

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
20 March 2008 (20.03.2008)

PCT

(10) International Publication Number
WO 2008/031433 A1

(51) International Patent Classification:
F03D 7/02 (2006.01) **F03D 9/00** (2006.01)

(21) International Application Number:
PCT/DK2007/000404

(22) International Filing Date:
12 September 2007 (12.09.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PA 2006 01186 14 September 2006 (14.09.2006) DK

(71) Applicant (for all designated States except US): **VESTAS WIND SYSTEMS A/S** [DK/DK]; Alsvej 21, DK-8900 Randers (DK).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **NYBORG, Anders** [DK/DK]; Hans Broges Gade 8, 2. tv, DK-8000 Aarhus C (DK).

(74) Agent: **PATENTGRUPPEN A/S**; Arosgaarden, Aaboulvarden 31, DK-8000 Aarhus C (DK).

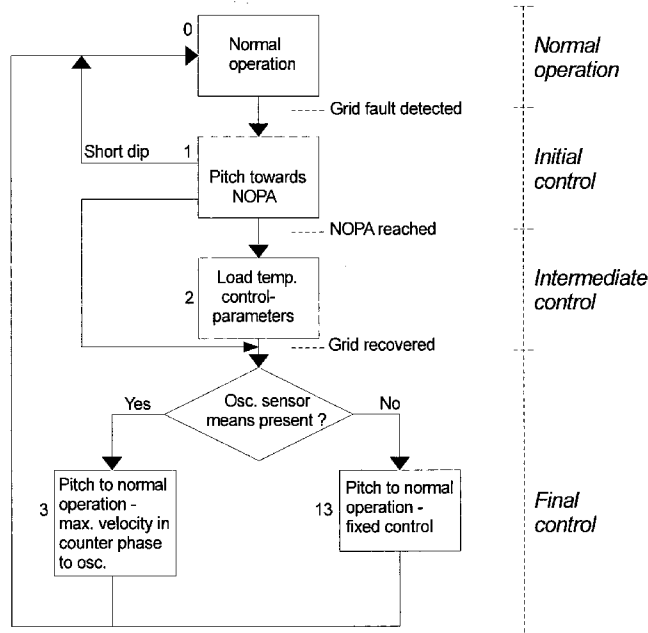
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(54) Title: METHODS FOR CONTROLLING A WIND TURBINE CONNECTED TO THE UTILITY GRID, WIND TURBINE AND WIND PARK



(57) Abstract: The invention relates to methods for controlling a wind turbine connected to the utility grid by detecting status of the utility grid, and controlling one or more rotor blades and/or emitted power to the grid when returning to the operational wind turbine settings of normal grid mode. The invention also relates to a wind turbine and a wind park comprising at least two wind turbines.

METHODS FOR CONTROLLING A WIND TURBINE CONNECTED TO THE UTILITY GRID,
WIND TURBINE AND WIND PARK.

Field of invention

- 5 The invention relates to methods for controlling a wind turbine connected to the utility grid, a wind turbine and a wind park.

Description of the related art

- 10 National utility grid companies sets out the strategies and requirements for the connection of power generation equipment to the utility grid. These connection requirements are detailed described in Grid Codes and varies from nation to nation.

- One of the topics discussed in the grid codes is the capabilities of a wind turbine when the utility grid experiences a fault. It is essential for the operation of a wind turbine and for a reliable supply of power that a wind turbine can stay connected and synchronized to the utility grid during said grid fault.
- 15

- System faults are typically short circuits and can be any combination of a three phases and earth short circuits. When a short circuit occur the flow of current results in voltage drops (low voltage situation) throughout the utility grid and the magnitude is dependent of the magnitude of the fault current, the impedance of the short circuit path and the type of short circuit. Further, a low voltage situation may comprise more than one voltage drop e.g. two successive voltage drops.
- 20

- 25 When a wind turbine experience a utility grid fault the generator speed increases almost immediately as a result of the excessive aerodynamical power that can not be converted to electrical power. Therefore the aerodynamical power must be reduced drastically throughout the period of utility grid fault.

- 30 One method of prior art is to turn the blades of the wind turbine from an operating position to a park position and allow the wind turbine generator to trip offline when

the utility grid fault occurs. But as the grid codes typically sets up requirements for a low voltage ride through (LVRT) that requires the wind turbine generator to stay connected, said method of prior art is not compatible with the grid codes.

- 5 US patent no. 6,921,985 discloses a LVRT system for a wind turbine connected to a utility grid. The blade pitch angle is varied when a low voltage is detected in order to maintain the rotor speed below an over speed trip limit.

10 It is an object of the present invention to provide advantageous methods of operating a wind turbine in returning to the operational wind turbine settings of normal grid mode.

The invention

15 The invention provides a method for controlling a wind turbine connected to the utility grid comprising steps of:

detecting status of the utility grid,

20 detecting mechanical oscillations and/or loads of the wind turbine, and

controlling one or more rotor blades and/or emitted power to the grid in dependency of said mechanical oscillations and/or loads in returning to the operational wind turbine settings of normal grid mode.

25 Hereby it is ensured that when the rotor blade or blades are pitched back to operational pitch angle settings of normal grid mode they can be controlled in such a way that the hereby caused oscillations and/or loads will not significantly add to already existing oscillations and/or loads of the wind turbine.

30 In another aspect of the invention said detecting status of the utility grid comprises detecting at least one value indicating the status of the utility grid e.g. a normal grid

mode or fault grid mode. Hereby it is ensured that the wind turbine can return to operational wind turbine settings as soon as possible after the recovery of a grid fault such as a low voltage grid fault.

- 5 In another aspect of the invention said returning to the operational wind turbine settings comprises returning to normal grid mode from a fault of the utility grid.

In another aspect of the invention returning to the operating settings of normal grid mode comprises reapplying of thrust in counter phase to said mechanical oscillations
10 and/or loads of the wind turbine e.g. the tower oscillation, rotor blade oscillation, foundation oscillation or combinations hereof.

Hereby it is ensured that oscillations and/or loads produced in the wind turbine by returning to operating settings of normal grid mode does not give cause to
15 constructive interference of said oscillations and/or loads. Constructive interference can cause excessive loads on said wind turbine that will exceed load limits and result in damage to the wind turbine.

Furthermore it is ensured that oscillations and/or loads produced in the wind turbine
20 by returning to operating settings of normal grid mode can cause destructive interference of said oscillations and/or loads, whereby said oscillations is damped.

In another aspect of the invention said mechanical oscillations and/or loads is detected by means located in the wind turbine e.g. in the tower, nacelle, rotor blades
25 and/or foundation. Hereby it is ensured that means to detect oscillations and/or loads are located in wind turbine components that is under influence of said oscillations and/or loads whereby a more accurate detection can be obtained.

In another aspect of the invention said detecting status of the utility grid comprises
30 detection of the grid voltage and/or the voltage/sec slope of an alternating utility grid

voltage. Hereby it is ensured that vital parameters are detected in order to give a valid detection of said status.

