DESCRIPTION

Reference to Related Applications

[0001] This application claims priority to U.S. Provisional Application No. 61/490,765, filed May 27, 2011.

Field of the Invention

[0002] The invention generally relates to controlling wind turbines, especially in conditions of extreme or variable winds.

Background

[0003] Wind energy is an attractive alternative to fossil fuels because it is plentiful, renewable, widely distributed, clean, and produces no greenhouse gas emissions. In order to maximize electrical generation, wind turbines are typically sited in high-wind areas such as mountainsides and canyons. Wind turbines are also sited offshore, to harness strong coastal winds.

[0004] The wind harnessed for power generation can also damage a turbine, however. While stronger winds generate more power, high and fast wind speed and direction change, e.g. extreme gusts, may generate tremendous stress on the components of the turbine. In particular, blades, hubs, and gearboxes are vulnerable to stress-related failure. By advanced materials and precision engineering, large, modern turbines can achieve reliable performance in wind speeds up to 30 m/s. Nonetheless, every wind turbine has a cut-out wind speed above which the turbine cannot safely operate for extended periods. If the speed of the wind substantially exceeds the cut-out wind speed while the turbine is producing, the turbine can lose its capability to control shaft torque and/or running speed and can be damaged, resulting in downtime and costly repairs. Also when the operating turbine is reached by an extreme gust, the turbine can be damaged if its control system doesn't respond promptly to bring it to shut down.

[0005] For example in the event of very rapid variation of wind speed and or wind direction (specifically in the case of the extreme coherent gust with wind direction change or other extreme gusts), the safe limits of rotor aerodynamic torque and speed can be exceeded, even after the control system starts the shut down (when based on shaft over-speed sensor). This can result in dangerous stresses on the blades, hub, drive train, and other subsystems - all of which can result in turbine failure.

[0006] To avoid damage in high winds , many wind turbines have rotor speed sensors which sense the speed of the rotor shaft, for example, through a speed pick-up, which is used for power control and for shutdown. In such wind turbines, a braking system is activated in the event of shaft over-speed. The response of the running speed lags the variation of the aerodynamic torque, however, because of the inertia of the rotor. Thus, the corrective action is not initiated until well after the onset of the wind event.

[0007] Thus, there is a need for a control system that can instantaneously sense rapid variations in wind speed seen by the rotor and initiate corrective action. Document WO 2011/042369 discloses the control of a wind turbine whereby based on load measurements on the blades or the rotor shaft the thrust on the rotor is estimated, and when this thrust exceeds a certain threshold, the turbine is stopped.

Summary

[0008] The invention provides wind turbine control systems to instantaneously detect increased thrust loads and initiate corrective action. In many instances, the increased thrust load results from a variation in the wind speed or direction, for example from a sustained gust or storm. The system can initiate a corrective action to limit the overshoot of the rotor speed by activating a braking system. The corrective action may lead to a shutdown. In some embodiments, the thrust sensor comprises an axial load sensor or a combined torque/thrust sensor.

[0009] Once an increase in thrust load is sensed, the control system can activate the blade pitch mechanism in the pitch control turbines or the yaw actuation mechanism in the yaw control turbines and/or also a mechanical or electrical (or regenerative) braking system coupled to the rotor shaft to reduce the growth rate of the rotor speed. In most of the wind turbines the control system initiates the actuation of the braking system when the rotor running speed reaches a threshold (over-speed set point) which value is set so that the overshoot of the rotor speed transient should not reach the design limit.

[0010] However by considering the transient behavior due to extreme gusts it may be necessary to lower the over-speed set point at a value that might cause not wanted shutdown in normal operation.

[0011] This risk can be mitigated or removed by using the signal of a sensor which responds immediately to any variation of wind speed, without or with little inertia, while the sensed running speed is delayed by the mass inertia of the rotor and drive train.

[0012] In the event a thrust load increase exceeds a safe limit, i.e. an over-thrust threshold, the controller can initiate turbine shut down, through the braking system e.g. by using the pitch control system or the yaw control system and/or also a braking system coupled to the rotor shaft. In some embodiments, the controller receives measurements of the shaft running speed during activation of the braking system and uses the speed measurements to calculate a deceleration of the rotor shaft. The controller then modulates the braking system as needed to keep the deceleration rate below a maximum allowed level.

[0013] The invention is useful for any wind turbine.

Brief Description of the Drawings

[0014]

Fig. 1 is a diagram of a wind turbine rotor shaft comprising a thrust sensor.

