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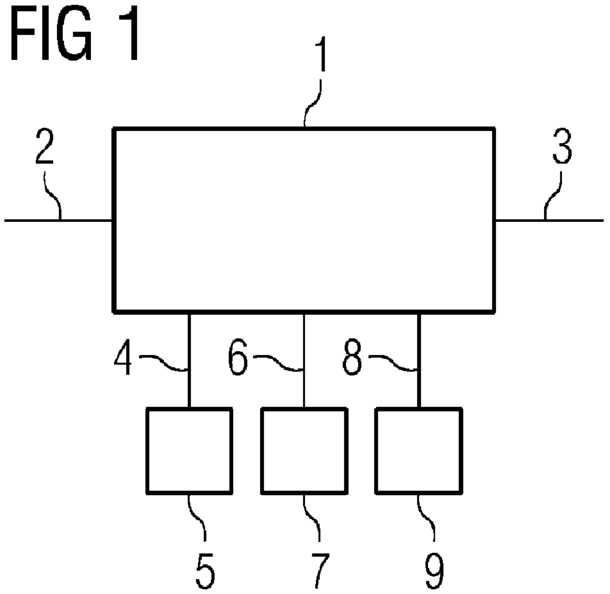
[Continued on next page]

(54) Title: SYSTEM AND METHOD FOR OPERATING A WIND TURBINE USING AN ADAPTIVE SPEED REFERENCE

FIG 1



(57) Abstract: It is described a method for operating a wind turbine, the method comprising attributing a significance to at least two wind turbine operating parameters, determining the values of the at least two wind turbine operating parameters, and choosing a desired wind turbine rotor speed based on the significance of the two wind turbine operating parameters and on the determined values of the wind turbine operating parameters. Furthermore, the invention concerns a corresponding wind turbine controller and wind turbine.

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— *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))*

DESCRIPTION

System and method for operating a wind turbine using an adaptive speed reference

Field of invention

The present invention relates to the field of power generation by wind turbines. In particular, the invention relates to a method for operating a wind turbine, a wind turbine controller, a program element, and a computer-readable medium.

Art Background

Wind turbines are becoming more and more popular for ecological power generation. The kinetic energy of the wind is converted to rotational energy of a wind turbine rotor by the wind turbine rotor blades and therefrom to electric energy by a generator. So naturally wind turbine rotors have to rotate to be of use. The maximum allowed wind turbine rotor speed is based on various factors e.g. turbine loads, limitations on electrical components, structural properties, etc. Typically, wind turbines have been designed for wind turbine rotors operating at or below a constant wind turbine rotor speed, in particular the maximum allowed speed of rotation also known as the rated rotor speed or the nominal rotor speed.

It has been proposed in EP 2 128 437 A2 to monitor at least two wind turbine operating parameters to determine whether the wind turbine rotor speed can be increased without immediately damaging the wind turbine to capture more energy.

There may be a need for a more versatile method for operating a wind turbine, for a more versatile wind turbine controller, and a more versatile wind turbine.

Summary of the Invention

This need may be met by the subject matter according to the independent claims. Advantageous embodiments of the present invention are described by the dependent claims.

According to a first aspect of the invention there is provided a method for operating a wind turbine, the method comprising attributing a significance to at least two wind turbine operating parameters, determining the values of the at least two wind turbine operating parameters, and choosing a desired wind turbine rotor speed based on the significance of the two wind turbine operating parameters and the determined values of the wind turbine operating parameters.

One can measure the rotor speed and/or the generator speed, which are approximately separated by the gear ratio of the drive train of the wind turbine. The generator speed measurement may have a better quality since the generator speed may be higher due to the gearbox up-scaling the rotational speed of the rotor, so some control systems may operate at the generator speed and not on the rotor speed.

Operating parameters may be of differing importance when choosing the desired wind turbine rotor speed. For example, it may be more important to care about wind turbine component load than about demanded reactive power. Furthermore, the significance of operating parameters may be time dependent. For example, wind turbine noise may be acceptable to a lesser extend during nighttime than during daytime.

