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(54) Title: DE-RATING A WIND TURBINE AS A FUNCTION OF WIND SPEED

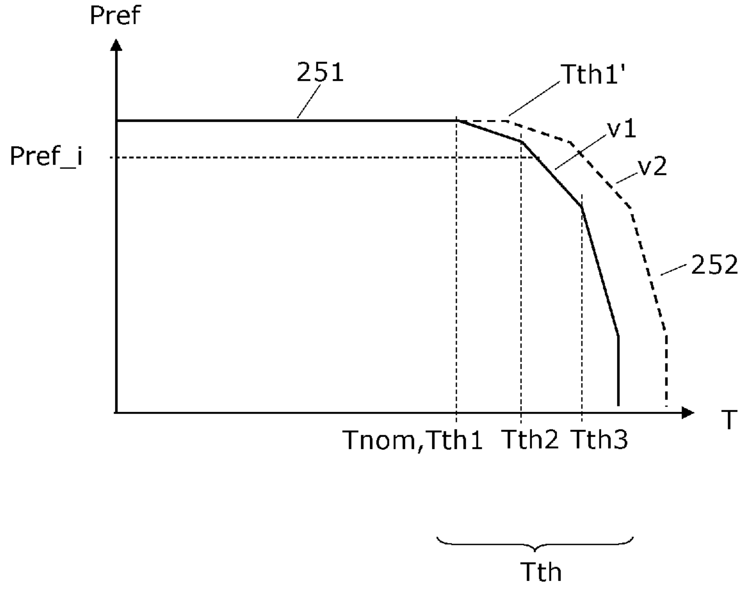

Fig. 2B

(57) Abstract: The invention relates to a method for utilizing a cooling system of a wind turbine. The method includes obtaining a temperature (T) which correlates with a nacelle temperature or a nacelle component temperature, obtaining a wind speed (v), determining a temperature threshold (Tth) of a power de-rating function 5 dependent on the wind speed, where the power de-rating function provides power references (Pref_i) as a function of the temperature and where the power references for temperatures above the temperature threshold are reduced compared to power references for temperatures below the temperature threshold, and determining a power reference (Pref) for the wind turbine based on the power 10 de-rating function and the temperature (T).

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DE-RATING A WIND TURBINE AS A FUNCTION OF WIND SPEED

FIELD OF THE INVENTION

The invention relates to methods for controlling a wind turbine, particularly to methods for de-rating wind turbines.

BACKGROUND OF THE INVENTION

Wind turbines may utilize cooling systems for cooling various components of the wind turbines, such as the power converters. Thus, by providing active cooling of such components, operation of the wind turbine may be improved. However, at high ambient temperatures, the capability of cooling system to exchange heat with the ambient surroundings is reduced and thereby the cooling of the wind turbine components. Accordingly, to prevent damages of the wind turbine components, it may be necessary to de-rate the power production of the wind turbine when the ambient temperature increases. De-rating wind turbines may imply reduced production of electric energy.

It follows that there is a need for improving wind turbine's capabilities to operate at high ambient temperatures or for improving cooling capabilities of wind turbines. Similarly, there is a need for limiting reductions in power production due to de-rating at high temperatures.

SUMMARY

It is an object of the invention to improve control of wind turbines, particularly to improve operation of wind turbines at high temperatures. It is also an object of the invention to improve the cooling of wind turbines and to improve production of electric energy at high temperatures.

In a first aspect of the invention there is provided a method for controlling a wind turbine is provided, wherein the wind turbine comprises a cooling system arranged to provide cooling of wind turbine components and to exchange heat with ambient air, and a power generating system which is controllable to generate power according to a power reference, the method comprises

- obtaining a temperature which correlates with a nacelle temperature or a nacelle component temperature,

- obtaining a wind speed,
- determining a temperature threshold of a power de-rating function dependent on the wind speed, where the power de-rating function provides power references as a function of the temperature and where the power references for temperatures above the temperature threshold are reduced compared to power references for temperatures below the temperature threshold, and
- determining the power reference based on the power de-rating function and the temperature.

