(19) DANMARK

(10) **DK/EP 2759699 T3**

Patent- og Varemærkestyrelsen

(12) Oversættelse af europæisk patentskrift

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(51) Int.Cl.: ***F 03 D 9/00 (2016.01)*** ***F 03 D 7/02 (2006.01)***

(45) Oversættelsen bekendtgjort den: **2019-10-07**

(80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2019-07-17**

(86) Europæisk ansøgning nr.: **13198089.8**

(86) Europæisk indleveringsdag: **2013-12-18**

(87) Den europæiske ansøgnings publiceringsdag: **2014-07-30**

(30) Prioritet: **2013-01-28 DE 102013001368**

(84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

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(54) Benævnelse: **Vindenergisystem og fremgangsmåde til drift af et vindenergisystem**

(56) Fremdragne publikationer:
WO-A1-2012/175110
US-A1- 2012 217 824
US-A1- 2012 300 510
HONGLIN ZHOU ET AL: "Modeling, Analysis, and Control for the Rectifier of Hybrid HVdc Systems for DFIG-Based Wind Farms", IEEE TRANSACTIONS ON ENERGY CONVERSION, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, Bd. 26, Nr. 1, 1. März 2011 (2011-03-01), Seiten 340-353, XP011382789, ISSN: 0885-8969, DOI: 10.1109/TEC.2010.2096819

METHOD OF OPERATING AN OFFSHORE WINDPARK WITH A HIGH VOLTAGE DIRECT CURRENT TRANSFER STATION

The invention relates to a wind energy system, in particular an offshore wind energy system comprising a plurality of wind power turbines electrically connected to a high-voltage direct current transmission station. The invention further relates to a method for operating a wind energy system.

The demand for energy from renewable sources is constantly growing. One of the available resources here is the kinetic wind energy. A wind power turbine converts the kinetic energy of the wind by means of a rotor and a generator into electrical energy.

To maximise the electric energy yield, a wind energy system or a wind farm can be formed from a plurality of wind power turbines. The wind power turbines can be erected in particular in regions having a high probability and intensity of wind. Sites on the open sea, also called offshore regions, are particularly suitable.

Typically (see US 2012/0300510 A1 or "*Modeling, Analysis, and Control for the Rectifiers of Hybrid HVDC Systems for DFIG-Based Wind Farms*", Honglin Zhou et al., In IEEE Transactions on Energy Conversion, Vol. 26, No 1, March 2011) in a wind energy system, a plurality of wind power turbines are electrically connected to a first offshore substation. In particular, the offshore substation can be a high-voltage direct transmission station. To transmit the power generated by the wind power turbines in the form of a direct current, the high-voltage direct current transmission station is in turn connected to another substation, which is located on the mainland. This transforms the received direct current into alternating current and feeds same preferably into the public network.

Each wind energy system is designed for economic reasons always only for a maximum nominal power. For example, components of the wind energy system, such as power cables, inverters, etc. are usually designed for a maximum allowable current. Exceeding the maximum permissible current can cause damage to the inverters and/or power cables used. It is understood that different specifications can exist for different components. In particular, an overload, i.e., too high a current or too high a power, can cause damage to components.

A constant concern here is to operate the wind energy system to the extent possible with this maximum nominal power to maximise the energy yield. In other words, as close as possible the maximum allowable current should be generated and transmitted to the public network by means of the high-voltage direct current transmission station.

To achieve this, it is known from the prior art to adapt the blade angle of the rotor blades of a wind power turbine to the (current) meteorological conditions, in particular to the current wind force. A wind power turbine has at least one suitable actuator device for adjusting the blade angle of the rotor blades. Such an actuator device for adjusting the rotor blade angle controls, for example, depending on the measured generator speed, the angle of attack of the air on the rotor blade and thus controls the speed caused by the aerodynamic buoyancy of the rotor. If an upper or lower speed limit is exceeded, this can be counteracted by means of the actuator device.

To prevent an overload of the wind energy system, for example an overload power and/or an overload current, the rotational speed is monitored at the generator. If an overspeed is detected, the actuator device is adjusted accordingly. This control concept implies a certain speed variability of wind power turbines, since the actuator devices for the blade angle adjustment only intervene when an overspeed is detected on the generator.

The problem with this control is, in particular, the lag of the actuator devices (several seconds), which under certain conditions does not allow a timely regulation to avoid damage due to overload. For example, due to a short circuit but also in strong winds with simultaneously occurring gustiness, overshoots above the permissible rated power can occur which lead to an overload and damage to the wind energy system, since a timely control with the above-described control concept is not sufficiently possible.

Under an overload or overloading of the wind energy system is to be understood in particular as an electrical overload of at least one component of the wind energy system. Such overload can lead to a failure of the component and thus to a failure of the network connection. This is the case in particular when a component of the high-voltage direct current transmission is affected, such as the converter system. A renewed start after starting the protection system and/or a repair, especially in an offshore wind energy system is/are associated with a high expenditure of effort and corresponding costs.