According to a first embodiment of the method for operating a wind turbine, at least one of the two wind turbine operating parameters is selected from the group consisting of wind turbine rotor synchronization, wind turbine noise, wind turbine component load, wind turbine component lifetime consumption, wind speed, wind turbulence, wind gusts, temperatures, in particular ambient temperature or wind turbine component temperature, humidity, in particular ambient humidity or wind turbine component humidity, air density, demanded active power, demanded reactive power.

A wind turbine may be grouped with further wind turbines at one site to form a wind park. The wind turbine rotor speed influences wake and thereby neighboring turbines, in particular downwind turbine, and thus their power production capabilities and turbine component loading. Reducing rotor speed (and power capture) on upwind turbine may reduce loading on the downwind turbines without decreasing overall part performance on park level.

Wind turbine in groups may exhibit a visual chaotic impression caused by the rotors of the individual turbines rotating at different speeds and at different rotor azimuth angles. The visual impression of a wind turbine park may be improved by rotor synchronization, where the azimuth angles of the turbine rotors are aligned by controlling the rotor speeds collectively.

The amount of wind turbine noise generated by wind turbines essentially depends on wind turbine rotor speed. Taking wind turbine noise into account, in particular during nighttime, when choosing the desired wind turbine rotor speed may improve the acceptance of wind turbines, especially when the wind turbine is erected in or near residential areas.

A wind turbine typically comprises several wind turbine components, inter alia wind turbine blades, wind turbine blade roots, wind turbine gearboxes, which wear and tear is influenced by the wind turbine rotor speed. Determining the value of a wind turbine component load and choosing the desired wind turbine rotor speed based on this value may enhance the lifetime of this wind turbine component.

Usually, wind turbines are rated and designed for a certain lifetime, e.g. twenty years, under the estimation of a mean wear and tear of its wind turbine components. However, a wind turbine component may have experienced a lower mean wear and tear in the past, i.e. its lifetime consumption may be low. Therefore, a higher desired wind turbine rotor speed typically augmenting wear and tear of the wind turbine component may be acceptable without jeopardizing the rated lifetime. Increasing the desired wind turbine rotor speed may be beneficial as more electrical power may be provided. Accordingly, if the lifetime consumption of the wind turbine component is higher than estimated a lower desired wind turbine rotor speed might be preferred.

Taking wind speed into account may be beneficial as wind speed may influence the load experienced by wind turbine components, e.g. the wind turbine tower. Wind speed may even allow estimating the different wind turbine component loads. Additionally, higher wind speeds may allow reducing the desired wind turbine rotor speed while maintaining the active power and/or reactive power produced. However, at very high wind speeds the rotor speed and power may be limited to reduce the loading of the wind turbine components to an acceptable level. At extreme wind speeds it may become necessary to shut down the wind turbine.

Wind turbulences may induce additional loads on the wind turbine components. Accordingly, it may be beneficial to reduce the desired wind turbine rotor speed when wind turbulences become too important to maintain the wind turbine component load at an acceptable level.

Typically, wind does not blow with a constant speed, but rather at some turbulence level. Occasionally, wind gust occur, exceeding the normal wind speed variation. Alternatively, or in addition, wind gusts may manifest in wind direction changes. Changing wind directions may impose supplemental wind turbine component loads, which may be more important when the wind turbine rotor speed is higher. Taking wind gusts into consideration when choosing the desired wind turbine rotor speed may therefore reduce wear and tear.

Wind turbine component temperature may be a further parameter to be taken into account when choosing the desired wind turbine rotor speed. If a wind turbine component, e.g. a gearbox, gets to hot the desired wind turbine rotor speed may be reduced. However, it may be thinkable that the rotating wind turbine rotor or other rotating wind turbine components with rotational speeds linked to the rotor speed, in particular blowers or fans in cooling systems, provides cooling air for a certain wind turbine component. Accordingly, it may in this case be beneficial to increase the desired wind turbine rotor speed.

In case of a low ambient temperature ice may form on the wind turbine rotor blades augmenting their mass. Accordingly, it may be also advantageous to evaluate the ambient temperature when choosing the desired wind turbine rotor speed.

Ambient humidity may cause water drops or ice formation on the wind turbine rotor blades and therewith change the aerodynamic properties of the wind turbine rotor blades. Accordingly, it may be preferred to reduce the desired wind turbine rotor speed. The formation of ice on wind turbine rotor blades may occur at particular combinations of ambient temperature and ambient humidity. Accordingly, it may be also advantageous to evaluate the combination of temperature and humidity when choosing the desired wind turbine rotor speed.

