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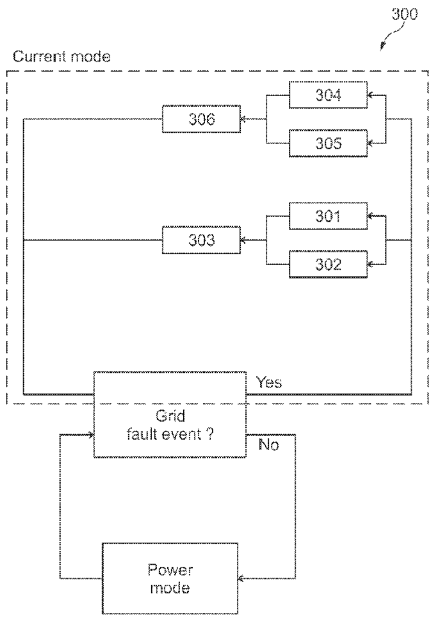

Fig. 3

(57) Abstract: Aspects of the present invention relate to a method for controlling an amount of power to be delivered from a wind turbine generator to a power grid during an abnormal power grid event, the method comprising the steps of detecting an abnormal power grid event; controlling an active current delivered to the power grid in response to a measured or determined total active current; and controlling a reactive current delivered to the power grid in response to a measured or determined total reactive current. Aspects of the present invention further relate to a computer program product for carrying out the method as well as a wind turbine generator being capable of carrying out embodiments of the invention.

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OPERATING A WIND TURBINE GENERATOR DURING AN ABNORMAL GRID EVENT

TECHNICAL FIELD

Aspects of the present invention relate to a wind turbine generator and a method for controlling an amount of power to be delivered from a wind turbine generator to a power grid during an abnormal power grid event.

BACKGROUND OF THE INVENTION

During an abnormal power grid event, it may be advantageous to maintain delivery of both active and reactive power to the power grid. In order to comply with this, the power producing units, such as wind turbine generators, coupled to the power grid should remain connected thereto.

DESCRIPTION OF ASPECTS OF THE INVENTION

During normal power grid conditions, wind turbine generators are typically operated in a so-called power mode. Upon detection of an abnormal power grid event the power mode operation is typically disabled and replaced by a so-called current mode operation.

In known arrangements, the current mode operation is implemented by delivering active and reactive currents to the power grid in a feed-forward implementation, i.e. in an open control loop implementation. It is well established that control systems which have only feed-forward behavior respond to input/control signals in a pre-defined manner without responding to how the loads on the control systems react. This may be disadvantageous when implemented for a control system of a doubly-fed induction generator (DFIG), e.g., where the rotor current references are to be set accurately.

It may be seen as an object of embodiments of the present invention to provide a method and a wind turbine generator that facilitate that a more accurate rotor current reference may be provided during an abnormal power grid event.

The above-mentioned object is complied with by providing, in a first aspect, a method for controlling an amount of power to be delivered from a wind turbine generator to a power grid during an abnormal power grid event, the method comprising the steps of

1) detecting an abnormal power grid event;

2) controlling an active current delivered to the power grid in response to a measured or determined total active current; and

3) controlling a reactive current delivered to the power grid in response to a measured or determined total reactive current.

In the present disclosure the abnormal power grid event may involve a voltage change on the power grid, such as in connection with a low-voltage ride through (LVRT) event, an under-voltage ride through (UVRT) event, an over-voltage ride through (OVRT) event or a high-voltage ride through (HVRT) event, where the wind turbine generator remains connected to the power grid in order to support the power grid during the abnormal power grid event.

The step of the detecting that an abnormal power grid event has occurred may involve detection of a grid voltage change. In case of an LVRT or a UVRT event, the grid voltage may in principle drop to any voltage level between 0 and 100% of the nominal grid voltage level. In case of an OVRT or an HVRT event, the grid voltage may in principle take any voltage level above the nominal grid voltage level.

The voltage change may be measured using one or more software controlled voltage sensors connected to one or more phases.

The duration of an abnormal power grid event may typically vary from a fraction of a second to perhaps several minutes depending on the type of abnormality.. Before and after an abnormal power grid event the wind turbine generator may be operated in a power mode, whereas during the abnormal power grid events, such as an LVRT, an UVRT, an OVRT or an HVRT event, the wind turbine generator is operated according to embodiments of the method according to the present invention.

