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- (71) **Applicant (for all designated States except US):** **NORTHERN POWER SYSTEMS, INC.** [US/US]; 29 Pitman Road, Barre, VT 05641 (US).
- (72) **Inventors; and**
- (75) **Inventors/Applicants (for US only):** **BYWATERS, Garrett, L.** [US/US]; Northern Power Systems, Inc., 29 Pitman Road, Barre, VT 05641 (US). **COLE, Trevor, H.** [US/US]; Northern Power Systems, Inc., 29 Pitman Road, Barre, VT 05641 (US). **PETTER, Jeffrey, K.** [US/US]; Northern Power Systems, Inc., 29 Pitman Road, Barre, VT 05641 (US).
- (74) **Agent:** **KOHLER, Thomas, D.**; Downs Rachlin Martin PLLC, 199 Main Street, P.O. Box 190, Burlington, VT 05402-0190 (US).
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(54) **Title:** SYSTEMS FOR LOAD REDUCTION IN A TOWER OF AN IDLED WIND-POWER UNIT AND METHODS THEREOF

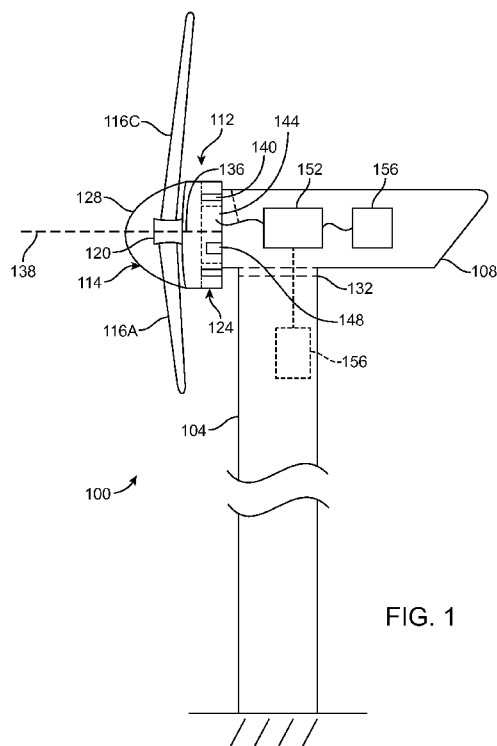


FIG. 1

(57) **Abstract:** Systems and methods for reducing dynamic loading in an idled wind power unit include sensing at least one parameter indicative of dynamic loading and executing a reduced torque brake mode, which may comprise a controlled brake and brake-release sequence, with the turbine braking system when the sensed parameter exceeds a selected value. The reduced torque brake mode absorbs energy and reduces dynamic loading thereby.

**Declarations under Rule 4.17:**

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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SYSTEMS FOR LOAD REDUCTION IN A TOWER OF AN IDLED WIND-POWER UNIT AND METHODS THEREOF

RELATED APPLICATION DATA

[0001] This application claims the benefit of priority of U.S. Provisional Patent Application Serial No. 61/421,479, filed 12/9/2010, and titled "Method and System for Load Reduction in a Tower of an Idled Wind-Power Unit," which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

[0002] The present disclosure generally relates to the field of wind-power units. In particular, the present disclosure is directed to systems for load reduction in a tower of an idled wind-power unit and methods thereof.

BACKGROUND

[0003] Wind-power units ("WPU"s), which generate electrical power from the energy in wind, continue to increase in importance as alternative, or "renewable," energy sources. In some weather or turbine conditions the WPU must be "idled", and in some cases fully parked, to limit the loads imposed on the WPU and ensure personnel and equipment safety at all times. For a typical horizontal axis WPU, idling usually entails pitching the blades roughly 90 degrees to a shutdown position, permitting the rotor of the WPU to rotate slowly. In some other examples, a WPU's control logic may call for an additional brake to be applied and for the WPU to be "parked", with the brake bringing the rotor to a complete stop and essentially locking the rotor from rotating. The WPU may also include a yaw drive that permits an idled or parked rotor to be turned into the wind. Each of these actions, either separately or together, typically reduces the forces the wind exerts on the WPU, thereby reducing the risk of damage to the WPU. However in some cases while the WPU is in an idled or a parked state, off-axis winds interacting with the rotor can result in unsteady and oscillating loads applied to the rotor blades. These oscillating loads can result in dynamic loading of the WPU structure and in the supporting tower that can exceed normal loading conditions and cause equipment damage.

SUMMARY OF THE DISCLOSURE

[0004] The present disclosure describes exemplary embodiments of methods and apparatus for sensing and responding to dynamic loading conditions that might result in damage to reduce overall loads imposed on the WPU, as well as the WPU's supporting tower and foundation system.

[0005] In one implementation, the present disclosure is directed to a system for reducing dynamic loading in a wind power unit in a parked or idled condition, the wind power unit including a turbine, a turbine axle having a longitudinal axis, and a wind power unit brake system including at least one turbine brake. The system includes a sensor adapted to be positioned with the wind power unit and configured to sense at least one parameter indicative of dynamic loading in the wind power unit and produce a dynamic loading signal representative thereof; and a logic circuit in communication with the sensor to receive the dynamic loading signal, the logic circuit being configured to generate a braking signal in response to the dynamic loading signal indicating a level of dynamic loading exceeding a selected value; wherein the brake system is configured to receive the braking signal and execute a reduced torque brake mode in response to the braking signal to reduce the dynamic loading of the wind power unit by permitting intermittent slip of the brake system.

[0006] In another implementation, the present disclosure is directed to a method of reducing dynamic loading in an idled wind power unit, the wind power unit including a turbine on a turbine axle and a brake system. The method includes sensing a parameter indicative of dynamic loading of the wind power unit; determining if the sensed parameter is at least at a selected value; and instructing the brake system, when the sensed parameter is at least at the selected value, to execute a reduced torque brake mode to reduce the dynamic loading of the tower.

[0007] In still another implementation, the present disclosure is directed to a system for reducing dynamic loading in a tower of a wind power unit. The system includes a sensor configured to detect dynamic loading in the wind power unit and generate a signal indicating the detected loading; and a logic circuit configured to receive the signal and to send a second signal to a turbine brake system in the wind power unit wherein the second signal causes the brake system to execute a reduced torque brake mode to reduce the dynamic loading of the tower.

[0008] In yet another implementation, the present disclosure is directed to a system for reducing dynamic loading in a wind power unit in a parked or idled condition, the wind power unit including a turbine, a turbine axle having a longitudinal axis, and a wind power unit brake system including at

least one turbine brake. The system includes a sensor adapted to be positioned with the wind power unit and configured to sense at least one parameter indicative of dynamic loading in the wind power unit and produce a signal representative thereof; means, communicating with the sensor to receive the dynamic loading signal, for generating a braking signal in response to the level of dynamic loading exceeding a selected value and outputting the braking signal to the braking system, wherein the braking signal includes instructions for execution of a reduced torque brake mode to reduce the dynamic loading of the wind power unit by permitting intermittent slip during the parked condition.

