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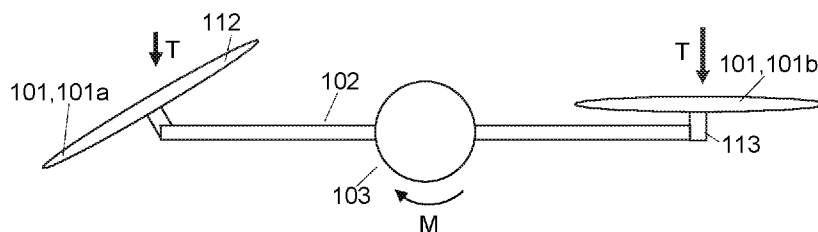


Fig. 3B

(57) Abstract: The invention relates to a method for testing yaw system operation of a multi- rotor wind turbine. The multi-rotor wind turbine comprises a tower with a support structure, at least two wind turbine modules mounted to the support structure and a yaw system arranged to enable rotation of the support structure around the tower. The method comprises applying a yaw moment on the yaw system in order to rotate the support structure, increasing the applied yaw moment towards a yaw moment threshold, measuring a yaw parameter indicative of yaw movement, and determining a condition of the yaw system based on the measured yaw parameter.



YAW SYSTEM MONITOR FOR A MULTI-ROTOR WIND TURBINE SYSTEM

FIELD OF THE INVENTION

The present invention relates to a wind turbine system with multiple rotors and to
5 yaw systems of such wind turbine systems.

BACKGROUND OF THE INVENTION

In order to create further improvements in the development of wind turbines, a
new wind turbine system has been developed. The new wind turbine system
10 includes a plurality of wind turbine modules or nacelles and, therefore, a plurality
of rotors. The wind turbine modules can be mounted on a support structure which
is carried by a single tower.

The multi-rotor wind turbine may have a common yaw system arranged for
15 providing common yawing for two or more of the wind turbine modules. During
operation, the yaw system has a function for holding the wind turbine modules up
against the wind. High torsion moments may be generated since the wind turbine
modules may be located a distance away from the tower. Due to the holding
function, yaw moments on the yaw system is transferred to the tower and could
20 lead to damages of the tower and the wind turbine system.

Accordingly, there is a need for improving multi-rotor wind turbines with a
common yaw system in order to prevent damages due to large yaw moments.

25 GB2443886B discloses a wind turbine arrangement with a tower and at least two
arms projecting outwards therefrom. A wind turbine is attached to an end of each
arm. A method of control is disclosed which can align the turbines with the wind
direction by means of blade pitch adjustment.

30 SUMMARY OF THE INVENTION

It is an object of the invention to improve multi-rotor wind turbines, particularly to
improve the capabilities of multi-rotor wind turbines to prevent damages caused
by torsion moments. It is also an object of the invention to improve testing of the
of the yaw system to ensure proper operation.

In a first aspect of the invention there is provided a method for testing yaw system operation of a wind turbine system, the wind turbine system comprises a tower with a support structure, at least two wind turbine modules mounted to the support structure and a yaw system arranged to enable rotation of the support structure about a longitudinal axis of the tower, the method comprises

- applying a yaw moment on the yaw system for rotating the support structure,
- increasing the applied yaw moment towards a yaw moment threshold,
- measuring a yaw parameter indicative of yaw movement, and
- determining a condition of the yaw system based on the measured yaw parameter.

Dependent on the setting of the yaw moment threshold it is possible to test if the yaw system starts moving at low yaw moments. This could indicate that the holding force of the holding function is not sufficient to constrain motion. Or it is possible to test if the yaw system does not move as intended at high yaw moments which could indicate that the slippage function is functional. In this way it is possible to test if the yaw system operates as intended.

According to an embodiment, the method comprises determining if the monitored yaw parameter indicates that the support structure is not rotated by the yaw system during the increase of the yaw moment up to the yaw moment threshold. Accordingly, if the yaw system has not rotated when the applied yaw moment has been increased up to the yaw moment threshold where rotation is expected a fault condition of the yaw system can be assumed.

Accordingly, the yaw moment threshold may be a maximum yaw moment threshold expected to be large enough to exceed a yaw holding-moment generated by the yaw system to constrain motion of the support structure about the rotation axis of the yaw system.

According to an embodiment, the method comprises determining if the measured yaw parameter indicates that the support structure is rotated by the yaw system during the increase of the yaw moment up to the yaw moment threshold. Accordingly, if the yaw system rotates or moves before the applied yaw moment

has reached the yaw moment threshold where the holding function of the yaw system should still constrain motion a fault condition can be assumed.

Accordingly, the method may comprise determining if the monitored yaw
5 parameter indicates that the support structure is rotated by the yaw system during the increase of the yaw moment up to a minimum yaw moment threshold below which the yaw system should not enable rotation of the support structure.

According to an embodiment, the applied yaw moment is generated by controlling
10 the thrust force of at least one of the wind turbine modules to achieve a difference in thrust forces generated by at least two of the wind turbine modules located on opposite sides of the tower. For example, a pair of wind turbine modules located on opposite sides of the tower may be utilized to generate a difference in thrust forces for creating the yaw moment.

15 For example, controlling the thrust force of at least one of the wind turbine modules may comprise adjusting blade pitch or rotation speed of a rotor of the at least one wind turbine module, yaw angle of the at least one wind turbine module, or power generated by the at least one wind turbine module, or a combination
20 thereof.