To solve this problem, it is known from the prior art to throttle the wind power turbines, for example, in strong winds by a blanket, predetermined value. In particular, the wind power turbines are throttled in such a way that even a short-term increase in the power and thus of the electricity generated by the wind power turbines, for example due to a gust of wind, does not lead to an overload of the wind energy system. However, a blanket and stationary throttling of individual wind power turbines is disadvantageous for economic reasons. In particular, such throttling should at least be reduced.

The invention is therefore based on the object to provide a wind energy system and a method for operating a wind energy system which enables safe operation while maximising power output.

The object is attained according to the invention with a wind energy system, in particular an offshore wind energy system, according to patent claim 1. The wind energy system comprises a plurality of wind power turbines which are

electrically connected to a high-voltage direct current transmission station. At least one overload detection device is provided for detecting an overload of the wind energy system. At least one control device is provided for triggering at least one overload reduction circuit at least when an overload is detected. The overload reduction circuit is arranged such that upon triggering the overload reduction circuit, at least the current received at the high-voltage direct current transmission station is reduced.

In contrast to the prior art, high operational reliability can be ensured such that an overload is detected by an overload reduction circuit and is dissipated/eliminated in a timely manner. By detecting an overload, the overload reduction circuit dissipates the overload in particular by a power reduction when, where it is not necessary to effect a blanket throttling of one or more wind power turbines even with strong wind and risk of wind gusts. The energy yield can be increased while increasing reliability.

The wind energy system or wind farm can in particular be an offshore wind energy system. A plurality of wind power turbines can be connected to one another by means of an energy cable network comprising a plurality of energy cables. A wind power turbine converts the kinetic energy of the wind into electrical energy by means of a rotor and a generator.

The wind power turbines are electrically connected to a high-voltage direct current transmission station via the power cable network. In other words, the power generated by the wind power turbines is transmitted to the high-voltage direct current transmission station for further transmission. The wind energy system can also include several wind power turbines from different wind farms, the wind power turbines being electrically connected to the same high-voltage direct current transmission station,

A high-voltage direct current transmission station, in particular an offshore high-voltage direct current transmission station, has at least one current conversion device to transform the received current. The received current is the (alternating) current generated by the plurality of wind power turbines.

Furthermore, at least one overload detection device is provided for detecting an overload. The overload detection device can be arranged, for example, on the high-voltage direct current transmission station. Alternatively or additionally, one, preferably each wind power turbine can have an overload detection device.

If an overload, such as an unacceptably high current in the network of the wind energy system, an impermissible voltage in the network of the wind energy system, an unacceptable power in the network of the wind energy system or an impermissible high speed of one or more generators is detected, a control device controls an overload reduction circuit. The overload reduction circuit is configured to prevent at least an overload of the wind energy system by discharging an overload current. Thus, it has been recognised that the critical components that can be damaged in an overload in a wind energy system are typically components of the high-voltage direct current transmission station. Therefore, according to the invention, the current received by the high-voltage direct current transmission station is reduced by the overload reduction circuit.

By the overload reduction circuit reducing the received current in the case of an overload, damage to the wind energy system can be prevented. There is no blanket throttling or only a little blanket throttling of wind power turbines required.
Overshoots can be reduced. A maximum energy yield can be generated even in strong winds with gusts of wind.

The overload reduction circuit can be located at the high-voltage direct current transmission station, for example in front of a current conversion device, and/or at one, preferably at all of the wind power turbine(s). It is understood that the at least one overload reduction circuit can also be arranged between the high-voltage direct current transmission station and the wind power turbines, for example at an optional interposed substation.

The overload detection device can further preferably detect when the overload condition is no longer present. Then, the overload reduction circuit can be controlled accordingly by the control device and deactivated again.

The detection of an overload can basically be done in different ways. According to a first embodiment of the wind energy system according to the invention, the overload detection device can be set up to detect at least one electrical grid parameter of the wind energy system. The overload detection device can be configured to detect an overload of the wind energy system by comparing the measured network parameter with a predetermined network parameter limit value. The electrical grid parameter is, in particular, a grid parameter that is indicative of an overload of the wind energy system. For example, a (current) mains current, a (current) mains voltage and/or a (current) mains power of the wind energy system can be detected. In particular, at least one suitable measuring device can be provided for this purpose.

The detected network parameter is preferably compared with a network parameter limit value. The network parameter limit value specifies the maximum permissible value of the measured network parameter. If the grid parameter limit is exceeded, an overload is present in the wind energy system. A corresponding overload detection has the advantage that an overload can be detected extremely rapidly (between 10 ms and 1 s) and exactly.

The at least one network parameter detected by the overload detection device can be, for example, the currently generated power or a current mains voltage. According to a preferred embodiment, the overload detection device can be set up to measure the current generated by at least one wind power turbine as a network parameter. In particular, the overload detection device can measure the power generated by each wind power turbine. For example, a corresponding overload detection device can be available for each wind power turbine. For measuring the current, the overload detection device can have a suitable measuring device. From the sum of all the measured current values, the current received at the high-voltage direct current transmission station can then preferably be calculated.

Alternatively or additionally, the overload detection means can be arranged to measure the current received at the high-voltage direct current transmission station as a network parameter. For example, the high-voltage direct current transmission station can have an overload detection device.

It is understood that a plurality of different network parameters can be measured and compared with corresponding network parameter limits. An overload can be detected very reliably. Possible measurement errors can be detected.

