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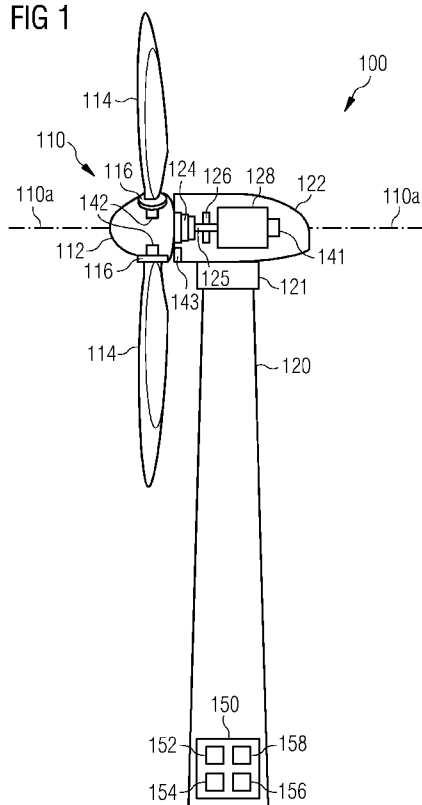
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(54) Title: PROACTIVE CONTROL OF THE OPERATION OF A WIND TURBINE

FIG 1



(57) Abstract: It is described a method for controlling the operation of a wind turbine (100) comprising a structural component (110, 14, 120, 122, 125), which during an operation of the wind turbine (100) is exposed to a mechanical load. The method comprises determining a value of a quantity being indicative for an operational condition of the wind turbine (100), predicting, based on the determined value, the mechanical load acting on the structural component (110, 114, 120, 122, 125) within a future time period, selecting a control mode for operating the wind turbine (100) in response to the predicted mechanical load, and controlling, during the future time period, the operation of the wind turbine (100) with the selected control mode. It is further described a machine load control system (150), which is adapted for controlling and/or for carrying out the described wind turbine operating control method.



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DESCRIPTION

Proactive control of the operation of a wind turbine

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Field of invention

The present invention relates to the technical field of wind turbines. In particular, the present invention relates to a
10 method and to a machine load control system for controlling the operation of a wind turbine comprising a structural component, which during an operation of the wind turbine is exposed to a mechanical load.

15

Art Background

Structural components of a wind turbine such as for instance the rotor blades and/or the tower are typically exposed to
20 large dynamic mechanical loads in particular when the wind turbine is operated in turbulent wind conditions or in conditions of flow distortion, e.g. high wind shear. Therefore, the structural components and the corresponding supporting structures have to be designed in such a way that
25 they are able to withstand all the mechanical loads that could occur at a specific site of erection. This causes a lot of constructional expenses in particular for a wind turbine which is supposed to be erected at a site where extreme mechanical loads can be expected. Therefore, wind turbines
30 are typically designed for certain wind classes, and prior to installing a wind turbine at a given site of erection, the wind conditions of the site have to be measured in a period of time to ensure that the wind turbine, which is supposed to be installed at that site, is not mechanically overloaded.

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However, it is also known to curtail a wind turbine. This means that the amount of power generation of the wind turbine

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is reduced in order to reduce the mechanical load acting on at least one structural component of the wind turbine.

Specifically, a wind turbine curtailment can comprise for instance stopping the turbine for predefined sectors or predefined wind directions, or running the wind turbine at a reduced power and speed in predefined sectors.

US 2009/0261588 A1 discloses a method for operating a wind turbine wherein there are determined an oblique incident flow value, which represents the difference between (a) the actual wind direction and (b) the actual direction of a rotor axis of the wind turbine, and a load value, which represents the mechanical load state of the wind turbine. A total load value is determined based on the load value and the oblique incident flow value. The rotor rotation speed is reduced when the total load value is above a first limit value. Further, if in addition a second limit value is exceeded, the wind turbine is shut down. Since both the load value and the oblique incident flow value have to be measured, the disclosed method has to rely on two measurement values, wherein naturally each one of the two measurement values has a certain inaccuracy. This makes the disclosed method defective.

US 7351033 B2 discloses a method for limiting mechanical loads in a wind turbine by using measured loads or wind speed to increase the minimum pitch angle for extended periods. The minimum pitch angle will be allowed to relax down to the default when load excursions diminish. The disadvantage of this method is that the loads or wind speed may become very high before the system reacts and limits the loads and it may especially be difficult to avoid peak loads as they have already occurred when the system finally reacts.

There may be a need for providing a control procedure for a wind turbine, which will lower extreme mechanical loads

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acting on structural component(s) of the wind turbine with only a minimal reduction of the electric power being generated by the wind turbine.

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Summary of the Invention

This need may be met by the subject matter according to the independent claims. Advantageous embodiments of the present
10 invention are described by the dependent claims.

According to a first aspect of the invention there is provided a method for controlling the operation of a wind turbine comprising a structural component, which during an
15 operation of the wind turbine is exposed to a mechanical load. The provided method comprises (a) determining a value of a quantity being indicative for an operational condition of the wind turbine, (b) predicting, based on the determined value, the mechanical load acting on the structural component
20 within a future time period, (c) selecting a control mode for operating the wind turbine in response to the predicted mechanical load, and (d) controlling, during the future time period, the operation of the wind turbine with the selected control mode.

25

The described wind turbine operation control method is based on the idea that by monitoring at least one value of a quantity being indicative for the actual operational condition of the wind turbine one can predict the mechanical
30 load which will act on the structural component of the wind turbine in the near future. This means that based on the determined value of a quantity being indicative for an operational condition of the wind turbine one can classify near future time periods where it is likely that extreme
35 mechanical loads occur. By changing the actual control mode of the wind turbine (with a high amount of power production) to a more gentle control mode (with a smaller amount of power

production) the mechanical loads which will act on the structural component within the future time period can be effectively reduced.

5 In this document the term "future time period" refers to a time period, which on a time axis occurs later than the time of determining the value of the quantity being indicative for the operational condition of the wind turbine. It is mentioned that the time at which the value of the quantity
10 being indicative for the operational condition of the wind turbine is determined may be a point in time or also a period during which a plurality of values are acquired, which are indicative for the operational condition of the wind turbine. Thereby, the data acquisition may comprise an acquisition of
15 measurement values, an acquisition of estimated values and/or an acquisition of control values of a wind turbine controller.