Wind turbine component humidity may lead to electric short circuits. Thus, it may be beneficial to increase the desired wind rotor speed to heat the wind turbine component or provide increased airflow surrounding the component and therewith reduce the wind turbine component humidity.

Not only the kinetic energy of the wind beside the wind speed depends on the air density but also the aerodynamic properties of the rotating wind turbine blades. Hence, monitoring the air density and choosing the wind turbine rotor speed accordingly may result in a better power generation efficiency.

Two further parameters which be taken into account are demanded active power and demanded reactive power. More and more wind turbines are grouped in wind farms. The electrical power is then transmitted to consumer via power grids. However, the demanded active power and the demanded reactive power may vary. Hence, in times of less demanded active power and/or demanded reactive power the desired wind turbine rotor speed may be reduced to spare lifetime consumption.

Wind turbine operating parameters like those presented above may be of different importance. For example, a high acceptance of a wind turbine in a residential area may be a nice to have feature whereas reducing wind turbine component loading may be absolutely necessary.

Attributing a significance to at least two wind turbine operating parameters may ensure that important wind turbine operating parameters have more influence when choosing the desired wind turbine rotor speed than minor important wind turbine operating parameters.

According to another embodiment of the method for operating a wind turbine, the method comprises defining an upper wind turbine rotor speed threshold value and choosing the desired wind turbine rotor speed to be less or equal to the defined upper wind turbine rotor speed threshold value.

Lifetime of wind turbine components may be limited due to wear and tear as well as due to overload. Defining an upper wind turbine rotor speed threshold value and choosing the desired wind turbine rotor speed to be less or equal to the defined upper wind turbine rotor threshold value may prevent as sudden disintegration of wind turbine components.

According to yet another embodiment of the method for operating a wind turbine, choosing the desired wind turbine rotor speed comprises using a look-up table, applying a fuzzy logic routine and/or applying a neural network and/or applying mathematical linear or non-linear functions.

Using a look-up table may be a particularly fast method for choosing the desired wind turbine rotor speed. Applying a fuzzy logic routine may allow to take more wind turbine operating parameters into account. Applying a neural network may be easily adaptable to different wind turbine operating parameters. Applying mathematical linear or non-linear functions may provide a particularly optimized desired wind turbine rotor speed.

According to a further embodiment of the method for operating a wind turbine, the method comprises choosing an initial desired wind turbine rotor speed to be equal to the wind turbine rotor speed threshold value.

Typically, a higher wind turbine rotor speed is beneficial in terms of active power generation and reactive power generation, which is what wind turbines are built for. Choosing an initial desired wind turbine rotor speed to be equal to the wind turbine rotor speed threshold value may ensure that the wind turbine complies with demanded active power and demanded reactive power while at the same time not putting the structural integrity of the wind turbine at risk.

According to a second aspect of the invention there is provided a wind turbine controller being adapted for operating a wind turbine according to a method as set forth above, the wind turbine controller comprising an output for setting the rotor speed and/or setting the generator speed.

Wind turbine rotors may be coupled to a wind turbine generator either directly or via a gearbox. Accordingly, the desired wind turbine rotor speed may be achieved by either setting the wind turbine rotor speed directly or by setting the wind turbine generator speed.

According to a first embodiment of the wind turbine controller, the wind turbine controller comprises a rate severity module, an external constraints module, a supervisory system module, and a reduction module.

According to another embodiment of the wind turbine controller, the wind turbine controller comprises a memory module. The memory module may be used to keep record of lifetime consumption of wind turbine components. It may therefore contribute to ensuring that the rated lifetime of the wind turbine is achieved.

According to another embodiment of the wind turbine controller, the wind turbine controller comprises an input for receiving an input signal indicative of the upper wind turbine rotor speed threshold.

An input for receiving an input signal indicative of the upper wind turbine rotor speed threshold may be used to manually set the upper wind turbine rotor speed threshold.