In a further embodiment of the wind energy system according to the invention, the overload reduction circuit can have at least one switchable load. For example, a grounded resistor can be provided.
The resistor can be connected via a suitable switching device with a power cable. When an overload is detected, closing the switching device can dissipate an overload current across the load. This allows a particularly rapid control. To avoid excessive voltage dips, in particular a plurality of loads can be provided which can be connected in stages.

Alternatively or in addition to a switchable load, the overload reduction circuit can be a chopper circuit. A chopper circuit can be controlled so that an overload current is dissipated.

Moreover, alternatively or additionally, the overload reduction circuit can be a voltage boost circuit. A voltage boost circuit is adapted to increase the mains voltage with constant network power, in particular at the high-voltage direct current transmission station. With constant network power and increased mains voltage, the received current is reduced. For example, the voltage boost circuit can feed reactive power into the grid of the wind energy system to increase the voltage.

The control device can preferably be a power-electronic control device, wherein the power-electronic control device is set up in particular for the pulsed control of the at least one load. Voltage jumps can be reduced through a pulsed control. An accurate derivation or reduction of (only) the overload current is possible. The exact value of the overload current to be dissipated can be determined, for example, as a function of the result of the comparison of a measured network parameter and network parameter limit value by the control device.

Furthermore, it has been recognised that a chopper circuit already arranged in a wind power turbine can be used as an overload reduction circuit. According to one embodiment, the chopper circuit can be a chopper circuit provided in the direct current intermediate circuit of a wind power turbine. To prevent damage to the already provided chopper circuit in the event of a required overload discharge, the chopper circuit can preferably be modified accordingly and in particular have components with a higher current carrying capacity. Alternatively or additionally, the components can have a longer current carrying capacity.

The wind energy system according to a further embodiment of the invention can comprise at least one wind detection device, wherein the wind detection device can be configured to detect at least one wind parameter at a predetermined distance from at least one wind power turbine. The wind detection device can be configured to transmit the detected wind parameter to the control device. For example, a wind detection device can be arranged at least 200 m in front of the next wind power turbine. It is understood that several wind detection devices can be arranged at different distances to different wind power turbines. As wind parameters, for example, the wind speed and/or wind direction can be detected. The at least one detected wind parameter can be transmitted to the control unit via a communications channel. As a result, the control device can be informed in a timely manner about a possibly imminent overload situation, for example, due to a detected change in wind speed. The control device can then take appropriate countermeasures. Thus, the triggering of an overload reduction circuit can be prepared at least by the control device. The available control time can be extended.

Preferably, at least one wind power turbine can have at least one actuator device for adjusting a rotor blade angle of the wind power turbine. The actuator device can be set up to adjust the rotor blade angle as a function of the detected wind parameter. This can (additionally) preventively reduce the generated power and thus reduce the current received at the high-voltage direct current transmission station. In particular, overload peaks that arise, such as current peaks, can be reduced.

It can also be provided that the turbine is switched off preventively by at least one wind power turbine. It is understood that a plurality of turbines can be deactivated in advance of expected current peaks.

In particular, for the wind energy system, such as a wind farm, the power set point can be adjusted accordingly. The individual wind power turbines can then be regulated according to the power set point. This can, as already described, proceed up to the shutdown of turbines. For example, the set point specification can be an internal specification of the wind energy system and/or an external specification, such as from a network operator and/or an adjacent wind energy system, such as another wind farm. Thus, preferably at least two wind energy systems can be connected to one another via a communication network and exchange messages. In particular, the central control devices of the wind energy systems can be coupled to one another. Preferably, a plurality of wind power systems can communicate with each other and exchange data such as actual power data and target power data. Thus, the control device can be set up to transmit actual power data and target power data to at least one further control device of another wind energy system and/or to receive the actual power data and target power data from at least one further control device of another wind energy system. It is already possible to react in advance to expected current peaks or overshoots.

The shutdown of turbines, for example, already take place (as a precaution) when the limit of the HVDC capacity is achieved by the connected wind energy systems together. The informative cooperation on the availability of the wind energy systems or wind farms and thus the entire power supply can thus be used for optimal utilisation of the maximum connection capacity without causing capacity overruns.

In addition, it can preferably be provided that only when enough wind turbines or wind power turbines are on the grid, that is are activated, will a regulation or a power reduction as described above be possible. Thus, it is conceivable that the wind energy system is set up (together with at least one neighbouring wind farm) to perform an online detection of operational wind power turbines. A previously described control can only be activated if all or a (specifiable) critical number of active wind power turbines is exceeded. The control device can for example be deactivated until a critical number of active wind power turbines is exceeded. This reduces the energy consumption for monitoring.

According to a further embodiment, the at least one wind detection device can be at least one LIDAR (Laser Imaging Detection and Ranging) system or at least one wind measurement mast. Preferably, at least one wind power turbine, preferably each wind power turbine, can comprise a LIDAR system. With this wind detection device, for example, the wind speed and/or the wind direction at a certain distance from the respective wind power turbine, for example 100 to 500 m, in particular 200 m, are measured in front of the wind power turbine. This allows wind gusts to be detected in advance. Additionally or alternatively to the LIDAR system, at least one wind measuring mast can be provided.

