(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 January 2010 (28.01.2010)

PCT

(10) International Publication Number
WO 2010/010476 A1

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

(21) International Application Number:
PCT/IB2009/052947

(22) International Filing Date:
7 July 2009 (07.07.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PA 2008 01033 22 July 2008 (22.07.2008) DK
61/135,710 22 July 2008 (22.07.2008) US

(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)*: **QUOTTRUP, Michael, Melholt** [DK/DK]; Næssundvej 113, DK-9220 Aalborg Ø (DK).

(74) Agent: **BUDDE SCHOU A/S**; Vester Søgade 10, DK-1601 Copenhagen V (DK).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, 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, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, 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, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

[Continued on next page]

(54) Title: METHOD OF CONTROLLING A VARIABLE SPEED WIND TURBINE GENERATOR

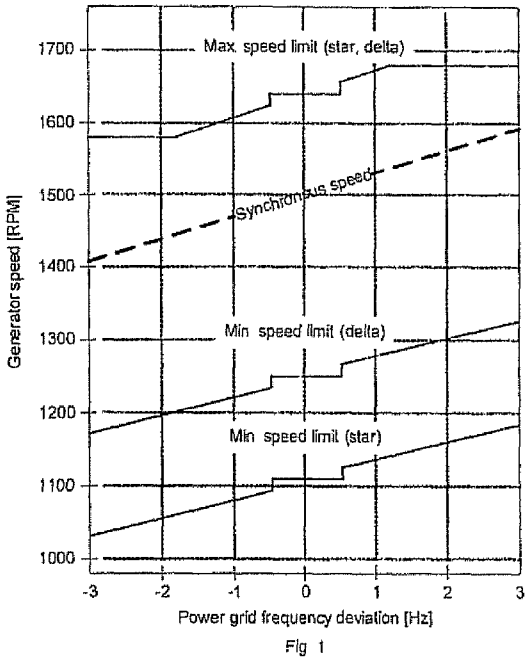


Fig 1

(57) Abstract: In a method of controlling a variable speed wind turbine generator connected to a power grid and comprising means for controlling the generator speed, said method comprises the steps of - measuring the frequency f of the power grid, - controlling the speed of the generator for optimizing the power delivered to the power grid, - setting limits for the generator speed. The setting of the limits for the generator speed is performed in dependency of the measured frequency of the power grid. This provides a dynamical set of limits providing improved possibilities of optimizing the power production.

WO 2010/010476 A1

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

METHOD OF CONTROLLING A VARIABLE SPEED WIND TURBINE GENERATOR

Technical field

The present invention relates to variable speed wind turbine generators connected to the power grid and more specifically to the control of such wind turbine generators when the power grid frequency deviates from the nominal frequency.

Background art

Typically, such wind turbines have been controlled in generator speed to deliver maximum power to the power grid and certain fixed maximum and minimum speed limits have been imposed in order to limit the load on the turbine components, e.g. the converter, drive train, generator, etc.

US 5,729,118 discloses a variable speed induction generator-motor with controllable excitation frequency, in which the slip frequency is kept constant during variations of the power grid frequency.

Disclosure of the invention

Based on this prior art it is the object of the present invention to provide a method of controlling a variable speed wind turbine generator with which it is possible to optimize the power generation by optimizing the generator speed. Preferably, the generator speed is controlled in dependency of the wind speed, and the control is performed by pitch control of the wind turbine blades. Furthermore, it is desirable to be able to set dynamical limits to the generator speed, said dynamical limits taking into account the possible variations in the power grid frequency, even at relatively large variations thereof. This object is achieved by a method of said kind, which according to the present invention also comprises the features set forth in the characterising part of claim 1. With this arrangement the limits for the speed of the generator are dynamically adapted to the frequency of the power grid, whereby the optimization of the power delivery from the generator is subjected to appropriate limits during periods of varying power grid frequencies. Preferred embodiments of the method, the

advantages of which will be evident from the following detailed description of the invention, are revealed in the subordinate claims.

Brief description of the drawings

In the following detailed part of the present description, the invention will be explained in more detail with reference to exemplary embodiments of a method according to the invention with reference to the drawing, in which

Fig. 1 schematically shows a diagram of the generator speed limits as a function of the deviation in grid frequency Δf in accordance with one preferred embodiment of the method, the deviation in grid grid frequency Δf being defined to be the measured grid frequency minus the nominal grid frequency, and

Fig. 2 schematically shows a corresponding diagram of the generator speed limit as a function of the deviation in grid frequency Δf in accordance with another preferred embodiment of the present invention.

