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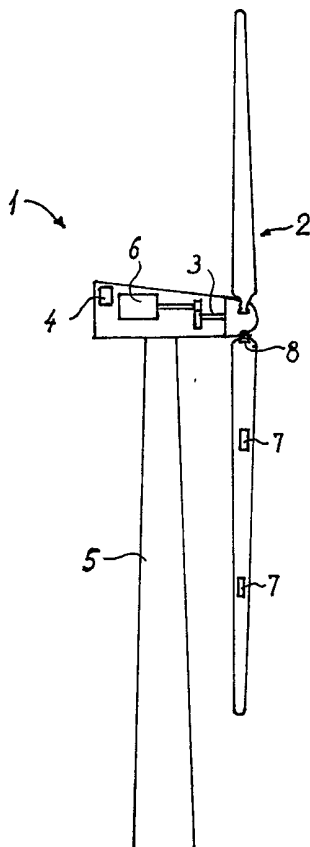
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(54) Title: METHOD OF CONTROLLING THE OPERATION OF A WIND TURBINE AND WIND TURBINE FOR USE IN SAID METHOD



(57) Abstract: The wind turbine (1) comprises a rotor (2) with a number of blades mounted for rotation about a mainly horizontal axis, and the pitch of the blades of the wind turbine is controlled in dependence on measured parameters in order to optimize the operation of the wind turbine with respect to produced energy under varying weather and wind conditions. By measuring mechanical loads on the blades (7, 8), and controlling the pitch of the blades of the wind turbine in such a way, that the measured mechanical loads are maintained below certain limits during operation, the control can be performed closer to the mechanical load limits of the blades without risk of exceeding these limits.



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METHOD OF CONTROLLING THE OPERATION OF A WIND TURBINE AND
WIND TURBINE FOR USE IN SAID METHOD

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TECHNICAL FIELD

The present invention relates to a method of controlling the operation of a wind-turbine and a wind turbine for use in said method of the kind set forth in the
10 preamble of claim 1 and 7 respectively.

BACKGROUND ART

15 In wind turbines of this kind, it is known to control the pitch of the blades of the wind turbine in dependence on measured parameters such as wind speed, wind turbulence, i.e. varying wind speed, etc., in order to optimize the operation of the wind turbine with respect to producing as much energy as possible under the varying weather and wind conditions. The conventional procedure for dimensioning
20 the blades of the wind turbines has been to dimension the blade to withstand the mechanical loads which they are subjected to during normal operation, taking necessary safety margins into account. At very high wind speeds, the wind turbines are normally stopped in order to avoid mechanical overload. During such stop periods, the yaw control is still active, keeping the rotor plane perpendicular to the
25 wind direction, but the blades are pitched out of the wind and rotation is stopped. When the wind speed is again reduced below a certain limit, the wind turbine is started again.

From US-4,339,666 it is known to control the pitch of the blades of a wind turbine
30 in such a way, that the safe operation is secured, i.e. controlled to keep maximum loads on rotor, gearbox and generator below the maximum allowable values. This patent describes the use of average wind velocity and turbulence factor as the primary controlling parameters. This has the disadvantage, that variations in wind speed over the surface of the rotor (wind shear) is not taken into account.

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DISCLOSURE OF THE INVENTION

It is the object of the present invention to provide a method of controlling the
5 operation of a wind turbine and a wind turbine for use in said method of the kind
referred to above, with which it is possible to perform the controlling of the wind
turbine in such a way, that the mechanical loads on the blades during operation are
monitored, controlled and reduced, whereby the mechanical dimensioning of the
blades can be reduced correspondingly, and this object is achieved with a method
10 of said kind, which according to the present invention also comprises the features
set forth in the characterising clause of claim 1, and with a wind turbine of said
kind, which according to the present invention also comprises the features set forth
in the characterising clause of claim 7. With this arrangement the controlling
function in the wind turbine has access to the instantaneous mechanical loads on
15 the blades and can control the wind turbine in such a way that the measured
mechanical loads are maintained below certain limits during operation and in this
way, the blades of the wind turbine can be mechanically dimensioned to lower
mechanical loads, which are maintained by the controlling method. Due to the fact,
that the controller has access to the measured mechanical loads on the blades, the
20 controller can control the wind turbine close to the mechanical load limits of the
blades without any risk of exceeding these limits, whereby the control can be
optimized with respect to maximizing the energy output to a higher degree than in a
situation in which the optimisation is limited by the possible, unknown mechanical
load on the blades during operation, which may be highly dependent on weather
25 and wind conditions, and varying from top to bottom position of the blades (wind
shear). This control of the wind turbine close to the mechanical load limits is in the
following description designated aggressive control.