[0009] In still yet another implementation, the present disclosure is directed to a system for reducing dynamic loading in a wind power unit in a parked or idled condition, the wind power unit including a turbine, and a turbine axle having a longitudinal axis. The system includes a sensor adapted to be positioned with the wind power unit and configured to sense at least one parameter indicative of dynamic loading in the wind power unit and produce a signal representative thereof, the dynamic loading including at least a component of motion perpendicular to the longitudinal axis of the turbine axle; a processor in communication with the sensor to receive the representative signal, the processor being configured and programmed to determine a level of dynamic loading indicated by the sensed parameter and compare the level to at least one selected value, the processor being further programmed to generate a braking instruction in response to the level of dynamic loading exceeding a selected value; and a wind power unit brake system including at least one turbine brake, the system configured to receive the braking instruction from the processor, wherein the braking instruction includes a controlled braking and brake-release command for the brake, the controlled braking and brake-release command causing execution by the brake system of a reduced torque brake mode to reduce the dynamic loading of the wind power unit by permitting intermittent slip during the parked condition.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For the purpose of illustrating the invention, the drawings show aspects of one or more embodiments of the invention. However, it should be understood that the present invention is not limited to the precise arrangements and instrumentalities shown in the drawings, wherein:

FIG. 1 is an elevational schematic view of a wind-power unit (WPU);

FIG. 2 is a plot of simulated bending moments in a tower of a WPU as a function of time operating without the benefit of the present invention, wherein the WPU includes a turbine with blades oriented approximately as illustrated in FIG. 3;

FIG. 3 is a free body diagram of exemplary wind conditions described herein that can accentuate oscillations of a tower of a WPU;

FIG. 4 is a flow diagram illustrating an exemplary method of detecting and reducing oscillations in a WPU tower in accordance with the present disclosure;

FIG. 5 is a plot of simulated rotor azimuth angle as a function of time in a WPU operating in accordance with an exemplary embodiment of the present disclosure; and

FIG. 6 is a plot of simulated bending moments in a tower of a WPU as a function of time with the system operating according to an embodiment of the invention beginning at time 200 seconds, wherein the turbine blades of the WPU are oriented approximately as illustrated in FIG. 3.

FIG. 7 is a block diagram of an analog logic circuit according to an alternative embodiment of the invention.

DETAILED DESCRIPTION

[0011] Disclosed herein are systems and methods for using controlled rotor braking of an idling or a parked WPU so as to reduce dynamic loading that can occur in a WPU tower and foundation under certain environmental conditions. Exemplary manifestations of dynamic loading include, but are not limited to, oscillation, elastic or plastic strain, a bending moment, or other physical or electrical response exhibited by a WPU tower or component that indicate a dynamic load is being experienced by the WPU. The disclosed systems and methods include sensing one or more indicia of dynamic loading within the WPU, determining if the dynamic loading warrants intervention, and then reducing the dynamic loading by modulating excitation factors. As will be appreciated by persons of ordinary skill in the art, systems in accordance with embodiments of the invention may be designed with the control logic executed in digital or analog logic circuits. In one exemplary embodiment, excitation factors may be modulated while the WPU is in a braked and parked state by performing a controlled partial release of the brake to produce a reduced torque brake mode. In such an embodiment, the braking control absorbs energy by allowing a limited, intermittent rotor slip, thereby damping the excitation factors and reducing dynamic loading.

[0012] Referring now to the drawings, FIG. 1 illustrates one exemplary embodiment of a WPU 100, which includes a tower 104, a nacelle 108 disposed on top of the tower, and a turbine 112 that is proximate to the nacelle. In this embodiment, hub assembly 114 comprises an assembly of blades 116A – C, hub 120, and nose cone 128. Electrical power generator 124 includes rotor shaft 136, stator 140, and rotor 144. Turbine 112 is an assembly of hub assembly 114 and electrical power

generator 124. In this example, the rotation of turbine 112 turns rotor shaft 136, which in turn rotates rotor 140 with respect to stator 144, thereby generating electricity. A yaw-drive 132 is disposed on top of tower 104 and within nacelle 108. The general arrangement of the main components may be consistent with known WPUs and describes a gearless, direct drive configuration. The invention could be applied equally to a wind turbine configuration that uses a single or multiple stage gearbox to interface the hub assembly with the electrical power generator.

[0013] WPU 100 also includes a brake system 148, a processor 152 and a sensor 156. Braking system 148 may comprise any appropriate WPU braking system as may be selected by a person of ordinary skill in the art for use with embodiments of the invention as taught herein. Such systems generally include a brake acting on a braking surface, which may be, for example, on the rotor, shaft, a break drum or disk attached to the rotor or shaft, or other appropriate structure. Processor 152, which may comprise a programmable logic controller, may be generally conventional, with the processor additionally configured for control according to embodiments as described herein. Sensor 156 is attached to WPU 100 at a location facilitating the detection of stress, strain, movement, acceleration or other indicia of dynamic loading of WPU 100 in accordance with the particular embodiments as will be appreciated by persons of ordinary skill in the art based on the teachings herein. The location of sensor 156, shown alternatively in dashed lines on tower 104, as well as the type of the sensor, depends on the indicia of dynamic loading to be detected. In one example, if the skilled artisan chooses to detect oscillation in WPU 100 by measuring the elastic strain experienced by tower 104, then sensor 152 may be a strain gauge attached to the tower. The specific location of sensor 156 on tower 104, and even the type of sensor used, are a function of the sensitivity of the sensor, the physical (or electrical) response to be detected, the location that the physical (or electrical) response is expected to occur on the tower or WPU 100, convenience of attachment, and other factors known to those skilled in the art. The use of brake system 148, processor 152, and sensor 156 in the context of the present disclosure will be described in more detail below.

[0014] In one example, when WPU 100 is idled, damaging oscillations can occur when, for example, the rotor shaft 136 of turbine 112 is angled between 20° and 40° with respect to the wind. FIG. 3 is a free body diagram that illustrates the forces in this situation. Wind vector V_{wind} and rotor shaft 136 are separated by a 30° angle resulting in a bending moment being generated. FIG. 2 illustrates an example of the bending moments experienced by tower 104 when WPU 100 is in the situation depicted in FIG. 3. As shown in FIG. 2, the side-side tower bending moment in this case can begin to oscillate between positive and negative moment values with increasing magnitude over

time. In other words, WPU 100 can start to oscillate from one side to the other, in a direction approximately perpendicular to a longitudinal axis 138 of rotor shaft 136. The values depicted in FIG. 2 can be several multiples of the maximum load levels that tower 104 is otherwise designed to withstand.

[0015] As further shown in FIG. 3, in addition to the force of the wind acting on WPU 100 as a whole, another source of energy that can contribute to dynamic loading in WPU 100 is the aerodynamic force induced in blades 116A – C. Blades 116A – C have an airfoil shape used to improve the conversion of the energy in wind into electricity. Even when turbine 112 and blades 116A – C are not rotating, the blades can still be a source of force when the wind is moving relative to the blades. This relative movement may cause an aerodynamic force to be exerted on blades 116A – C, which may then be transferred to tower 104.

[0016] As also illustrated by FIG. 3, blades having an adjustable angle of attack can further contribute to conditions leading to damaging dynamic loading of WPU 100. This contribution occurs because the blade orientation can be adjusted to a position that optimizes aerodynamic forces. For example, as shown in FIG. 3, oscillations can be increased when at least one blade of blades 116A – C is pitched to about 90 degrees. Pitching a blade, in this example blade 116A, at an angle can increase oscillations because the aerodynamic force exerted by the wind on blade 116A, F_{aero} , is in the same direction as tower 104 movement, V_t . These loads, which cause blade and tower deflections that can couple with loads and become unsteady and dynamic in nature, can create an oscillating load condition.

[0017] Turning now to FIG. 4, with continuing reference to FIG. 1, an exemplary method 400 for reducing dynamic loading, as indicated in this example by oscillation in tower 104, is described. At step 404, oscillations in tower 104 are monitored and detected using sensor 156. As explained above, in one example, sensor 156 may be a strain gauge that detects physical distortions in tower 104. In another example, sensor 156 may be a motion or displacement sensor used to measure the movement of tower 104 or nacelle 108. The location of sensor 156 may be a function of, for example, the sensitivity of the sensor, the type of motion or force that the sensor can detect, and the expected location of the motion or force in WPU 100, as well as other factors that may be determined by persons skilled in the art based on the particular tower – WPU configuration. In yet another example, sensor 156 may be an accelerometer if the motion to be detected is the acceleration of an oscillating WPU. Sensor 156 may measure either the acceleration in velocity or direction, or

both, or a combination of the two. Other types of sensors used to detect movement are well known in the art.