Description of the preferred embodiments

As indicated above, the aim of the present invention is to perform a dynamic correction or adjustment of the upper and lower limits for the generator speed in accordance with deviations in the grid frequency. As indicated in the accompanying figures, such dynamical correction of the maximum and minimum speed for the generator can be performed in different intervals. As shown in Fig. 1, the maximum and minimum speed for the generator is set to fixed values, as long as the deviation from the nominal frequency is less than ± 1%, corresponding to the interval 49.5 Hz to 50.5 Hz or 59.4 Hz to 60.6 Hz, respectively, for a 50 Hz and 60 Hz nominal grid frequency, respectively. The purpose of this deadband is to avoid corrections as long as the frequency deviations are insignificant and only perform corrections when the frequency deviations are extreme.

For the 50 Hz generator, typical values for the fixed values of the upper and lower limits would be synchronous speed, e.g. 1500 rpm, plus 12% and minus 16,7%, respectively. As can be seen in Fig. 1, the upper speed limit is furthermore fixedly

limited to 1680 rpm in order to avoid overspeeding. This can be seen as the horizontal part of the upper limit above approx. 1.2 Hz deviation in grid frequency. Furthermore, as again seen in Fig. 1, this upper limit may be expanded below a deviation of approx. approx. -1.8 Hz to a generator speed of 1580 rpm. This fixation of the upper limit at approx. 1580 rpm is introduced in order to prevent the generator torque from increasing significantly at a negative deviation in the grid frequency.

For the lower speed limit, Fig. 1 indicates a constant percentage deviation from the synchronous speed calculated based on the deviating grid frequency. Thus, the lower limit, apart from the interval from 49.5 to 50.5 Hz, is limited to the calculated synchronous speed based on the deviating grid frequency minus 16.7%.

In certain types of wind turbines, it is preferred to operate the speed of the generator below synchronous speed, i.e. operating sub-synchronously, at all times. The reason for this may be different, e.g. due to the fact that the possible back-to-back converter connected between the rotor windings and the grid, can be constructed to only deliver power in one direction.

In this situation, the upper and lower speed limits for the generator may be as shown in Fig. 2, where the rotational speed of the generator is kept below the calculated synchronous speed minus 2.3% for frequency deviations between -3.6 Hz and -0.6 Hz and kept below synchronous speed -2.3% for deviations in grid frequency between -0.6 Hz and +3.6 Hz. The lower limit for the generator speed is, as also shown in Fig. 1 above, -16.7% of calculated synchronous speed for the intervals of grid frequency deviation between -6% and -1% and between +1% and +6%, and nominal synchronous speed minus 16.7% at grid frequency deviation between -1% and +1%.

The stator of the generator can be connected to the power grid in two different configurations, star and delta configuration. Different restrictions apply to both speed and power in these two configurations, and examples of this can be seen in Figs. 1 and 2, where, as typically found, the maximum speed limit will be identical for star and delta configuration, respectively, whereas the minimum speed limit will be lower for delta configuration than for star configuration, as indicated.

PATENT CLAIMS

1. Method of controlling a variable speed wind turbine generator connected to a power grid and comprising means for controlling the generator speed, said method comprising the steps of

- measuring the frequency f of the power grid,
- controlling the speed of the generator for optimizing the power delivered to the power grid,
- setting limits for the generator speed,
- wherein the setting of the limits for the generator speed is performed in dependency of the measured frequency of the power grid.

2. Method in accordance with claim 1, wherein the dependency is set as follows:

a) whenever the measured frequency is within predetermined limits, a set of normal, fixed limits for the generator speed is imposed,

b) whenever the measured frequency is outside said predetermined limits, the speed limits for the generator are adjusted relative to said fixed limits.

3. Method in accordance with claim 2, wherein the dependency, whenever the measured frequency is outside said predetermined limits, is an adjustment of the upper and lower speed limits with the same percentage as the frequency deviation Δf of the grid frequency from the nominal grid frequency.