The invention also provides a method for controlling a wind turbine connected to the
5 utility grid comprising steps of:

detecting status of the utility grid, and

controlling one or more rotor blades and/or emitted power to the grid in dependency
10 of a fixed control value such as constant pitch rate and/or predefined time period in returning to the operating settings of normal grid mode.

Hereby it is ensured that when the rotor blade or blades are pitched back to operational pitch angle settings of normal grid mode, the hereby caused oscillations
15 and/or loads will not significantly add to already existing oscillations and/or of the wind turbine.

In another aspect of the invention said fixed control value is substantial different from its extremes. By the term "extremes" is meant the highest and/or lowest
20 possible value of said control value. Hereby it is ensured that returning to the operating settings of normal grid mode is done by using control values that does not result in significant additional loads on the wind turbine.

In another aspect of the invention returning to the operating settings of normal grid
25 mode comprises reapplying of thrust with a constant pitch rate such as less than 10 degree/sec. preferably 8 degree/sec. and/or over a predefined time period such as more than 0,5 seconds preferably 4 seconds.

In another aspect of the invention returning to the operating settings of normal grid
30 mode comprises reapplying of thrust in dependency of the wind turbine tower

eigenfrequency. Hereby it is ensured that reapplying of thrust can be optimized to different types of tower whereby loads on said tower can be minimized.

In another aspect of the invention said detecting status of the utility grid comprises
5 detection of the grid voltage and/or the voltage/sec slope of an alternating utility grid voltage. Hereby it is ensured that vital parameters are detected in order to give a valid detection of said status.

The invention also relates to a wind turbine connected to a utility grid comprising:
10 at least one blade pitch system to control the pitch of one or more rotor blades, and at least one wind turbine control system including a system performing a method according to one or more of the preceding claims in returning to the operating settings of normal grid mode .

15 Hereby it is ensured that the wind turbine is controlled with control values that are adapted to the specific operating situation when returning from a grid fault mode to a normal grid mode.

Even further the invention relates to a wind turbine further comprising at least one
20 detector for detecting failures in the utility grid e.g. at least one voltage detector. Hereby an advantageous control of the wind turbine is ensured.

The invention also relates to a wind park comprising at least two wind turbines according to the wind turbine claim and at least one detector for detecting failures in
25 the utility grid.

Figures

The invention will be described in the following with reference to the figures in which

30

fig. 1 illustrates a large modern wind turbine including three wind turbine blades in the wind turbine rotor,

- fig. 2 illustrates schematically a preferred embodiment of a wind turbine with a control system for controlling the pitch angles of the wind turbine blades,
- 5 fig. 3 illustrates the conceptual state-sequence for the present invention
- fig. 4 illustrates two of at least three conditions that must be met in order to detect a utility grid fault event,
- 10 fig. 5 illustrates the conditions that must be met in order to detect that the utility grid has recovered,
- fig. 6 illustrates a timing diagram for one preferred embodiment of the invention
- 15 fig. 7 illustrates a timing diagram for another preferred embodiment of the invention

20 Detailed description

Fig. 1 illustrates a modern wind turbine 1 with a tower 2 and a wind turbine nacelle 3 positioned on top of the tower.

The wind turbine rotor, comprising at least one blade such as three wind turbine blades 5 as illustrated, is connected to the hub 4 through pitch mechanisms 4a. Each pitch mechanism includes a blade bearing and pitch actuating means which allows the blade to pitch. The pitch process is controlled by a pitch controller.

As illustrated in the figure, wind over a certain level will activate the rotor and allow it to rotate in a perpendicular direction to the wind. The rotation movement is

30

converted to electric power which usually is supplied to the utility grid as will be known by skilled persons within the area.

Fig. 2 illustrates schematically one preferred embodiment of a control system for
5 controlling the pitch angles of the wind turbine blades

Data of the wind turbine 1 are measured with sensor means 7 such as pitch position sensors, blade load sensors, rotor azimuth sensors, tower acceleration sensors etc.

The measured sensor data are supplied to computing means 8 in order to convert the
10 data to feedback signals. The feedback signals are used in various control systems e.g. the pitch control system 9 for controlling the pitch angle by establishing control values for controlling said at least one wind turbine blade 5.

The computing means 8 preferably includes a microprocessor and computer storage
15 means for continuous control of the said feedback signal.

As indicated by the dashed arrows at the nacelle 3 the wind turbine tower 2 can oscillate resulting in a displacement of said nacelle 3. As will be known by skilled persons within the area said tower can oscillate at its eigen frequency e.g. as a result
20 of a sudden change in thrust applied to the rotor. Said oscillation can result in excessive loads on said tower and in worst case cause damage.

Figure 3 illustrates for one preferred embodiment of the invention schematically a conceptual state-sequence diagram for the invented control algorithm comprising
25 steps of:

- Normal operation (state 0)
- detecting a utility grid fault event,
- an initial control of a wind turbine 1 in order to stabilize the wind turbine
30 rotor speed with new control parameters as a response to said utility grid fault event (state 1),

- an intermediate control of the wind turbine at a stabilized level during the fault event (state 2),
- detecting a recovery of the grid, and
- a final control of the wind turbine while returning to normal operating conditions (state 3 or state 13). As indicated on the figure state 3 is entered if means for measuring values of the mechanical oscillations and/or loads are present (a preferred embodiment). State 13 is entered if said means are not present.

For one embodiment of the invention comprising a wind turbine 1 comprising sensor means for measuring values representing mechanical oscillations and/or loads of the wind turbine, a description of each state and the state switch conditions between said states is:

	State	Action in state	Switch condition (to go to next state)
	0	Normal operation	If utility grid fault detected then switch to state 1.
Initial control	1	Estimation of no acceleration pitch angle (NOPA). Pitch towards NOPA with predefined control parameters e.g. pitch velocity.	If "short dip" then switch to state 0. If grid recovery has been detected before NOPA has been reached then switch to state 2. If estimated NOPA has been reached then switch to state 2.
Intermediate control	2	If NOPA reached: Wind turbine controller is loaded with new temporary parameter settings at an rotor over speed. If NOPA not reached: Wind turbine controller is loaded with pre-defined control parameters.	If grid recovery is detected AND wind turbine oscillations and/or loads indicate that pitching in will occur in counter phase with said oscillations and/or loads then switch to state 3.
Final control	3	Pitch back to pitch angle value obtained before detected grid fault with predefined control parameters e.g. with maximal pitch rate.	If actual pitch angle value = pitch angle value obtained before detected grid fault then switch to state 0.

For another embodiment of the invention comprising wind turbine 1 without sensor means for measuring values representing the wind turbine mechanical oscillations and/or loads, a description of each state and the state switch conditions between said states is:

5

	State	Description	Switch condition (to go to next state)
	0	Normal operation	If utility grid fault detected then switch to state 1.
Initial control	1	Estimation of no acceleration pitch angle (NOPA). Pitch towards NOPA with predefined control parameters e.g. pitch velocity.	If "short dip" then switch to state 0. If grid recovery has been detected before NOPA has been reached then switch to state 2. If estimated NOPA has been reached then switch to state 2.
Intermediate control	2	If NOPA reached: Wind turbine controller is loaded with new temporary parameter settings at a rotor over speed. If NOPA not reached: Wind turbine controller is loaded with pre-defined control parameters.	If grid recovery is detected then switch to state 13.
Final control	13	Pitch back to pitch value obtained before detected grid fault with predefined control parameters e.g. fixed pitch rate.	If actual pitch angle value = pitch angle value obtained before detected grid fault then switch to state 0.