The measured or determined total active current and the measured or determined total reactive current may comprise respective active and reactive current contributions from both the stator and rotor currents of a generator of the wind turbine generator.

When an abnormal power grid event has been detected the method may further comprise the step of enabling an active current regulator and a reactive current regulator. The active current regulator as well as the reactive current regulator may form part of respective outer closed control loops where the measured or determined total active current and the measured or determined total reactive current may form the respective feedback signals.

The active and reactive current regulators may in principle be any kind of regulators, including PI, PD, PID regulators or combinations thereof.

In the outer closed control loop for active current control the measured or determined total active current may be subtracted from an active current reference so as to form an input signal to the active current regulator. Similarly, in the outer closed control loop for reactive current control the measured or determined total reactive current is subtracted from a reactive current reference so as to form an input signal to the reactive current regulator.

The active current regulator may provide an active rotor reference signal that may form at least a portion of a control signal to an active current rotor controller which may form part of an inner closed control loop for active current control. In the inner closed control loop for active current control a measured or determined active rotor current may be subtracted from the active rotor reference signal provided by the active current regulator so as to form an input signal to the active current rotor controller.

Similarly, the reactive current regulator may provide a reactive rotor reference signal that may form at least a portion of a control signal to a reactive current rotor controller which may form part of an inner closed control loop for reactive current control. In the inner closed control loop for reactive current control a measured or determined reactive rotor current may be subtracted from the reactive rotor reference signal provided by the reactive current regulator so as to form an input signal to the reactive current rotor controller.

The active current rotor controller may be arranged to generate a q-axis rotor voltage, whereas the reactive current rotor controller may be adapted to generate a d-axis rotor voltage.

Embodiments of the method according to the present invention may further comprise the step of disabling the active and reactive current regulators when then abnormal power grid event is no longer present. With the disabling of the active and reactive current regulators the wind turbine generator may return to power operation.

The generator of the wind turbine generator may be a doubly-fed induction generator (DFIG). However, other types of generators may be applicable as well.

In a second aspect, the present invention relates to a computer program product directly loadable into the internal memory of at least one digital computer, said computer program product comprising software code portions for carrying out the steps of the method according to the first aspect when said computer program product is run on the at least one digital computer.

In a third aspect, the present invention relates to a wind turbine generator comprising a power controller for controlling an amount of power to be delivered to a power grid during an abnormal power grid event, the power controller comprising

1) a detector for detecting an abnormal power grid event;

2) a first closed control loop for controlling an active current delivered to the power grid; and

3) a second closed control loop for controlling a reactive current delivered to the power grid.

Again, the abnormal power grid event may involve a voltage drop on the power grid, such as in connection with an LVRT, an UVRT, an OVRT or an HVRT event, where the wind turbine generator remains connected to the power grid in order to support the power grid during the abnormal power grid event. The generator of the wind turbine generator may comprise DFIG.

The detector for detecting that an abnormal power grid event has occurred may involve one or more software controlled voltage sensors capable of detecting when the grid voltage changes.. In case of an LVRT or a UVRT event the grid voltage may in principle drop to any voltage level between 0 and 100% of the nominal grid voltage level. In case of an OVRT or an HVRT event the grid voltage may in principle take any voltage level above the nominal grid voltage level. The voltage changes may be detected in one or more phases.

As previously addresses the duration of an abnormal power grid event may typically vary from a fraction of a second to several minutes. Before and after an abnormal power grid event the wind turbine generator may be operated in a power mode, whereas during the abnormal power grid events, such as an LVRT, an UVRT, an OVRT or an HVRT event, the wind turbine generator is operated according to embodiments of the method of the first aspect of the present invention.

The first closed control loop may comprise an outer active closed control loop comprising an active current regulator, and an inner active closed control loop comprising an active current rotor controller, and wherein the active current regulator provides at least a portion of a control signal to the active current rotor controller. As part of the outer active closed control loop a measured or determined total active current may be subtracted from an active current reference so as to form an input signal to the active current regulator. As part of the inner active closed control loop a measured or determined active rotor current may be subtracted from an active rotor reference provided by the active current regulator so as to form an input signal to the active current rotor controller.