4. Method in accordance with claim 2 or 3, wherein said predetermined limits are provided as a percentage of deviation from the nominal frequency, said percentage of deviation preferably being in the interval ± 0-6%.

5. Method in accordance with claim 4, wherein said percentage is ± 1%.

6. Method in accordance with any of the claims 2-5, wherein the set of normal, fixed limits for the generator speed are set to provide an interval surrounding the synchronous speed at nominal frequency.

7. Method in accordance with any of the claims 1-6, wherein the generator speed is further limited by a fixed maximum generator speed.

8. Method in accordance with any of the claims 1-7, wherein the generator is disconnected from the power grid whenever the grid frequency exceed predetermined limits, e.g. set as a certain percentage deviation from the nominal frequency.

9. Method in accordance with any of the claims 1-8, wherein the generator is disconnected whenever the grid frequency deviates more than a predetermined percentage from the nominal frequency.

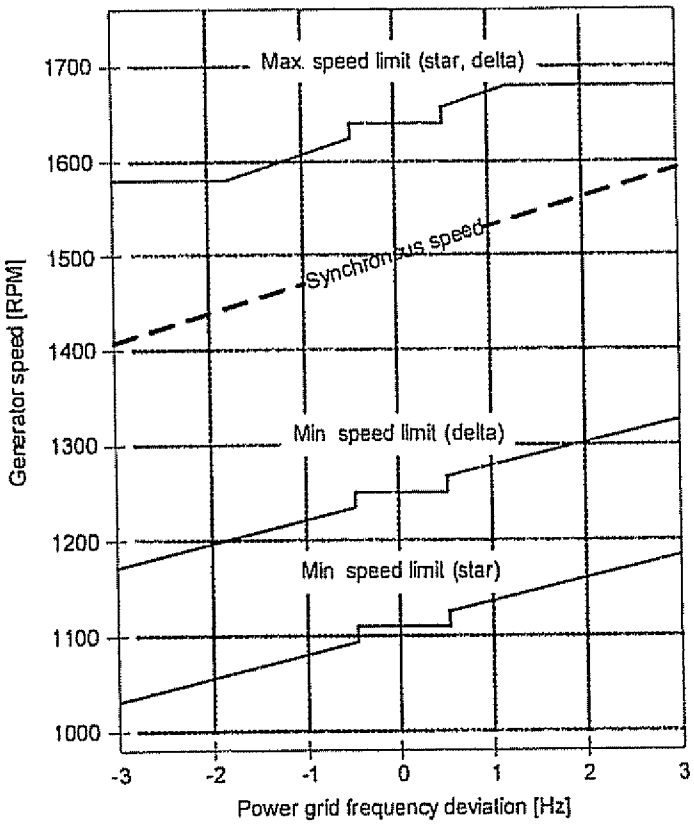

Max. speed limit (star, delta)
Synchronous speed
Min speed limit (delta)
Min speed limit (star)
Generator speed [RPM]
1700
1600
1500
1400
1300
1200
1100
1000
-3
-2
-1
0
1
2
3
Power grid frequency deviation [Hz]