Advantageously, by determining the temperature thresholds as a function of the wind speed, the increased cooling of the cooling system for increasing wind speeds and, thereby, the increased cooling of the wind turbine components can be utilized to increase the temperature thresholds for increasing wind speeds. Accordingly, it may be possible to operate the wind turbine at high temperatures without de-rating the power production or reducing the de-rating compared with solutions where the temperature thresholds are not adjusted as a function of the wind speed. Thus, the time where the wind turbine is de-rated may be reduced and, consequently, the power production may be increased.

According to an embodiment, determining the temperature threshold comprises increasing the temperature threshold to a value above a nominal temperature threshold, when the wind speed is above a nominal wind speed. The nominal temperature threshold may be threshold defined for normal operation, e.g. full load operation, for wind speeds at or above a given specified wind speed such as a nominal wind speed. Advantageously, for wind speeds above the specified wind speed, the additional wind cooling may be utilized for increasing the temperature threshold.

According to an embodiment, the temperature threshold is a function of the wind speed so that increasing wind speeds provides increasing temperature thresholds. For example, the function may be a look-up table or a mathematical function such as a stepped function, a piece-wise linear function, a monotonically increasing function or other.

According to an embodiment, the method comprises at least first and second temperature thresholds for a given value of the wind speed above the nominal wind speed. Advantageously, the de-rating function may comprise different slopes dependent on the obtained temperature relative to the different temperature thresholds, e.g. so that the slope of the de-rating is increased for increasing temperatures.

According to an embodiment, determining the temperature threshold comprises selecting the temperature threshold based on a predetermined relation between different temperature thresholds and different wind speeds.

According to an embodiment, the temperature is a temperature selected from a list comprising any of: an ambient temperature from an ambient temperature sensor of the wind turbine, a mast temperature, an ambient temperature from an ambient temperature sensor of another wind turbine, a nacelle temperature, an estimated temperature, a temperature of a wind turbine component, or a combination thereof.

A second aspect of the invention relates to control system of a wind turbine, the wind turbine comprises a cooling system arranged to provide cooling of wind turbine components and to exchange heat with ambient air, and a power generating system which is controllable to generate power according to a power reference, the control system comprises

- a de-rate controller comprising a power de-rating function arranged to provide power references as a function of a temperature and dependent on a temperature threshold, wherein the power references for temperatures above the temperature threshold are reduced compared to power references for temperatures below the temperature threshold, wherein the temperature threshold is dependent on a wind speed, and wherein the de-rate controller is arranged to determine the power reference for the power generating system from the de-rating function based on the temperature and the wind speed.

A third aspect of the invention relates to a wind turbine comprising a control system according to the second aspect.

A fourth aspect of the invention relates to computer program product comprising software code adapted to control a wind turbine when executed on a data processing system, the computer program product being adapted to perform the method according to the first aspect.

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 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

Fig. 1 shows a wind turbine,
Fig. 2A illustrates a part of a control system of the wind turbine for controlling power generation by use of a de-rating function,
Fig. 2B shows a specific implementation of the de-rating function, and
Fig. 3 shows an example of the utilization percentage of the cooling system as a function of wind speed together with a partial- and full load power curve.

DESCRIPTION OF EMBODIMENTS

Fig. 1 shows an example of a wind turbine 100 (WTG) comprising a tower 101 and a rotor 102 with at least one rotor blade 103, such as three blades. The blades 103 are connected with the hub 105 which is arranged to rotate with the blades. The rotor is connected to a nacelle 104 which is mounted on top of the tower 101 and is adapted to drive a generator situated inside the nacelle via a drive train. The rotor 102 is rotatable by action of the wind. The wind induced rotational energy of the rotor blades 103 is transferred via a shaft to the generator. Thus, the wind turbine 100 is capable of converting kinetic energy of the wind into mechanical energy by means of the rotor blades and, subsequently, into electric power by means of the generator. The generator is connected with a power converter, which comprises a generator side converter and a line side converter. The generator side converter converts the generator AC power into DC power and the grid side converter converts the DC power into an AC power for injection into the power grid via output inductors of the wind turbine 100. The generator and the power converter is part of the power generating system of the wind turbine.