According to an embodiment the applied yaw moment is generated by controlling a yaw drive of the yaw system to rotate the support structure. Alternatively or additionally, the yaw moment may be generated using the yaw drive.
25 Advantageously, use of the yaw drive for generating the yaw moment does not significantly generate a loss in power production during the application of the yaw moment.

According to an embodiment, the yaw moment is applied in response to a
30 detection of a change in wind speed direction during operation when the wind turbine system is connected to the grid. Advantageously, by performing the test of the yaw system when yawing is required anyway loss of power reduction can be reduced.

According to an embodiment, the method comprises reducing or stopping power production of at least some of the at least two wind turbine modules dependent on the determined condition of the yaw system. For example, if the determined condition shows that the yaw system does not rotate as intended for an applied
5 yaw moment above the yaw moment threshold, the wind turbine modules which are connected to the same yaw system may be stopped or they may be operated in a de-rated state with reduced power production. This may prevent damages to the wind turbine system, e.g. due to a faulty slippage function of the yaw system.

10 According to an embodiment, the method comprises performing the test of the yaw system operation dependent on a state of the wind turbine system.

For example, the test may be performed based on a state of the wind turbine system indicating the last time the test was performed. Thus, the wind turbine
15 system may be configured to perform the test periodically, e.g. once every day.

In an other example, the test may be performed based on a state of the wind turbine system indicating that the wind turbine system or a part of the wind turbine modules are about to be started or connected to the grid. Accordingly, the
20 yaw moment may be applied before the wind turbine system is connected to the grid. Advantageously, by performing the test of the yaw system before grid connection, critical faults of the yaw system which could lead to damages may be detected before start of wind turbine operation.

25 According to an embodiment, the state of the wind turbine system is determined on basis of a yaw angle of the yaw system. Accordingly, the test may be performed based on the yaw angle, e.g. a determined yaw angle reference or a measured yaw angle. In a wind turbine park, a wind turbine system may be exposed due large yaw moments due to wake effects from neighbor wind turbine
30 systems. Thus, the controller of a wind turbine system may be configured to determine or predict a potentially critical wake situation dependent on its position relative other wind turbine systems and its yaw angle which is more or less common for all wind turbine systems in the park. Advantageously, but performing the test dependent on the yaw angle, the function of the yaw system can be
35 tested to avoid high torsion moments caused by wake effects.

According to an embodiment, the method further comprises adjusting the yaw moment threshold in order to adapt the yaw moment threshold to a change of a yaw holding-moment generated by the yaw system to constrain rotation of the support structure. Advantageously, by adapting the yaw moment threshold to changes in the holding moment of the yaw system, e.g. actively induced changes or naturally occurring changes, the test results will be more reliable. The actively induced change of the holding moment may be controlled via a control signal applied e.g. to the yaw system to cause the change the holding-moment.

10 A second aspect of the invention relates to a test system for testing yaw system operation of a wind turbine system, where the test system is arranged to perform the test by performing the steps according to the method of the first aspect.

A third aspect of the invention relates to a wind turbine system comprising:

- 15 - a tower with a support structure, at least two wind turbine modules mounted to the support structure, and a yaw system arranged to enable rotation of the support structure about a longitudinal axis of the tower, and
- the test system according to the second aspect.

20 A fourth aspect of the invention relates to a computer program product directly loadable into a memory accessible by a computing system, the computer program product comprises instructions for performing the steps of the method according to the first aspect when the computer program product is run on the computer system.

25

In general, the various aspects and embodiments of the invention may be combined and coupled in any way possible within the scope of the invention. These and other aspects, features and/or advantages of the invention will be apparent from and elucidated with reference to the embodiments described

30 hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be described, by way of example only, with reference to the drawings, in which

35

Fig. 1 shows a wind turbine system which comprises a plurality of wind turbine modules,

Fig. 2 shows different yaw moment thresholds for use in testing yaw system operation,

5 Fig. 3A shows a situation where wind turbine modules oriented against the wind are used for generating the yaw moment by thrust force control,

Fig. 3B shows a situation where one of the wind turbine modules is yawed out by use of a local yaw drive for adjusting the thrust force for the purpose of generating the yaw moment, and

10 Fig. 4 shows a test system for testing yaw system operation of a wind turbine system.

DESCRIPTION OF EMBODIMENTS

Fig. 1 shows a wind turbine system 100 which comprises a plurality of wind
15 turbine modules 101 mounted to a common support structure 102. The common support structure may be configured in various ways, but is generally arranged to enable mounting of at least some wind turbine modules 101 at a distance from the tower 103 and on opposite sides of the tower 103. For example, the common support structure 102 may consist of different support structure parts, e.g. in the
20 form of one or more beam structures 121 extending outwardly from the tower 103 from opposite sides of the tower 103.

Each of the wind turbine modules 101 comprises a rotor 111, a power generation system (not shown) driven by the rotor and a rotor blade pitch adjustment system
25 (not shown) for pitching rotor blades 112. The power generation system and the pitch adjustment system may be included in nacelles 113 of the respective wind turbine modules 101.