By means of the overload detection device and overload reduction device described above, a control can be carried out within less than 100 ms, in particular less than 50 ms, particularly preferably less than 10 ms. Immediate damage to the components of the high-voltage direct current transmission station can be prevented. In particular, damage to the converter circuit, which preferably has bipolar transistors with insulated gate electrodes (i.e., insulated gate bipolar transistor, or IGBT), can be prevented. Nevertheless, the IGBTs can be strongly heated and overloaded by the current overload current. If the maximum permissible current flows immediately after a heating which does not lead to damage, i.e., after deactivation of the overload reduction circuit, damage can occur in the event of a further, contemporaneous overload situation due to the still intense heating. In particular to enable a cooling of the IGBTs after an overload situation, according to a further embodiment of the wind energy system according to the invention, the control device can be set up to control the at least one actuator device after detection of an overload of the wind energy system to adjust the rotor blade angle for a predefinable time duration such that the power generated by the wind power turbine is reduced. The time duration can in particular depend on the amount and/or duration of the overload. By reducing the power and the concomitant reduced current for a certain period of time, in particular, the IGBTs can be cooled down to a normal temperature. The risk of damage due to a plurality of wind gusts occurring in quick succession can be reduced.

Another aspect of the invention is a method for operating a wind energy system, in particular an offshore wind energy system, according to claim 10. The wind energy system, in particular a previously described wind energy system, has a plurality of wind power turbines electrically connected to a high-voltage direct current transmission station. The method comprises the steps:

- Detecting an overload of the wind energy system, and
- Triggering an overload reduction circuit upon detection of an overload,
- wherein upon triggering of the overload reduction circuit, at least the current received at the high-voltage direct current transmission station is reduced by the overload reduction circuit.

By the overload reduction circuit reducing the received current in case of overload, damage to the wind energy system can be prevented. No blanket throttling or only a slight blanket throttling of wind power turbines is required. Overshoots can be reduced. A maximum energy yield can be generated even in strong winds with gusts of wind.

The features of the methods and devices can be freely combined with one another. In particular, features of the description and/or of the dependent claims can be independently inventive in isolation or freely combined with one another, also by completely or partially avoiding features of the independent claims.

There are now many options for designing and further developing the wind energy system according to the invention and the method according to the invention for operating a wind energy system. In this regard, reference is made, on the one hand, to the patent claims subordinate to the independent patent claims, and, on the other hand, to the description of exemplary embodiments in conjunction with the drawing. Brief description of the drawings:

Fig. 1 shows a schematic view of a first exemplary embodiment of a wind energy system according to the present invention,

Fig. 2 shows a schematic view of an exemplary embodiment of a wind power turbine for a wind energy system according to Fig. 1,

Fig. 3 shows a schematic view of an exemplary embodiment of an overload reduction circuit according to the present invention, and

Fig. 4 shows a flow chart of an exemplary embodiment of a method for operating a wind energy system according to the present invention.

The same reference signs are used below for the same elements.

Figure 1 shows a schematic view of a first exemplary embodiment of a wind energy system 2 according to the present invention. In the present exemplary embodiment, in particular, an offshore wind energy system 2 is shown.

The illustrated offshore wind energy system 2 comprises a plurality of offshore wind power turbines 4. The offshore wind power turbines 4 are set up to convert the wind energy into electrical energy. In particular, an alternating current is generated by a wind power turbine 4 through a generator device.

Further, the offshore wind energy system 2 comprises a high-voltage direct current transmission station 6. The wind power turbines 4 and the high-voltage direct current transmission station 6 are electrically connected to one another via a plurality of undersea cables 8. It is understood that between the high-voltage direct current transmission station 6 and the wind power turbines 4 can be interposed more substations, for example, for the transformation of one voltage level to another voltage level.

An undersea cable 8 is designed to transmit electrical energy generated by a wind power turbine 4 to the next wind power turbine 4 or to the high-voltage direct current transmission station 6.

In the present exemplary embodiment, a plurality of wind power turbines 4 are connected in series in a plurality of lines 12 or strings 12. For example, eight lines can be provided, each comprising six wind power turbines.

In the present case, only two lines 12, each comprising three wind power turbines 4, are illustrated to provide a better overview. One end of a line 12 is electrically connected to the high-voltage direct current transmission station 6 via an undersea cable 8. The two other ends can be connected to each other via an additional undersea cable (not shown). Furthermore, a line can optionally be connected to a plurality of other lines. Naturally, according to other embodiments of the invention, the wind power turbines can also be arranged in ring structures.

The high-voltage direct current transmission station 6 is in particular configured to transform an alternating current generated by the wind power turbines 4. An alternating current can be transformed into a direct current for transmission over a long distance. The illustrated high-voltage direct current transmission station 6 has at least one current conversion device 18 for this purpose. The current conversion device 18 is configured to transform the received alternating current into a direct current for high-voltage direct current transmission. Preferably, the current converter device 18 has IGBTs for this purpose. IGBTs have proven to be particularly efficient in transforming high-voltages and currents.