The wind turbine comprises a cooling system 110 which is arranged to provide of cooling various components of the wind turbines, such as the power converter, the gear-box and the generator. The cooling system 110 may be a fluid based cooling system which circulates a cooling fluid between an external condenser or heat exchanger arranged to dissipate heat from the cooling fluid to the surroundings so that a cooled fluid can be circulated back for cooling the wind turbine components. Fig. 1 schematically illustrates an externally located heat exchanger while the internal part of the cooling system situated inside the nacelle is not illustrated.

Fig. 2A illustrates a part of a control system 200 for controlling power generation. The control system 200 of a wind turbine may further include controllers for controlling the power generation during partial and full load dependent on the wind speed which are not described in further detail herein.

The power system 201 generally illustrates a power system which can be controlled dependent on a power reference Pref so that the generated power Pgen supplied to the power grid approaches the desired power reference Pref. The power system 201 may include the generator and the power converter. The power may be controlled by controlling a pulse width modulation of the line side converter.

In addition to controlling the power system 201, the pitch of the blades 103 may be controlled via a generator speed reference ωref determined dependent on the power reference Pref so that the extracted wind energy corresponds to the power reference Pref.

The power reference Pref may be determined based on an external power reference Pext which may be provided by a central wind park controller. For example, the external power reference may be equal to the rated power of the wind turbine.

Fig. 2A shows that the control system 200 comprises a de-rating function 202. Thus, the wind turbine may be operated in a de-rated mode where the power reference is set to a reduced power reference. The de-rated mode is also referred to as a reduced power mode. Thus, the de-rated power mode refers to a situation where the wind turbine is operated to produce a reduced amount of power, i.e. a situation where the wind turbine is controlled to produce an amount of power which is reduced e.g. compared to the nominal power production of the wind turbine.

Fig. 2B shows a specific implementation of the de-rating function 202. The curve 251 gives values Pref_i for the power reference Pref as a function of the temperature T. For temperatures below a temperature threshold Tth such as a nominal temperature threshold Tnom or a first temperature threshold Tth1, the de-rating function 202 provides values which are not de-rated or reduced. The power reference values Pref_i of the curve 251 may be determined dependent on the external power reference Pext.

Thus, the power de-rating function 202 provides power references Pref_i as a function of the temperature T so that the power references Pref_i for temperatures above a given temperature threshold Tth such as the first threshold Tth1 are reduced compared to power references for temperatures below the temperature threshold Tth, Tth1.

Alternatively, the curve 251 may give a de-rating percentage, e.g. ranging between 0% and 100% of the external power reference Pext. In this case, for temperatures below the nominal temperature threshold Tnom or a first temperature threshold Tth1, the de-rating function 202 may provide de-rating percentages of 100%.

For temperatures above the first temperature threshold, Tth1, Tnom, the power reference values Pref_i provides reductions of the power reference Pref as a function of the temperature T. Accordingly, for temperatures above Tth1 or Tnom, the maximal generated power Pgen is de-rated to avoid overheating various wind turbine components.

In addition to the first temperature threshold, Tth1, Tnom, the de-rating function 202 may include further temperature thresholds Tth2, Tth3 which set thresholds for further increases in the slope of the decreasing curve 202 as a function of the temperature T.

The curve 202 may be a piece-wise linear function, a continuous function or other which may be monotonically decreasing for temperatures above the first temperature threshold Tth1, Tnom.