Fig. 2 is an embodiment of a wind turbine control system of the invention.

Detailed Description

[0015] In many wind turbines, the braking system is activated by the shaft over-speed threshold through a speed pick-up. In such systems the response of the running speed lags any variation of the aerodynamic torque because of the inertia of the rotor, therefore, activation of the braking is delayed, leading to a higher overshoot of the operating parameters (and drive train loads). Such overshoot conditions can result in damaging stresses on the turbine and subsystems. In contrast, the invention provides wind turbine control systems capable of instantaneously detecting increased thrust loads on a wind turbine due to changes in wind speed.

[0016] Increasing wind speeds result in an axial force down the rotor shaft prior to an increase in the rotor speed due to the increased wind energy. By measuring axial load changes in real time, it is possible to initiate corrective actions as soon as the wind changes, decreasing the chance of turbine overload. The corrective action may be reducing the growth rate of the rotor shaft speed or shutting down the turbine by activating a braking system.

[0017] Thrust sensors suitable for use with the invention may be axial load sensors. Axial load sensors can be arranged in the support of the axial bearing of the rotor shaft and may be continuously monitored by a turbine monitoring and control system. Axial load sensors may be bearing assemblies with torque and thrust sensors integrated within. The axial load sensors output a signal indicative of the axial load on the rotor shaft. The signal is received by a turbine controller. In some embodiments, it is beneficial to incorporate redundant thrust sensors into the system to avoid maintenance in the event that one or more sensors fail.

[0018] A time-dependent increase in axial load received by the turbine controller is indicative of an increased wind speed and will result in activation of a braking system. In the event the axial load exceeds an over-thrust signal, shutdown procedures will be initiated.

[0019] Thrust sensors suitable for use with the invention may also comprise pressure sensors, for example piezoelectric sensors. The sensors may be in contact with, or incorporated into, the rotor shaft or its supports, or the sensors may be in contact with, or incorporated into, the rotor blades or the hub. In a teetering hub turbine with elastomeric teeter bearings, the sensors may be coupled to the teeter bearings, thereby providing a measurement of the axial load.

[0020] An exemplary rotor shaft assembly 100 comprising a thrust sensor 120 is shown in Fig. 1. The thrust sensor 120 is located at an interface between the radial and thrust bearing 130 and the bedplate 140. According to this arrangement, the thrust sensor 120 is able to measure an axial load on the main shaft 150 due to increased thrust 160 on the main shaft 150. By activating a braking system (not shown) it is possible to avoid a speed overshoot condition that can result in overloading the turbine components. The invention applies to turbines with or without gearboxes.

[0021] An embodiment of a wind turbine control system of the invention is shown in Fig. 2. Thrust sensors 2 are in communication with the axial bearing support of the turbine main shaft 1, i.e., as shown in Fig. 1. The thrust load sensors 2 detect the axial load transferred by the shaft to the bedplate.

[0022] A signal from the thrust load sensors 2 is sent to the turbine controller 3. The turbine controller 3 also receives a shaft running speed signal output by the shaft running speed sensors 4. The turbine controller 3 compares the detected thrust load with a defined over-thrust threshold 5. Using the shaft running speed signal, the turbine controller 3 calculates the acceleration/deceleration of the running rotor. For example, the controller may receive a first shaft running speed at a first time and a second shaft running speed at a second time, and calculate a deceleration based upon the difference of the first and second shaft running speeds over the difference of the first and second times. The turbine controller 3 then compares the calculated deceleration with the maximum deceleration allowed 6. The maximum deceleration may be input by a user on the basis of a design value and may be adjusted in operation on the basis of the turbine testing results.

[0023] When the thrust load reaches the over-thrust threshold 5, the turbine controller 3 promptly initiates 7 the braking system 9. The braking system 9 may comprise a yaw control system alone or operably coupled to a mechanical braking system, for example a drum or disc brake, or an electrical braking system, for example inverter torque control or resistive braking, or a combination of both.

[0024] In some embodiments, the braking system 9 may comprise a pitch control system alone or operably coupled to a mechanical braking system, for example a drum or disc brake, or an electrical braking system, for example inverter torque control or resistive braking, or a combination of both.

[0025] A yaw control system suitable for use with a wind turbine control system of the invention in a two-bladed teetering hinge turbine is described in PCT/US2012/36637, "Systems for Minimizing Yaw Torque Needed to Control Power Output in Two-Bladed, Teetering Hinge Wind Turbines that Control Power Output by Yawing" filed May 4, 2012, and incorporated by reference herein in its entirety.