In addition to at least one current conversion device 18, the high-voltage direct current transmission station 6 in the present exemplary embodiment, has at least one overload detection device 20. The overload detection device 20 is configured to detect an overload of the wind energy system 2. In particular, an electrical grid parameter of the wind energy system which is indicative of an overload can be measured. For example, the overload detection device 20 can comprise a device for power measurement and/or voltage measurement. Alternatively or additionally, the current received by the high-voltage direct current transmission station 6, i.e., the current generated by and transmitted to the wind power turbines 4 connected to the high-voltage direct current transmission station 6, can be measured. In other words, the current can be detected (directly) in front of the converter installation 18. The measurement(s) preferably takes place at least almost continuously.

To detect an overload, the present overload detection device 20 is set up to compare the detected network parameter, such as the mentioned current, with a predefined network parameter limit value, such as a maximum permissible current value. For example, the network parameter limit can be based on (previously performed) tests, simulations, and/or manufacturer information. An overload is detected in particular if the network parameter limit value is exceeded (or undershot).

It has been recognised that in a current conversion device 18 constructed from IGBTs, the overload depends in particular on the current carrying capacity of the IGBTs. IGBTs can already be damaged if the maximum permissible current is temporarily exceeded. Other components of the wind energy system are generally less prone to short-term power, especially current spikes.

It is understood that more than two network parameter limits can be specified. In addition to the received power, for example, a maximum allowable power can be specified. Furthermore, it is understood that other components of the wind energy system, such as undersea cables, etc., can be decisive for the determination of the at least one network parameter limit value. For example, when no IGBTs are used as power converters.

It is also understood that according to other variants of the invention, multiple overload detection devices can be arranged alternatively or additionally at a different position in the wind energy system 2, for example, in each case one in/on a wind power turbine 4.

In addition,

high-voltage direct current transmission station 6 in the present case comprises a control device 22. The (central) control device 22, in particular a power electronic control device 22, can have a communication connection with the overload detection device 20. As a result, the overload detection device 20 can notify the control device 22 (directly) of a detected overload. Also, both devices 20, 22 can be implemented in a single device.

In the illustrated exemplary embodiment, the high-voltage direct current transmission station 6 further comprises an overload reduction circuit 24. The overload reduction circuit 24 is (directly) triggerable by the control device 22. This has the advantage that the overload reduction circuit 24 can be activated immediately upon detection of an overload. As a result, a current reduction can be effected within a few ms, for example within 10 ms.

The overload reduction circuit 24 is configured to reduce at least the current received by the high-voltage direct current transmission station 6. In particular, at least part of the current can be dissipated or the current can be reduced by a voltage increase. Possible embodiments of an overload reduction circuit 24 are explained below. In principle, the reduction of the current could also be achieved by deriving a current (or increasing the voltage) at another position of the wind energy system 2, such as at a wind power turbine 4 or an intermediate substation (not shown).

As can also be seen from Figure 1, communication connections 26 are provided between the wind power turbines 4 and the high-voltage direct current transmission station 6, in particular the control device 22. The communication links 26 can be wireless and/or wired connections.

The high-voltage direct current transmission station 6 is in turn electrically connected to a further substation 14 preferably arranged on the mainland. In the present exemplary embodiment, two power cables 10 are provided. The further substation 14 is adapted to convert the received direct current back into a suitable alternating current and then feed it into the public power mains 16.

Finally, in the present exemplary embodiment, a wind detection device 28 in the form of a wind measuring mast 28 is shown. A wind measuring mast 28 can be arranged to detect at least one wind parameter, such as the wind speed or the wind direction. In particular, the wind gauge mast 28 can have devices for measuring wind speed (anemometers) and direction (anemoscopes).

The wind measuring mast 28 is arranged at a certain distance from (all) wind power turbines. This distance makes it possible, for example, to detect a (sudden) increase in the wind strength in the form of a gust of wind before it arrives at the wind power turbines 4. As a result, an overload of the wind energy system can be at least subsequently be reduced, as explained below.

The wind measuring mast 28 is connected to the control device 22 via a communication link 26 to the high-voltage direct current transmission station 6 for transmitting the wind parameter. In particular, the at least one detected wind parameter can be made available to the control device 22.

Figure 2 shows a more detailed schematic view of an exemplary embodiment of a wind power turbine 4, which can be used in the wind energy system 2 described above.

The illustrated wind power turbine 4 has a rotor with a plurality of rotor blades 30. A generator 40 is in operative connection with the rotor for generating electrical energy. The generated power is supplied to a DC intermediate circuit 42 of the wind power turbine 4.

A DC intermediate circuit 42 of a wind power turbine 4 usually already comprises a chopper circuit 44. It has been recognised that this chopper circuit 44 can be used as an overload reduction circuit. Preferably, the chopper circuit 44 should be modified such that a larger amount of current can be dissipated without damaging the chopper circuit 44.

For triggering the chopper circuit 44, this can be connected via a (central) control device 22, which can be arranged for example at the high-voltage direct current transmission station 6 via the communication channel 26.