Similarly, the second closed control loop may comprise an outer reactive closed control loop comprising a reactive current regulator, and an inner reactive closed control loop comprising a reactive current rotor controller, and wherein the reactive current regulator provides at least a portion of a control signal to the reactive current rotor controller. As part of the outer reactive closed control loop a measured or determined total reactive current may be subtracted from a reactive current reference so as to form an input signal to the reactive current regulator. As part of the inner reactive closed control loop a measured or determined reactive rotor current may be subtracted from a reactive rotor reference provided by the reactive current regulator so as to form an input signal to the reactive current rotor controller.

BRIEF DESCRITPION OF THE DRAWINGS

The present invention will now be described in further details by way of embodiments and with reference to the accompanying figures, wherein

Fig. 1 schematically shows a wind turbine generator applying a doubly-fed induction generator,

Fig. 2 schematically shows closed control loops for controlling the active and reactive currents during an abnormal power grid event, and

Fig. 3 shows a flow-chart schematically illustrating the method according to aspects of the present invention.

While the invention is susceptible to various modifications and alternative forms specific embodiments have been shown by way of examples in the drawings and will be described in details herein. It should be understood, however, that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE EMBODIMENTS

An aspect of the present invention relates to a method for operating a wind turbine generator during an abnormal power grid event, such as during a power grid voltage change including an LVRT event, an UVRT event, an OVRT event or an HVRT event. When an abnormal power grid event is detected the operation of the wind turbine generator is shifted from a power mode to a current mode. After the abnormal power grid event operation is resumed in power mode.

Referring now to Fig. 1 a wind turbine generator 100 involving a DFIG 104 is depicted. As seen in Fig. 1 the rotor 106 of the DFIG 104 is coupled to a set of rotor blades 102 via an optional gearbox 103. The rotor blades 102 rotate in response to incoming wind power 101. The DFIG 104 is adapted to deliver power to the power grid 112 via an optional grid transformer 111 via two three phase branches 113, 114 and 115. In the latter of the two three phase branches 115 power is delivered from the stator 105 of the DFIG 104 to the optional grid transformer 111. The other of the two three phase branches 113, 114 further comprises a frequency power converter involving a rotor-side AC/DC inverter 107 and a grid-side DC/AC inverter 108 being separated by an intermediate DC link 109. The rotor-side AC/DC inverter 107 and the grid-side DC/AC inverter 108 is controlled by a power controller 110. Power may flow in both directions in the three phase branches 113, 114.

During normal operation the wind turbine generator 100 is typically operated in a so-called power mode where the amount of active and reactive power to be delivered to the power grid 112 is set by respective active and reactive power references.

As addressed above the abnormal power grid event may involve an LVRT, an UVRT, an OVRT or an HVRT event. In case of an LVRT or a UVRT event, the grid voltage may in principle drop to any voltage level between 0 and 100% of the nominal grid voltage level. In case of an OVRT or an HVRT event, the grid voltage may in principle take any voltage level above the nominal grid voltage level. When an abnormal power grid event has been detected the power mode is disabled and the wind turbine generator is reconfigured to be operable in a so-called total current mode. This implies that two current control loops – one active current control loop and one reactive current control loop - are established, cf. Fig. 2.

Referring now to Fig. 2 two closed control loops 200 are depicted. The upper closed control loop controls the d-axis rotor voltage 204 and thereby the reactive rotor current, whereas the lower closed control loop controls the q-axis rotor voltage 211 and thereby the active rotor current. Referring now to the upper reactive control loop a reactive current reference I_{Qref} is provided to the left. This reactive current reference is compared to a total reactive current 205 being provided by the stator of the DFIG 207 and the grid-side inverter (not shown). The difference between the reactive current reference, I_{Qref}, and the measured or determined total reactive current 205 is provided to the regulator 201 (reactive current regulator) which generates a reactive rotor reference 203. The reactive rotor reference 203 is compared to a measured or determined reactive rotor current 206 and the difference between them is provided to the regulator 202 (reactive current rotor controller) which generates the d-axis rotor voltage 204. Referring now to the lower active control loop an active current reference I_{Pref} is provided to the left. This active current reference is compared to a total active current 212 being provided by the stator of the DFIG 214 and the grid-side inverter (not shown). The difference between the active current reference, I_{Pref}, and the measured or determined total active current 212 is provided to the regulator 208 (active current regulator) which generates an active rotor reference 210. The active rotor reference 210 is compared to a measured or determined active rotor current 213 and the difference between them is provided to the regulator 209 (active current rotor controller) which generates the q-axis rotor voltage 211. The regulators 201, 202, 208 and 209 may in principle be of any type, such as for example PI, PD or PID. Thus, during the abnormal power grid event the DFIG 207, 214 is controlled in a closed loop current configuration where current input references I_{Qref} and I_{Pref} are provided for the reactive and active current loops, respectively. When the abnormal power grid event has terminated the power mode of the wind turbine generator is reinstated.