[0026] If the turbine controller 3 determines that the calculated deceleration is greater than the maximum deceleration allowed 6 (above), the turbine controller 3 can command the braking system 9 to modulate the braking torque softly 8 with a deceleration not higher than the max deceleration allowed 6. In some embodiments, a hydraulic braking system will be used to provide for softer braking of the rotor shaft.

[0027] In an alternative embodiment, an additional function of turbine controller 3 would be to manage an over-speed condition, e.g. by monitoring an over-speed threshold. Such a system would be able to brake the shaft rotor in the event that the over-speed threshold was reached before the over-thrust threshold. Such a condition would be rare, but likely indicative of a mechanical failure within the drive train.

[0028] Thus the invention provides a wind turbine control system for decelerating the rotor shaft in the event of an increased thrust load, typically caused by an extreme gust, storm, hurricane, or typhoon. The systems provided have faster response time than rotor speed sensor based systems, and therefore, can prevent damage to the wind turbine during extreme wind events.

Equivalents

[0029] The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments are therefore to be considered in all respects illustrative rather than limiting on the invention described herein. Scope of the invention is thus indicated by the appended claims rather than by the foregoing descrition.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US61490765A [0001]
- WO2011042369A [0007]
- US201236637W [0025]

Patentkrav

1. Vindmølle med et fremdriftssystem omfattende:

et rotoraksel-trykleje omfattende en aksial belastningssensor til direkte at måle en aksial trykkraft på en rotoraksel; og

et bremsesystem koblet til rotorakslen, hvor bremsesystemet aktiveres, når en aksial trykkraftsgrænse er oversteget.

2. Vindmøllen ifølge krav 1, hvor bremsesystemet omfatter et vingepitchstyresystem.

3. Vindmøllen ifølge krav 1, hvor bremsesystemet omfatter elektrisk bremsning eller mekanisk bremsning.

4. Vindmøllen ifølge krav 3, hvor elektrisk bremsning omfatter at øge et fastholdelsesdrejemoment på rotorakslen med en inverter eller generator.

5. Vindmøllen ifølge krav 3, hvor mekanisk bremsning omfatter at aktuere en skive- eller tromlebremse koblet til rotorakslen.

6. Vindmøllen ifølge krav 1, hvor bremsesystemet er koblet til et giringsstyresystem, og en giringsvinkel af vindmøllen øges, når en aksial trykkraft er detekteret.

7. Vindmøllen ifølge krav 1, yderligere omfattende en vindmøllekontroller, der regulerer en decelerationshastighed af rotorakslen.

8. Vindmøllen ifølge krav 1, hvor vindmøllen har to vinger og et vippenav.

9. Fremgangsmåde til at styre hastigheden af en vindmølles rotoraksel, omfattende:

at detektere direkte en aksial trykkraft på vindmøllens rotoraksel; og

at aktivere et bremsesystem.

10. Fremgangsmåden ifølge krav 9, yderligere omfattende:

at måle en aksial trykkraft på rotorakslen; og

at sammenligne den målte aksiale trykkraft til en overtrykstærskel.

11. Fremgangsmåden ifølge krav 9, yderligere omfattende:

at detektere en første rotorakseldriftshastighed på et første tidspunkt;

at detektere en anden rotorakseldriftshastighed på et andet tidspunkt;

at beregne en decelerationshastighed af rotorakslen; og

at sammenligne den beregnede decelerationshastighed med en maksimumdecelerationsgrænse.

12. Fremgangsmåden ifølge krav 11, yderligere omfattende at modulere bremsesystemshandlingen, når den beregnede decelerationshastighed af rotorakslen er større end maksimumdecelerationsgrænsen.

13. Fremgangsmåden ifølge krav 9, yderligere omfattende:

at detektere en første rotorakseldriftshastighed på et første tidspunkt;

at detektere en anden rotorakseldriftshastighed på et andet tidspunkt;

at beregne en accelerationshastighed af rotorakslen; og

at sammenligne den beregnede accelerationshastighed med en maksimumaccelerationsgrænse.

14. Fremgangsmåden ifølge krav 13, yderligere omfattende at modulere bremsesystemshandlingen, når den beregnede accelerationshastighed af rotorakslen er større end maksimumaccelerationsgrænsen.