The control mode for operating the wind turbine may be
20 defined by one or more reference values for operational parameters of the wind turbine. Therefore, a change of the control mode may mean that at least one of such reference values is changed. Examples for such reference values are (a) a pitch reference value for the blade pitch angle, (b) a
25 rotational speed reference value for the rotational speed of a rotor of the wind turbine, (c) a power reference value for the electric power being generated by the wind turbine, (d) a torque reference value for the torque acting on a central shaft of the rotor, (e) a strain reference value for the
30 strain acting on at least one structural component of the wind turbine and (f) a reference value for the fatigue life time consumption rate of one or more structural components of the wind turbine. Examples for quantities being indicative for the operational condition of the wind turbine are for
35 instance (a) the actual blade pitch angle, (b) the actual rotational speed of the rotor, (c) the actual electric power being generated by the wind turbine, (d) the actual torque

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acting on the central shaft, (e) the actual strain acting on at least one structural component and (f) the actual fatigue life time consumption rate of one or more structural components. It is mentioned that these enumerations for the reference values and for the quantities being indicative for the operational condition of the wind turbine are not exclusive. Depending on the applied operational control procedure of the wind turbine also other reference values can be used for defining the control mode and also other quantities can be used to characterize the operational condition of the wind turbine.

It is mentioned that depending on the predicted mechanical load the selected control mode may be an updated control mode being different from the previous control mode. This may be in particular the case if the predicted mechanical load is different compared to the mechanical load acting on the structural component during the time at which the value of the quantity being indicative for the operational condition of the wind turbine determined. Specifically, if the predicted mechanical load is larger than the mechanical load at the time of determining the value of the quantity being indicative for the operational condition of the wind turbine, a more gentle control mode should be selected in order to reduce the mechanical load acting on the structural component during the future time period. Correspondingly, if the predicted mechanical load is smaller than the mechanical load at the time of determining the value of the quantity being indicative for the operational condition of the wind turbine, a more aggressive control mode can be selected in order to increase the electric power production during the future time period. Of course, if the predicted mechanical load is at least approximately the same as the mechanical load at the time period of determining the value of the quantity being indicative for the operational condition of the wind turbine the selected control mode should be the same as the previous control mode.

It is further mentioned that extreme mechanical loads are often driven by the wind condition which affects a large number for operational parameters of the wind turbine.

5 Therefore, it is apparent that there will be a strong correlation between (a) the actual wind conditions, (b) the actual operational condition of the wind turbine and (c) the actual reference values being used for controlling the operation of the wind turbine.

10

According to an embodiment of the invention selecting a control mode comprises (a) changing at least one operational parameter of the wind turbine and/or (b) changing at least one reference value for at least one quantity being
15 indicative for an operational condition of the wind turbine.

The changes of an operational parameter and/or a reference value may be described for instance with reference to the standard deviation, the variance, the difference between a
20 minimum value and a maximum value within a certain time period. However, it is mentioned that the size or the amount of the changes can also be described with reference to other statistical parameters or with reference to a predefined factor.

25

According to a further embodiment of the invention the operational condition of the wind turbine comprises an extrinsic operational condition of the wind turbine. Thereby, the extrinsic operational condition may be in particular any
30 environmental condition, which affects and/or which is characteristic for the movement of the air (i.e. the wind) which is driving the rotor of the wind turbine.

Specifically, the extrinsic operational condition may be (a)
35 the wind speed, (b) the wind direction, (c) the magnitude of wind turbulences in the region where the wind turbine is erected, (d) the difference between a maximum wind speed and

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a minimum wind speed which occur within a predefined time interval and/or (e) any other statistic quantity describing how much the wind speed and/or the wind direction changes.

- 5 It is mentioned that the above described enumerated extrinsic operational conditions may be directly measured by at least one sensor (e.g. an anemometer). Alternatively or in combination, the above described enumerated extrinsic operational conditions may be estimated from other
10 observations such as e.g. the values of a quantity being indicative for an intrinsic operational condition of the wind turbine.

- According to a further embodiment of the invention the
15 operational condition of the wind turbine comprises an intrinsic operational condition of the wind turbine. Thereby, the intrinsic operational condition may be in particular any internal state of the wind turbine.

- 20 According to a further embodiment of the invention the quantity being indicative for the intrinsic operational condition of the wind turbine is a mechanical load acting on at least one structural component of the wind turbine.

- 25 The mechanical load may be for instance a strain, an elongation, a compression, curvature or any other condition being indicative for a deformation of the at least one structural component.

- 30 The described mechanical load can be directly measured by appropriate sensors and/or can be estimated from other operational data being influenced by the mechanical load.

- According to a further embodiment of the invention the
35 mechanical load is a torque acting on a shaft of the rotor of the wind turbine. This may provide the advantage that changes of the wind condition can be immediately and easily

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recognized e.g. by a sensor which directly measures the torque or the dynamic variation of the torque.

5 According to a further embodiment of the invention the quantity being indicative for the intrinsic operational condition of the wind turbine is a fatigue life time consumption or a fatigue life time consumption rate.

10 The fatigue life time consumption or the fatigue life time consumption rate can be determined in particular from estimated or measured mechanical loads which at the time of determining the value of the quantity being indicative for the operational condition of the wind turbine are acting on one or more structural components of the wind turbine.
15 Thereby, different structural components can be exposed to the same or to different mechanical loads.

The term "fatigue life time consumption rate" may be in particular the time rate of change of a fatigue life time
20 consumption or an accumulated fatigue life time consumption, which during a previous operation of the wind turbine has been consumed or exhausted by the respective structural component(s).

25 In this document the terms "fatigue life time consumption rate", "consumed fatigue life time" and "(accumulated) fatigue life time consumption" are related to the generally known term "fatigue life", which according to the American Society for Testing and Materials (ASTM) is defined as the
30 number of stress cycles of a specified character that a structural component sustains before a failure of the structural component of a specified nature occurs. In this document the term "fatigue life" is also referred to as "fatigue life time".

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According to a further embodiment of the invention the quantity being indicative for the intrinsic operational

condition of the wind turbine is an electric parameter, in particular the amount of power, which is generated by an electric generator of the wind turbine. This may provide the advantage that changes of the wind condition can be easily
5 recognized. As a consequence, the described control method will be highly sensitive and, in response to a change of the wind condition and in particular in response to an increase of the wind speed, a fast reaction of the control procedure can be realized.