[0018] At step 408, motion, force or other parameter detected by sensor 156 as indicative of oscillations are communicated to processor 152. Processor 152 determines whether the indicated oscillations are of sufficient frequency, velocity, amplitude, force, or magnitude to intervene. Part of this determination requires knowledge of the types and degrees of oscillation that are acceptable. For example, WPUs are generally expected to oscillate to some degree and tower 104 is expected to be elastically strained to some degree. This expectation arises because of the natural elasticity in tower 104 construction materials and design, combined with the fact that WPUs are routinely exposed to high winds. Based on the teachings contained herein, persons of ordinary skill in the art will be able to determine appropriate oscillation magnitude for intervention depending on the specific WPU design.

[0019] At step 412, once processor 152 determines at step 408 that the oscillations merit intervention, the processor then determines the type of control signal to send to braking system 148 based on the state of WPU 100. If WPU 100 is in an idling condition with the blades pitched to a feathered angle and hub assembly 114 free to slowly rotate, a controlled, partial brake application can be initiated at step 416a. Several methods of controlled braking are feasible to provide the reduced torque brake mode. One example of controlled braking is to apply partial brake pressure, or clamping force, with braking system 148, thereby applying a reduced braking torque to the rotating components. This reduced brake torque state will continue to restrict the movement of turbine 112, while still allowing it to slip periodically depending on wind conditions. Such an operational mode dampens the oscillations by absorbing some of the energy of the oscillations. In another example of controlled braking, a position of a brake-pad (not shown) of braking system 148 is adjusted to decrease the braking force exerted on the turbine as compared to the full force setting of the system. In a further alternative, the brake may be sequentially applied and released in a controlled manner.

[0020] However, if WPU 100 is instead in a braked condition as determined at step 412, with the turbine completely locked by full application of braking system 148, then a controlled, partial brake release can be initiated at step 416b by reducing the brake pressure, or clamping force, thereby applying a reduced braking applied torque to the turbine. As in the prior example, the reduced torque brake mode will continue to restrict the movement of turbine 112 while still allowing it to slip periodically depending on wind conditions, again dampening the oscillations by absorbing some of

the energy of the oscillations. Any of the reduced torque brake modes mentioned above may be applied.

[0021] FIG. 5 provides results of an exemplary simulation illustrating movement of turbine 112 subjected to controlled braking as described above. The movement of turbine 112, which is represented by the rotor azimuth angle in FIG. 5, may be characterized as “stick-slip.” The Y-axis of FIG. 5 shows the rotational position of a reference blade in degrees, with the “12 o’clock” position being equal to 360°. The X-axis of FIG. 5 shows the time of the simulation in seconds, with application of braking reduced torque brake mode in accordance with embodiments of the invention applied at time = 200 seconds. As illustrated by the many plateaus in the graph, controlled braking causes the turbine, as indicated by the position of the reference blade, to “stick” in a position for a brief period of time before “slipping” into a new position.

[0022] The effect of this “stick-slip” behavior in terms of reduced bending moment at the base of tower 104 is illustrated in FIG. 6. The exemplary simulation results depicted in FIG. 6 show that the bending moment is reduced when the methods of the present disclosure are applied to a parked WPU 100 when compared to the bending moments shown in FIG. 2 in which the methods of the present disclosure were not applied. As is clear when comparing these two figures, the maximum simulated bending moment is reduced by a factor of between 2 and 3 times when the methods of the present disclosure are applied.

[0023] As mentioned above, the control logic in embodiments of the present invention may be executed in analog logic circuits as well as digital logic circuits, for example implemented in a programmable logic controller as previously described. One example of a suitable analog implementation of a logic circuit 160 is shown in FIG. 7. In this example, sensor 156 is a vibration sensor, which communicates with threshold detector 164 through low pass filter 162. When the vibration threshold is met, the signal is latched (held) by latching relay 166. When so latched, latching relay 166 signals braking system 148 to apply the reduced torque brake mode depending on the current operation state of the turbine as described above in connection with FIG. 4. As also shown in FIG. 7, in one implementation, processor 152, in this case a conventional wind power programmable logic controller, may be programmed and communicate with latching relay 166 and braking unit 148 to reset logic circuit 160 when the conditions leading to a reduced torque brake mode application are alleviated. To add a further safety feature, logic circuit 160 may be powered by an uninterruptable power supply (not shown). Specific details of low pass filter 162, threshold

detector 164 and latching relay 166 are conventional and may be designed in any number of ways by persons of ordinary skill in the art based on the teachings contained herein.

[0024] Further alternative, exemplary embodiments of the present invention are described in the paragraphs below.

[0025] In one example, a system according to an embodiment of the invention includes reducing dynamic loading in a wind power unit in a parked or idled condition. The wind power unit includes a turbine, a turbine axle having a longitudinal axis, and a wind power unit brake system including at least one turbine brake. The system includes a sensor adapted to be positioned with the wind power unit and configured to sense at least one parameter indicative of dynamic loading in the wind power unit and produce a dynamic loading signal representative thereof, and a logic circuit in communication with the sensor to receive the dynamic loading signal, the logic circuit being configured to generate a braking signal in response to the dynamic loading signal, which indicates a level of dynamic loading exceeding a selected value. The brake system is configured to receive the braking signal and execute a reduced torque brake mode in response to the braking signal to reduce the dynamic loading of the wind power unit by permitting intermittent slip of the brake system. Such an exemplary embodiment may also include one or more of the following features:

The logic circuit includes a threshold detector that communicates with a latching relay.

The logic circuit includes a low pass filter that receives the signal from the sensor and communicates with the threshold detector.

The wind power unit includes a processor, and the logic circuit includes a program configured to be executed by the processor consisting of the steps of determining a level of dynamic loading indicated by the dynamic loading signal, comparing the level of dynamic loading to the selected value, and outputting the braking signal in response to the dynamic loading exceeding the selected value.

The braking signal includes instructions for execution of a controlled application and release of the turbine brake by the brake system.

The sensor is configured to sense dynamic loading that includes at least a component of motion perpendicular to the longitudinal axis of the turbine axle.

The wind power unit is mounted on a tower and the sensor comprises a strain sensor positioned on the tower.

The sensor is an accelerometer.

The sensor is a displacement sensor.

The parameter includes oscillation frequency.

The sensor is a vibration sensor.

The reduced torque brake mode includes a controlled application and release of the brake system.

The reduced torque brake mode includes application of partial braking torque.

The reduced torque brake mode includes adjustment of a brake pad position within the braking system.

[0026] In another example, a method according to an embodiment of the invention includes reducing dynamic loading in an idled wind power unit. The wind power unit includes a turbine on a turbine axle and a brake system. The method includes sensing a parameter indicative of dynamic loading of the wind power unit, determining if the sensed parameter is at least at a selected value, and instructing the brake system, when the sensed parameter is at least at the selected value, to execute a reduced torque brake mode to reduce the dynamic loading of the tower. Such an exemplary embodiment may also include one or more of the following features:

The sensing dynamic loading includes a component of movement perpendicular to the turbine axle.

Determining if the turbine is rotating freely before instructing the brake system to execute a full brake operation followed by the reduced torque brake mode, and executing the instructing step when the turbine is rotating freely.

The reduced torque brake mode includes execution of a controlled brake and brake-release sequence by the brake system.