Common for both embodiments are states 0, 1 and 2:

State 0:

10 The mode of normal operation.

If the generated power by the wind turbine is below a predefined limit such as 25% of nominal power, said fault mode will not be initiated upon detecting a grid fault, as the normal control algorithm will be able to avoid over speeding of the rotor during

said grid fault event and will continue operating in normal mode since there is no imminent danger due to the low power in the wind.

State 1 (initial control):

When a grid fault has been detected said state 1 is entered. The basis of this state of
5 the invented control algorithm is to pitch one or more wind turbine rotor blades 5 out of the wind immediately after a fault on the utility grid is detected in order to avoid over speeding of the rotor due to excessive aerodynamically power acting on said rotor.

10 For one embodiment of the invention the wind turbine rotor blades 5 are pitched to a no acceleration pitch angle (NOPA) which is defined to be the pitch angle that gives equilibrium between aerodynamically power and any wind turbine losses and electrical generated power, hence giving no or substantially no acceleration of the generator. For one embodiment NOPA is calculated immediately after the grid fault
15 is detected by table lookup in a C_p -table. For another embodiment NOPA is established by calculation e.g. with a mathematical algorithm.

For one embodiment of the invention if the grid fault is sufficiently short (a short dip) to have only a low impact on the turbine load, a short dip situation is detected
20 and it is preferred to obtain normal operation and active power production as before said short dip as soon as possible. Consequently for this embodiment the invented algorithm is able to determine the level of significant loads on the turbine and on that basis determine if the grid fault control sequence can be quitted or it needs to be completed.

25

For another embodiment of the invention where the grid fault lasts too long to be detected as a said short dip but a grid recovery occurs before NOPA is reached, it is preferred to obtain normal operation and active power production as before the grid fault as soon as possible. For this situation a direct jump to normal operation mode
30 would have a too high impact on the wind turbine. Consequently for this

embodiment the invented algorithm jumps directly to state 2 where predefined control parameters are re-obtained as explained below.

5 A good indicator of how much the turbine has been affected, is how much said aerodynamical thrust has been reduced. Pitch angle, tower acceleration, tower load, time or combinations hereof can be fair assumptions herefore. For the example of pitch angle as said indicator, to determine when to use said short dip control strategy or to continue the grid fault control strategy to the next state, said algorithm continuously supervises how far the actual pitch angle is from the recent pitch angle before the
10 grid fault. Consequently if a grid recovery is detected and the difference between the actual pitch angle and a recent pitch angle immediately before said grid fault exceed a certain predefined level, said control algorithm will continue the grid fault control algorithm. Otherwise the grid fault control algorithm will be terminated as fast as possible by returning to state 0 i.e. setting the references for e.g. pitch angle, power
15 and generator rpm to the settings immediately before detecting said grid fault.

State 2 (intermediate control):

The basis of this state of the invented control algorithm is to keep the wind turbine operating within a defined range controllable by the wind turbine controller and
20 connected to the utility grid until the grid has recovered.

For one embodiment when NOPA is reached, wind turbine control is initialized with the present control settings as reference e.g. generator rpm and pitch angle, in order to keep the generator rpm constant or nearly constant at a level above the nominal
25 speed.

For one embodiment where pitching out has been stopped due to detected grid recovery before reaching said NOPA, said state 2 is initiated and predefined control parameters are re-obtained.

30

The control sequence stays in this state with the present control settings at least until recovery of the utility grid has been detected.

For one preferred embodiment, when means for measuring values representing the
5 wind turbine mechanical oscillations and/or loads are present, a switch to the next
state (state 3) can be initiated when pitching in the rotor blades will occur in counter
phase to the mechanical oscillations and/or loads of the wind turbine e.g. oscillations
resulting from a tower acceleration. I.e. pitching said rotor blades will be done in
10 such a way that the oscillations and/or loads that will be generated by pitching said
rotor blades back to normal operation is controlled and generated in counter phase to
the existing oscillations and/or loads causing a dampening of the summarized
oscillations and/or loads.

For another preferred embodiment, when means for measuring values representing
15 the wind turbine mechanical oscillations and/or loads are not present, said switching
to the next state (state 13) can be initiated as soon as recovery of the utility grid has
been detected.

State 3: (final control - if sensor means for measuring mechanical wind turbine
20 oscillations and/or loads are present).

In order to return to normal production, reapplying of thrust is necessary by pitching
the rotor blades back to their operation position.

As an example of this preferred embodiment, the alternating aerodynamic torque
25 under which the tower has been influenced caused by the sudden drop in thrust when
pitching out to NOPA (state 1), the tower will oscillate with its eigenfrequency when
the grid fault has recovered resulting in excessive physical loads on the wind turbine
components, especially the tower construction.

30 For this example a switch to state 3 has been initiated when the tower acceleration
signal is within a predefined window regarding amplitude and direction.

The pitch angle is ramped back in towards normal production pitch angle with a maximum pitch velocity. Said pitch angle can e.g. be the value as before the detected grid fault event or if conditions has changed during the grid fault event, a new
 5 desired pitch angle. Hereby it is achieved that a maximal dampening of said tower oscillation is obtained as well as the rotor speed is decreased towards the rotor speed before the grid fault event.

State 13: (final control - if sensor means for measuring wind turbine oscillations
 10 and/or loads are not present).

In order to return to normal production reapplying of thrust is necessary by pitching the rotor blades back to their operation position i.e. the pitch value obtained before detecting a grid fault with predefined control parameters e.g. fixed pitch rate.
 15

As an example of this preferred embodiment the slope of the pitch rate can be calculated as:

$$\text{Pitchrate} = \frac{(\theta_{\text{actual}} - \theta_{\text{predip}})}{\text{Trampback}}$$

20

where

θ_{actual} = is the actual pitch angle

θ_{predip} = is the pitch angle before the grid fault event or, if conditions has
 changed during the fault event, a new desired pitch angle.

25 Trampback = a predefined ramp back time

In one embodiment the *Trampback* must be defined to be longer than one period of the wind turbine tower eigenfrequency in order not to cause positive interference on the tower oscillation when ramping back i.e. for a wind turbine tower with an eigen-

frequency of e.g. 0,5 Hz the *Tramback* must be defined to be longer than 2 seconds such as up to 4 seconds.

In another embodiment for another type of tower with an eigenfrequency of e.g. 1 Hz
5 the *Tramback* must be defined to be longer than 1 second such as 1,5 seconds.

For an embodiment of a wind turbine tower wherein the tower is very rigid e.g. a short tower the *Tramback* may be chosen to a shorter period of time than a taller and more flexible tower such as the above mentioned embodiments.