According to the embodiment in Fig. 1, each of the plurality of wind turbines
30 modules 101 are mounted on an end part of a corresponding beam structure 121, though other positions on the beam structures are possible, particularly when more than one wind turbine module is mounted on an a single beam structure or a part of a beam structure 121 extending in a given direction from the tower 103.

Specifically, Fig. 1 shows a support structure 102 with two beam structures 121 each carrying two wind turbine modules 101, but other embodiments are of course conceivable, e.g., four beam structures 121 with four wind turbine modules each or three beam structures with lower, middle and upper beam structures, 5 respectively having six, four and two wind turbine modules.

The plurality of wind turbine modules carried by the support structure 102 may be in the same vertical plane, or they may be shifted relative to each other. In the wind turbine modules 101, the kinetic energy of the wind is converted into 10 electrical energy by a power generation system (not shown), as it will be readily understood by a person skilled in wind turbines.

Individual wind turbine modules 101 are referred to as the first to fourth wind turbine modules 101a-101d. 15

The power generation system is controllable to produce a power corresponding to a power reference by adjusting the pitch of the rotor blades 112 or by controlling a power converter to adjust the power production.

20 The pitch adjustment system may be configured to control the rotor blades 112 of a given rotor 111 by individual pitch adjustments of each rotor blade or by a common pitch adjustment of all rotor blades.

The wind turbine system 100 comprises a yaw system 130 arranged to enable 25 rotation of the support structure 102 or parts of the support structure about a longitudinal axis of the tower 103. For example, each beam structure 121 may be connected to the tower by a yaw bearing 131, 132 which enables rotation of the beam structure 121. Alternatively, the wind turbine system 100 may be configured so that the entire support structure 102 is connected to the tower by a 30 yaw bearing 132 - in this case the upper yaw bearing may be omitted and the upper part of the tower 103 may be part of the support structure 102. As another alternative, the yaw system 130 may be configured as a yaw bearing 133 arranged in the foundation of the wind turbine system 100 to enable rotation of the entire wind turbine system 100, i.e. the tower 103 and the support structure

102. Accordingly, the yaw system may be embodied by one or more of the yaw bearings 131-133.

Additionally, the wind turbine system 100 may comprise optional module yaw systems (not shown) arranged between the beam structure 121 and each of the wind turbine modules 101. Accordingly, the optional module yaw systems are arranged to enable yaw rotation of each wind turbine module 101 independent of other wind turbine modules 101, i.e. rotation about axes substantially parallel with the longitudinal axis of the tower.

10

The rotors 111 of the of the wind turbine modules 101 arranged at a distance from the tower 103 can potentially generate very high yaw moments M around the tower which could damage or even cause a collapse of the tower. This may particularly be a problem for multi-rotor wind turbine systems 100 where the tower may be guy wire supported to enable a tower with relative low material thickness. Accordingly, the tower 103 of a the wind turbine system 100 may not be dimensioned to withstand large yaw moments M .

Therefore, the yaw system 130 has to be configured to ensure that the support structure 102 is able to yaw out in case the yaw moment M becomes critical to the tower 103.

High yaw moments can occur in case one wind turbine module 101 shuts down and the wind turbine module 101 on the other side of the tower 103 continues operating, e.g. for the purpose of reducing lost production. High yaw moments can also occur during normal operation with very high turbulence or in case one of the wind turbine modules 101 for some reason is not fully aligned up against the wind. In order to prevent high yaw moments, the yaw system 130 is arranged to provide yaw slippage, i.e. to enable yaw rotation, in case the yaw moment exceeds a given maximum yaw threshold. On the other hand, the yaw system 130 also needs to prevent yaw rotation during normal operation for yaw moments below a given minimum yaw threshold.

Accordingly, the yaw system 130 is configured with a holding function to prevent yaw rotation for yaw moments below a given minimum yaw threshold and to

provide yaw slippage for yaw moments above a given maximum yaw threshold. The holding function may be embodied by a passive friction brake or holding mechanism configured with a specific stiction friction to provide the desired holding properties. The friction may be present between rotation parts in a yaw
5 bearing.

The slippage function of the yaw system 130 may be inhibited in functioning as intended. For example, in case the yaw system has been locked manually for service purposes and unlocking has been forgotten, due to ambient conditions
10 such as special temperature conditions which affects the friction properties of the yaw bearing, a fault in a drive system of the yaw system, e.g. a pressure valve defect in a hydraulic yaw drive system, or if a controller has not released yaw brakes (which may installed in the yaw system) due to a software fault.

15 Accordingly, it is important that the slippage function of the yaw system 130 is functional.

Fig. 2 illustrates different yaw moment thresholds 201-203 for the purpose of explaining a method for testing if the slippage function of the yaw system 130 is
20 functional. Thus, Fig. 2 illustrates the yaw moment capacity 203 of the tower 103, i.e. the maximum yaw moment before damage may occur. Fig. 2 further illustrates a maximum yaw moment threshold 202 expected to be large enough to exceed a yaw holding-moment M_h generated by the yaw system 130 to constrain rotation of the support structure 102. Fig. 2 also illustrates a minimum yaw
25 moment threshold 201. The yaw system 130 should not enable rotation of the support structure 102 for yaw moments M below the minimum yaw moment threshold 201. The yaw holding-moment M_h may be equal to the minimum yaw moment threshold 201.

30 Fig. 2 further shows an applied yaw moment 210 which is generated and acting on the yaw system 130 for the purpose of rotating the support structure 102.