10 According to a further embodiment of the invention the quantity being indicative for the intrinsic operational condition of the wind turbine is a control parameter being used by a controller of the wind turbine.

15 The control parameter may be any parameter which defines the state of a control element of the wind turbine. The control parameter may be for instance the actual measured or specified blade pitch angle, the actual change rate of the
20 blade pitch angle and/or the number of blade pitch angle reversals (change of direction of change of the blade pitch angle) within a certain period of time (e.g. including the time of determining the value of the quantity being indicative for the operational condition of the wind
25 turbine).

The value of the quantity being indicative for the operational condition of the wind turbine may also be a reference value for a control parameter. As has already been
30 mentioned above the reference value may be for instance (a) a pitch reference value for the blade pitch angle, (b) a rotational speed reference value for the rotational speed of a rotor of the wind turbine, (c) a power reference value for the electric power being generated by the wind turbine, (d) a
35 torque reference value for the torque acting on a central shaft of the rotor, (e) a strain reference value for the strain acting on at least one structural component of the

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wind turbine and/or (f) a reference value for the fatigue life time consumption rate of one or more structural components of the wind turbine.

- 5 According to a further embodiment of the invention the quantity being indicative for the intrinsic operational condition of the wind turbine is a quantity being indicative for a movement of a component of the wind turbine.
- 10 The movement may be a velocity, an acceleration (i.e. a change of velocity) and/or a change of the acceleration of at least one component of the wind turbine. The movement may be a rotational movement or a linear movement.
- 15 Specifically, the quantity being indicative for the movement of the wind turbine may be the actual rotational speed of the rotor, the actual rotational acceleration of the rotor, the actual acceleration of a tower of the wind turbine and/or the actual acceleration of a nacelle of the wind turbine.
- 20 According to a further embodiment of the invention, if the predicted mechanical load is different from and in particular larger than a predefined mechanical load or a pre-calculated reference for the mechanical load, the selected control mode
- 25 causes at least one of the following control actions: (a) The rotational speed of the rotor of the wind turbine is changed and in particular reduced, (b) the operation of the wind turbine is stopped, (c) a change of a blade pitch angle of at least one blade is initiated, (d) a cyclic blade pitch angle
- 30 control is initiated, and (e) the energy production from the wind turbine (100) is changed and in particular reduced. This may provide the advantage that mechanical peak loads acting on the structural component within the future time period can be effectively limited to a range wherein a damage of the
- 35 wind turbine can be effectively avoided.

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In this respect the term "cyclic blade pitch angle control", which is often also denominated "cyclic pitching" refers to a method wherein the blade pitch angle setting of each rotor blade is changed during each revolution. More details about "cyclic pitching" can be found for instance in US 4,298,313.

According to a further embodiment of the invention the method further comprises (a) determining a further value of a further quantity being indicative for the operational condition of the wind turbine. Thereby, the mechanical load acting on the structural component within the future time period is predicted further based on the determined further value. This may provide the advantage that the mechanical load acting on the structural component within the second time period can be predicted more precisely. As a consequence an optimal control mode operating the wind turbine during the second time period can be selected.

According to a further embodiment of the invention a delay between the time of determining the value of the quantity being indicative for the operational condition of the wind turbine and the begin of the future time period is at least 2 seconds and preferably at least 5 seconds. This may provide the advantage that there is enough time for completing the control actions which are related to a change from a previous control mode to the selected control mode.

According to a further embodiment of the invention (a) a time difference between the time of determining the value of the quantity being indicative for the operational condition of the wind turbine and the begin of the future time period and/or (b) the length of the future time period depends on the determined value of the quantity being indicative for the operational condition of the wind turbine. This may provide the advantage that the described control procedure can adaptively react e.g. on the strength of a perturbation of the

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operational condition or the wind turbine which occurs during the first time period.

According to a further aspect of the invention there is
5 described a machine load control system for controlling the operation of a wind turbine comprising a structural component, which during an operation of the wind turbine is exposed to a mechanical load. The described machine load control system comprises (a) a determining unit for
10 determining a value of a quantity being indicative for an operational condition of the wind turbine, (b) a predicting unit for predicting, based on the determined value, the mechanical load acting on the structural component within a future time period, (c) a selecting unit for selecting a
15 control mode for operating the wind turbine in response to the predicted mechanical load, and (d) a control unit for controlling, during the future time period, the operation of the wind turbine with the selected control mode.

20 Also the described machine load control system is based on the idea that by monitoring at least one value of a quantity being indicative for the actual operational condition of the wind turbine one can predict the mechanical load which will act on the structural component of the wind turbine in the
25 near future. Changing the actual control mode of the wind turbine (with a high amount of power production) to a more gentle control mode (with a smaller amount of power production) may provide the advantage that mechanical loads which will act on the structural component within the future
30 time period can be effectively reduced.

It is mentioned that the various units of the machine load control system may be realized by at least one processing unit, which combines at least two of the described units.

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According to a further aspect of the invention there is described a wind turbine comprising a machine load control system as described above.

5 According to a further aspect of the invention there is described a computer program for controlling the operation of a wind turbine comprising a structural component, which during an operation of the wind turbine is exposed to a mechanical load. The computer program, when being executed by
10 a data processor, is adapted for controlling and/or for carrying out the wind any embodiment of the above described method for controlling the operation of a wind turbine.

As used herein, reference to a computer program is intended
15 to be equivalent to a reference to a program element and/or to a computer readable medium containing instructions for controlling a computer system to coordinate the performance of the above described method.

20 The computer program may be implemented as computer readable instruction code in any suitable programming language, such as, for example, JAVA, C++, and may be stored on a computer-readable medium (removable disk, volatile or non-volatile memory, embedded memory/processor, etc.). The instruction
25 code is operable to program a computer or any other programmable device to carry out the intended functions. The computer program may be available from a network, such as the World Wide Web, from which it may be downloaded.

30 The invention may be realized by means of a computer program respectively software. However, the invention may also be realized by means of one or more specific electronic circuits respectively hardware. Furthermore, the invention may also be realized in a hybrid form, i.e. in a combination of software
35 modules and hardware modules.