The controlled brake and brake-release sequence includes application and release of the brake system.

The reduced torque brake mode includes applying the brake system at partial braking torque.

The reduced torque brake mode includes adjusting of a brake pad position within the braking system.

The parameter is displacement.

The parameter is vibration frequency.

The parameter is acceleration.

The wind power unit is mounted on a tower and the parameter is strain measured in a tower structure.

[0027] In yet another example, a system according to an embodiment of the invention includes reducing dynamic loading in a tower of a wind power unit. The system includes a sensor configured to detect dynamic loading in the wind power unit and generate a signal indicating the detected loading; and a logic circuit configured to receive the signal and to send a second signal to a turbine brake system in the wind power unit wherein the second signal causes the brake system to execute a reduced torque brake mode to reduce the dynamic loading of the tower. Such an exemplary embodiment may also include one or more of the following features:

The logic circuit includes a threshold detector communicating with a latching relay.

The logic circuit includes a low pass filter receiving the signal from the sensor and communicating with the threshold detector.

The logic circuit includes a processor executing program instructions.

[0028] In still another example, a system according to an embodiment of the invention includes reducing dynamic loading in a wind power unit in a parked or idled condition. The wind power unit includes a turbine, a turbine axle having a longitudinal axis, and a wind power unit brake system including at least one turbine brake. The system includes a sensor adapted to be positioned with the wind power unit and configured to sense at least one parameter indicative of dynamic loading in the wind power unit and produce a signal representative thereof; means, communicating with the sensor to receive the dynamic loading signal, for generating a braking signal in response to the level of dynamic loading exceeding a selected value and outputting the braking signal to the braking system, wherein the braking signal includes instructions for execution of a reduced torque brake mode to reduce the dynamic loading of the wind power unit by permitting intermittent slip of the parked turbine. Such an exemplary embodiment may also include one or more of the following features:

Means for generating a braking signal include a processor executing program instructions that include determining whether the dynamic loading exceeds a selected value, determining a state of the turbine brake system as currently on or currently off, instructing the braking system to change the braking torque from full to reduced braking torque if the brake is currently on, and instructing the braking system to apply reduced braking torque if the brake is currently off.

Means for generating a braking signal includes a threshold detector communicating with a latching relay.

Means for generating a braking signal include a low pass filter receiving the signal from the sensor and communicating with the threshold detector.

[0029] In still yet another example, a system according to an embodiment of the invention includes reducing dynamic loading in a wind power unit in a parked or idled condition. The wind power unit includes a turbine, and a turbine axle having a longitudinal axis. The system includes a sensor adapted to be positioned with the wind power unit and configured to sense at least one parameter indicative of dynamic loading in the wind power unit and produce a signal representative thereof, the dynamic loading including at least a component of motion perpendicular to the longitudinal axis of the turbine axle; a processor in communication with the sensor to receive the representative signal, the processor being configured and programmed to determine a level of dynamic loading indicated by the sensed parameter and compare the level to at least one selected value, the processor being further programmed to generate a braking instruction in response to the level of dynamic loading exceeding a selected value; and a wind power unit brake system including at least one turbine brake, the system configured to receive the braking instruction from the processor, wherein the braking instruction includes a controlled braking and brake-release command for the brake, the controlled braking and brake-release command causing execution by the brake system of a reduced torque brake mode to reduce the dynamic loading of the wind power unit by permitting intermittent slip of the parked turbine.

[0030] Exemplary embodiments have been disclosed above and illustrated in the accompanying drawings. It will be understood by those skilled in the art that various changes, omissions and additions may be made to that which is specifically disclosed herein without departing from the spirit and scope of the present invention.

What is claimed is:

1. A system for reducing dynamic loading in a wind power unit, the system comprising:
 - a sensor configured to detect dynamic loading in said wind power unit and generate a signal indicating the detected dynamic loading; and
 - a logic circuit configured to receive said signal and to send a second signal to a turbine brake system in the wind power unit wherein said second signal causes the brake system to execute a reduced torque brake mode to reduce the dynamic loading of the tower.
2. The system of claim 1, wherein:
 - the second signal is a braking signal;
 - the logic circuit is configured to generate the braking signal in response to the dynamic loading signal indicating a level of dynamic loading exceeding a selected value; and
 - the brake system is configured to receive said braking signal and execute the reduced torque brake mode in response to said braking signal to reduce the dynamic loading of the wind power unit by permitting intermittent slip of the braked turbine.
3. The system according to claim 1, wherein the logic circuit comprises a threshold detector communicating with a latching relay.
4. The system according to claim 3, wherein the logic circuit further comprises a low pass filter receiving the signal from the sensor and communicating with the threshold detector.
5. The system according to claim 1, wherein the wind power unit further includes a processor, and the logic circuit comprises a program configured to be executed by the processor comprising steps of:
 - determining a level of dynamic loading indicated by said dynamic loading signal;
 - comparing the level of dynamic loading to said selected value; and
 - outputting said second signal in response to the dynamic loading exceeding said selected value.
6. The system according to claim 5, wherein the second signal includes instructions for execution of a controlled application and release of the at least one turbine brake by the brake system.
7. The system according to claim 1, wherein said sensor is configured to sense dynamic loading including at least a component of motion perpendicular to the longitudinal axis of the turbine axle.
8. The system according to claim 1, wherein the wind power unit is mounted on a tower and said sensor comprises a strain sensor positioned on the tower.

9. The system according to claim 1, wherein said sensor is an accelerometer.
10. The system according to claim 1, wherein said sensor is a vibration sensor.
11. The system according to claim 1, wherein said reduced torque brake mode permits intermittent slip of the braked turbine.
12. The system according to claim 11, wherein said reduced torque brake mode comprises a controlled application and release of the brake system.
13. The system according to claim 11, wherein said reduced torque brake mode comprises application of partial braking torque.
14. The system according to claim 11, wherein said reduced torque brake mode comprises adjustment of a brake pad position within the braking system.
15. The system of claim 1, wherein the wind power unit includes a turbine mounted on a tower, a turbine axle having a longitudinal axis, and a wind power unit brake system including at least one turbine brake, the system being configured to reduce dynamic loading when the wind power unit is in a parked or idled state.
16. The system of claim 2, wherein the logic circuit comprises means, communicating with said sensor to receive said dynamic loading signal, for generating the braking signal in response to the level of dynamic loading exceeding a selected value and outputting the braking signal to the braking system, wherein the braking signal includes instructions for execution of the reduced torque brake mode to reduce the dynamic loading of the wind power unit by permitting intermittent slip of the braked turbine.
17. The system according to claim 16, wherein means for generating a braking signal comprises a processor executing program instructions comprising:
 - determining whether the dynamic loading exceeds a selected value;
 - determining a state of the turbine brake system as currently on or currently off;
 - instructing the braking system to change the braking torque from full to reduced braking torque if the brake is currently on; and
 - instructing the braking system to apply reduced braking torque if the brake is currently off.
18. The system according to claim 16, wherein means for generating a braking signal comprises a low pass filter receiving the signal from the sensor and communicating with a threshold detector, the

threshold detector communicating with a latching relay when the dynamic loading signal exceeds a set threshold value, the latching relay communicating with the breaking system.

19. A method of reducing dynamic loading in a wind power unit, the wind power unit including a turbine on a turbine axle and a brake system, the method comprising:

sensing a parameter indicative of dynamic loading of the wind power unit;

determining if the sensed parameter is at least at a selected value; and

instructing the brake system, when said sensed parameter is at least at the selected value, to execute a reduced torque brake mode to reduce the dynamic loading in the wind power unit.

20. The method according to claim 19, wherein said sensing includes sensing dynamic loading including a component of movement perpendicular to the turbine axle.