According to a third aspect of the invention there is provided a wind turbine comprising a wind turbine controller and at least one sensor providing the wind turbine controller with a signal indicative of a value of at least one parameter of the group consisting of wind turbine rotor synchronization, wind turbine noise, wind turbine component load, wind speed, wind turbulence, wind gusts, temperature, in particular ambient temperature or wind turbine component temperature, humidity, in particular ambient humidity or wind turbine component humidity, air density, demanded active power, and demanded reactive power.

Suitable sensors may inter alia be selected from the group consisting of thermometers, thermocouples and thermistors for measuring the temperature, anemometers for measuring wind speed, wind turbulence and wind gusts, pressure sensors, optical sensors, proximity sensors, hygrometers, encoders, accelerometers, gyroscopes, inertial measurement units, strain gauges, and Light Detection And Ranging devices (LIDAR).

According to a forth aspect there is provided a program element for operating a wind turbine, the program element, when being executed by a data processor, is adapted for controlling and/or for carrying out a method as set forth above.

The program element may be implemented as computer readable instruction code in any suitable programming language, such as, for example, JAVA, C++, and may be stored on a computer-readable medium (removable disk, volatile or non-volatile memory, embedded memory/processor, etc.). The instruction code is operable to program a computer or any other programmable device to carry out the intended functions. The program element may be available from a network, such as the World Wide Web, from which it may be downloaded.

According to a fifth aspect there is provided a computer readable medium on which there is stored a computer program for processing a physical object, the computer program, when being executed by a data processor, is adapted for controlling and/or for carrying out a method as set forth above.

The computer-readable medium may be readable by a computer or a processor. The computer-readable medium may be, for example but not limited to, an electric, magnetic, optical, infrared or semiconductor system, device or transmission medium. The computer-readable medium may include at least one of the following media: a computer-distributable medium, a program storage medium, a record medium, a computer-readable memory, a random access memory, an erasable programmable read-only memory, a computer-readable software distribution package, a computer-readable signal, a computer-readable telecommunications signal, computer-readable printed matter, and a computer-readable compressed software package.

It has to be noted that embodiments of the invention have been described with reference to different subject matters. In particular, some embodiments have been described with reference to method type claims whereas other embodiments have been described with reference to apparatus type claims. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters, in particular between features of the method type claims and features of the apparatus type claims is considered as to be disclosed with this document.

The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

Brief Description of the Drawing

Figure 1 shows a first wind turbine controller according to an exemplary embodiment of the invention.

Figure 2 shows a second wind turbine controller according to an exemplary embodiment of the invention.

Figure 3 shows a first lifetime consumption versus time diagram of a wind turbine component when the wind turbine is operated according to the state of the art.

Figure 4 shows a second lifetime consumption versus time diagram of a wind turbine component when the wind turbine is operated according to an exemplary embodiment of a method according to the invention.

Detailed Description

The illustration in the drawing is schematically.

Figure 1 shows a first wind turbine controller 1 according to the invention. The wind turbine controller 1 comprises an input 2 for receiving an input signal indicative of an upper wind turbine rotor speed threshold and an output 3 for setting a wind turbine rotor speed and/or a wind turbine generator speed. Additionally, there is provided an input 4 for receiving a rotor synchronization value of a rotor synchronization sensor 5, an input 6 for receiving a load monitoring value from a load monitoring sensor 7, and an input 8 for receiving noise control values from a noise control sensor 9. During operation the wind turbine controller 1 assesses the values received and chooses based on the significance, in particular the priority, which has been attributed to them a desired wind turbine rotor speed. Further, the wind turbine controller outputs via its output 3 a value for setting the rotor speed to become equal to the desired wind turbine rotor speed.

Figure 2 shows another wind turbine controller 10 according to an exemplary embodiment of the invention. The wind turbine controller 10 comprises a rate severity module 11, an external constraints module 12, supervisory system module 13, and a reduction module 14. Furthermore, the wind turbine controller 10 comprises a blade root module 15, a blade module 16, a gearbox module 17, and a tower module 18. The blade root module 15, blade module 16, gearbox module 17, and tower module 18 calculate the lifetime consumption rate based on sensor data received from corresponding inputs 19, 20, 21, 22. Additionally, blade root module 15, blade module 16, gearbox module 17, and tower module 18 each comprise a memory module to keep record of the lifetime consumption rate. This memory module allows integrating the lifetime consumption rate of the past to obtain the lifetime consumption of the wind turbine components. Lifetime consumption rate and lifetime consumption of the wind turbine components are then transmitted to the rate severity module 11, which determines a lifetime consumption rate and lifetime for the whole wind turbine, via connections 23, 24, 25, 26, 27, 28, 29, and 30. The supervisory system module 13 receives the lifetime consumption rate and lifetime consumption for the whole wind turbine via its inputs 31 and 32.