30 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 the exemplary embodiment of a wind

turbine for use in the method in accordance with the invention shown in the drawings, in which

Figure 1 shows a sketch of a wind turbine comprising mechanical load sensors mounted to measure the mechanical loads on the blades, and

Figure 2 schematically shows different power curves for wind turbines controlled in different ways, and

Figure 3 schematically shows the mechanical load on the blades as a function of wind velocity corresponding to the different power curves shown in Figure 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

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The wind turbine 1 shown in Figure 1 comprises a rotor 2 with a number of blades mounted for rotation about a mainly horizontal axis 3 and driving an electric generator 6 all mounted on top of a tower 5. In order to position the plane of the rotor 2 against the wind (yaw control), the top rotate around a vertical axis. The wind turbine is of the kind, in which the rotation of the rotor 2 is controlled by individually controlling the pitch of each of the blades of the rotor, in dependence on measured parameters. A control unit 4 for controlling the pitch of the blades and possibly the position of the rotor relative to the wind direction and other controlling parameters is positioned in a suitable place in the wind turbine 1 to receive information on measured parameters such as wind speed, wind turbulence, power output from the generator 6, wind direction, etc. The control unit 4 is also connected to receive measurements from sensors such as strain-gauges 7, 8 positioned on the blades of the rotor 2, in order to measure mechanical loads on said blades by means of the optical-fibre strain-gauge type sensors 7 and the drive moments from each blade at the root of the blade by means of the optical-fibre strain-gauge 8. The wind turbine may comprise further control units functioning together with the control unit 4 in a multi controller system.

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When dimensioning the blades in order to avoid mechanical overload, essentially two possibilities are present, one being dimensioning the blades to be more rigid and the other being to control the wind turbine less aggressively whereby the bending of the blade will be reduced. However, the first possibility will increase the price of the construction and the second possibility will reduce the amount of energy produced, as illustrated in Figure 2 and explained in the following.

By measuring the mechanical loads on the blades and using this information for controlling the wind turbine, it is possible to control the wind turbine in such a way that a less rigid construction of the blades can be used and a relatively aggressive control of the wind turbine can be used most of the time, as information is present which indicates when to use less aggressive control of the wind turbine. Naturally, the individual measured loads are used for the individual pitch control of each blade.

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By means of the measuring of the mechanical loads on the blades, the control can deduct the bending of the blades and thereby the position of the tips of the blades whereby the safety distance between the tower and the tips of the blades can be varied as long as the character of the instant wind is known. A variation of the safety distance can be obtained by using different control algorithms.

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Figure 2 shows a typical power curve A for a wind turbine which is controlled to optimize the energy production. At low winds, the wind turbine is not producing any energy and at a certain minimum wind velocity, the energy production is started up, and with increasing wind velocity, the energy production is raised until nominal power, P_N , is reached. At higher winds, the wind turbine produces energy at the level P_N and the pitch of the blades is controlled to keep a constant power output. At a certain wind velocity (typically 25 m/s), the wind turbine is stopped as previously described, in order to avoid mechanical overload of the blades and other constructional parts of the wind turbine. (The typical limit for restarting, as previously described, is at wind speed 20 m/s).

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Figure 3 shows the typical mechanical load on the blades of the rotor, i.e. the bending torque in a direction perpendicular to the rotor plane, and shows that the

load is increasing with increasing wind speed until the point where nominal power is generated whereafter the blades are pitched out of the wind and the mechanical load is reduced correspondingly. If the wind turbine is producing energy close to the point where the pitching out of the wind is started, gusty wind conditions will
5 provide a mechanical load which is higher than the maximum of the curve A, as indicated by the dotted line E.