21. The method according to claim 19, further comprising determining if the turbine is rotating freely before instructing the brake system to execute a full brake operation followed by the reduced torque brake mode and executing said instructing step when the turbine is rotating freely.

22. The method according to claim 15, wherein said reduced torque brake mode comprises permitting intermittent slip of the braked turbine.

23. The method according to claim 22, wherein the reduced torque brake mode comprises sequentially applying and releasing the brake.

24. The method according to claim 22, wherein the reduced torque brake mode comprises applying the brake system at partial braking torque.

25. The method according to claim 22, wherein the reduced torque brake mode comprises adjusting a brake pad position within the braking system.

26. The method according to claim 19, wherein the parameter is displacement.

27. The method according to claim 19, wherein the parameter is vibration.

28. The method according to claim 19, wherein the parameter is acceleration.

29. The method according to claim 19, wherein the wind power unit is mounted on a tower and the parameter is strain measured in a tower structure.

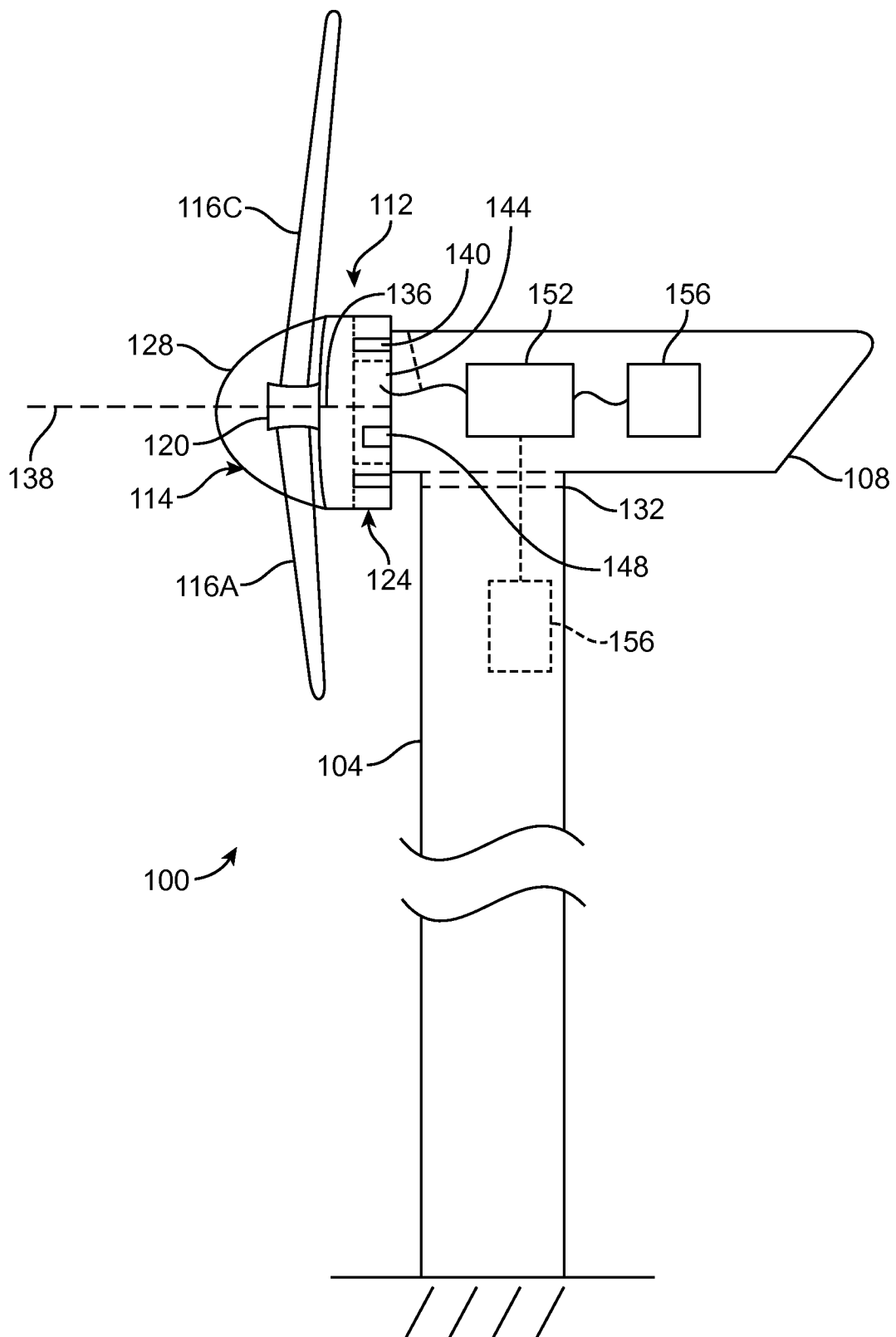


FIG. 1

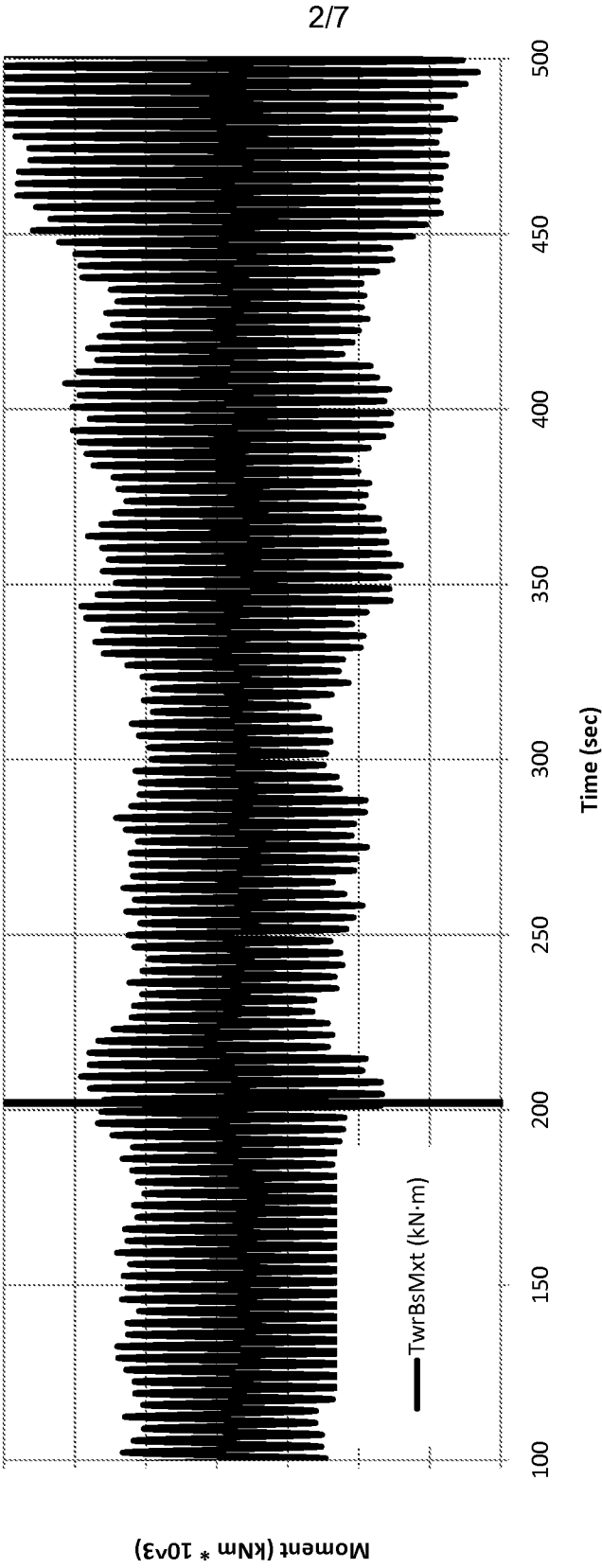


FIG. 2

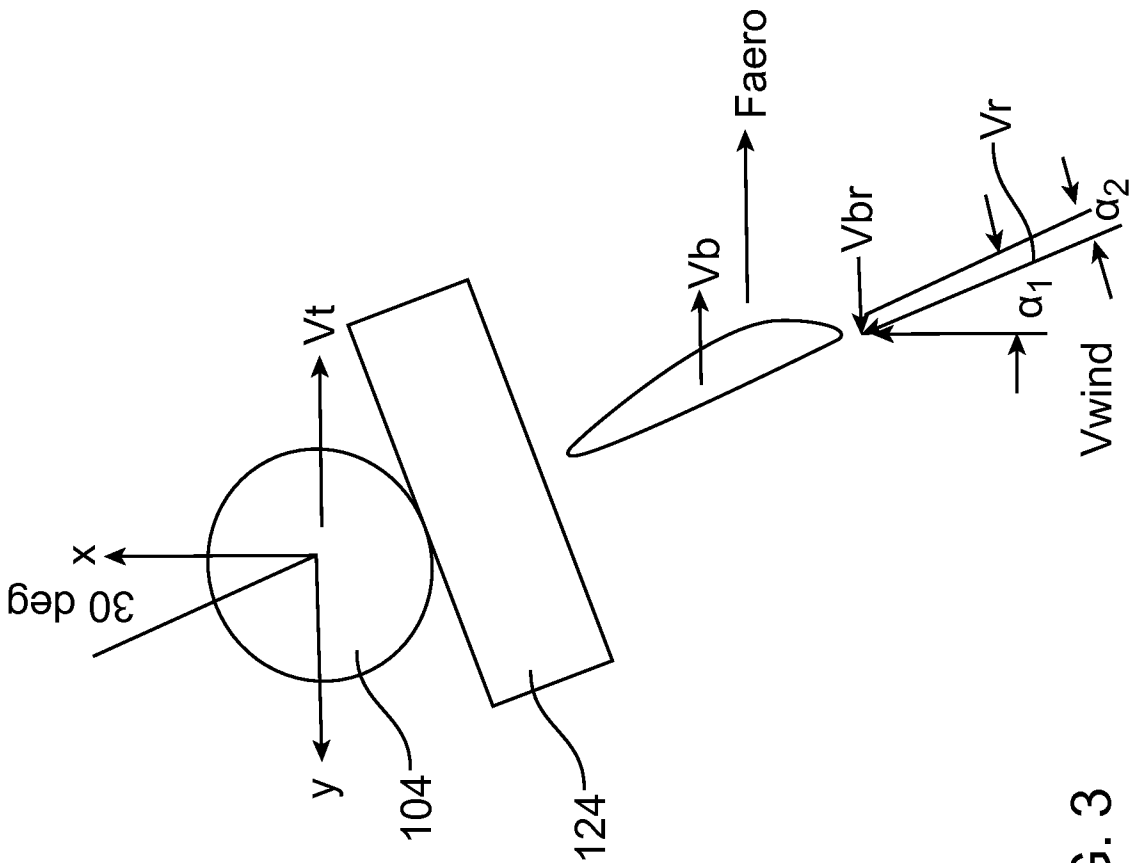


FIG. 3

- V_{wind} : wind velocity
- F_{aero} : Blade aerodynamic force
- V_t : velocity of tower top/nacelle
- V_b : velocity of blade
- V_{br} : velocity of blade motion induced wind speed
- V_r : relative wind speed
- α = angle of attack