The external constraints module 12 provides the power module 13 with signals 33, 34, 35, 36, 37, 38 and 39 indicative of the maximum power, which may be provided by the wind turbine, an upper wind turbine rotor speed threshold value, demanded reactive power, demanded active power, wind turbine converter limitations, wind turbine transformer limitations, and wind turbine generator limitations. Demanded active power and demanded reactive power may be set via inputs 40 and 41 of the external constraints module 12.

The supervisory system module 13 chooses a desired wind turbine rotor speed based on these signals 33, 34, 35, 36, 37, 38, 39 from the external constraints module 12 and the signals from the rate severity module 11 transmits the desired wind turbine rotor speed to the reduction module 14. The reduction module 14 compares the desired wind turbine rotor speed with the current wind turbine rotor speed and determines a correction value based on this comparison. The correction value is then transmitted to an actuator to influence the wind turbine rotor speed.

Figure 3 shows a lifetime consumption (LC) versus time t diagram of a wind turbine component when the wind turbine is operated according to the state of the art. Typically, wind turbine manufacturers warrant a certain product lifetime of wind turbines (LT), for example twenty years. Lifetime consumption is an assessment of the wear and tear inflicted on its components relative to the warranted period. Similarly the same assessment will be made for blade root, tower and the gearbox, and other components of the turbine, the method of deriving the information can very from component to component. Typically, a wind turbine is operated such that the wind turbine components lifetime consumption rate follows the dashed line, meaning that the structural mechanical loading follows the intended distribution (10 years of lifetime means 50 percent consumption).

Figure 4 shows a lifetime consumption LC versus time t diagram of a wind turbine component when the wind turbine is operated according to an exemplary embodiment of a method according to the invention.

The wind turbine component lifetime consumptions may be chosen so that the turbine will be loaded excessively in the early years of its lifetime, thereby yielding a higher power extraction. And subsequently spare the turbine in later years by operating so the loads are below the expected loading, and thereby even out the difference, as illustrated in Figure 4 by area A having the same size as area B. This may be beneficial under circumstances when power generation is more profitable in early years than in later years.

It should be noted that the term "comprising" does not exclude other elements or steps and the use of articles "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

List of reference signs:

1	wind turbine controller
2	input
3	output for setting a wind turbine rotor speed and/or a wind turbine generator speed
4	input for receiving a rotor synchronization value
5	rotor synchronization sensor
6	input for receiving a load monitoring value
7	load monitoring sensor
8	input for receiving noise control values
9	noise control sensor
10	wind turbine controller
11	rate severity module
12	external constraints module
13	supervisory system module
14	reduction module
15	blade root module
16	blade module
17	gearbox module
18	tower module
19 to 22	inputs
23 to 30	connections
31, 32	inputs
33 to 39	signals
40, 41	inputs

CLAIMS:

1. Method for operating a wind turbine, the method comprising

attributing a significance to at least two wind turbine operating parameters,

determining the values of the at least two wind turbine operating parameters, and

choosing a desired wind turbine rotor speed based on the significance of the two wind turbine operating parameters and on the determined values of the wind turbine operating parameters.

2. Method for operating a wind turbine according to preceding claim 1, wherein at least one of the two wind turbine operating parameters is selected from the group consisting of
wind turbine rotor synchronization,
wind turbine noise,
wind turbine shadow flicker,
wind turbine component load,
wind turbine component lifetime consumption,
wind speed,
wind direction,
wind shear,
wind turbulence,
wind gusts,
temperature, in particular ambient temperature or wind turbine component temperature,
humidity, in particular ambient humidity or wind turbine component humidity,
air density,
blade condition, in particular ice, dirt, or other material on the blades,
demanded active power,
demanded reactive power.