In addition, the wind power turbine 4 comprises a control device 20.1. This can measure, for example, the electricity generated by the wind power turbine 4. For example, the overload detection device 20.1 can detect an overload by means of a comparison operation described above. The detected overload can be transmitted directly to the control device 22 via the communication channel 26. Also, the overload detection device 20.1 can (additionally) comprise a further control device (not shown), which can be configured to directly control the chopper circuit 44. A particularly rapid control can be achieved.

It can also be provided that the overload detection device 24.1 is designed only as a measuring device 24.1. The detected current value can be provided to a higher-level further overload detection device 24 for determining an overload in a previously described manner. In particular, in this case all wind power turbines 4 can each have at least one corresponding measuring device 24.1, which are connected to the further higher-level overload detection device 24. In this case, the entire current generated in the wind energy system 2 can be taken into account. In the event of an overload, one or more chopper circuits can be triggered by one or more wind power turbines. As already described, an overload detection can also take place at another position in the wind energy system 2.

For controlling the speed of the rotor of the wind power turbine 4 caused by the aerodynamic buoyancy forces, the rotor blade angle can be adjusted by an actuator device 32 comprising at least one actuator 34, such as a motor, and a controller 36. In particular, the power or the current generated by the wind power turbine 4 can thereby be regulated.

Furthermore, a wind detection device 38 is provided. The wind detection device 38 can in particular be a LIDAR (Laser Imaging Detection and Ranging) system. With this wind detection device 38, wind speed and/or wind direction at a certain distance, for example 100 to 500 m, in particular 200 m, are measured in front of the wind power turbine 4. As a result, wind gusts can be detected in advance. The advantage of an earlier detection is the associated longer available control times. In addition, for example, upon detection of a significant wind change, the actuator can (additionally) adjust the rotor blade angle for the (temporary) power reduction. Also, based on the detected wind parameters, the wind power turbine 4 can be permanently throttled or even switched off.

The detected wind parameters can further be provided to a control device 22, which can be arranged, for example, at the high-voltage direct current transmission station 6.

The LIDAR system 38 can be provided alternatively or in additionally to the at least one wind gauge mast 28.

It is understood that in the illustrated wind power turbine 4, for reasons of clarity, only the relevant components of a wind power turbine 4 of the present invention are shown and, for example, other components, such as transmission, brake, etc., are not shown.

Figure 3 shows an exemplary embodiment of an overload reduction circuit 24.2 according to the present invention. In this case, the overload reduction circuit 24.2 is arranged, in particular, at the high-voltage direct current transmission station 6 in front of the current conversion device 18, that is, on the alternating current side.

The overload reduction circuit 24. 2 comprises a load 48. The load is in particular a grounded resistor 48. In addition, a switching device 50 is provided. This switching device 50 can be controlled by the control device 22, for example.

Upon detection of an overload, the switching device 50 is closed due to a triggering signal. Of the current received from the high-voltage direct current transmission station 6, a partial current can be dissipated. An overload can be avoided, in particular in the current conversion device 18. If the overload situation no longer exists, for example, the wind gust has passed, the switching device 50 can be opened again. To avoid excessive voltage jumps, stepped load arrangements can be used and/or a pulsed control of the power electronics can be provided. In particular, the control device 22 can be configured to determine the amount of current to be dissipated, for example as a function of the comparison of the measured network parameter and with the predetermined network parameter limit value, which is at least and in particular also at most required to avoid an overload. Accordingly, a stepped load can be triggered and/or a pulsed triggering signal can be generated. Only the overload current can be dissipated.

Figure 4 shows a flowchart of an exemplary embodiment of a method according to the present invention for operating a wind energy system, such as the offshore wind energy system 2 described above.

In a first step 401, for example, wind parameters can be detected to prevent an overload. This can be done for example by a wind measuring mast 28 and/or a LIDAR system 38. Preferably, a continuous wind measurement of both the wind speed and the wind direction takes place.

If a significant wind change is detected in step 402, for example a wind increase as a result of a gust of wind, then the power generated by the wind power turbine(s) 4 can already be reduced by changing the rotor blade angle of one or more wind power turbines 4. Also, corresponding information can be passed to the controller 22 to prepare for triggering the overload reduction circuit 24 or to (preventively) trigger the overload reduction circuit 24 (see also subsequent step 404).

Preferably, parallel to the wind measurement in step 401, the load of the wind energy system 2 can be monitored in step 403 by at least one overload detection device 20. For example, the current generated by all wind power turbines can be continuously measured.

If, in step 403, an overload condition such as a maximum permissible current is exceeded, countermeasures can be taken immediately in step 404, and at least the current received at the high-voltage direct current transmission station 6 can be reduced.

For example, in a step 404.1, a shiftable load 48 can be triggered by a control device 22 (directly) upon detection of an overload. If a step-shaped load arrangement is provided, the discharged current quantity can be regulated, for example as a function of the detected overload, in particular as a function of a quantitative difference between the network parameter limit value and the measured network parameter, such that only enough current is dissipated to avoid an overload.

Alternatively or additionally, a chopper circuit 44, for example a (modified) chopper circuit 44 of one or more, for example, all wind power turbines 4, and/or a chopper circuit additionally installed in the wind energy system 2, for example, a chopper circuit arranged at the high-voltage direct current transmission station 6, is triggered by a control device 22 (immediately) upon detection of an overload (step 404.2).