The determination of the power reference Pref based on the de-rating function 202 may be performed only during full load operation of the wind turbine, i.e. when the wind is above a nominal wind speed v_nom so that the wind turbine can produce a maximal power or nominal power. That is, during partial load where the wind speed is insufficient to produce the maximal power, the power losses in the wind turbine components are lower, so that less cooling is required.

The cooling efficiency of the cooling system depends on the ambient temperatures which leads to decreasing efficiencies for increasing temperatures, but the cooling efficiency also depends on the wind speed v which leads to increasing cooling efficiencies for increasing wind speeds.

Fig. 3 shows an example of a power curve 301 for a wind turbine. The power curve 301 shows that for wind speeds above the nominal wind speed v_nom, the external power reference Pext is set to the maximal nominal power Pn. For wind speeds below the nominal wind speed v_nom, the external power reference Pext is set according to the available wind energy. For temperatures T above the first temperature threshold Tth1, the power curve 301 would be de-rated, e.g. in the full load range for wind speeds above v_nom.

The utilization curve 302 shows the utilization percentage of the cooling system 110. The cooling system 110 may be dimensioned so that at the nominal wind speed v_nom, the heat losses of the wind turbine components and the possible heat extraction of the cooling system are equal.

However, for wind speeds v above the nominal wind speed v_nom, the possible heat extraction from the cooling system 110 increases. Accordingly, the utilization of the cooling capacity of the cooling system 110 decreases as shown by the utilization curve 402. This implies that for wind speeds above the nominal wind speed v_nom or other wind speed where the cooling system is designed to remove the heat losses, the cooling system 110 is capable of extracting and dissipating more heat energy from the wind turbine components.

According to embodiments of the invention, this additional cooling capacity for wind speeds above a given design wind speed such as the nominal wind speed, is utilized as shown in Fig. 2B to increase the first temperature threshold Th1 to a temperature value above a nominal temperature threshold Tnom when the wind speed is above a nominal wind speed v_nom. Here the nominal wind speed v_nom, could be the design wind speed of the cooling system 110, the nominal wind speed of the wind turbine 100 or other predetermined wind speed threshold.

The de-rating curve 252 of Fig. 2B shows that the nominal de-rating curve 251 of the de-rating function 202 merely has been shifted - e.g. from a nominal curve 251 valid for wind speeds around v1 to a shifted curve 252 valid for higher wind speeds v2 - since the wind speed is above the nominal wind speed v_nom. For example, the first temperature threshold Tth1 has been shifted to the higher temperature threshold Tth1'. Advantageously, this allows operation at higher temperatures without de-rating the power reference Pref.

Similarly, any higher temperature thresholds Tth2, Tth3 of the nominal de-rating curve 251 may be shifted to new temperature thresholds Tth2', Tth3'.

Therefore, in an embodiment, the temperature threshold Tth1, or thresholds Tth1-Tth3, or in general any temperature threshold Tth of the de-rating function 202, is determined dependent on the wind speed v, e.g. for wind speeds v above a given wind speed threshold.

In general, determining the temperature threshold(s) Tth of the de-rating function may involve increasing the temperature threshold(s) to a value or values above a nominal temperature threshold Tnom and/or above the initial temperature thresholds, when the wind speed is above a nominal wind speed v_nom. Thus, the temperature threshold is a function of the wind speed so that increasing wind speeds provides increasing temperature thresholds.

Two or more temperature thresholds Tth1-Tth3 are determined for a given value of the wind speed above the nominal wind speed v_nom. The temperature thresholds Tth1-Tth3 may be shifted equally in response to variations in the wind speed, or the thresholds may be determined independently based on the wind speed.

The determination of the temperature thresholds Tth may be based on predetermined relations, e.g. in the form of a look up table, between different temperature thresholds Tth and different wind speeds v. The temperature thresholds Tth could also be computed based on a model of the cooling system 210.

Since the embodiments of the invention are based on utilizing the cooling capacity of the cooling system which increases for increasing wind speeds, the embodiments of the invention applies in general to cooling systems 110 wherein there is a correlation between the cooling efficiency and the wind speed.