10

Figure 4 illustrates for one embodiment of the invention conditions that are to be met for the detection of said grid fault event and thereby initiation of a safety mode where the wind turbine is controlled by the invented grid fault control algorithm.

15 Firstly (not illustrated) the recent generated power must be higher than a predefined limit. If the generated power is less, the normal control algorithm will be able to avoid over speeding or the rotor during a grid fault event and the wind turbine will continue operating in normal mode since there is no imminent danger for e.g. over speeding of the rotor due to the low power in the wind.

20

Secondly the slope of the grid voltage drop 10 must be higher than a predefined slope limit 11. The slope limit is defined by the operating range of the normal wind turbine controller and its ability to adapt to alternating grid voltages in order to keep control and avoid over speeding of the rotor.

25

Thirdly the voltage drop must be of a certain predefined size i.e. the grid voltage must drop to below a threshold value $U_{\text{threshold}}$ 12.

If said three conditions are met the grid voltage is within the crossed area 15 meaning
30 that a utility grid fault is detected and said grid fault control algorithm is initiated.

Figure 5 illustrates for one embodiment of the invention conditions that are to be met for the detection of a grid recovery and thereby allowing the control algorithm to proceed towards normal operation.

- 5 Firstly if the grid voltage rises above a predefined low voltage limit for normal operation $U_{\text{threshold}}$ 12 the turbine may obtain normal operation.

Otherwise the turbine may obtain normal operation if the grid voltage rises a predefined amount $U_{\text{grid,add}}$ above the present low voltage level $U_{\text{grid,minimum}}$ during the
10 grid fault AND the voltage is a certain predefined amount $U_{\text{converter,add}}$ above the limit $U_{\text{converter,minimum}}$ where the wind turbine converter is able to produce active power.

If said conditions are met the grid voltage is within the crossed area 14 meaning that the grid has recovered and said grid fault control algorithm is allowed to proceed
15 towards normal production.

Figure 6 illustrates schematically one embodiment of the invention, where sensor means for measuring tower acceleration is present, a simplified timing diagram showing the relation between control states, pitch angle, tower acceleration, tower
20 displacement and generator rpm during a grid fault.

State 0:

The pitch angle, tower acceleration, tower displacement and generator rpm. are ideal constant during normal operation.

25

State 1:

When a utility grid fault is detected 15 the wind turbine rotor blade or blades are pitched towards NOPA 16. The hereby sudden change in aerodynamical thrust is reflected by a tower acceleration and displacement 17, 18. Furthermore the generator
30 rpm is increased due to an excessive amount of aerodynamical power 19.

State 2:

When said pitch angle reaches NOPA 20, yet another opposite directed change in thrust occurs and the tower will start oscillating at its eigen frequency 21, 22. The generator rpm is here stabilized at an over speed level 23 as there now is a balance
5 between incoming aerodynamic power and generated power.

State 3:

The rotor blade or blades are pitched back to operational settings 24 when a grid recovery has been detected and for this embodiment state 3 is entered when said
10 tower acceleration goes negative 25 i.e. reapplying of aerodynamical thrust is in counter phase to the tower acceleration. The result is damped tower acceleration 26 when returning to normal operating mode (state 0), producing only a damped tower displacement 27 whereby loads on the tower has been reduced. Furthermore the generator rpm is decreased 28 ideal to the level as before entering said grid fault
15 mode 29.

Figure 7 illustrates schematically one embodiment of the invention, where sensor means for measuring mechanical oscillations and/or loads are not present, a simplified timing diagram showing the relation between control states, pitch angle,
20 tower acceleration and generator rpm. during a grid fault.

The description for states 0, 1 and 2 are same for this embodiment as described for figure 6 and will not be repeated here.

25 State 13:

The rotor blade or blades are pitched back to operational settings 30 with predefined control parameters e.g. *Tramback*. For this embodiment state 13 is entered immediately after grid recovery has been detected. The pitch rate is chosen to be of a value that does not result in significant further excessive mechanical oscillations e.g.
30 tower acceleration 31, 32.

The result is a tower acceleration 31, 32 when returning to normal operating mode (state 0), producing a tower displacement 33 whereby loads on the tower are kept within allowable limits. Furthermore the generator rpm is decreased 34 ideal to the level as before entering said grid fault mode 29.

5

The invention described has been exemplified above with reference to specific examples of control algorithms for a wind turbine during LVRT. However, it should be understood that the invention is not limited to the particular examples but may be designed and altered in a multitude of varieties within the scope of the invention as
10 specified in the claims e.g. with use of other algorithm states or measured/detected/established/estimated values.

Reference list

In the drawings the following reference numbers refer to:

- | | | |
|----|-----|---|
| 5 | 1. | Wind turbine or wind turbine system |
| | 2. | Wind turbine tower |
| | 3. | Wind turbine nacelle |
| | 4. | Low speed shaft |
| | 4a. | Pitch mechanisms |
| 10 | 5 | Wind turbine rotor blade |
| | 6 | Wind turbine rotor blade rotation |
| | 7 | Sensor means |
| | 8 | Computing means |
| | 9 | Pitch control system |
| 15 | 10 | Slope of voltage drop (Slope) |
| | 11 | Predefined slope limit (SlopeLim) |
| | 12 | Predefined $U_{\text{threshold}}$ |
| | 13 | Area for initialization of grid fault control algorithm |
| | 14 | Area for grid recovery |
| 20 | 15 | Grid fault detection |
| | 16 | State 1 pitch angle towards NOPA |
| | 17 | State 1 tower acceleration |
| | 18 | State 1 tower displacement |
| | 19 | State 1 generator rpm |
| 25 | 20 | NOPA |
| | 21 | State 2 tower acceleration |
| | 22 | State 2 tower displacement |
| | 23 | State 2 generator rpm – over speed level |
| | 24 | State 3 pitch angle back to operational setting |
| 30 | 25 | State 2 tower acceleration crosses 0 |

- 26 State 0 damped tower acceleration
- 27 State 0 damped tower displacement
- 28 State 3 generator rpm – decreasing
- 29 State 0 generator rpm
- 5 30 State 13 predefined pitch rate
- 31 State 13 tower acceleration
- 32 State 0 tower acceleration
- 33 State 0 tower displacement
- 34 State 13 generator rpm

Claims:

1. Method for controlling a wind turbine connected to the utility grid comprising steps of:

5

detecting status of the utility grid,

detecting mechanical oscillations and/or loads of the wind turbine, and

10 controlling one or more rotor blades and/or emitted power to the grid in dependency of said mechanical oscillations and/or loads in returning to the operational wind turbine settings of normal grid mode.

2. Method according to claim 1 wherein said detecting status of the utility grid
15 comprises detecting at least one value indicating the status of the utility grid e.g. a normal grid mode or fault grid mode, such as low voltage grid fault.

3. Method according to claims 1 or 2 wherein said returning to the operational wind turbine settings comprises returning to normal grid mode from a fault of the utility
20 grid.

