces the amount of energy collected from the high turbulence wind due to premature pitching.

Power electronics allow the system to operate with variable speed generation and yet deliver synchronized 3-phase power to the grid. Further, the power electronics help to manage the torque on the mechanical drive system by controlling the load on the generator and back torque. Power electronic controls are very fast, and the sampling and response time is within a few cycles (16ms/cycle for 60Hz). The power electronic controls recognize the current state of the wind turbine machine (its inertia, the pitch setting, and the wind speed) and control the electrical power production to help control the torque in the wind turbine.

The design of CWind wind turbines also features the use of multiple small generators allowing wide range of electrical power production at high efficiency. At low wind speeds, only one generator is engaged, as wind speed increases, additional generators are brought into service, maintaining an overall high generating efficiency over a wide range of wind speeds. Engaging additional generators, bringing them on line as the average wind speed increases helps to manage the average torque seen by the mechanical drives.

At the same time the design uses the independent load paths with the multiple small generators that would be operating independently of each other (not hard coupled). Even if one or more of the generators would fail, it will not affect the operation of the other generators and the turbine can continue to operate with part load. This feature will increase the turbine availability, especially for remote applications.

The use of small generators in this design allows a wide range of electrical power production at a high efficiency. For instance, the 2.0 MW friction drive wind turbine of the new design would have eight generators; each generator is rated at 250 KW. The number of active generators will be controlled so that the optimum part load electrical efficiency is maintained at all below rated wind speeds.

Using multiple small generators also simplifies serviceability and maintainability of the turbine. The turbine nacelle is also equipped with a crane that is capable of lifting any of the drives and changing or servicing it without the requirement for a large external crane. For example, in offshore applications using conventional wind turbines, it would require the use of a special jack-up crane ship to replace any of the major turbine components such as the gearbox or generator in the case of a failure, whereas for this new turbine design, replacing a drive mechanism or a generator would require only the use of the built-in nacelle crane and a fairly small boat.

Scaling up to higher wind turbine rated power for this design is comparatively different than other conventional technologies. The CWind turbine is much simpler than conventional turbines and the modular design of the friction drive components allows for scaling up of the power train by adding more generators to increase the rated power of the turbine. For example, the same drive mechanism used in the 2.0 MW turbines with eight 250 KW power generating mechanisms can be used for the 3.0 MW turbines by using a larger rotor and drivewheel and 12 power generating mechanisms. Alternatively the number of mechanisms can be reduced to 10 by increasing the rated power of the electrical generators from 250 KW to 300 KW.

CWind has initiated a product development plan that has several stages as shown below:

1. Proof of Concept Stage: 65 KW wind turbine prototype.
2. Friction Drive Shop Testing Stage: Tire testing for the 2.0 MW turbine.
3. 2.0 MW Wind Turbine Stage: Design, manufacture and assembly of 2.0 MW wind turbines.
4. Develop wind turbines with rated power larger than 2.0 MW for offshore market.

CWind has successfully completed the first stage, is currently finalizing the second and has started the third stage.

CWind has successfully designed, manufactured, installed and tested a 65 KW proof of concept friction drive wind turbine prototype. The prototype is a retrofit of a 65 KW Nordtank wind turbine. The Nordtank turbine was manufactured in the mid 1980s and operated for a number of years in California. The gearbox of the used Nordtank wind turbine was replaced by the new friction drive system with four PM generators and a friction drivewheel.

The nacelle of the prototype turbine was redesigned, and was equipped with new mechanical components of the friction drive, supporting and auxiliary systems, control system, data acquisition system, power electronics, and safety systems.

The CWind FD 65 KW wind turbine was installed in Clinton, Ontario, Canada in March, 2007 and was connected to the grid in June, 2007.

The 65 KW wind turbine is not only used as a proof of concept but also as a test bed to collect important data, therefore a comprehensive data acquisition system is used in this turbine that is capable of collecting "close to real time data" for approximately 100 key variables and signals.
A comprehensive field testing program was completed successfully; the friction drive system has operated as anticipated by the design in this wind turbine limiting the power transmitted from the wind to the power generation components (generators). The multiple generator concept with independent load paths was also proven using a control system that allowed the turbine to operate in part load when either one of the drives was not functional. Also the operation in staggered mode for the electrical generators was proven. The effectiveness of utilizing the friction drive in high turbulence intensity winds was proven at this scale.

In the next stage, CWind preformed the preliminary design of the FD 2 M (2.0 MW) wind turbine to assess the feasibility of scaling up the friction drive. The CWind FD 2M is a three blade, up-wind, horizontal axis, variable speed wind turbine with eight permanent magnet generators. The eight permanent magnet generators operate at variable speed and produce variable frequency AC current. Power electronics turn the variable frequency AC power into a constant 60 or 50 Hz frequency AC current, which will be transmitted directly to the power grid.

The preliminary design was completed by MPR Associates of Alexandria, VA, USA; the design effort concluded that building a 2.0 MW wind turbine using the friction drive is technically feasible. MPR stated: "The CWind technology is a simple and reliable friction drive which replaces the expensive and failure-prone gear box in existing designs…the successful implementation of this technology will provide wind turbines that have a lower cost of electricity."

In order to mitigate the risk of scaling up of the friction drive from the 65 KW proof of concept level to the 2.0 MW commercial size level; CWind has implemented a shop tire testing program. The program started early 2008 on a single tire subjected to normal loads, transmitted torque and rotational speeds similar to those anticipated for the 2.0 MW wind turbine tires. The testing covered a complete tire operational envelop and collected data for the transmitted torque, rotational speeds, tire temperature and longevity of the tire material.

The results of the shop tire testing program encouraged CWind and its partners to start the development of the 2.0 MW friction drive wind turbine. CWind started the detailed design process of the 2.0 MW wind turbine incorporation with Global Energy Concepts of Seattle, WA, USA and Linamar Corporation of Guelph, Ontario, Canada.