Moreover, as an alternative or in addition to the overload reduction circuits described above, in a step 404.3 the current can at least be reduced by means of a voltage boost circuit. The use of a rapid voltage increase on the AC side of the high-voltage direct current transmission station 6 upon detection of exceeding of a maximum permissible current can lead to a reduction in current at constant power through a corresponding increase in voltage. For example, the voltage boost circuit can be configured to feed additional reactive power into the network of the wind energy system 2.

The overload reduction circuits previously described in steps 404.1 to 404.3 can also be controlled by a control device 22 as a precaution when detecting certain wind conditions (see step 402).

If it is detected in step 405, for example by the overload detection device 20, that there is no longer an overload of the wind energy system 2, for example by undershooting a determinable further network parameter limit value, any activated overload reduction circuit can be deactivated again in this step. It is understood that this can be done gradually.

Since undesired heating of, for example, the IGBTs of the power converter arrangement 18 can have occurred despite an immediate control in the event of an overload, a cooling of the IGBTs can be achieved by a temporary power reduction of the wind energy system. For example, in step 405, the control device 22 triggers at least one actuator device 32 to adjust the rotor blade angle of a wind power turbine 4 such that the generated power is reduced at least for a predefinable period of time. In other words, the wind energy system is operated at a lower rated power for a certain period of time.

Vindenergisystem og fremgangsmåde til drift af et vindenergisystem

PATENTKRAV

1. Vindenergisystem (2), særligt offshore-vindenergisystem (2), der omfatter en flerhed af vindkraftanlæg (4), der er elektrisk forbundet med en højspændings-jævnstrømstransmissionsstation (6), **kendetegnet ved, at**

- der er tilvejebragt mindst én overbelastningsregistreringsanordning (20, 20.1) til detektering af en overbelastning i vindenergisystemet (2), og
- der er tilvejebragt mindst én styreanordning (22) til aktivering af mindst ét overbelastningsreduktionskredsløb (24, 24.2, 44) i det mindste ved detektering af overbelastningen,
- hvor overbelastningsreduktionskredsløbet (24, 24.2, 44) er indrettet på sådan, at i det mindste strømmen, der modtages ved højspændings-jævnstrømstransmissionsstationen (6), reduceres ved en aktivering af overbelastningsreduktionskredsløbet (24, 24.2, 44).

2. Vindenergisystem (2) ifølge krav 1, **kendetegnet ved, at**

- overbelastningsregistreringsanordningen (20, 20.1) er indrettet til at registrere i det mindste én elektrisk netparameter i vindenergisystemet (2), og
- overbelastningsregistreringsanordningen (20, 20.1) er indrettet til at detektere en overbelastning i vindenergisystemet (2) ved hjælp af en sammenligning af den målte netparameter med en forudbestemt netparametergrænseværdi.

3. Vindenergisystem (2) ifølge krav 2, **kendetegnet ved, at**

- overbelastningsregistreringsanordningen (20.1) er indrettet til som netparameter at måle den producerede strøm fra mindst ét vindkraftanlæg (4),

og/eller

- overbelastningsregistreringsanordningen (20) er indrettet til som netparameter at måle strømmen, der modtages ved højspændings-jævnstrømstransmissionsstationen (6).

4. Vindenergisystem (2) ifølge et af de foregående krav, **kendetegnet ved, at**

- overbelastningsreduktionskredsløbet (24, 24.2) indeholder en last (48), der kan tilkobles, særligt en flerhed af laster, der kan tilkobles trinvist,

og/eller

- overbelastningsreduktionskredsløbet (24, 44) er et chopperkredsløb (44),

og/eller

- overbelastningsreduktionskredsløbet (24) er et spændingsforøgelseskredsløb.

5. Vindenergisystem (2) ifølge krav 4, **kendetegnet ved, at** styreanordningen (22) er en effektelektronik-styreanordning (22), hvor effektelektronik-styreanordningen (22) særligt er indrettet til pulset aktivering af den i det mindste ene last (48), der kan tilkobles.

6. Vindenergisystem (2) ifølge krav 4 eller 5, **kendetegnet ved, at** chopperkredsløbet (44) er et chopperkredsløb (44), der er tilvejebragt i vekselstrømsmellemkredsen (42) i et vindkraftanlæg (4).

7. Vindenergisystem (2) ifølge et af de foregående krav, **kendetegnet ved, at**

- vindenergisystemet (2) omfatter mindst én vindregistreringsanordning (28, 38),
- hvor vindregistreringsanordningen (28, 38) er indrettet til at registrere mindst én vindparameter i en forudbestemt afstand til mindst ét vindkraftanlæg (4), og
- hvor vindregistreringsanordningen (28, 38) er indrettet til at overføre den registrerede vindparameter til styreanordningen (22).

8. Vindenergisystem (2) ifølge krav 7, **kendetegnet ved, at**

- mindst ét vindkraftanlæg (4) udviser mindst én aktuatoranordning (32) til indstilling af en rotorbladvinkel i vindkraftanlægget (4),
- hvor aktuatoranordningen (32) er indrettet til at indstille rotorbladvinklen som funktion af den registrerede vindparameter.