The yaw moment 210 can be generated in different ways as exemplified below.

According to an embodiment of the invention the applied yaw moment 210 is increased towards a yaw moment threshold such as maximum yaw moment threshold 202 or the minimum yaw moment threshold 201. The yaw moment 210 may be increased linearly as shown, but could also be increased stepwise, nonlinearly or in other ways. During or after the applying the yaw moment a yaw parameter indicative of yaw movement is measured. The measured yaw parameter is used for determining a condition of the yaw system operation, e.g. if yaw system operates as intended in response to the applied yaw moment.

Examples of the measured yaw parameter includes obtaining the wind vane direction, obtaining the yaw orientation from a yaw position sensor or obtaining operational values from the yaw drive of the yaw system 130. The operational values from the yaw drive may be values relating to the fluid flow in a hydraulic yaw drive or current in an electric yaw drive. That is, if the yaw system 130 is rotated, the hydraulic or electric yaw drive may generate a measurable fluid flow from the hydraulic drive or an electric current from an electric motor, respectively. The yaw parameter could also be obtained from measured torsion moments, e.g. torsion moments of the tower. For example, a change from a state where the yaw system 130 holds the support structure 102 to a state where the support structure is rotated due to the applied yaw moment 210 would cause a measureable reduction in the torsion moments of the tower which would indicate movement of the yaw system 130.

Accordingly, the measured yaw parameter can be used for determining if the support structure 130 is rotated as intended for yaw moments above a maximum yaw moment threshold 202 and/or for determining if support structure 130 is not rotated, as intended, for yaw moments below a minimum yaw moment threshold 201.

Thus, the method according to an embodiment may be used for determining a rotation status of the support structure 102 based on the monitored yaw parameter. Determination of the rotation status may involve determining if monitored yaw parameter indicates that the support structure 102 is not rotated by the yaw system 130 during the increase of the yaw moment 120 up to the yaw moment threshold, e.g. the maximum yaw moment threshold 202. Alternatively

or additionally, determination of the rotation status may involve determining if the measured yaw parameter indicates that the support structure 102 is rotated by the yaw system during the increase of the yaw moment 120 up to the yaw moment threshold, e.g. the minimum yaw moment threshold below which the yaw system should not enable rotation of the support structure.

According to an embodiment, the applied a yaw moment is reduced, e.g. to zero, in response to detecting a yaw parameter which indicates yaw movement.

Fig. 3A and Fig. 3B show top views of the wind turbine system 100 with the first and second wind turbine modules 101a, 101b.

The aerodynamics of the blades 112 generates lift and drag forces which can be resolved into axial thrust forces T and tangential forces which drives the rotors 111.

As illustrated, generated thrust forces T which are different, e.g. for a pair of wind turbine modules 101a, 101b located on opposite sides of the tower 103, generates a yaw moment M around the tower 103.

20

The different thrust forces T can be generated in different ways. In general the applied yaw moment M can be generated by controlling the thrust force T of at least one of the wind turbine modules 101 to achieve a difference in thrust forces generated by at least two of the wind turbine modules located on opposite sides of the tower 103.

Accordingly, by controlling the thrust force generated by at least one of the wind turbine modules 101 it is possible to generate an applied yaw moment 120 which can be varied as described in connection with Fig. 2. For example, the thrust force T generated by the wind turbine module on one side of the tower 103 may be kept constant or uncontrolled, and the thrust force T generated by the wind turbine module on the opposite side of the tower 103 is controlled to achieve the desired yaw moment 120.

Control of the thrust force T of one or more wind turbine modules 101 may be achieved by adjusting pitch of blades 111 of wind turbine modules 101, rotation speed of the rotor 112 of wind turbine modules 101, yaw angle of the nacelles 113 of the wind turbine modules 101 or power generated by the wind turbine
5 modules 101.

Fig. 3A show a situation where the wind turbine modules 101 used for generating the yaw moment 120 are oriented against the wind. The thrust force T can be controlled by adjusting the amount of wind energy extracted by one or more of
10 the wind turbine modules 101. The amount of extracted wind energy can be adjusted by adjusting the pitch of the blades 111, rotation speed of the rotors 112 and/or power generated by the wind turbine modules 101. The rotation speed or generated power can be adjusted by controlling the power converter comprised by each of the wind turbine modules 101. The pitch of the blades can be controlled
15 via the pitch systems of the wind turbine modules 101. In general, the thrust force T can be controlled by adjusting a thrust force command to the one or more wind turbine modules 101 which generates the desired thrust force T by adjustment of pitch, rotation speed and/or power.

20 The generation of the yaw moment 120 can be performed before the wind turbine system is connected to the grid or during grid connection by rotating the rotors 111 and controlling the thrust forces T as described in connection with Fig. 3A. One of the wind turbine modules 101 may be shut down (rotor stopped or idle) whereas the wind turbine module 101 on the opposite side is operated, with or
25 without grid connection.

Fig. 3B shows a situation where the first of the wind turbine modules 101a is yawed out by use of a local yaw drive (not shown) arranged for the first wind turbine module 101a. In this situation, each of the wind turbine modules 101 may
30 have local yaw drives. In one example, the thrust force T generated by the wind turbine module 101a which is yawed out is controlled by adjusting the yaw angle, i.e. the degree of yawing out. The opposite wind turbine 101b has a rotating or non-rotating rotor 112 and may be grid connected or not. In another example, the wind turbine module 101a which is yawed out has a constant yaw angle and
35 therefore generates a substantially constant thrust force T . In this example, the

wind turbine module 101b located on the opposite side is controlled to generate a controlled thrust force T as described in connection with Fig. 3A while it is grid connected or disconnected from the grid.