4. Method according to any of claims 1 to 3 wherein returning to the operating settings of normal grid mode comprises reapplying of thrust in counter phase to said mechanical oscillations and/or loads of the wind turbine e.g. the tower oscillation,
25 rotor blade oscillation, foundation oscillation or combinations hereof.

5. Method according to any of claims 1 to 4 wherein said mechanical oscillations and/or loads are detected by means located in the wind turbine e.g. in the tower, nacelle, rotor blades and/or foundation.

30

6. Method according to any of claims 1 to 5, wherein said detecting status of the utility grid comprises detection of the grid voltage and/or the voltage/sec slope of an alternating utility grid voltage.
- 5 7. Method for controlling a wind turbine connected to the utility grid comprising steps of:
- detecting status of the utility grid, and
- 10 controlling one or more rotor blades and/or emitted power to the grid in dependency of a fixed control value such as constant pitch rate and/or predefined time period in returning to the operating settings of normal grid mode.
8. Method according to claim 7 wherein said fixed control value is substantial
- 15 different from its extremes.
9. Method according to claim 7 or 8 wherein returning to the operating settings of normal grid mode comprises reapplying of thrust with a constant pitch rate such as less than 10 degree/sec. preferably 8 degree/sec. and/or over a predefined time period
- 20 such as more than 0,5 seconds preferably 4 seconds.
10. Method according to claim 7, 8 or 9 wherein returning to the operating settings of normal grid mode comprises reapplying of thrust in dependency of the wind turbine tower eigenfrequency.
- 25 11. Method according to claim 7 wherein said detecting status of the utility grid comprises detection of the grid voltage and/or the voltage/sec slope of an alternating utility grid voltage.
- 30 12. Wind turbine connected to a utility grid comprising:

at least one blade pitch system to control the pitch of one or more rotor blades, and

at least one wind turbine control system including a system performing a method according to one or more of the preceding claims in returning to the operating
5 settings of normal grid mode.

13. Wind turbine according to claim 12, further comprising:

at least one detector for detecting failures in the utility grid e.g. at least one voltage
10 detector.

14. A wind park comprising

at least two wind turbines according to claim 11 and
15

at least one detector for detecting failures in the utility grid.

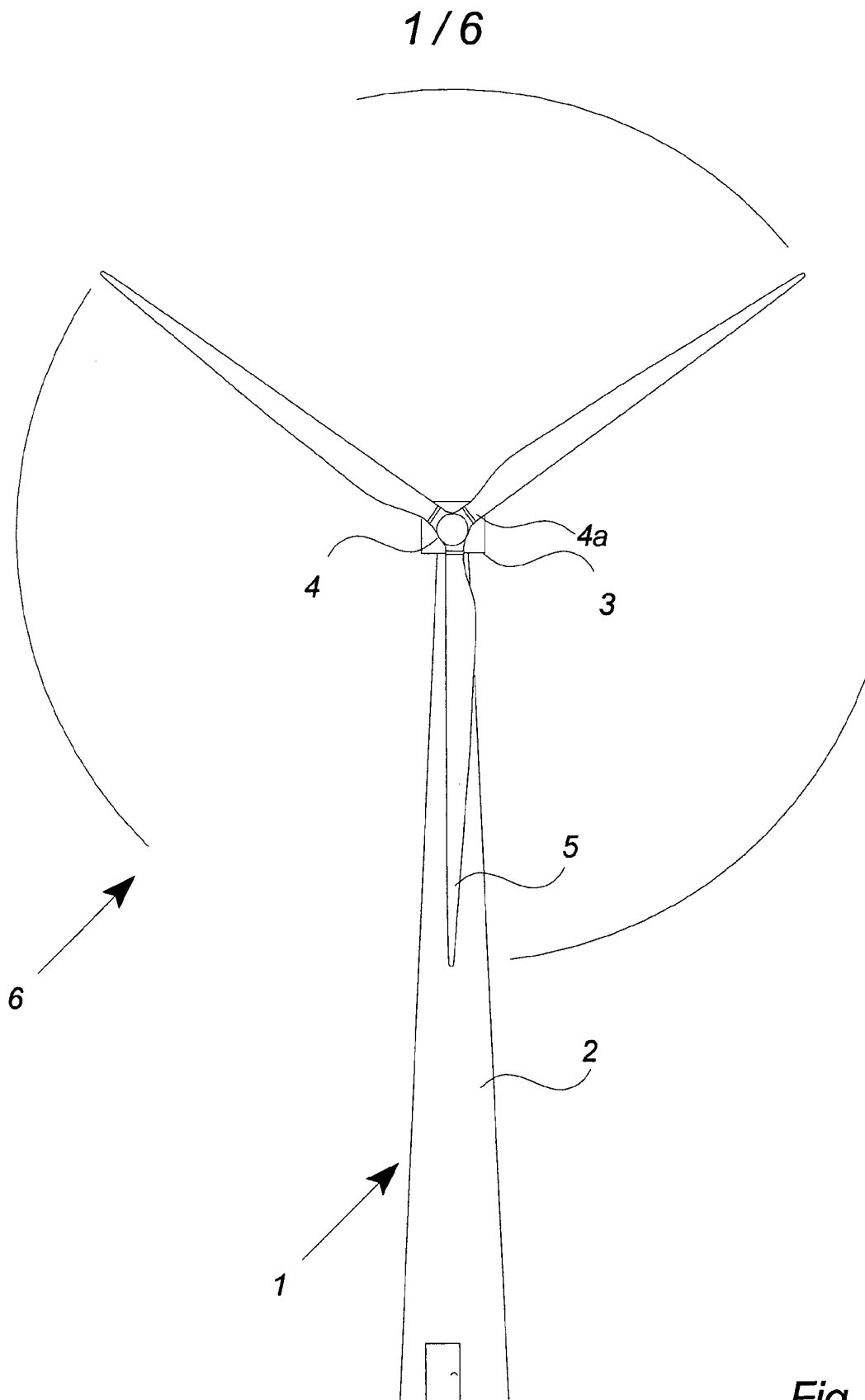
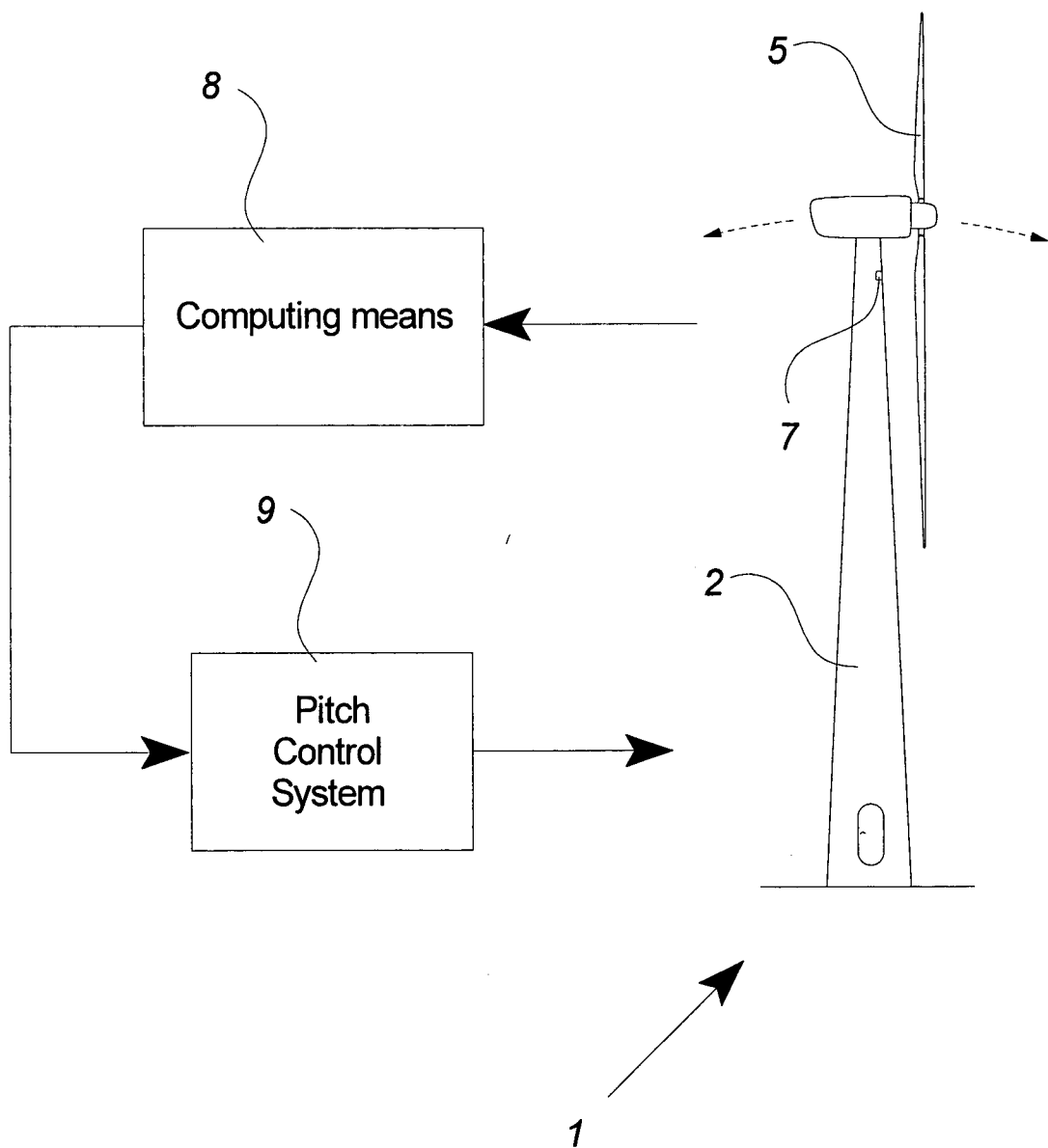