The wind turbine may also be provided with mechanical load sensors detecting the driving torque of each blade. The measured driving torque for each individual blade
10 will be the sum of the gravitational torque on each blade which is varying with the position of the blade during each rotation, i.e. a sinusoidal curve, and the wind torque on each blade, which is a function of the actual wind influencing the blade. The sinusoidal part of the torque curve for each blade can be used to calculate the angular position of the blade, and the wind dependent part of the torque on each
15 blade may be used to detect error conditions in the wind turbine if the expected correspondence between wind speed and blade torque is not achieved. Such errors may be due to over-icing, dirt deposition on the blades, not correctly functioning pitch control, errors in different sensors in the control system, etc.

20 Statistical information on measured mechanical loads on the blades may be collected in order to obtain a basis for evaluating the site on which the wind turbine is positioned whereby control functions of the wind turbine may be optimized using this information or the information may be used for planning new wind turbines. Furthermore, such statistical information can be used for planning maintenance
25 work on the wind turbine.

With the present invention, where the mechanical loads on the blades are measured, the control of the energy production of the wind turbine can be chosen, in accordance with the instant character of the wind and corresponding safety
30 margins for the blades, to a more or less aggressive operation, as indicated by the curves B and C in Figure 2. The resulting mechanical loads on the blades are as indicated in Figure 2 by the curves B and C. Under stable and laminar wind conditions, it is possible to obtain a more aggressive control as indicated by the curve B, and under less favourable conditions with turbulence and varying wind

velocities, it may be necessary to control the wind turbine in accordance with a substantially less aggressive curve as indicated by C in Figure 2. In this way, the optimisation for a given wind turbine is obtained by the fact that the wind turbine will only have to be controlled in a less aggressive way in a limited part of the time, whereas it may be possible to control it in a more aggressive way most of the time.

A further possibility is to let the wind turbine produce energy at a reduced energy production at wind velocities above the usual maximum velocity V_M , as indicated by the curve D in Figure 2. It is assumed that safe and optimized operation in this high-wind range will be possible when controlling the pitch of the blades in accordance with the measured mechanical loads on the blades.

CLAIMS

1. Method of controlling the operations of a wind turbine comprising a rotor with a number of blades mounted for rotation about a mainly horizontal axis, said method comprising
- 5 a) controlling the pitch of the blades of the wind turbine in dependence on measured parameters in order to optimize the operation of the wind turbine with respect to produced energy under varying weather and wind conditions, c h a r a c t e r i z e d by further comprising:
- 10 b) measuring mechanical loads on the blades, and
- c) controlling the pitch of the blades of the wind turbine in such a way, that the measured mechanical loads are maintained below certain limits during operation.
- 15 2. Method in accordance with claim 1, c h a r a c t e r i z e d by further comprising using the measured mechanical loads to deduct information on the character of the wind field and adapting the control of the wind turbine in dependence thereof.
- 20 3. Method in accordance with claim 1 or 2, c h a r a c t e r i z e d by comprising controlling the pitch of the blades of the wind turbine individually in dependence on the measured mechanical loads on the blades.
4. Method in accordance with any of the preceding claims, c h a r a c t e r i z e d by further comprising
- 25 using the measured mechanical loads to calculate the positions of the blade tips and adjusting the control of the wind turbine in order to maintain a certain safety distance between the blades and the tower.
- 30 5. Method in accordance with any of the preceding claims, c h a r a c t e r i z e d by further comprising using the measured mechanical loads to ensure safe operation of the wind turbine at reduced energy production at higher winds, where wind turbines would normally be stopped.

6. Method in accordance with any of the preceding claims, c h a r a c t e r-
i z e d by further comprising
collecting statistical information on the measured mechanical loads on the blades.
- 5
7. Wind turbine for use in a method in accordance with any of the preceding
claims, comprising
- a rotor with a number of blades mounted for rotation about a mainly
horizontal axis,
- 10 - means for controlling the pitch of the blades in dependence on measured
parameters,
c h a r a c t e r i z e d by comprising
mechanical load sensors mounted to measure the mechanical loads on the blades
and connected to influence the means for controlling the pitch of the blades.
- 15
8. Wind turbine in accordance with claim 7, c h a r a c t e r i z e d by
the mechanical load sensors being of the strain-gauge type.
9. Wind turbine in accordance with claim 8, c h a r a c t e r i z e d by
20 the mechanical load sensors being of the fibre-optical strain-gauge type.
10. Wind turbine in accordance with claim 7, c h a r a c t e r i z e d by
the mechanical load sensors being of a type measuring the angle between the
blade and the rotor plane in the measuring point, said angle being related to the
25 bending of the blade and usable for calculating the position of the tip of the blade.
11. Wind turbine in accordance with claim 10, c h a r a c t e r i z e d by
the mechanical load sensors being of the fibre-optical gyro type.
- 30 12. Wind turbine in accordance with any of the claims 7-11, c h a r a c t e r-
i z e d by comprising
several mechanical load sensors suitably distributed over the length of each blade.
13. Wind turbine in accordance with any of the claims 7-12, c h a r a c t e r-