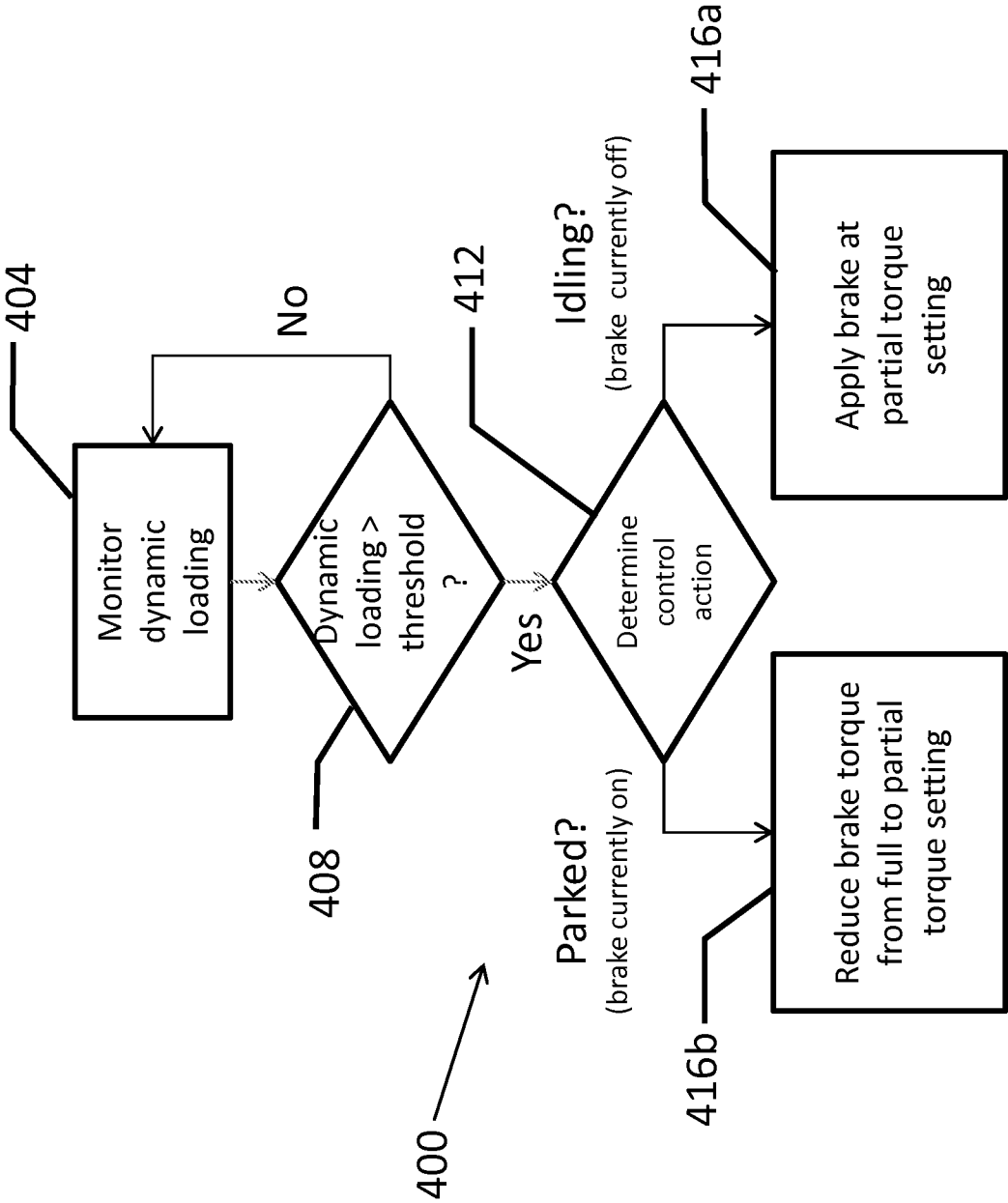


FIG. 4

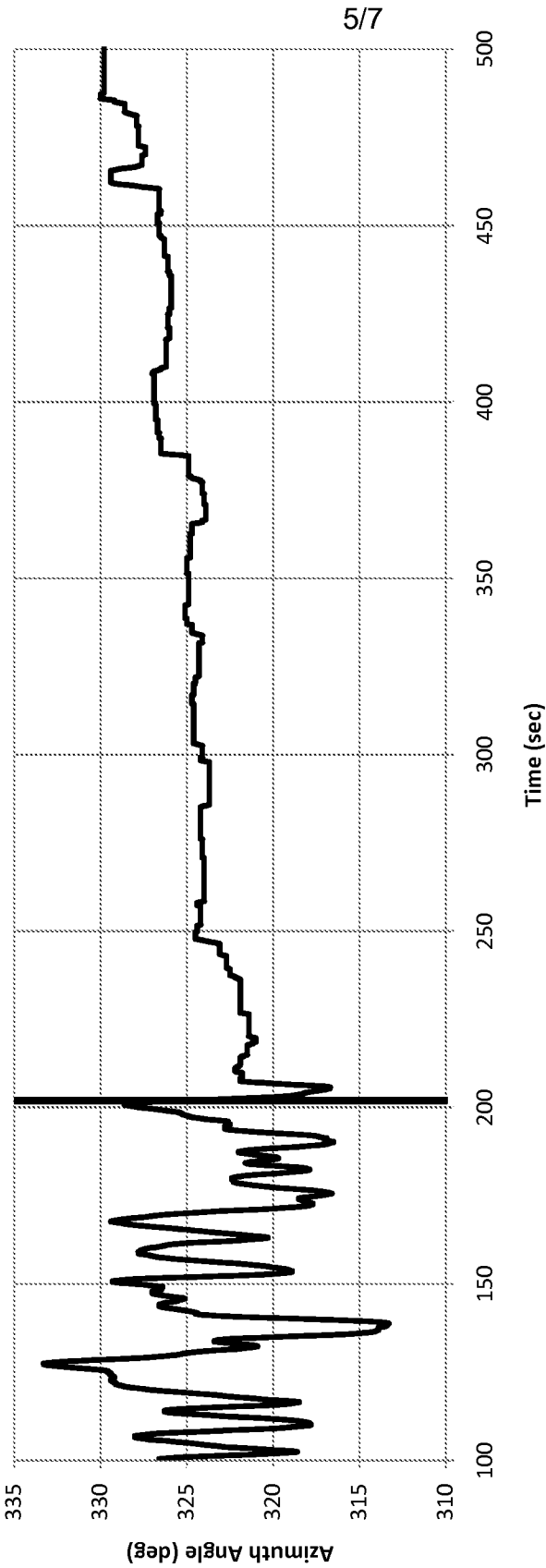


FIG. 5

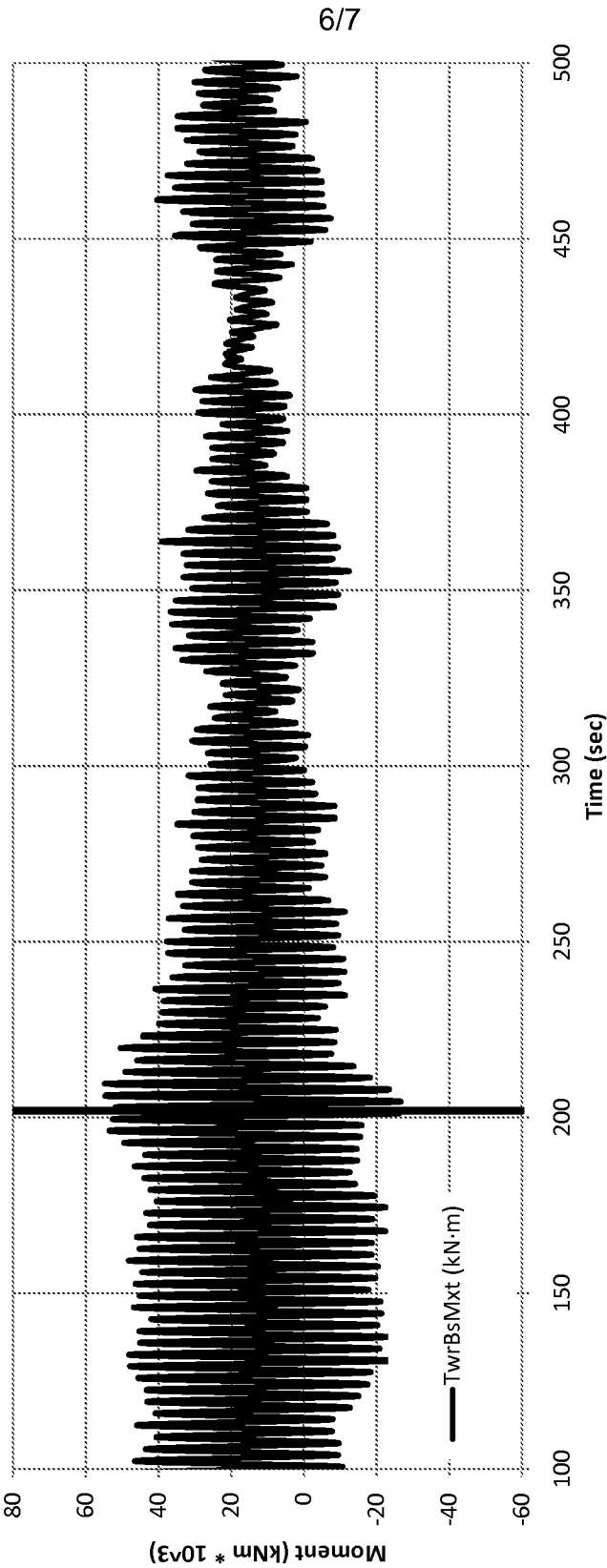


FIG. 6

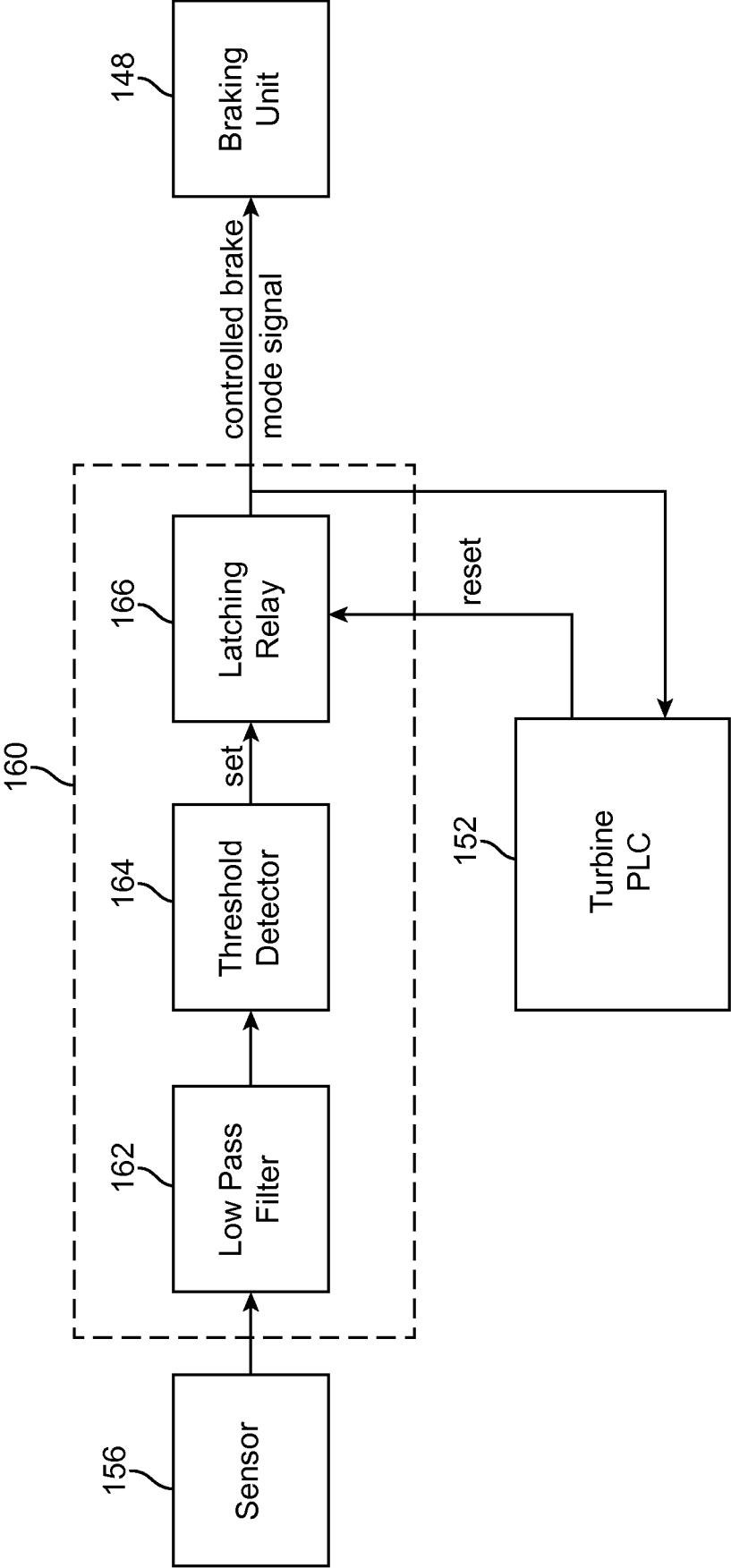


FIG. 7

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 08775 - 081WOU1	FOR FURTHER ACTION see Form PCT/ISA/220 as well as, where applicable, item 5 below.	
International application No. PCT/US2011/064231	International filing date (<i>day/month/year</i>) 09/12/2011	(Earliest) Priority Date (<i>day/month/year</i>) 09/12/2010
Applicant NORTHERN POWER SYSTEMS, INC.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 4 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

a. With regard to the **language**, the international search was carried out on the basis of:

- ☒ the international application in the language in which it was filed
- ☐ a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))

b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6**bis**(a)).

c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (See Box No. II)

3. ☐ **Unity of invention is lacking** (see Box No III)

4. With regard to the **title**,

- ☒ the text is approved as submitted by the applicant
- ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

- ☒ the text is approved as submitted by the applicant
- ☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority

6. With regard to the **drawings**,

- a. the figure of the **drawings** to be published with the abstract is Figure No. 1
- ☒ as suggested by the applicant
- ☐ as selected by this Authority, because the applicant failed to suggest a figure
- ☐ as selected by this Authority, because this figure better characterizes the invention