As illustrated in Fig. 2A, the de-rating function 202 may receive the temperature T, the wind speed v and optionally the external power Pext. In accordance with the examples described above, the de-rating function 202 may be arranged to determine a possible de-rating dependent on the temperature T. Furthermore, the de-rating function 202 may be arranged to determine adjustments of the temperature thresholds Tth, i.e. new temperature thresholds, as a function of the wind speed v.

The temperature T used for determining a possible de-rating may be an ambient temperature. For example, the ambient temperature may be measured by a temperature sensor located on the outside of the nacelle 104, by a temperature sensor located on a mast which is located in a wind turbine park, by a temperature sensor of another wind turbine. Even though it is not the ambient temperature which itself requires a de-rating of the power production, but e.g. the temperature of the wind turbine components, or the temperature of the wind turbine component with the most critical temperature, the correlation of the wind turbine component temperature with the ambient temperature or other temperature is utilized.

This correlation between temperatures T and the temperatures which are relevant for determining temperature thresholds Tth may be empirically determined from various experiments or may be determined from simulations. Accordingly, instead of determining temperatures of the wind turbine components directly or other temperatures which are useable for determining the temperature thresholds Tth, other more easily obtainable temperatures may be used.

Other temperatures which can be used for determining the temperature thresholds Tth comprises nacelle temperatures, i.e. temperatures obtained from a temperature sensor located within the nacelle, estimated temperatures, e.g. estimated nacelle or component temperatures.

The nacelle temperatures may similarly to the wind turbine component temperatures be a good measure for determining the temperature thresholds Tth. Accordingly, the obtained temperature T such as the ambient temperatures, which correlates with a nacelle temperature Tnac and/or a nacelle component temperature Tcomp, may be used according to embodiments and examples described herein.

The temperatures T could also be component temperatures obtained from one or more temperature sensors arranged to directly measure the temperature of one or more wind turbine components. The temperature T could also be obtained based on a combination of the different temperatures, e.g. a combination of ambient temperatures and nacelle temperatures.

The wind speed v may be measured by a wind speed sensor of the wind turbine, a mast or obtained in other way so that the obtained wind is relevant for the cooling effect of the cooling system 110.

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 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 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 controlling a wind turbine (100), the wind turbine comprises a cooling system (110) arranged to provide cooling of wind turbine components and to exchange heat with ambient air, and a power generating system (201) which is controllable to generate power according to a power reference (Pref), the method comprises

- obtaining a temperature (T) which correlates with a nacelle temperature or a nacelle component temperature,
- obtaining a wind speed (v),
- determining a temperature threshold (Tth) of a power de-rating function (202) dependent on the wind speed, where the power de-rating function provides power references (Pref_i) as a function of the temperature (T) and where the power references (Pref_i) for temperatures above the temperature threshold (Tth) are reduced compared to power references for temperatures below the temperature threshold, and
- determining the power reference (Pref) based on the power de-rating function (202) and the temperature (T).

2. A method according to claim 1, wherein determining the temperature threshold (Tth) comprises increasing the temperature threshold to a value above a nominal temperature threshold (Tnom), when the wind speed is above a nominal wind speed (v_nom).

3. A method according to claim 2, wherein the temperature threshold is a function of the wind speed so that increasing wind speeds provides increasing temperature thresholds.

4. A method according to any of the preceding claims, comprising determining at least first and second temperature thresholds (Tth1, Tth2) for a given value of the wind speed above the nominal wind speed (v_nom).

5. A method according to any of the preceding claims, wherein determining the temperature threshold comprises selecting the temperature threshold based on a predetermined relation between different temperature thresholds (Tth) and different wind speeds (v).

6. A method according to any of the preceding claims, wherein the temperature (T) is a temperature selected from a list comprising any of: an ambient temperature from an ambient temperature sensor of the wind turbine, a mast temperature, an ambient temperature from an ambient temperature sensor of another wind turbine, a nacelle temperature, an estimated temperature, a temperature of a wind turbine component, or a combination thereof.