In Fig. 3 a flow-chart 300 illustrating aspects of the method according to the present invention is depicted. As depicted in Fig. 3 if no abnormal power grid event is detected, i.e. if no grid fault is detected, the wind turbine generator is operated in a power mode. On the contrary, if an abnormal power grid event is detected the wind turbine generator is operated in a current mode. In the current mode the total active DFIG current 301 as well as the active rotor current 302 are measured, or determined, and a resulting q-axis rotor voltage 303 is generated. Similarly, the total reactive DFIG current 304 as well as the reactive rotor current 305 are measured, or determined, and a resulting d-axis rotor voltage 303 is generates. The generated q-axis and d-axis rotor voltages 303, 306 are provided to the DFIG as long as the abnormal power grid event is present. The method illustrated in Fig. 3 may be implemented using variable means, such as a pure software implementation.

CLAIMS

1. A method for controlling an amount of power to be delivered from a wind turbine generator to a power grid during an abnormal power grid event, the method comprising the steps of

1) detecting an abnormal power grid event;

2) controlling an active current delivered to the power grid in response to a measured or determined total active current; and

3) controlling a reactive current delivered to the power grid in response to a measured or determined total reactive current.

2. A method according to claim 1, wherein the abnormal power grid event involves a voltage change on the power grid.

3. A method according to claim 1 or 2, wherein the measured or determined total active current and the measured or determined total reactive current comprise respective active and reactive current contributions from both stator and rotor currents of an electrical generator of the wind turbine generator.

4. A method according to any of claims 1-3, further comprising the step of enabling an active current regulator and a reactive current regulator.

5. A method according to claim 4, wherein the measured or determined total active current is subtracted from an active current reference so as to form an input signal to the active current regulator.

6. A method according to claim 5, wherein the active current regulator provides at least a portion of a control signal to an active current rotor controller.

7. A method according to any of claims 4-6, wherein the measured or determined total reactive current is subtracted from a reactive current reference so as to form an input signal to the reactive current regulator.

8. A method according to claim 7, wherein the reactive current regulator provides at least a portion of a control signal to a reactive current rotor controller.

9. A method according to any of claims 4 to 8, further comprising the step of disabling the active and reactive current regulators when the abnormal power grid event is no longer present.

10. A method according to any of the preceding claims, wherein the wind turbine generator comprises a doubly-fed induction generator.

11. A computer program product directly loadable into the internal memory of at least one digital computer, said computer program product comprising software code portions for carrying out the steps of the method according to any of the preceding claims when said computer program product is run on the at least one digital computer.

12. A wind turbine generator comprising a power controller for controlling an amount of power to be delivered to a power grid during an abnormal power grid event, the power controller comprising

1) a detector for detecting an abnormal power grid event;

2) a first closed control loop for controlling an active current delivered to the power grid; and

3) a second closed control loop for controlling a reactive current delivered to the power grid.

13. A wind turbine generator according to claim 12, wherein the first closed control loop comprises

1) an outer active closed control loop comprising an active current regulator, and
2) an inner active closed control loop comprising an active current rotor controller

wherein the active current regulator provides at least a portion of a control signal to the active current rotor controller.

14. A wind turbine generator according to claim 13, wherein a measured or determined total active current is subtracted from an active current reference so as to form an input signal to the active current regulator.

15. A wind turbine generator according to any of claims 12-14, wherein the second closed control loop comprises

1) an outer reactive closed control loop comprising a reactive current regulator, and
2) an inner reactive closed control loop comprising an reactive current rotor controller

wherein the reactive current regulator provides at least a portion of a control signal to the reactive current rotor controller.

16. A wind turbine generator according to claim 15, wherein a measured or determined total reactive current is subtracted from a reactive current reference so as to form an input signal to the reactive current regulator.

17. A wind turbine generator according to any of claims 12-16, wherein the wind turbine generator comprises a doubly-fed induction generator.