Fig 1

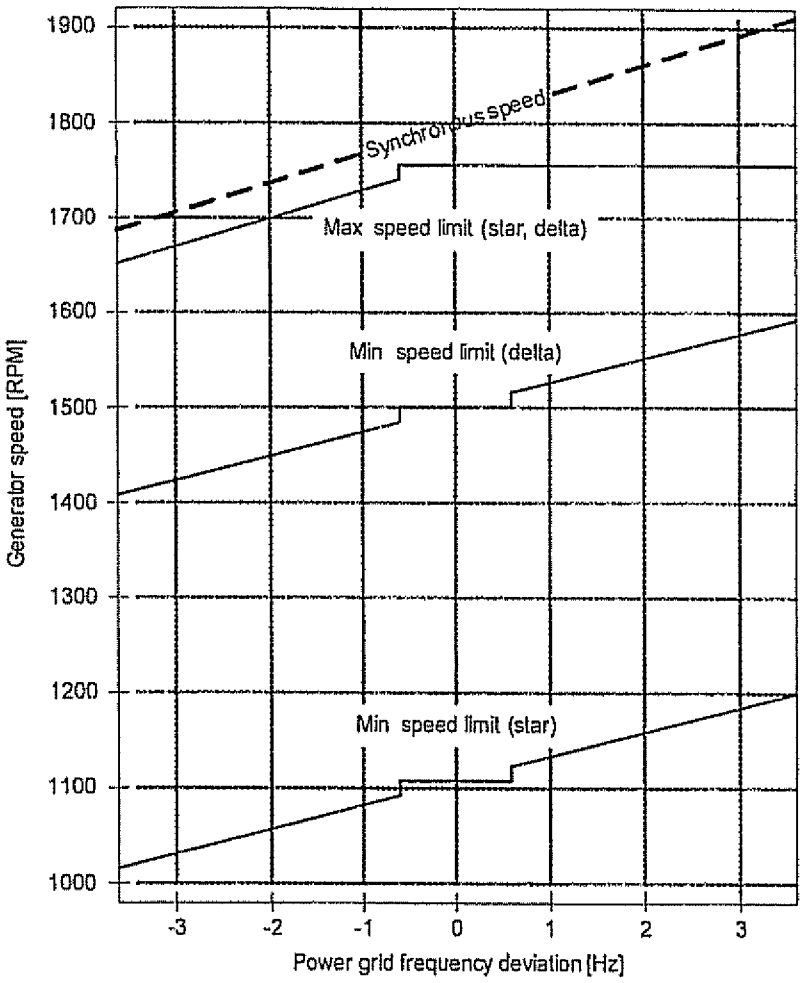

1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
Generator speed [RPM]
Synchronous speed
Max speed limit (star, delta)
Min speed limit (delta)
Min speed limit (star)
-3
-2
-1
0
1
2
3
Power grid frequency deviation [Hz]

Fig 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/052947

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D7/00 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 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 practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FELTES C ET AL: "Variable Frequency Operation of DFIG based Wind Farms connected to the Grid through VSC-HVDC Link" POWER ENGINEERING SOCIETY GENERAL MEETING, 2007. IEEE, IEEE, PI, 1 June 2007 (2007-06-01), pages 1-7, XP031118453 ISBN: 978-1-4244-1296-9 abstract page 2, paragraph 2 - page 3, paragraph 2 figures 1,7-10 Sections III, IV ----- -/--	1-9

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

[X] 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.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 December 2009	30/12/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kail, Maximilian

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/052947

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Berndt; Hermann; Kreye;Reinisch;Scherer; Vanzetta: "TransmissionCode 2007" Verband der Netzbetreiber - VDN 31 August 2007 (2007-08-31), XP002560580 Retrieved from the Internet: URL:https://www.n-ergie-netz.de/download/070801TransmissionCode_2007.pdf> [retrieved on 2009-12-14] page 24 - page 25; figure 3.4	1-9
A	Steven W. Saylors: "Meeting North American Grid Codes" Vestas Americas - North East Region Systems Operators Wind Integration Seminar 12 February 2008 (2008-02-12), XP002560579 Retrieved from the Internet: URL:http://www.weican.ca/documents/2008/080212-16-Steve%20Saylors-Technology%20Drivers%20%20NE%20Region%20Wind%20Integration%20Seminar.pdf> [retrieved on 2009-12-14] NERC Frequency & Voltage Ride-Through Proposal WECC proposed Frequency Ride-Through; page 5 - page 6	1-9
A	PARK J W ET AL: "Control of active power in a doubly-fed induction generator taking into account the rotor side apparent power" POWER ELECTRONICS SPECIALISTS CONFERENCE, 2004. PESC 04. 2004 IEEE 35T H ANNUAL AACHEN, GERMANY 20-25 JUNE 2004, PISCATAWAY, NJ, USA,IEEE, US, vol. 3, 20 June 2004 (2004-06-20), pages 2060-2064, XP010739588 ISBN: 978-0-7803-8399-9 figure 1 Section III B	1-9
A	EP 0 688 095 A2 (TOSHIBA KK [JP]) 20 December 1995 (1995-12-20) cited in the application page 8 - page 9, line 47; figures 7,8,11	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2009/052947

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0688095 A2	20-12-1995	CA 2152028 A1	18-12-1995
		CN 1126389 A	10-07-1996
		DE 69512139 D1	21-10-1999
		DE 69512139 T2	27-01-2000
		JP 2553319 B2	13-11-1996
		JP 8009692 A	12-01-1996
		US 5729118 A	17-03-1998