i z e d by comprising
mechanical load sensors mounted to measure the driving torque of each blade.

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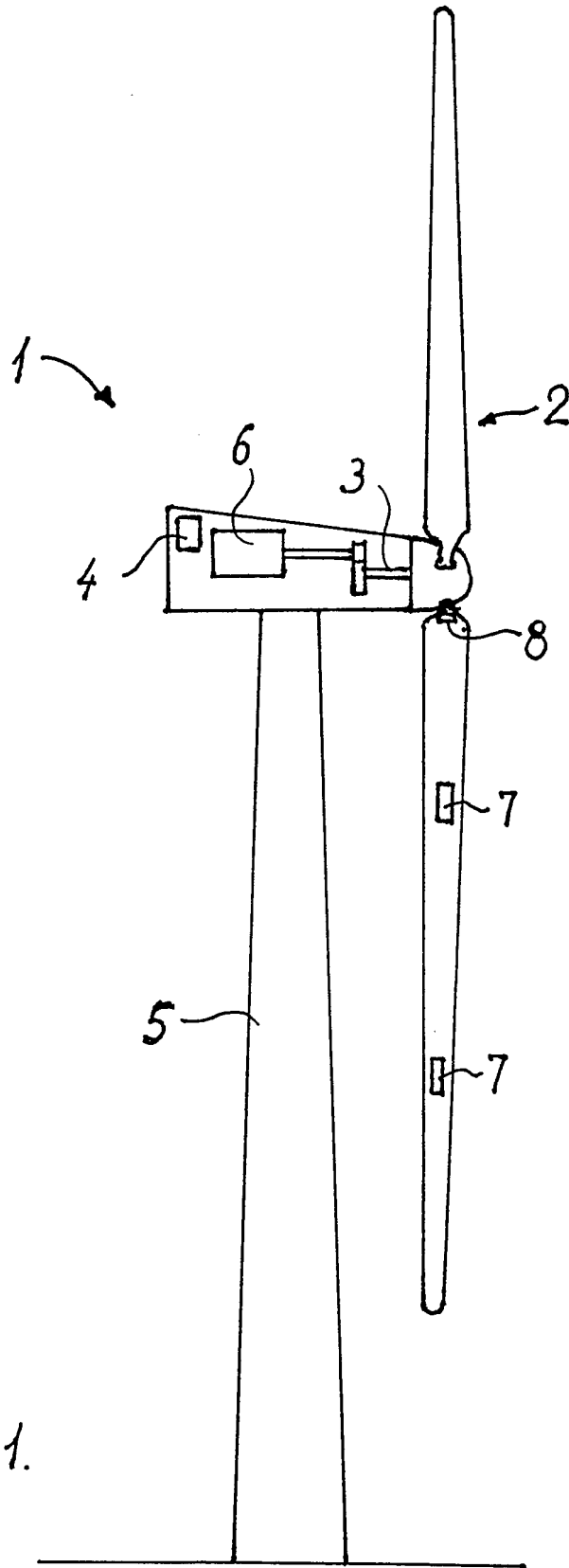


Fig. 1.