3. Method for operating a wind turbine according to any one of the preceding claims 1 or 2, the method comprising
defining an upper wind turbine rotor speed threshold value and
choosing the desired wind turbine rotor speed to be less or equal to the defined upper wind turbine rotor speed threshold value.

4. Method for operating a wind turbine according to any one of the preceding claims 1 to 3,
wherein choosing the desired wind turbine rotor speed comprises
using a look-up table,
applying a fuzzy logic routine and/or,
applying a neural network and/or,
applying logic functions and/or,
applying mathematical linear or non-linear functions.

5. Method for operating a wind turbine according to any one of preceding claims 1 to 4, the method comprising
choosing an initial desired wind turbine rotor speed to be equal to the wind turbine rotor speed threshold value.

6. Wind turbine controller being adapted for operating a wind turbine according to a method as set forth in any one of the claims 1 to 5, the wind turbine controller comprising an output for
setting the wind turbine rotor speed and/or
setting the wind turbine generator speed.

7. Wind turbine controller according to claim 6, comprising
a rate severity module,
an external constraints module,
a supervisory system module, and
a reduction module.

8. Wind turbine controller according to any one of the preceding claims 6 or 7, the wind turbine controller comprising
a memory module.

9. Wind turbine controller according to any one of the preceding claims 6 or 8, the wind turbine controller comprising an input for receiving an input signal indicative of the upper wind turbine rotor speed threshold.

10. Wind turbine comprising
a wind turbine controller according to any one of the preceding claims 6 to 8 and
at least one sensor providing the wind turbine controller with a signal indicative of a value of at least one parameter of the group consisting of
wind turbine rotor synchronization,
wind turbine noise,
wind turbine shadow flicker,
wind turbine component load,
wind turbine component lifetime consumption,
wind speed,
wind direction,
wind shear,
wind turbulence,
wind gusts,
temperature, in particular ambient temperature or wind turbine component temperature,
humidity, in particular ambient humidity or wind turbine component humidity,
air density,
blade condition, in particular ice, dirt, or other material on the blades,
demanded active power, and
demanded reactive power.

11. Program element for operating a wind turbine, the program element, when being executed by a data processor, is adapted for controlling and/or for carrying out the method as set forth in any one of the claims 1 to 5.

12. Computer readable medium on which there is stored a computer program for processing a physical object, the computer program, when being executed by a data processor, is adapted for controlling and/or for carrying out the method as set forth in any one of the claims 1 to 5.

FIG 1

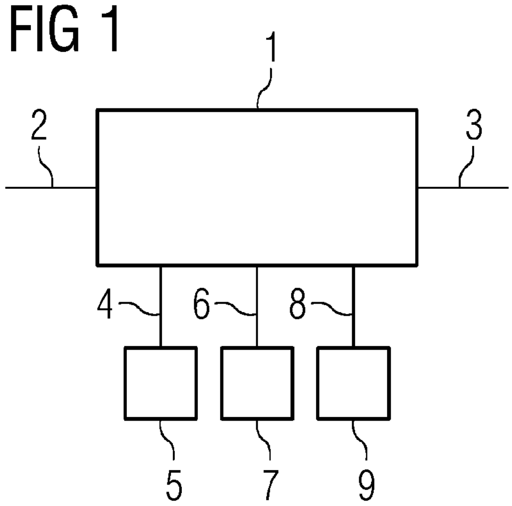
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FIG 2