- b. ☐ none of the figures is to be published with the abstract

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/064231

A. CLASSIFICATION OF SUBJECT MATTER
 INV. F03D7/02
 ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 F03D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/068035 A2 (VESTAS WIND SYS AS [DK]; NIELSEN THOMAS STEINICHE BJERT [DK]; PEDERSEN) 4 June 2009 (2009-06-04)	1,2, 4-17,19, 20,22-29
Y	page 2, lines 19-27 page 4, line 9 - page 6, line 4 page 7, lines 9-23 page 13, line 8 - page 16, line 30	3,4,14, 18,21,25
X	WO 2008/049426 A1 (VESTAS WIND SYS AS [DK]; NIELSEN THOMAS STEINICHE BJERT [DK]; PEDERSEN) 2 May 2008 (2008-05-02) page 7, line 24 - page 9, line 15	1,19
Y	EP 0 020 207 A1 (SCHACHLE CHARLES V [US]; SCHACHLE PATRICK JOSEPH [US]; SCHACHLE EDWARD) 10 December 1980 (1980-12-10)	3
A	columns 100-103 ----- -/-	18



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

17 April 2012

Date of mailing of the international search report

24/04/2012

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
 Tel. (+31-70) 340-2040,
 Fax: (+31-70) 340-3016

Authorized officer

Beran, Jiri

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2011/064231

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2007/170724 A1 (CALLEY DAVID GREGORY [US]) 26 July 2007 (2007-07-26) paragraphs [0022] - [0026]; figure 1 -----	3,18
Y	EP 2 133 563 A1 (SIEMENS AG [DE]) 16 December 2009 (2009-12-16) the whole document -----	4,18
Y	US 2010/194114 A1 (PECHLIVANOGLU GEORGIOS [DE] ET AL) 5 August 2010 (2010-08-05) paragraphs [0011], [0013] -----	14,25
Y	US 2007/187954 A1 (STRUVE JAN [DE] ET AL) 16 August 2007 (2007-08-16) paragraphs [0009], [0023] -----	21