Fig. 1

2/6

*Fig. 2*

3/6

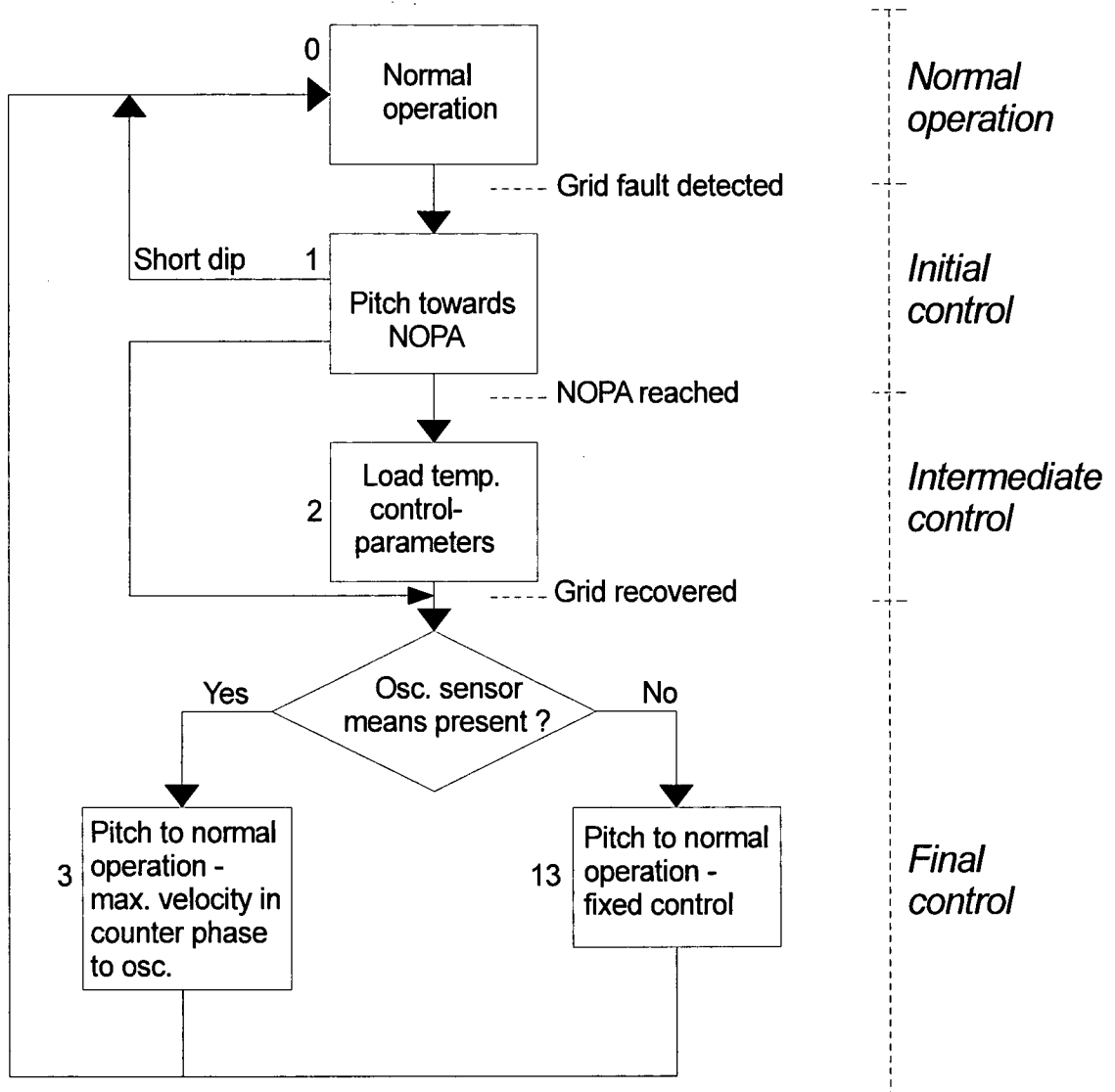


Fig. 3

4 / 6

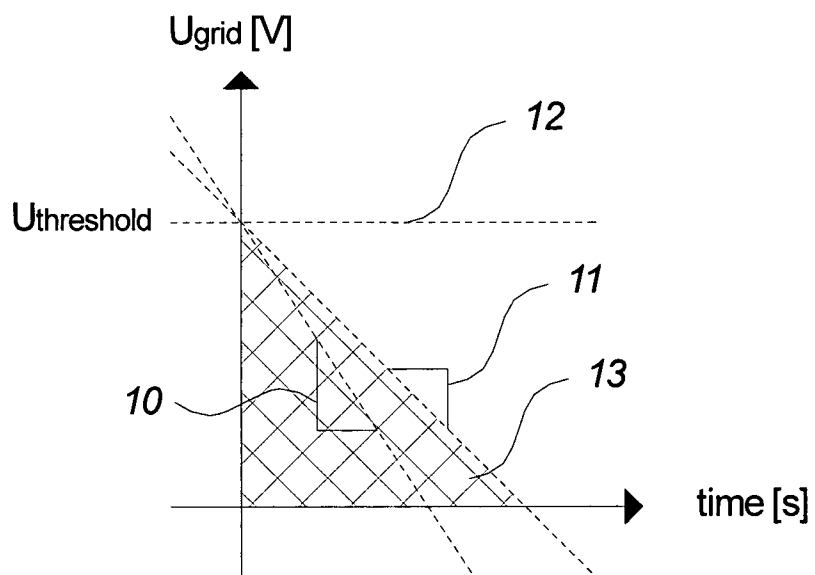


Fig. 4

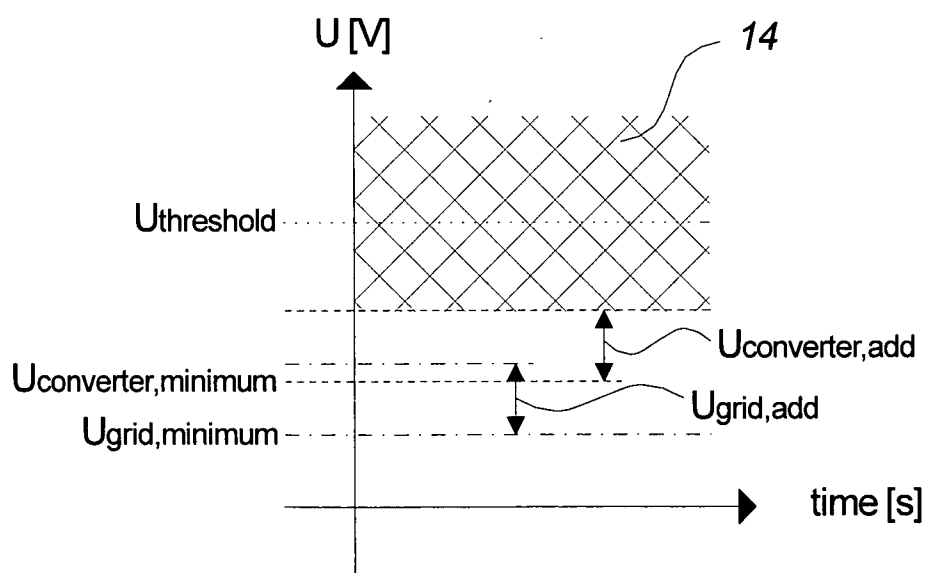


Fig. 5

5/6

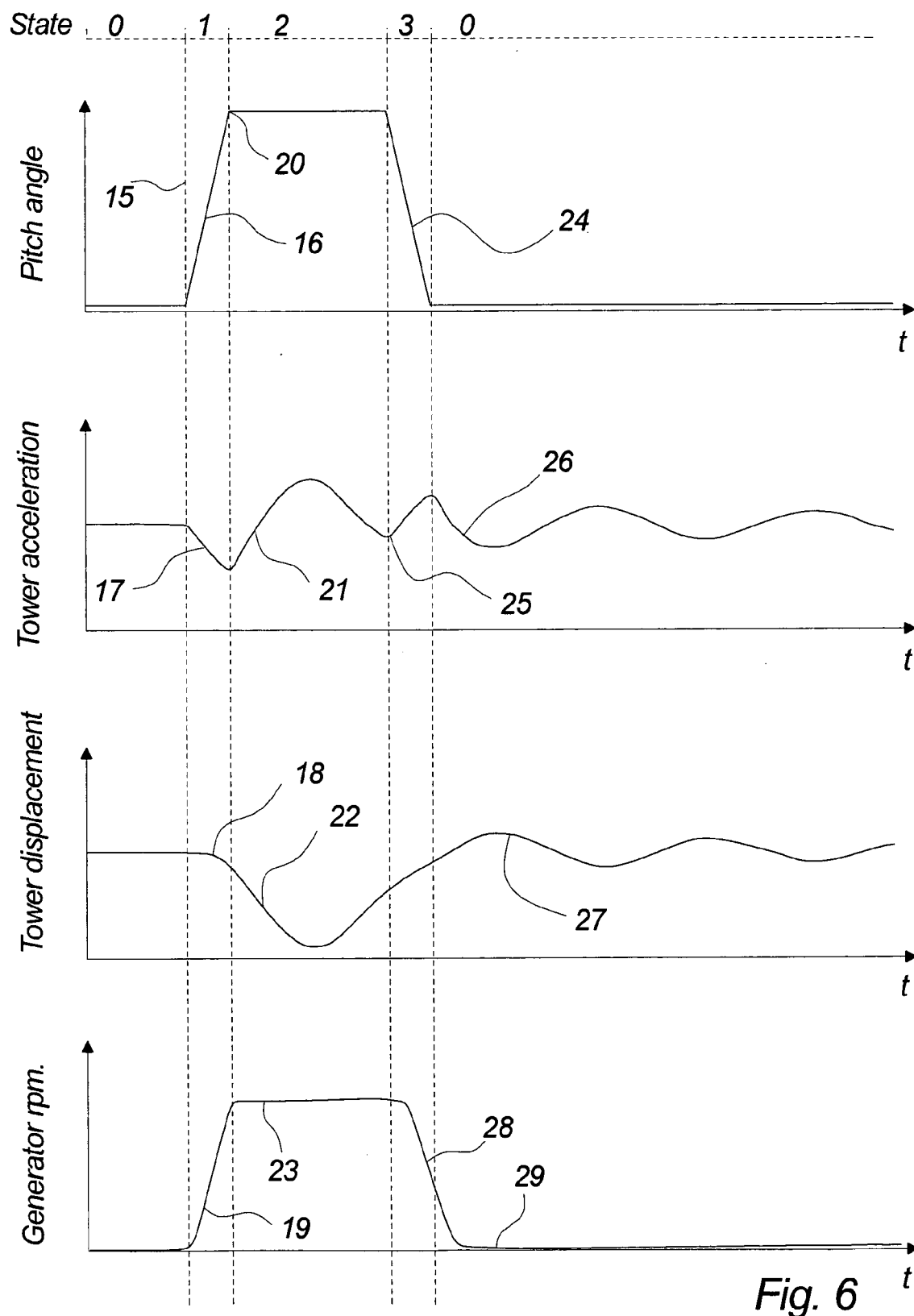
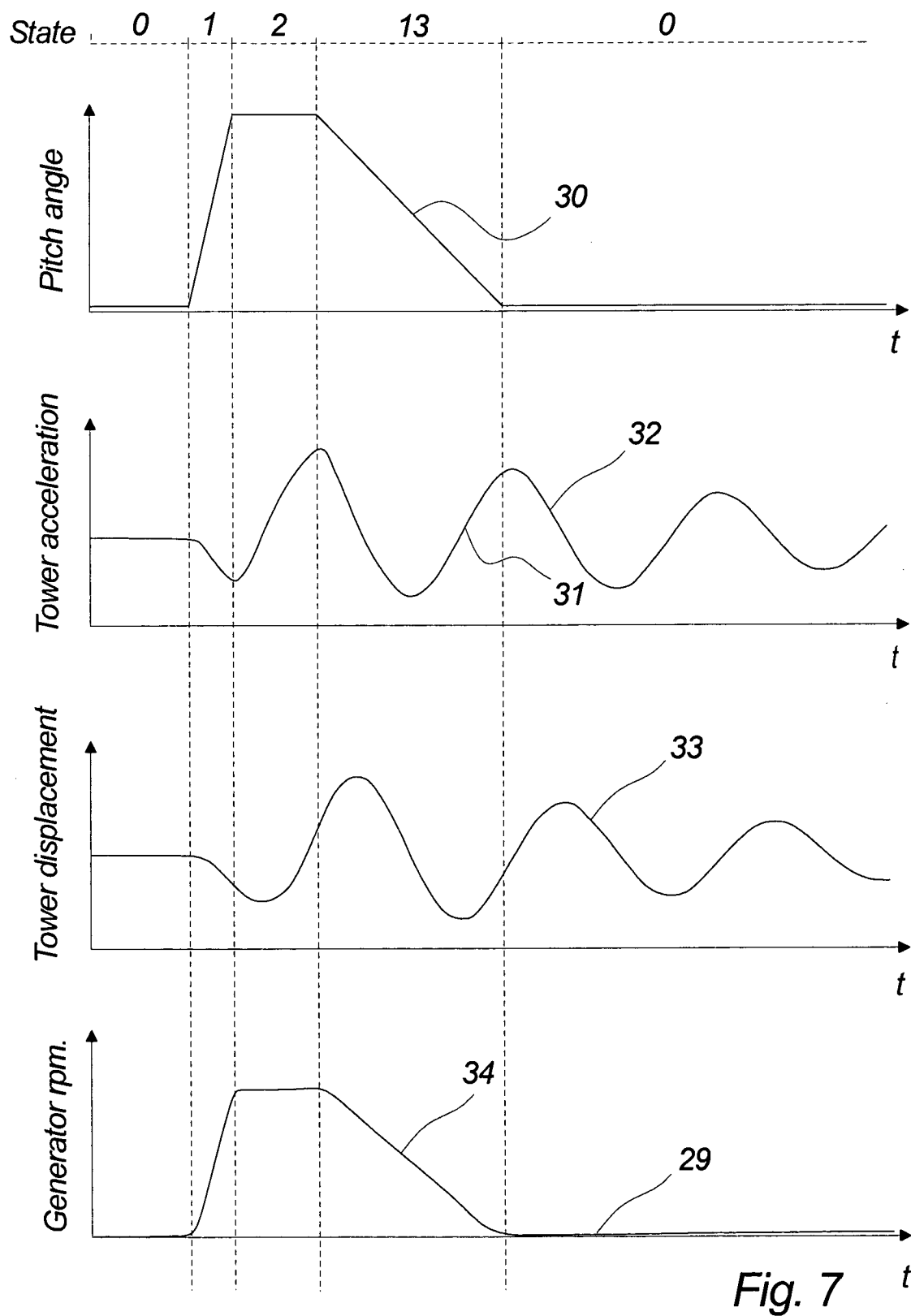


Fig. 6

6/6



INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2007/000404

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D7/02 F03D9/00

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2004/145188 A1 (JANSSEN WILHELM [DE] ET AL) 29 July 2004 (2004-07-29) column 2, lines 35-49 column 4, lines 20-28 column 6, lines 5-49	1-14
Y	GB 2 117 933 A (UNITED TECHNOLOGIES CORP) 19 October 1983 (1983-10-19) abstract page 1, lines 4-8 page 2, lines 5-58	1-14

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

A document defining the general state of the art which is not considered to be of particular relevance

E earlier document but published on or after the international filing date

L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