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It has to be noted that embodiments of the invention have been described with reference to different subject matters. In particular, some embodiments have been described with reference to method type claims whereas another embodiment
5 has been described with reference to an apparatus type claim. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject matter also any combination
10 between features relating to different subject matters, in particular between features of the method type claims and features of the apparatus type claim is considered as to be disclosed with this document.

15 The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of
20 embodiment but to which the invention is not limited.

Brief Description of the Drawing

25 Figure 1 shows a wind turbine with a machine load control system according to an embodiment of the present invention.

Figure 2 shows for a simulated operation of a wind turbine how to use a fatigue lifetime consumption rate of a blade
30 root flap-wise bending moment in order to predict a top tower tilt moment five seconds later within a future time period.

Figure 3 shows for a simulated operation of a wind turbine how to use a fatigue lifetime consumption rate of a blade
35 root flap-wise bending moment in order to predict a top tower yaw moment five seconds later within a future time period.

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Figure 4 shows a reduction of mechanical load peaks which occurs if the rotor speed is decreased within a future time period following a determination of an extreme fatigue lifetime consumption rate of a structural component of a wind turbine.

Detailed Description

The illustration in the drawing is schematically. It is noted that in different figures, similar or identical elements are provided with the same reference signs or with reference signs, which are different from the corresponding reference signs only within the first digit.

Figure 1 shows a wind turbine 100 according to an embodiment of the invention. The wind turbine 100 comprises a tower 120, which is mounted on a non-depicted fundament. On top of the tower 120 there is arranged a nacelle 122. In between the tower 120 and the nacelle 122 there is provided a yaw angle adjustment device 121, which is capable of rotating the nacelle 122 around a non depicted vertical axis, which is basically aligned with the longitudinal extension of the tower 120. By controlling the yaw angle adjustment device 121 in an appropriate manner it can be made sure, that during a normal operation of the wind turbine 100 the nacelle 122 is always properly aligned with the current wind direction. However, e.g. in case of a very strong wind the yaw angle adjustment device 121 can be used to adjust the yaw angle to a position, wherein the nacelle is intentionally not perfectly aligned with the current wind direction.

The wind turbine 100 further comprises a rotor 110 having three blades 114. In the perspective of Figure 1 only two blades 114 are visible. The rotor 110 is rotatable around a rotational axis 110a. The blades 114, which are mounted at a

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driving collar 112, extend radial with respect to the rotational axis 110a.

5 In between the driving collar 112 and a blade 114 there is respectively provided a blade adjustment device 116 in order to adjust the blade pitch angle of each blade 114 by rotating the respective blade 114 around a non depicted axis being aligned parallel with the longitudinal extension of the blade 114. By controlling the blade adjustment device 116 the blade
10 pitch angle of the respective blade 114 can be adjusted in such a manner that at least when the wind is not so strong a maximum wind power can be retrieved from the available wind power. However, as will be described below in more detail, the blade pitch angle can also be intentionally adjusted to a
15 position, in which only a reduced wind power can be captured.

As can be seen from Figure 1, within the nacelle 122 there is provided a gear box 124. The gear box 124 is used to convert the number of revolutions of the rotor 110 into a higher
20 number of revolutions of a shaft 125, which is coupled in a known manner to a generator 128. It is pointed out that the depicted gear box 124 is optional and not present in case of a so called direct drive wind turbine. Further, a brake 126 is provided in order to stop the operation of the wind
25 turbine 100 or to reduce the rotational speed of the rotor 110 for instance (a) in case of an emergency, (b) in case of too strong wind conditions, which might harm the wind turbine 100, and/or (c) in case of an intentional saving of the consumed fatigue life time and/or the fatigue life time
30 consumption rate of at least one structural component of the wind turbine 100.

The wind turbine 100 further comprises a machine load control system 150 for operating the wind turbine 100 in a highly
35 efficient manner. Apart from controlling for instance the yaw angle adjustment device 121 the depicted machine load control system 150 is also used for adjusting the blade pitch angle

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of the rotor blades 114 in an optimized manner. Further, the control system 150 may be used for adjusting the yaw angle of the nacelle 122 respectively of the rotor 110.

5 For controlling the operation of the wind turbine 100 the machine load control system 150 is connected to a rotational speed sensor 143, which is connected to the gear box 124. The rotational speed sensor 143 feeds a signal to the machine load control system 150, which is indicative for the actual
10 rotational speed of the rotor 110.

Further, the machine load control system 150 is connected to a power sensor 141 being connected to the generator 128. The power sensor 141 provides information about the actual power
15 production of the wind turbine 110.

Furthermore, the machine load control system 150 is connected to angle sensors 142, which, according to the embodiment described here, are connected to the respective blade
20 adjustment devices 116. Therefore, the machine load control system 150 always has a precise knowledge about the actual blade pitch angle settings of all rotor blades 114.

According to the embodiment described here the machine load
25 control system 150 is also used for selecting a control mode for operating the wind turbine 100 in such a manner, that in particular under extreme conditions a very high fatigue life time consumption rate of at least one structural component of the wind turbine or even a damaging of this structural
30 component will be avoided.

In order to perform an appropriate load control for at least one structural component of the wind turbine, the machine load control system 150 comprises a determining unit 152 for
35 determining a value of a quantity being indicative for an operational condition of the wind turbine. According to the embodiment described here the determining unit is or

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comprises a fatigue sensing unit 152, which is capable of determining, observing, estimating and/or measuring the actual fatigue life time consumption rate of one or more structural components of the wind turbine 100.

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Further, the machine load control system 150 comprises a predicting unit 154 for predicting, based on the determined value, the mechanical load acting on the structural component within a future time period following the time of determining the value of the quantity being indicative for the operational condition of the wind turbine 100.

Furthermore, the machine load control system 150 comprises a selecting unit 156 for selecting a control mode for operating the wind turbine 100 in response to the predicted mechanical load.

Last but not least the machine load control system 150 comprises a control unit 158 for controlling, during the future time period, the operation of the wind turbine 100 with the selected control mode.

In the following it will be described as an example how to use the fatigue lifetime consumption rate of a blade root flap-wise bending moment in order to predict the top tower tilt moment (Figure 2) and the top tower yaw moment (Figure 3) five seconds later within a future time period.