E	WO 2011/157342 A2 (BOSCH GMBH ROBERT [DE]; HESS FELIX [DE]; BUCHTALA BORIS [DE]) 22 December 2011 (2011-12-22) page 5 - page 6, line 10 -----	1,4-10, 17,19, 20,24, 26-29
X,P	EP 2 306 005 A2 (GEN ELECTRIC [US]) 6 April 2011 (2011-04-06) paragraphs [0011], [0019], [0020], [0023] - [0026]; figure 6 -----	1,5-8, 10,15, 17,19, 20,26-29

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2011/064231

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009068035 A2	04-06-2009	CN 101878365 A EP 2232063 A2 US 2010301605 A1 WO 2009068035 A2	03-11-2010 29-09-2010 02-12-2010 04-06-2009
WO 2008049426 A1	02-05-2008	AR 063512 A1 AU 2007308515 A1 CN 101595302 A EP 2076672 A1 NZ 576624 A US 2009200804 A1 WO 2008049426 A1	28-01-2009 02-05-2008 02-12-2009 08-07-2009 25-02-2011 13-08-2009 02-05-2008
EP 0020207 A1	10-12-1980	CA 1125177 A1 EP 0020207 A1 ES 8104505 A1 JP 55164785 A US 4503673 A	08-06-1982 10-12-1980 01-07-1981 22-12-1980 12-03-1985
US 2007170724 A1	26-07-2007	US 2007170724 A1 US 2009021022 A1 US 2010007145 A1	26-07-2007 22-01-2009 14-01-2010
EP 2133563 A1	16-12-2009	CN 101603823 A EP 2133563 A1 US 2010063769 A1	16-12-2009 16-12-2009 11-03-2010
US 2010194114 A1	05-08-2010	AT 546643 T AU 2008266546 A1 CN 101720388 A DE 102007058746 A1 EP 2165072 A2 US 2010194114 A1 WO 2008155053 A2	15-03-2012 24-12-2008 02-06-2010 24-12-2008 24-03-2010 05-08-2010 24-12-2008
US 2007187954 A1	16-08-2007	AT 510126 T CN 1954146 A DE 102004013624 A1 DK 1733143 T3 EP 1733143 A1 ES 2366790 T3 US 2007187954 A1 WO 2005090780 A1	15-06-2011 25-04-2007 06-10-2005 12-09-2011 20-12-2006 25-10-2011 16-08-2007 29-09-2005
WO 2011157342 A2	22-12-2011	DE 102010023887 A1 WO 2011157342 A2	15-12-2011 22-12-2011
EP 2306005 A2	06-04-2011	CN 102032110 A EP 2306005 A2 US 2011076142 A1	27-04-2011 06-04-2011 31-03-2011