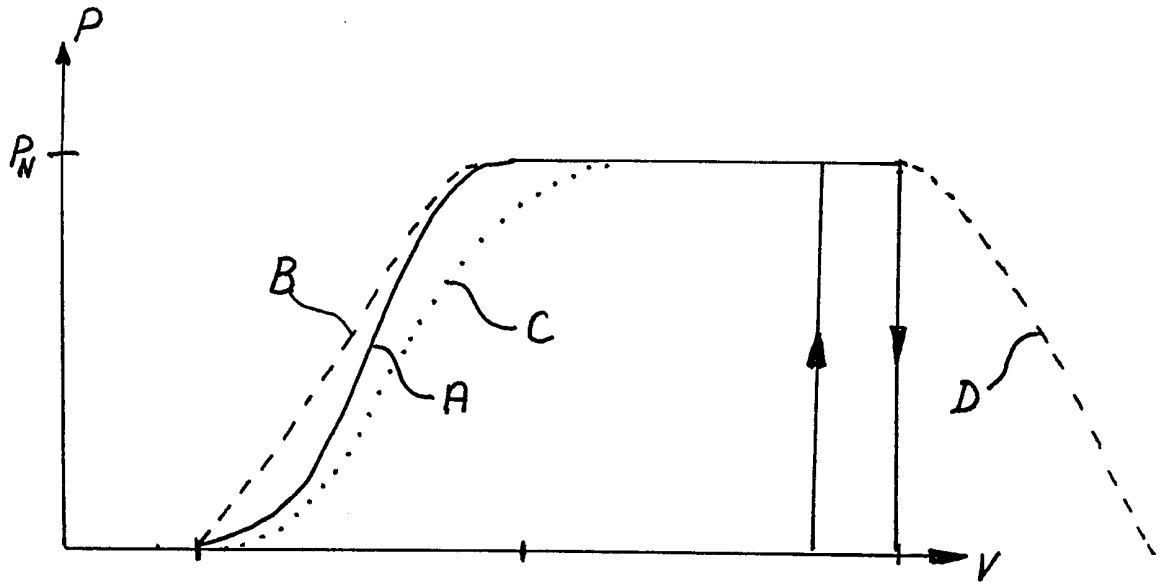


Fig. 2

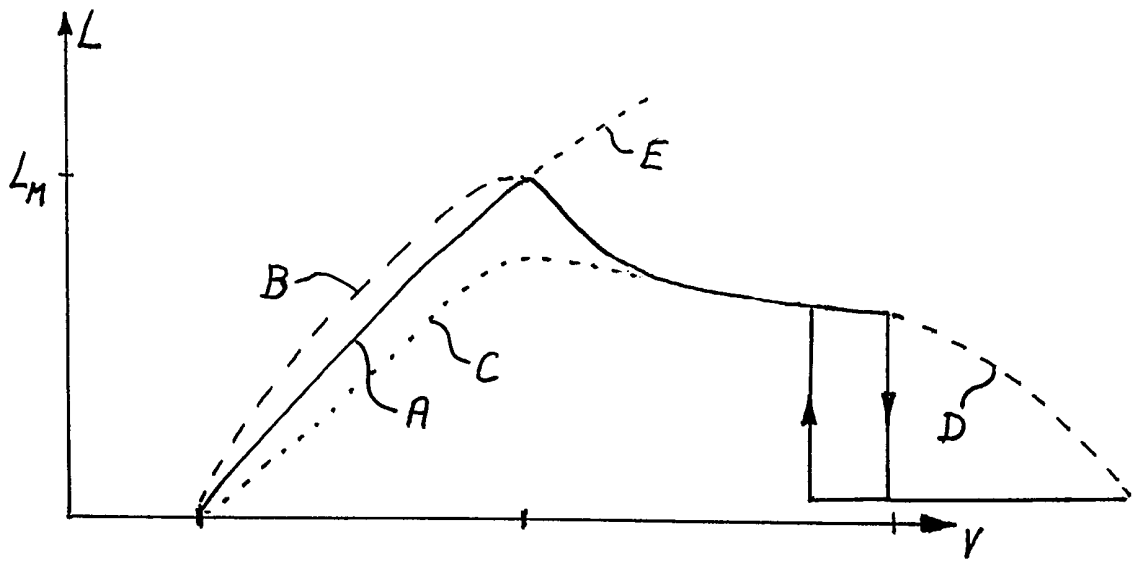


Fig. 3.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/DK 99/00595

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 7 F03D7/00 F03D11/00

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)

IPC 7 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, PAJ

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Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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- *E* earlier document but published on or after the international filing date
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- *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.
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Date of the actual completion of the international search

27 June 2000

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INTERNATIONAL SEARCH REPORT

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