- 5 Alternatively, the yaw drive of the yaw system 130 may be operated and controlled to generate the yaw moment by controlling, e.g. by activating the yaw system 130 to rotate the support structure 102.

In the example where the wind turbine system 100 is connected to the grid, the
10 the yaw moment 120 may be applied in response to a detection of a change in wind speed direction in order to align the wind turbine modules 101 up against the wind. Accordingly, if the wind direction changes, the yaw moment applied for rotating the support structure 102 up against the wind may be applied according to the methods for controlling the trust force T to achieve a desired applied yaw
15 moment and at the same time align the wind turbine modules 101 up against the wind.

The yaw holding-moment generated by the yaw system 130 to constrain rotation of the support structure 102 may inherently depend on ambient conditions such
20 as temperature and humidity. For example, the yaw holding-moment may be generated by the friction force of one or more friction brakes comprised by the yaw system 130. The stick-slip properties of the friction brake and therefore the holding moment M_h (i.e. the moment necessary for making the stick-slip transition) may depend on temperature and humidity.

25

The yaw system 130 may be configured with an adjustable yaw holding-moment M_h . In this case, the yaw holding-moment M_h may be adjusted e.g. for the purpose of compensating changes in the holding moment M_h caused by ambient conditions or other purposes. Thus, the adjustment of the yaw holding-moment
30 M_h may be performed actively during operation of the wind turbine system 100 when the wind turbine system 100 is connected to the grid. However, the active adjustment of the holding moment could also be performed when the wind turbine system is disconnected from the grid.

For example, the yaw holding-moment M_h may be adjusted dependent on wind speed. At low wind speed the wind direction may change more frequent than at higher wind speeds and, therefore, yawing of the wind turbine modules 101 may need to be performed more frequently at lower wind speeds than higher wind speeds. Yawing due to changes of wind speed direction performed using thrust control, i.e. by controlling the thrust force T , causes a loss of power production. The thrust force needed for yawing the support structure 102 can be reduced by lowering friction force of the yaw system 130. Since the holding moment M_h may be reduced at low wind speed, the friction force of the yaw system 130 may safely be reduced at low wind speeds for the benefit of improved power production.

In order to adapt the yaw moment threshold, e.g. the minimum yaw moment threshold 201 and/or the maximum yaw moment threshold 202, to a change of a yaw holding-moment M_h the yaw moment threshold may be adjusted. The change of a yaw holding-moment M_h or friction force may be caused by changes of ambient conditions. When the dependency of the yaw holding-moment M_h or friction force on the ambient conditions are known the yaw moment threshold can be adjusted accordingly. Otherwise, the change of a yaw holding-moment M_h may be due to an actively performed adjustment.

The active adjustment of the yaw holding-moment M_h may be performed by adjusting properties of a friction brake of the yaw system 130, e.g. by changing hydrodynamic properties in a hydraulic system used for establishing a friction force. Alternatively, a heating and/or cooling device can be used for changing the friction of a friction-bearing which provides the holding moment M_h of the yaw system 130.

The change the holding-moment M_h may be performed by applying a control signal, e.g. to controller of the wind turbine system 100 configured to control the holding-moment M_h of the yaw system 130.

Fig. 4 shows a test system 301 for testing yaw system operation of a wind turbine system 100. The test system 100 is arranged to perform the test by performing methods described above.

The test system 301 may be configured to generate a control signal Ctrl for applying the yaw moment 210 on the yaw system 130. The control signal controls the increase of the applied yaw moment towards a yaw moment threshold 201, 202. The control signal is supplied to the yaw moment generator 302 for effectuating the
5 desired yaw moment. The yaw moment generator 302 may be embodied by systems for controlling the thrust force T of the wind turbine modules 101 such as the pitch system, the power generation systems or power converters and the local yaw drives.

- 10 The test system 301 is further configured to obtain the yaw parameter R indicative of yaw movement or yaw rotation and to determine a condition of the yaw system, i.e. to test if the friction properties of the yaw system 130 works as intended, based on the obtained yaw parameter.
- 15 In order to control the applied yaw moment 210 the test system 301 may be configured to control yaw moment based on a measured, estimated or otherwise obtained values of the actually applied yaw moment. The actually applied yaw moment may be obtained from measured bending moments in the beam structures 121 or directly by measuring the torsion moment in the tower 103.
- 20 Alternatively, the actually applied yaw moment may be determined from estimated thrust loads of the wind turbine modules 101. For example, the thrust loads may be estimated from pitch angle, rotation speed, produced power and Ct-tables.
- 25 Furthermore, the test system 301 may be configured to detect changes in wind speed direction for the purpose of applying the yaw moment 120 when yawing of the wind turbine modules is required anyway.

- Furthermore, the test system 301 may be configured to adjust the yaw moment
30 threshold 201, 202 for adapting the yaw moment threshold to changes of the yaw holding-moment Mh.

The test system 301 may be comprised by the wind turbine system 100 or located externally.