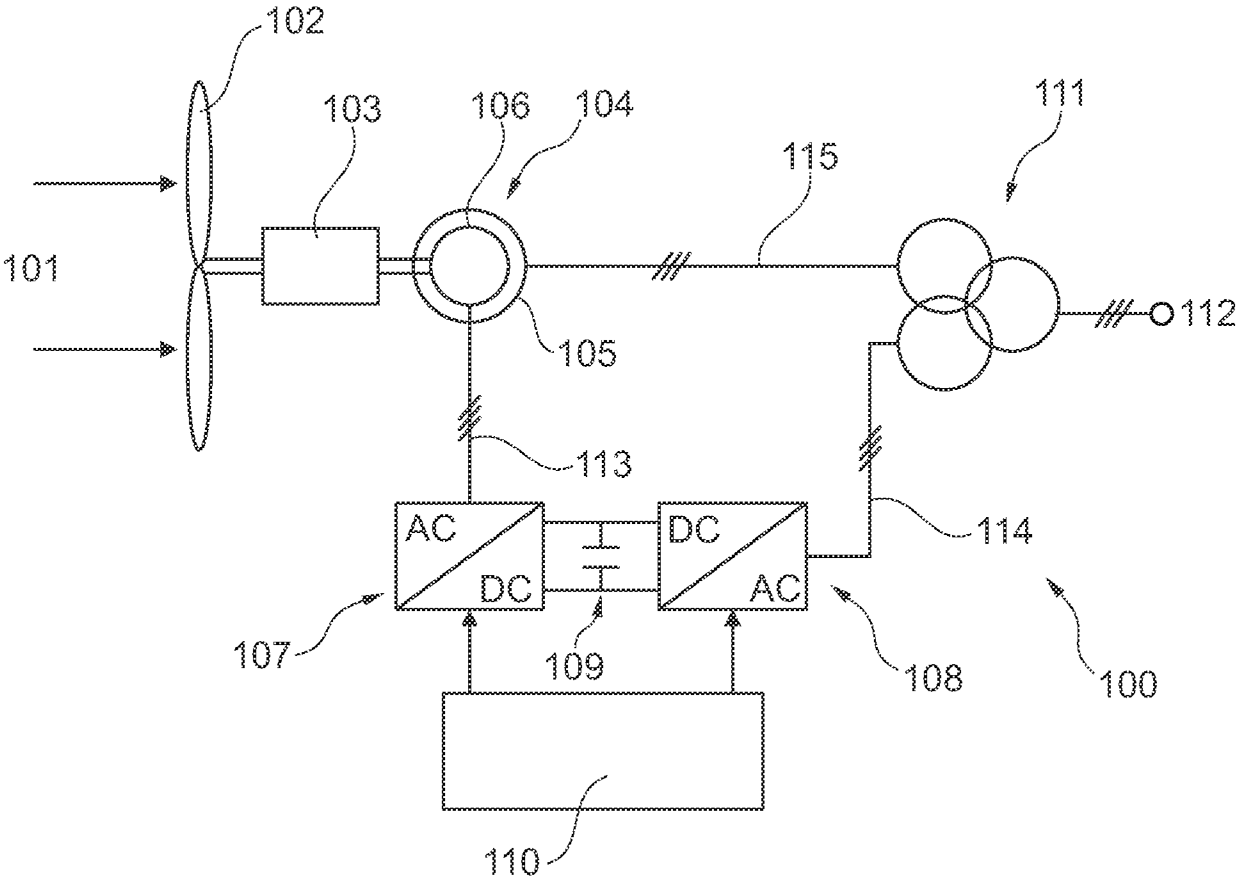
102
103
106
104
111
115
101
112
105
113
AC
DC
DC
AC
114
107
109
108
100
110