O document referring to an oral disclosure, use, exhibition or other means

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.

G document member of the same patent family

Date of the actual completion of the international search

31 January 2008

Date of mailing of the international search report

07/02/2008

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Souris, Christophe

INTERNATIONAL SEARCH REPORT

International application No

PCT/DK2007/000404

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	BOSSANYI E A: "INDIVIDUAL BLADE PITCH CONTROL FOR LOAD REDUCTION" WIND ENERGY, WILEY, CHICHESTER, GB, vol. 6, 8 October 2002 (2002-10-08), pages 119-128, XP008031928 ISSN: 1099-1824 the whole document	1-14
P,X	----- EP 1 788 237 A (GEN ELECTRIC [US]) 23 May 2007 (2007-05-23) the whole document	1-14
A	----- WO 2005/015012 A (VESTAS WIND SYS AS [DK]; REBSDORF ANDERS VARMINING [DK]; JENSEN MICHAEL) 17 February 2005 (2005-02-17) abstract the whole document	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/DK2007/000404

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004145188 A1	29-07-2004	AU 2004208135 A1 BR 0406712 A CA 2514264 A1 CN 1754042 A EP 1590567 A1 WO 2004067958 A1	12-08-2004 20-12-2005 12-08-2004 29-03-2006 02-11-2005 12-08-2004
GB 2117933 A	19-10-1983	AR 241661 A1 AU 552912 B2 AU 1247983 A BR 8301455 A CA 1186776 A1 DE 3308566 A1 DK 136583 A ES 8403200 A1 FI 831030 A FR 2524571 A1 IN 158212 A1 IT 1163197 B JP 58178884 A NL 8301058 A NO 830944 A SE 451872 B SE 8301551 A US 4420692 A ZA 8301631 A	30-10-1992 26-06-1986 06-10-1983 29-11-1983 07-05-1985 13-10-1983 03-10-1983 01-06-1984 03-10-1983 07-10-1983 27-09-1986 08-04-1987 19-10-1983 01-11-1983 03-10-1983 02-11-1987 03-10-1983 13-12-1983 30-11-1983
EP 1788237 A	23-05-2007	CN 1966973 A US 2007116572 A1	23-05-2007 24-05-2007
WO 2005015012 A	17-02-2005	AU 2003250314 A1 CA 2531770 A1 CN 1820142 A DE 60310143 T2 DK 1651865 T3 EP 1651865 A1 ES 2276170 T3 JP 2007506887 T	25-02-2005 17-02-2005 16-08-2006 20-09-2007 02-04-2007 03-05-2006 16-06-2007 22-03-2007