Embodiments of invention can be implemented by means of electronic hardware, software, firmware or any combination of these. Software implemented embodiments or features thereof may be arranged to run on one or more data processors and/or digital signal processors. Software is understood as a computer
5 program or computer program product which may be stored/distributed on a suitable computer-readable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware. Thus, the computer-readable medium may be a non-transitory medium. Accordingly, the computer program comprises software code portions for performing the steps
10 according to embodiments of the invention when the computer program product is run/executed by a computer or by a distributed computer system.

Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to
15 the presented examples. The scope of the present invention is to be interpreted in the light of the accompanying claim set. In the context of the claims, the terms "comprising" or "comprises" do not exclude other possible elements or steps. Also, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to
20 elements indicated in the figures shall also not be construed as limiting the scope of the invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mentioning of these features in different claims does not exclude that a combination of features is not possible and advantageous.

CLAIMS

1. A method for testing yaw system operation of a wind turbine system (100), the wind turbine system comprises a tower (103) with a support structure (102), at least two wind turbine modules (101) mounted to the support structure and a yaw system (130) arranged to enable rotation of the support structure about a longitudinal axis of the tower, the method comprises
- applying a yaw moment (210) on the yaw system for rotating the support structure (102),
 - increasing the applied yaw moment (210) towards a yaw moment threshold (201, 202),
 - measuring a yaw parameter (R) indicative of yaw movement, and
 - determining a condition of the yaw system (130) based on the measured yaw parameter.
2. A method according to claim 1, comprising determining if the monitored yaw parameter (R) indicates that the support structure (130) is not rotated by the yaw system during the increase of the applied yaw moment (120) up to the yaw moment threshold (201, 202).
3. A method according to any of the preceding claims, where the yaw moment threshold is a maximum yaw moment threshold (202) expected to be large enough to exceed a yaw holding-moment (M_h) generated by the yaw system (130) to constrain rotation of the support structure (102).
4. A method according to any of the preceding claims, comprising determining if the measured yaw parameter (R) indicates that the support structure (102) is rotated by the yaw system (130) during the increase of the applied yaw moment (120) up to the yaw moment threshold (201, 202).
5. A method according to any of the preceding claims, comprising determining if the monitored yaw parameter (R) indicates that the support structure (102) is rotated by the yaw system (130) during the increase of the applied yaw moment (120) up to a minimum yaw moment threshold (201) below which the yaw system should not enable rotation of the support structure (102).

6. A method according to any of the preceding claims, where the applied yaw moment (120) is generated by controlling the thrust force (T) of at least one of the wind turbine modules (101) to achieve a difference in thrust forces generated by at least two of the wind turbine modules located on opposite sides of the tower
5 (103).

7. A method according to claim 6, where controlling the thrust force (T) of at least one of the wind turbine modules (101) comprises adjusting blade pitch or rotation speed of a rotor of the at least one wind turbine module, yaw angle of the at least
10 one wind turbine module, or power generated by the at least one wind turbine module, or a combination thereof.

8. A method according to any of the preceding claims, where the applied yaw moment (210) is generated by controlling a yaw drive of the yaw system (130) to
15 rotate the support structure (102).

9. A method according to any of the preceding claims, where the yaw moment (120) is applied in response to a detection of a change in wind speed direction during operation when the wind turbine system (100) is connected to the grid.
20

10. A method according to any of the preceding claims, comprising reducing or stopping power production of at least some of the at least two wind turbine modules (101) dependent on the determined condition of the yaw system (130).

25 11. A method according to any of the preceding claims, comprising performing the test of the yaw system operation dependent on a state of the wind turbine system (100).

12. A method according to claim 11, where the state of the wind turbine system is
30 determined on basis of a yaw angle of the yaw system (130).

13. A method according to any of the preceding claims, further comprising adjusting the yaw moment threshold (201, 202) in order to adapt the yaw moment threshold to a change of a yaw holding-moment (Mh) generated by the
35 yaw system (130) to constrain rotation of the support structure (102).

14. A test system (301) for testing yaw system operation of a wind turbine system (100), where the test system is arranged to perform the test by performing the steps according to the method of claim 1.

5

15. A wind turbine system (100) comprising:

- a tower (103) with a support structure (102), at least two wind turbine modules (101) mounted to the support structure, and a yaw system (130) arranged to enable rotation of the support structure about a longitudinal axis of the tower, and

10 - the test system (301) according to claim 13.

16. A computer program product directly loadable into a memory accessible by a computing system, the computer program product comprises instructions for performing the steps of the method according to claim 1 when the computer

15 program product is run on the computer system.