7. A control system (200) of a wind turbine (100), the wind turbine comprises a cooling system (101) arranged to provide cooling of wind turbine components and to exchange heat with ambient air, and a power generating system (201) which is controllable to generate power according to a power reference (Pref), the control system comprises

- a de-rate controller (202) comprising a power de-rating function (203) arranged to provide power references (Pref_i) as a function of a temperature (T) and dependent on a temperature threshold (Tth), wherein the power references (Pref_i) for temperatures above the temperature threshold (Tth) are reduced compared to power references for temperatures below the temperature threshold, wherein the temperature threshold (Tth) is dependent on a wind speed (v), and wherein the de-rate controller (202) is arranged to determine the power reference (Pref) for the power generating system (201) from the de-rating function (202) based on the temperature (T) and the wind speed (v).

8. A wind turbine (100) comprising a control system according to claim 7.

9. A computer program product comprising software code adapted to control a wind turbine when executed on a data processing system, the computer program product being adapted to perform the method of any of the claims 1-7.

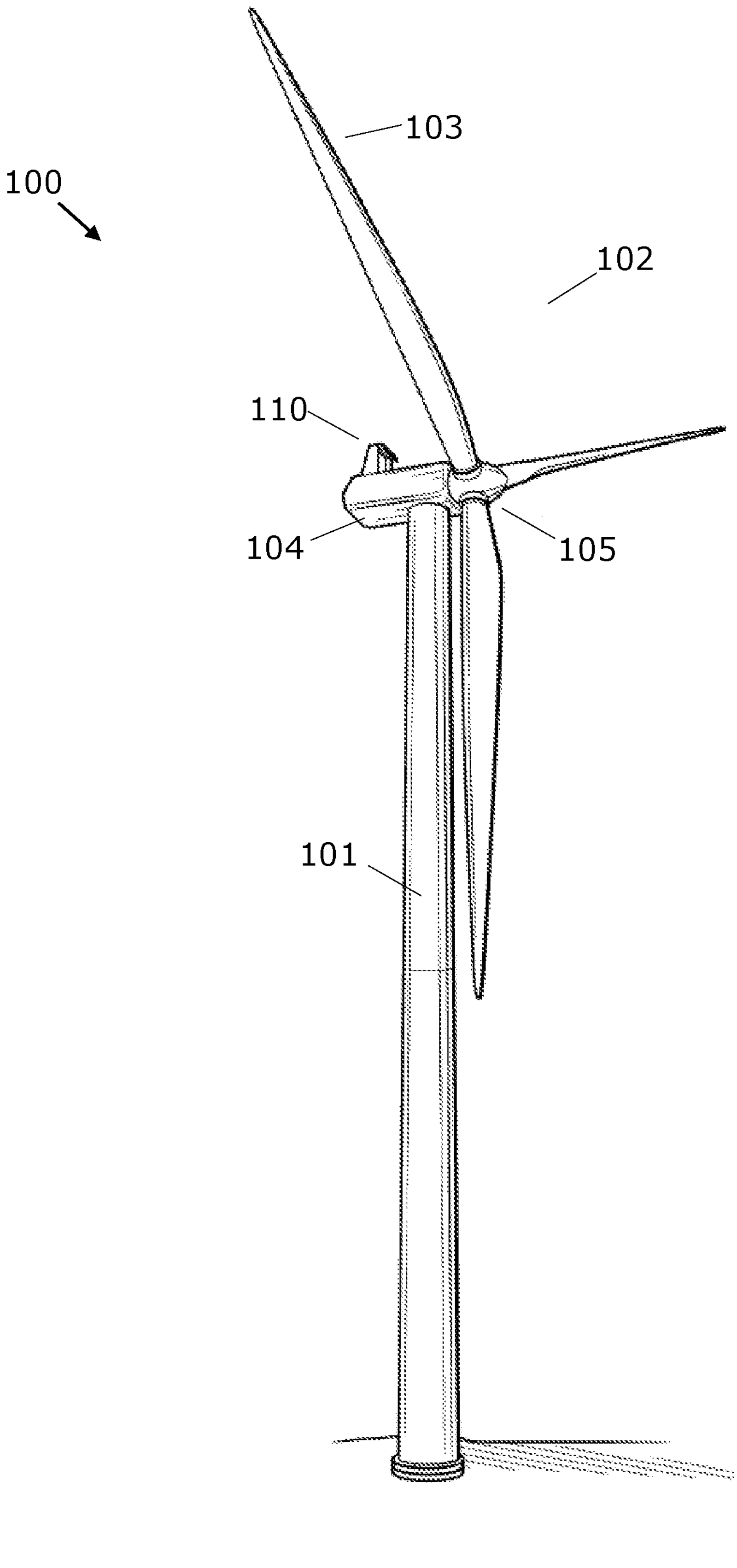

Fig. 1

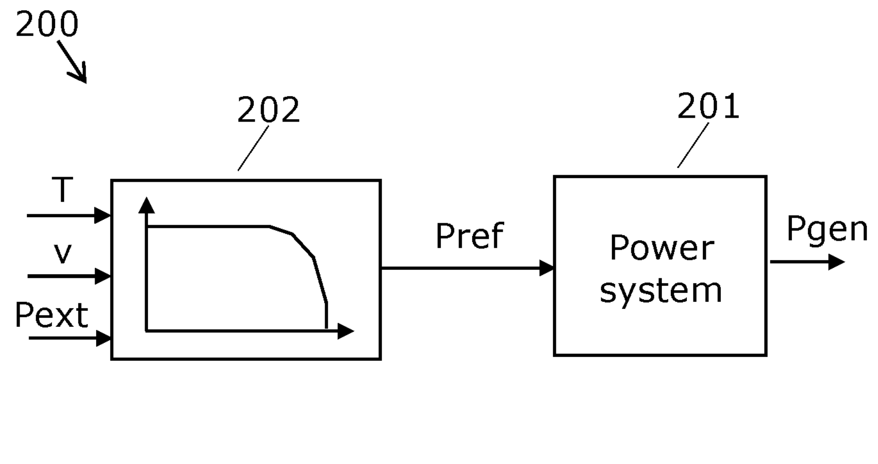
200
202
201
T
v
Pext
Pref
Power system
Pgen

Fig. 2A

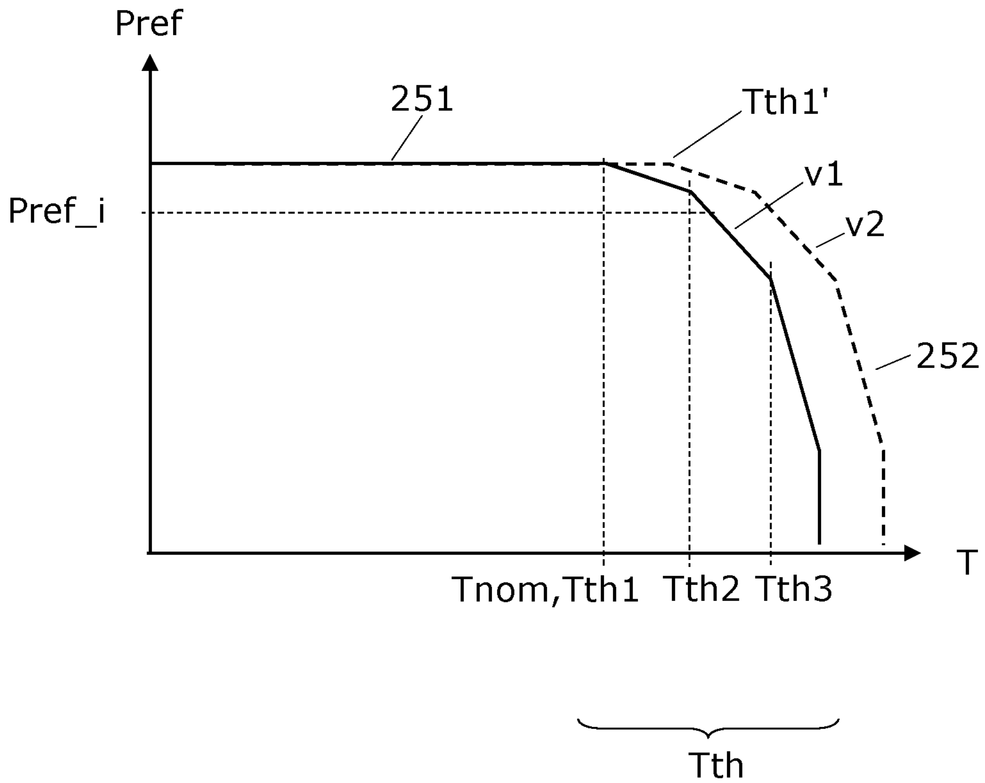
Pref
251
Tth1'
v1
v2
Pref_i
252
T
Tnom,Tth1
Tth2
Tth3
Tth