In Figure 2 load peaks above 3000 kNm of the tower top tilt moment of a simulated normal operation of a wind turbine are plotted versus the corresponding fatigue lifetime consumption rate of the blade root flap-wise bending moment. The full rhombuses are the loads peak plotted versus the fatigue lifetime consumption rate of the blade root flap-wise bending moment at the same time the load peaks above 3000 kNm occur. The open triangles are the load peaks plotted versus the

fatigue lifetime consumption rate five seconds prior to the occurrence of the respective load peak. It is observed that in all cases of high load peaks, also the fatigue lifetime consumption rate is high. For instance if a load peak is
5 larger than 4500 kNm, the corresponding fatigue lifetime consumption rate is higher than 3 s/s. Further, if a load peak is higher than 5200 kNm the corresponding fatigue lifetime consumption rate is higher than 60 s/s. This is the case even for the fatigue lifetime consumption rate five
10 seconds prior to the time the corresponding load peak occurs.

In Figure 3 load peaks above 3000 kNm of the tower top yaw moment of simulated normal operation of a wind turbine are plotted versus the corresponding fatigue lifetime consumption
15 rates of the blade root flap-wise bending moment.

The full rhombuses are the loads peak plotted versus the fatigue lifetime consumption rate of the blade root flap-wise bending moment at the same time the load peaks above 3000 kNm
20 occur. The open triangles are the load peaks plotted versus the fatigue lifetime consumption rate five seconds prior to the occurrence of the respective load peak. It can be observed that in all cases of high load peaks, the fatigue lifetime consumption rate is high. For instance, if a load
25 peak is larger than 6300 kNm, the corresponding fatigue lifetime consumption rate is higher than 500 s/s. Further, if the load peak is higher than 6700 kNm, the corresponding fatigue lifetime consumption rate is higher than 3000 s/s. This is the case even for the fatigue lifetime consumption
30 rate which occurs five seconds prior to the occurrence time of peak load.

From the illustrations shown in Figure 1 and Figure 2 one can conclude that the most extreme mechanical loads on a
35 structural component of a wind turbine can be detected five seconds prior to the occurrence of this extreme mechanical load by evaluating the fatigue lifetime consumption rate.

Figure 4 illustrates the limitation of load peaks by a rotor speed reduction. The time dependence of a mechanical load time signal from a top tower tilt moment is plotted for relative rotor speeds of 100% (reference numeral 470), 90% (reference numeral 472), 80% (reference numeral 474), and 70% (reference numeral 476). In order to provide as similar as possible conditions for the load peak at time = 511.5 s, the start rotor azimuth angle has been optimized in order to hit the same azimuth angle at the time = 511.5s. It is mentioned that if this optimization would be omitted, the mechanical load peak value would be significantly reduced only due to a different azimuth angle and the informative value of Figure 4 would also be significantly reduced.

From Figure 4 it can be observed that the load peak value is reduced significantly if the rotor speed is reduced.

The proactive control of the operation of a wind turbine described in this document may provide the advantage that extreme mechanical loads can effectively be predicted by determining a value of a quantity being indicative for an operational condition of the wind turbine and in particular by determining the fatigue lifetime consumption of a structural component of the wind turbine. Further, extreme mechanical loads can effectively be limited by a reduction of the rotational speed of the rotor of the wind turbine.

It is mentioned that the value of a quantity being indicative for an operational condition of the wind turbine may be any mechanical load channel which is available in the wind turbine. Further, different available load channels may be combined in order to improve the reliability of the mechanical load prediction.

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The extreme mechanical loads to be limited may be loads acting on any structural component of the wind turbine. The structural component may be for instance a blade, the hub, the rotor shaft, the nacelle and/or the tower of the wind turbine.

Since a rotor speed reduction typically depends on the settings (gains, thresholds, etc.) in a Turbine Load Controller (TLC) of a wind turbine the settings may be trimmed in order to provide optimal extreme load control.

It is mentioned that the mechanical load reduction remedy used by a TLC may be other than rotor speed reduction. A mechanical load reduction can also be achieved for instance by a wind turbine stop, by a pitch control, by a cyclic pitch control, by individual pitch control, etc..

It is further mentioned that the mechanical loads of the wind turbine may be reduced only for a time period depending on the measured mechanical loads of the wind turbine.

It should be noted that the term "comprising" does not exclude other elements or steps and the use of articles "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

List of reference signs:

	100	wind turbine
	110	rotor
5	110a	rotational axis
	112	driving collar
	114	blade
	116	blade adjustment device
	120	tower
10	121	yaw angle adjustment device / yaw angle control system
	122	nacelle
	124	gear box
	125	shaft
	126	brake
15	128	generator
	141	power sensor
	142	angle sensor
	143	rotational speed sensor
	150	machine load control system
20	152	determining unit / fatigue sensing unit
	154	predicting unit
	156	selecting unit
	158	control unit
25	470	mechanical load for a relative rotor speed of 100%
	472	mechanical load for a relative rotor speed of 90%
	474	mechanical load for a relative rotor speed of 80%
	476	mechanical load for a relative rotor speed of 70%

CLAIMS:

1. Method for controlling the operation of a wind turbine
5 (100) comprising a structural component (110, 114, 120, 122, 125), which during an operation of the wind turbine (100) is exposed to a mechanical load, the method comprising
determining a value of a quantity being indicative for
an operational condition of the wind turbine (100),
10 predicting, based on the determined value, the
mechanical load acting on the structural component (110, 114, 120, 122, 125) within a future time period,
selecting a control mode for operating the wind turbine
(100) in response to the predicted mechanical load, and
15 controlling, during the future time period, the
operation of the wind turbine (100) with the selected control
mode.
2. The method as set forth in the preceding claim, wherein
20 selecting a control mode comprises
changing at least one operational parameter of the
wind turbine (100) and/or
changing at least one reference value for at least
one quantity being indicative for an operational
25 condition of the wind turbine (100).
3. The method as set forth in any one of the preceding
claims, wherein
the operational condition of the wind turbine (100) comprises
30 an extrinsic operational condition of the wind turbine (100).
4. The method as set forth in any one of the preceding
claims, wherein
the operational condition of the wind turbine (100) comprises
35 an intrinsic operational condition of the wind turbine (100).
5. The method as set forth in the preceding claim 4, wherein

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the quantity being indicative for the intrinsic operational condition of the wind turbine (100) is a mechanical load acting on at least one structural component (110, 114, 120, 122, 125) of the wind turbine (100).