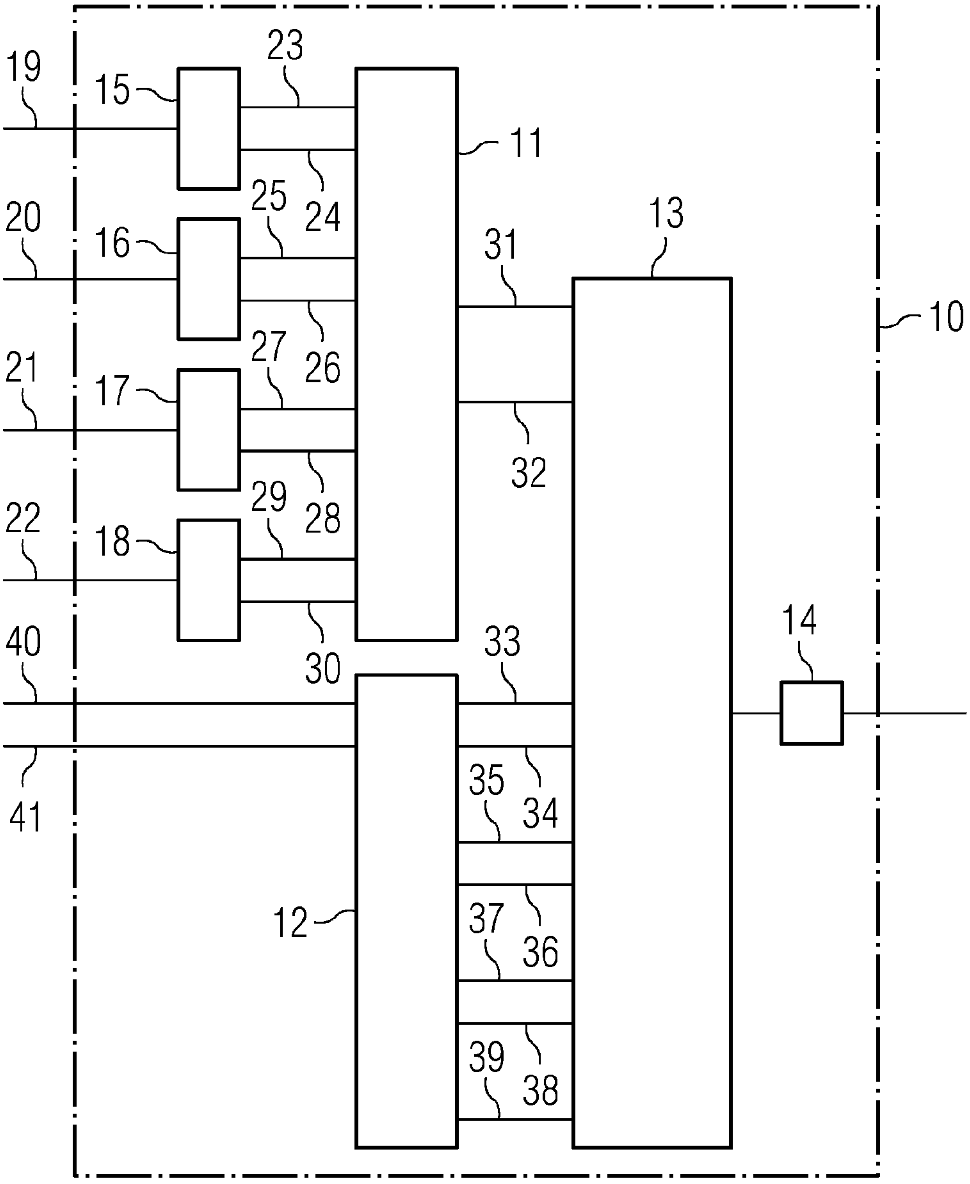
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FIG 3