Fig. 1

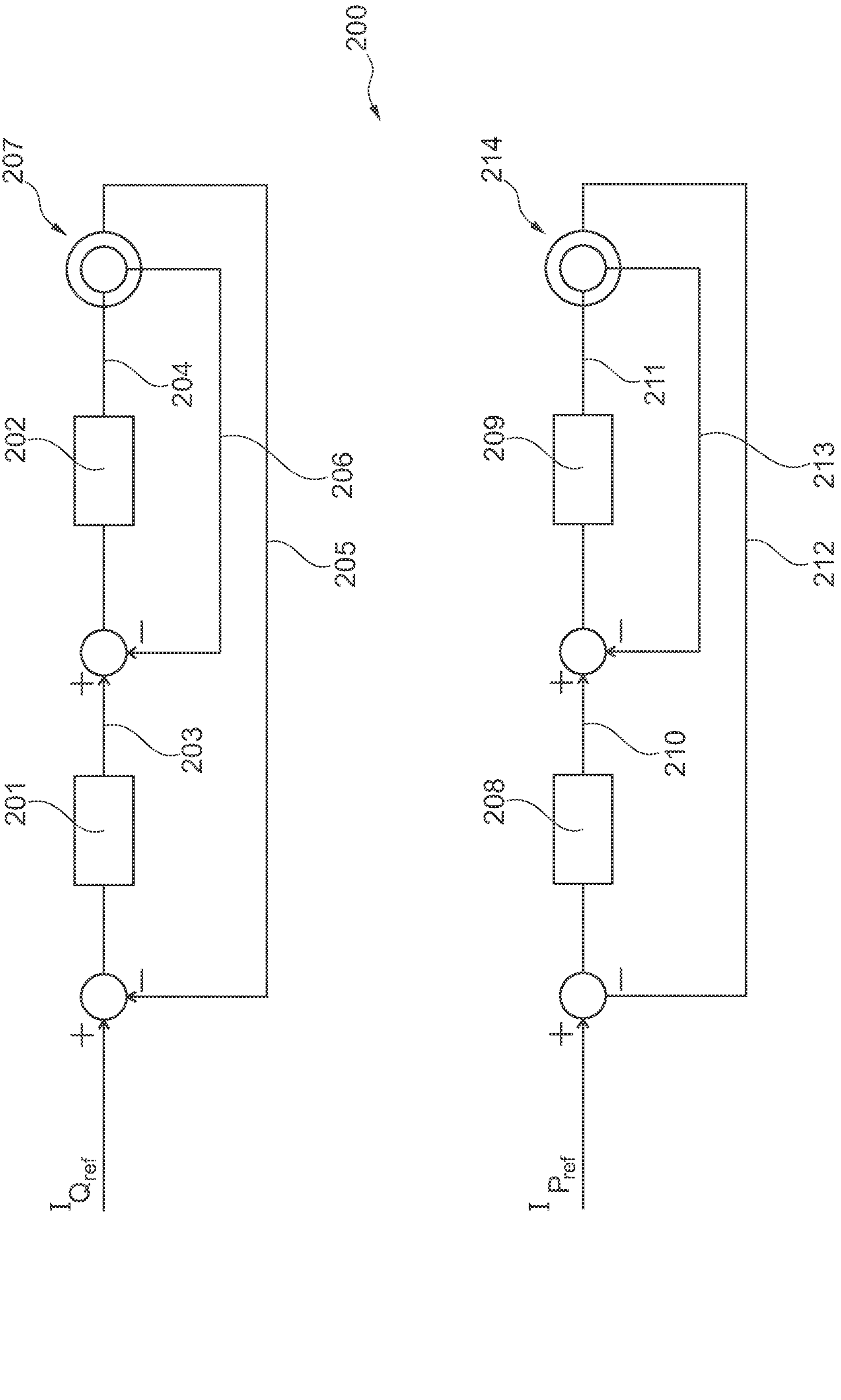
200
207
214
201
202
203
204
205
206
208
209
210
211
212
213
$I_{Q_{ref}}$
$I_{P_{ref}}$
+
−