Fig. 2B

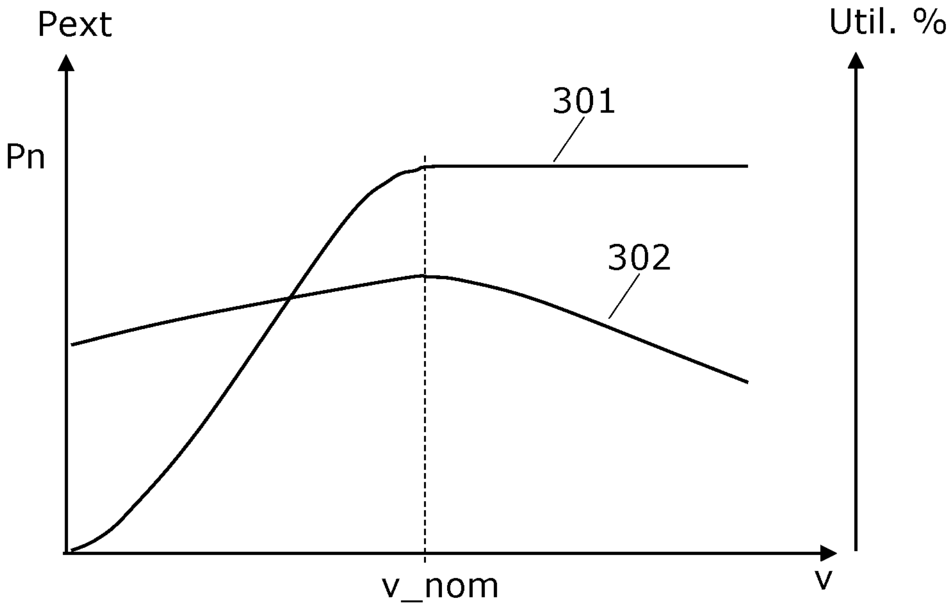

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2020/050182

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D7/02 F03D80/60
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.
X	US 2011/080001 A1 (GUNDTOFT SOEREN [DK] ET AL) 7 April 2011 (2011-04-07) paragraphs [0045] - [0065]; claims 1,27; figures 1-3	1,3,5-7, 9
X	CN 106 704 100 B (BEIJING GOLDWIND SCIENCE & CREATION WINDPOWER EQUIPMENT CO LTD) 2 July 2019 (2019-07-02) paragraphs [0002], [0022] - [0026], [0038], [0047], [0048]; figure 4	1-9

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

☒ See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent 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)

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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

"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
10 September 2020	21/09/2020

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	Król, Marcin

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/DK2020/050182

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