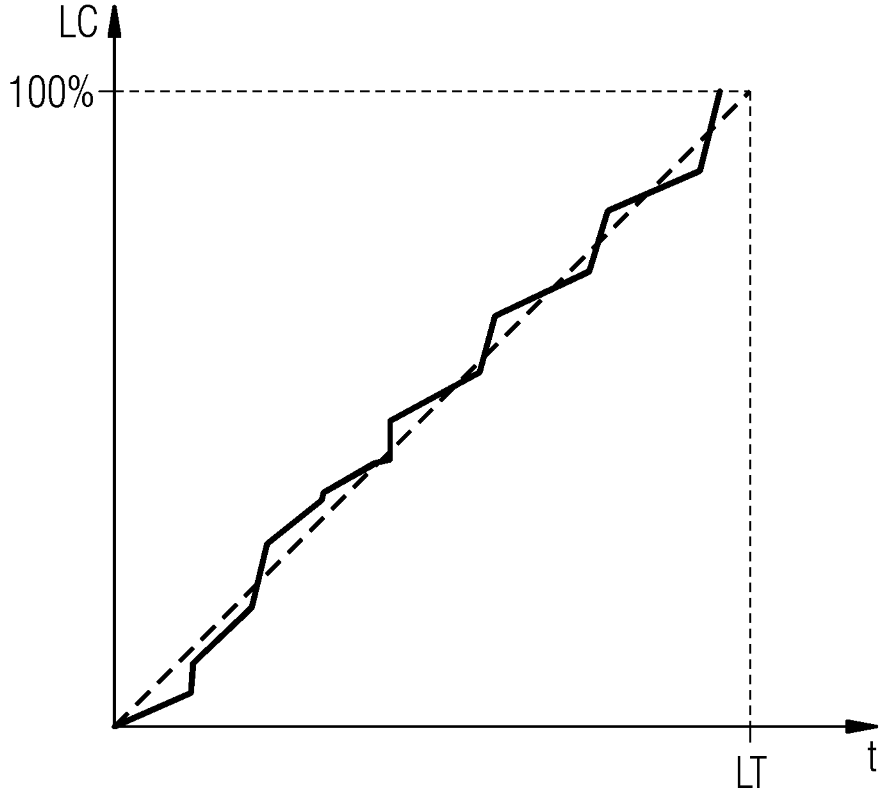
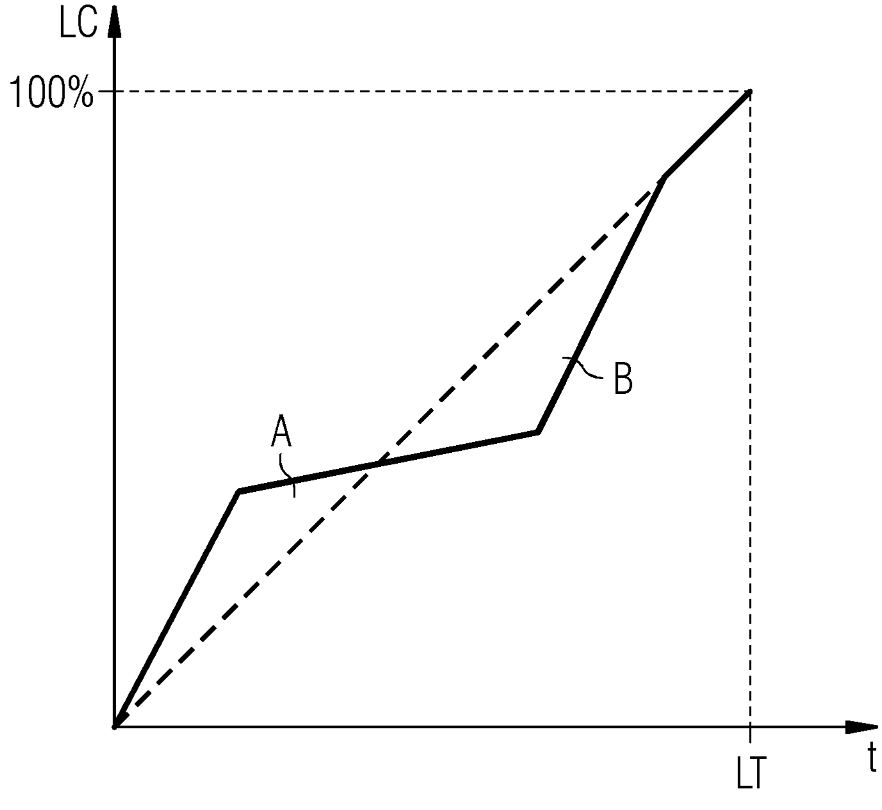


FIG 4



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/065796

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D7/02 F03D7/04
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	EP 2 128 437 A2 (GEN ELECTRIC [US]) 2 December 2009 (2009-12-02) cited in the application paragraphs [0016], [0017], [0020], [0022], [0024], [0025], [0031], [0035]; claims 1-3; figures 3-5 -----	1-12
X	US 2003/127862 A1 (WEITKAMP ROLAND [DE]) 10 July 2003 (2003-07-10) paragraphs [0016], [0025], [0026]; claims 1-13; figure -----	1-12
A	US 2010/135789 A1 (ZHENG DANIAN [US] ET AL) 3 June 2010 (2010-06-03) paragraphs [0027] - [0031], [0038] - [0040]; figures -----	1-12
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[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

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Date of the actual completion of the international search	Date of mailing of the international search report
8 October 2012	17/10/2012

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/065796

C(Continuation). 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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