Fig. 2

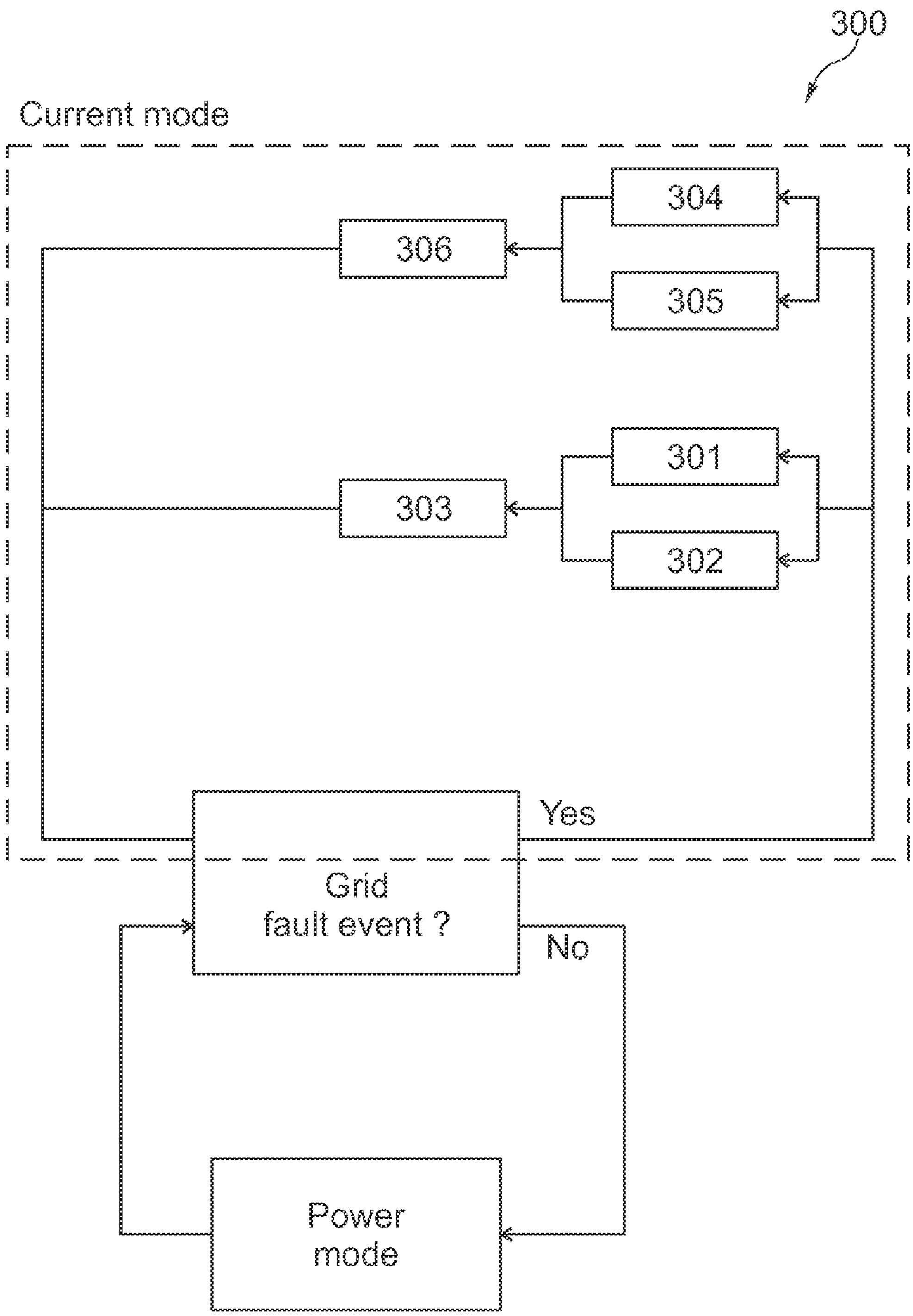
300
Current mode
304
306
305
301
303
302
Yes
Grid
fault event ?
No
Power
mode

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2017/050156

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D7/02 F03D9/25 H02P9/00 H02J3/38 F03D7/04
H02J3/00
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)
H02J F03D H02P

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	CN 102 082 543 A (UNIV TIANJIN) 1 June 2011 (2011-06-01) the whole document -----	1-17
A	CN 105 098 834 A (STATE GRID SHANDONG ELECTRIC POWER CO WEIFANG POWER SUPPLY CO; STATE G) 25 November 2015 (2015-11-25) the whole document -----	1-17
A	CN 104 362 668 A (ENG ACADEMY ARMORED FORCES PLA; STATE GRID CORP CHINA; STATE GRID XINY) 18 February 2015 (2015-02-18) the whole document ----- -/--	1-17

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2017	02/08/2017

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2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JIEFENG HU ET AL: "Control strategies of variable-speed wind system under new grid code requirement - A survey", IECON 2010 - 36TH ANNUAL CONFERENCE ON IEEE INDUSTRIAL ELECTRONICS SOCIETY, IEEE, PISCATAWAY, NJ, USA, 7 November 2010 (2010-11-07), pages 3061-3066, XP031840087, ISBN: 978-1-4244-5225-5 Sections II and IV; figure 4a -----	1-17
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2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/DK2017/050156

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CN 102082543	A	01-06-2011	NONE			
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