1/4

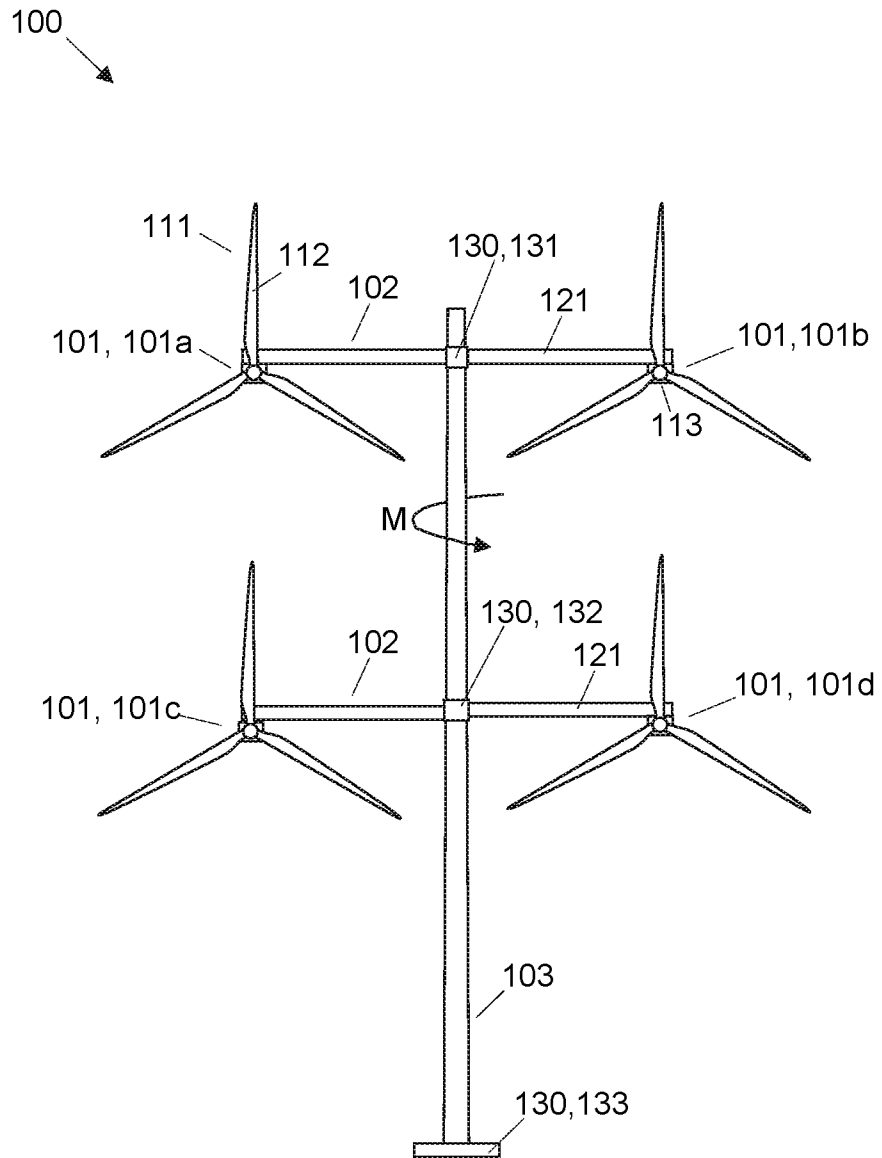


Fig. 1

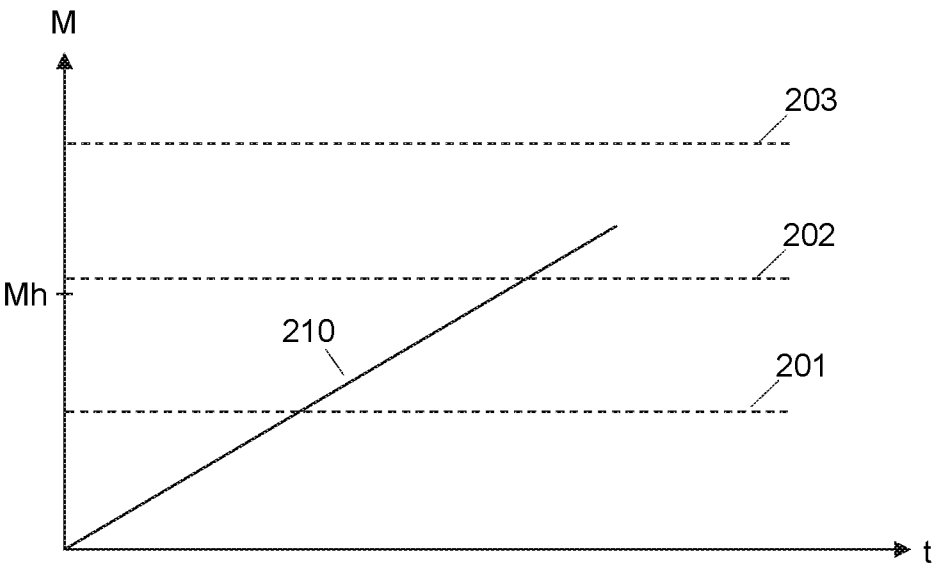


Fig. 2

3/4

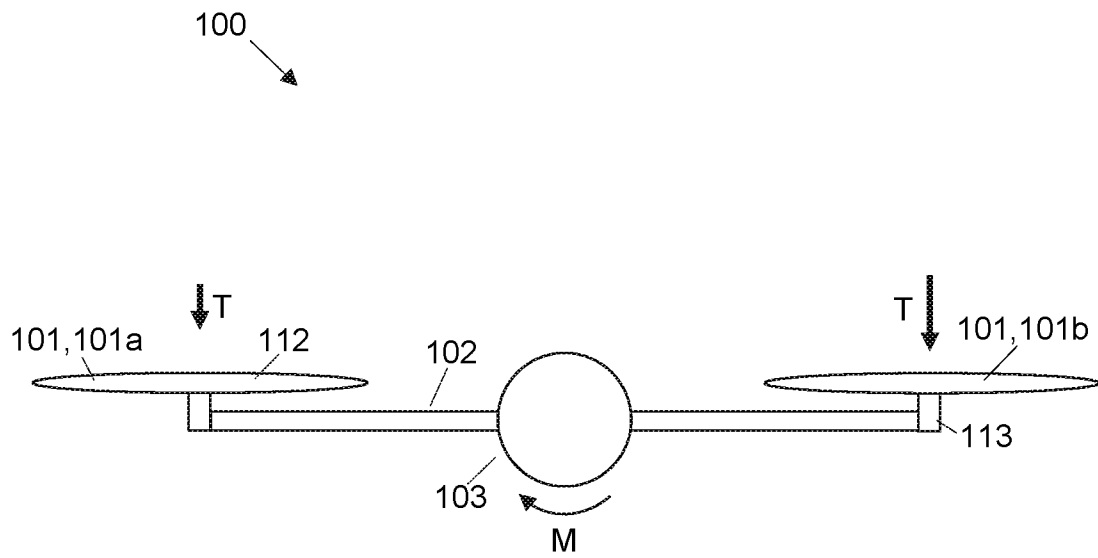


Fig. 3A

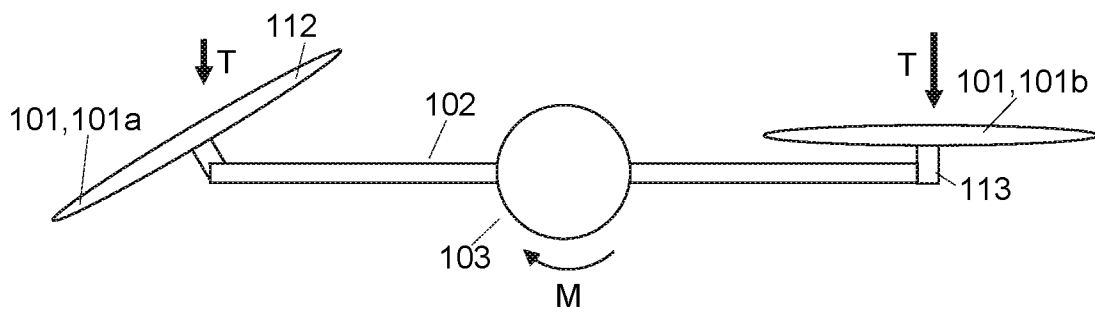


Fig. 3B

4/4

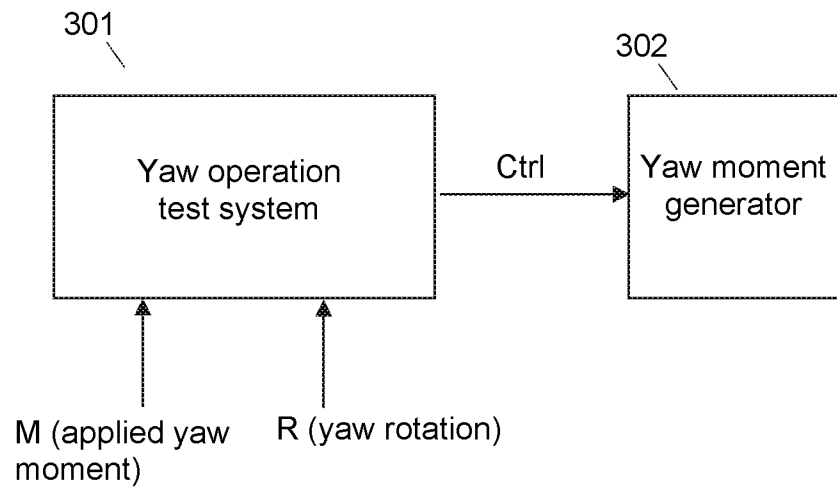


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2018/050038

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D7/02 F03D17/00 F03D1/02
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 practicable, 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.
Y	GB 2 443 886 A (TODMAN MICHAEL TORR [GB]) 21 May 2008 (2008-05-21) cited in the application page 8, lines 14-21 page 9, lines 12-26	1-16
Y	----- DE 10 2008 011148 A1 (NORDEX ENERGY GMBH [DE]) 8 October 2009 (2009-10-08) paragraphs [0004] - [0019], [0024] - [0029]	1-16
A	----- EP 2 189 656 A2 (VESTAS WIND SYS AS [DK]) 26 May 2010 (2010-05-26) paragraphs [0005] - [0016], [0023] - [0031] ----- -/-	1-16



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

9 May 2018

Date of mailing of the international search report

22/05/2018

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INTERNATIONAL SEARCH REPORT

International application No

PCT/DK2018/050038

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2011/131792 A2 (EWF ENERGY GROUP LTD [GB]; VAN RANST ALAIN [BE]; UG AVR LTD [MT]) 27 October 2011 (2011-10-27) the whole document -----	1-16
A	US 2013/115043 A1 (ROSENVARD PAW [DK] ET AL) 9 May 2013 (2013-05-09) the whole document -----	1-16

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/DK2018/050038

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WO 2011131792	A2	27-10-2011	NONE
US 2013115043	A1	09-05-2013	EP 2588751 A1 08-05-2013 US 2013115043 A1 09-05-2013 WO 2012000504 A1 05-01-2012