5

6. The method as set forth in the preceding claim, wherein the mechanical load is a torque acting on a shaft (125) of the rotor (110) of the wind turbine (100).

10 7. The method as set forth in the preceding claim 4, wherein the quantity being indicative for the intrinsic operational condition of the wind turbine (100) is a fatigue lifetime consumption or a fatigue life time consumption rate.

15 8. The method as set forth in the preceding claim 4, wherein the quantity being indicative for the intrinsic operational condition of the wind turbine (100) is an electric parameter, in particular the amount of power, which is generated by an electric generator (128) of the wind turbine (100).

20

9. The method as set forth in the preceding claim 4, wherein the quantity being indicative for the intrinsic operational condition of the wind turbine (100) is a control parameter being used by a controller (158) of the wind turbine (100).

25

10. The method as set forth in the preceding claim 4, wherein the quantity being indicative for the intrinsic operational condition of the wind turbine (100) is a quantity being indicative for a movement of a component (120, 122) of the
30 wind turbine (100).

11. The method as set forth in any one of the preceding claims, wherein, if the predicted mechanical load is different from and in particular larger than a predefined
35 mechanical load or a pre-calculated reference for the mechanical load, the selected control mode causes at least one of the following control actions:

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(a) The rotational speed of the rotor (110) of the wind turbine (100) is changed and in particular reduced,
(b) the operation of the wind turbine (100) is stopped,
(c) a change of a blade pitch angle of at least one blade
5 (114) is initiated,
(d) a cyclic blade pitch angle control is initiated, and
(e) the energy production from the wind turbine (100) is changed and in particular reduced.

10 12. The method as set forth in any one of the preceding claims, further comprising
determining a further value of a further quantity being indicative for the operational condition of the wind turbine (100), wherein
15 the mechanical load acting on the structural component (110, 114, 120, 122, 125) within the future time period is predicted further based on the determined further value.

13. The method as set forth in any one of the preceding
20 claims, wherein
a delay between the time of determining the value of the quantity being indicative for the operational condition of the wind turbine (100) and the begin of the future time period is at least 2 seconds and preferably at least 5
25 seconds.

14. The method as set forth in any one of the preceding claims, wherein
- a time difference between the time of determining the value
30 of the quantity being indicative for the operational condition of the wind turbine (100) and the begin of the future time period and/or
- the length of the future time period depends on the determined value of the quantity being
35 indicative for the operational condition of the wind turbine (100).

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15. A machine load control system (150) for controlling the operation of a wind turbine (100) comprising a structural component (110, 114, 120, 122, 125), which during an operation of the wind turbine (100) is exposed to a
5 mechanical load, the machine load control system (150) comprising

 a determining unit (152) for determining a value of a quantity being indicative for an operational condition of the wind turbine (100),

10 a predicting unit (154) for predicting, based on the determined value, the mechanical load acting on the structural component (110, 114, 120, 122, 125) within a future time period,

 a selecting unit (156) for selecting a control mode for
15 operating the wind turbine (100) in response to the predicted mechanical load, and

 a control unit (158) for controlling, during the future time period, the operation of the wind turbine (100) with the selected control mode.

20

FIG 1

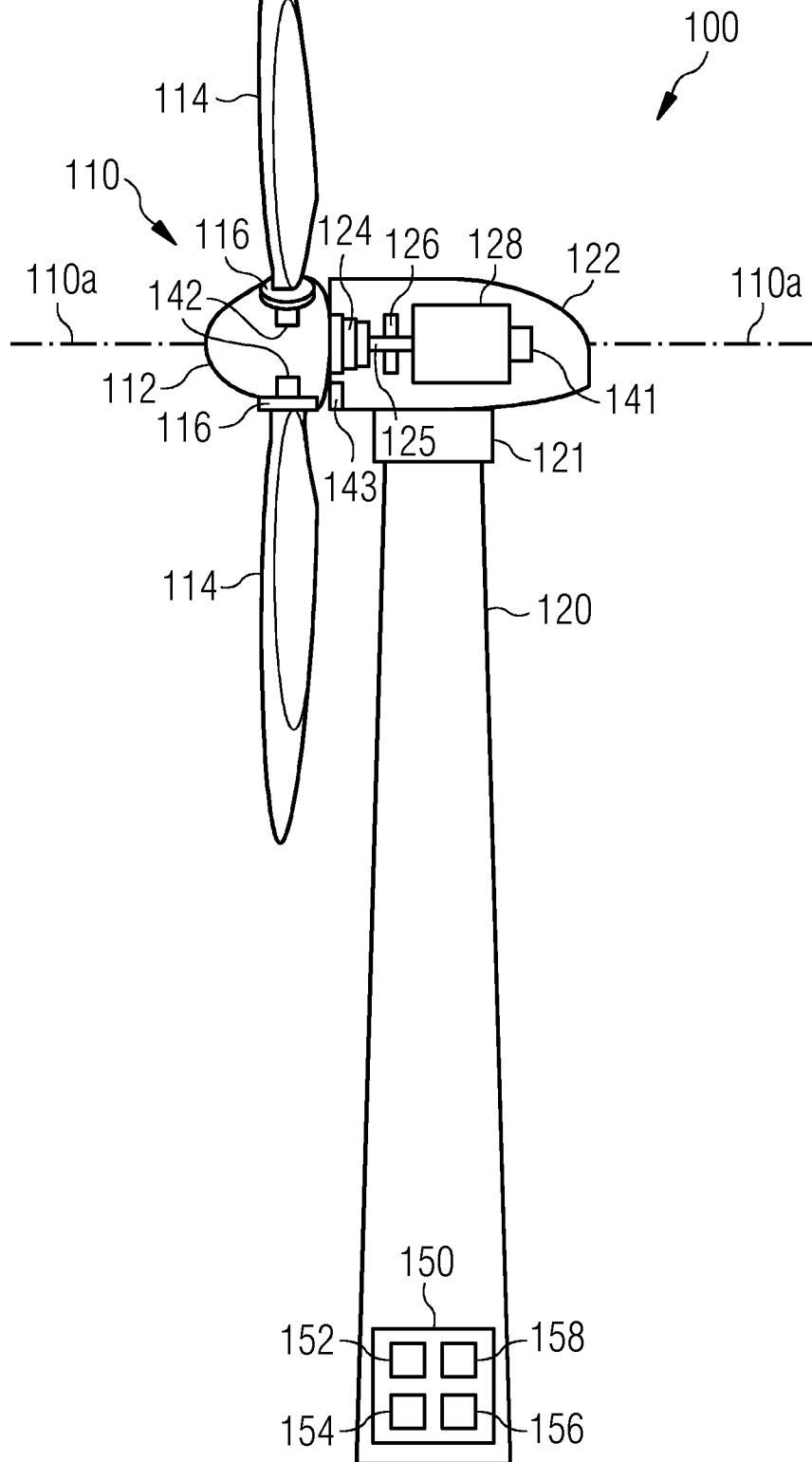


FIG 2

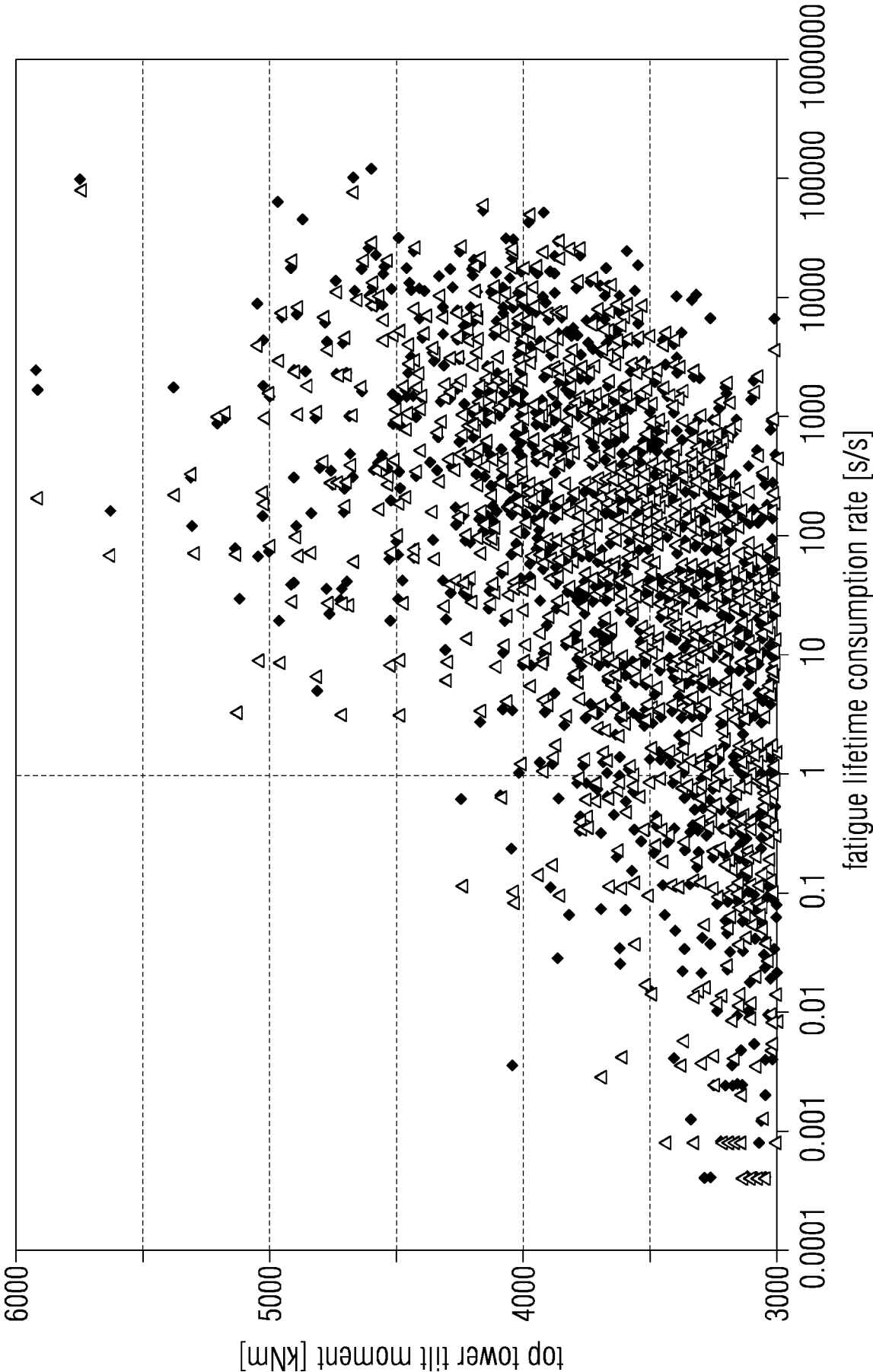


FIG 3

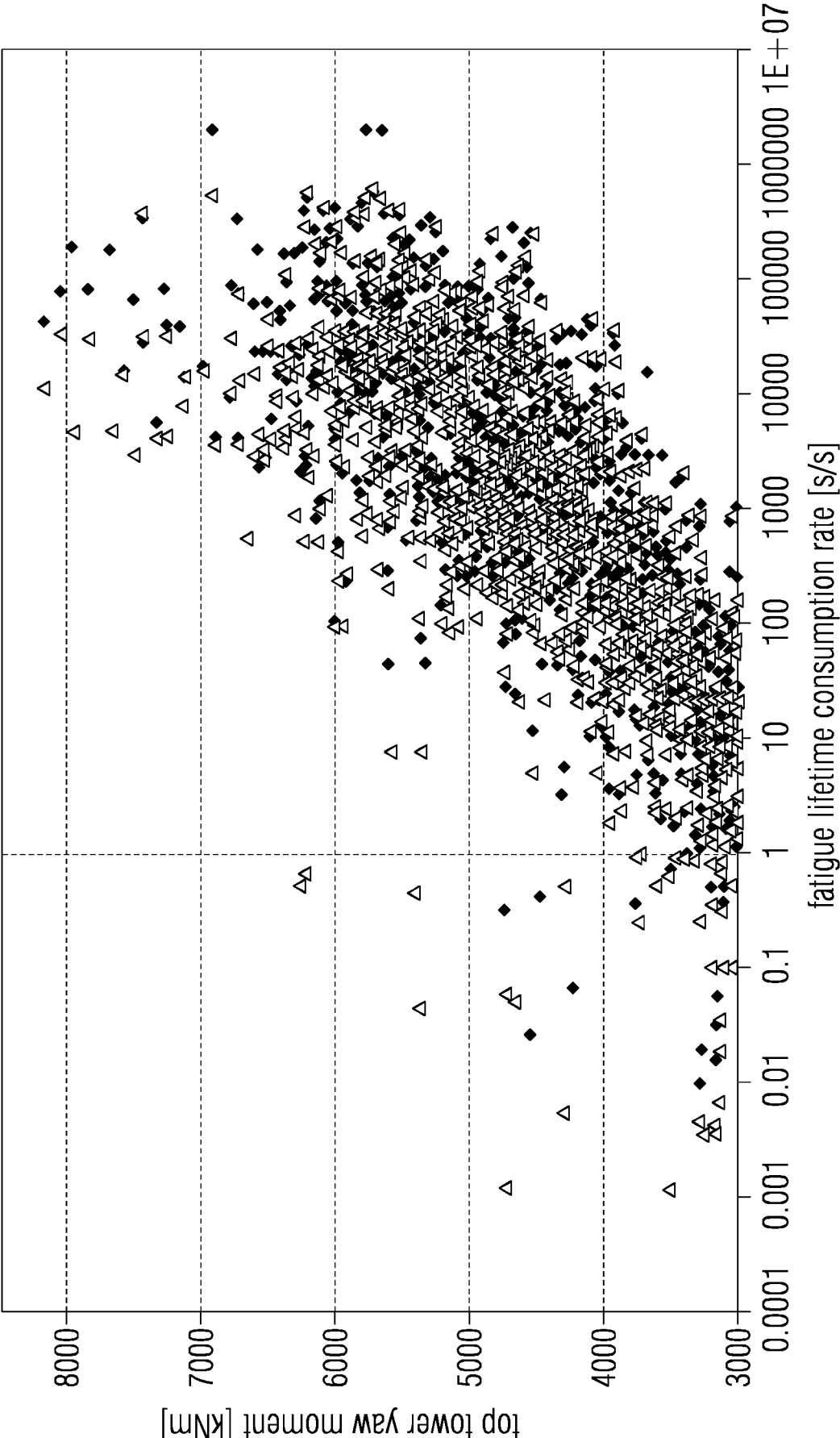
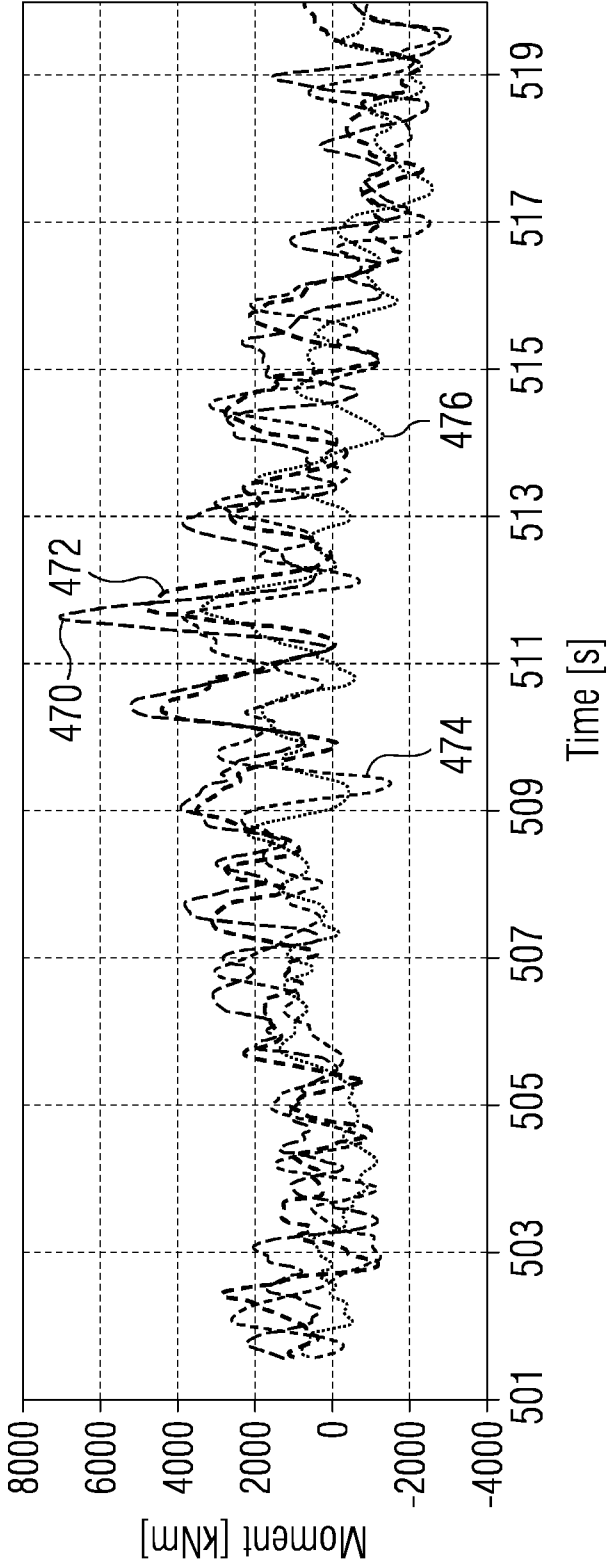


FIG 4



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/062736

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D7/04
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

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X	WO 2011/023308 A2 (BOSCH GMBH ROBERT [DE]; SCHINDELE LOTHAR [DE]; BUCHTALA BORIS [DE]; SC) 3 March 2011 (2011-03-03) page 2, line 11 - page 5, line 22 -----	1-15
X	WO 2011/035976 A1 (SIEMENS AG [DE]; EGEDAL PER [DK]; FRYDENDAL IB [DK]) 31 March 2011 (2011-03-31) page 3, line 29 - page 9, line 30 page 15, line 19 - page 16, line 9 page 21, line 19 - page 25, line 27 -----	1-15
X	EP 2 230 637 A1 (GEN ELECTRIC [US]) 22 September 2010 (2010-09-22) paragraphs [0014] - [0028] ----- -/-	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

24 April 2012

Date of mailing of the international search report

04/05/2012

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/062736

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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Information on patent family members

International application No

PCT/EP2011/062736

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