9. Vindenergisystem (2) ifølge et af de foregående krav, **kendetegnet ved, at** styreanordningen (22) er indrettet til ved detektering af en overbelastning i vindenergisystemet (2) at aktivere mindst én aktuatoranordning (32) for at indstille rotorbladvinklen i et forudbestemt tidsrum sådan, at den producerede effekt fra vindkraftanlægget (4) reduceres.

10. Vindenergisystem (2) ifølge et af de foregående krav, kendetegnet ved, at styreanordningen (22) er indrettet til at modtage effektdata fra mindst ét yderligere vindenergisystem, og at styreanordningen (22) er indrettet til som funktion af effektdataene (22) at deaktivere mindst ét vindkraftanlæg (4).

11. Fremgangsmåde til drift af et vindenergisystem (2), særligt et offshore-vindenergisystem (2), hvor vindenergisystemet (2) indeholder en flerhed af vindkraftanlæg (4), der er elektrisk forbundet med en højspændings-jævnstrømstransmissionsstation (6), omfattende:

- detektering af overbelastningen i vindenergisystemet (2) og
- aktivering af et overbelastningsreduktionskredsløb (24, 24.2, 44) ved detektering af overbelastningen,
- hvor i det mindste strømmen, der modtages ved højspændings-jævnstrømstransmissionsstationen (6), reduceres ved en aktivering af overbelastningsreduktionskredsløbet (24, 24.2, 44) ved hjælp af overbelastningsreduktionskredsløbet (24, 24.2, 44).

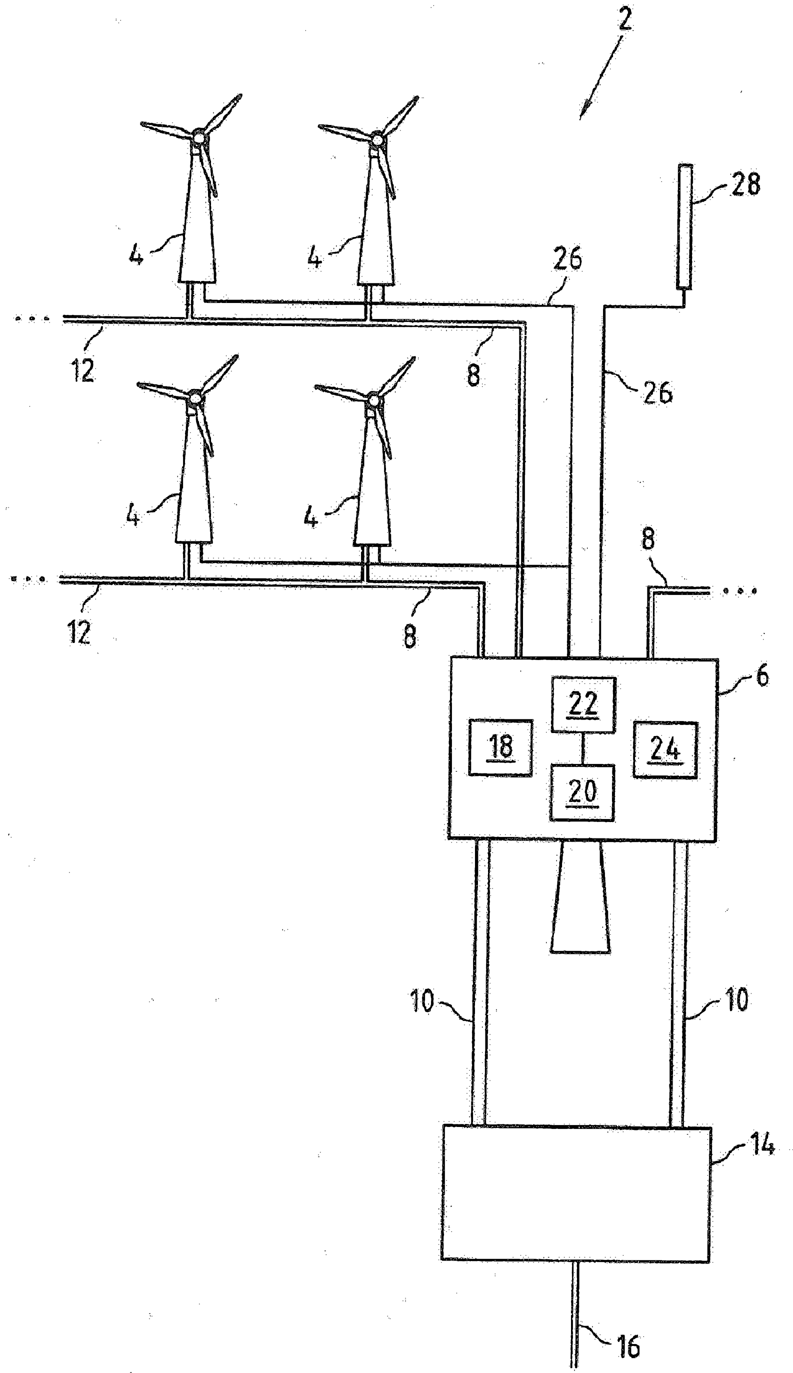

Fig.1

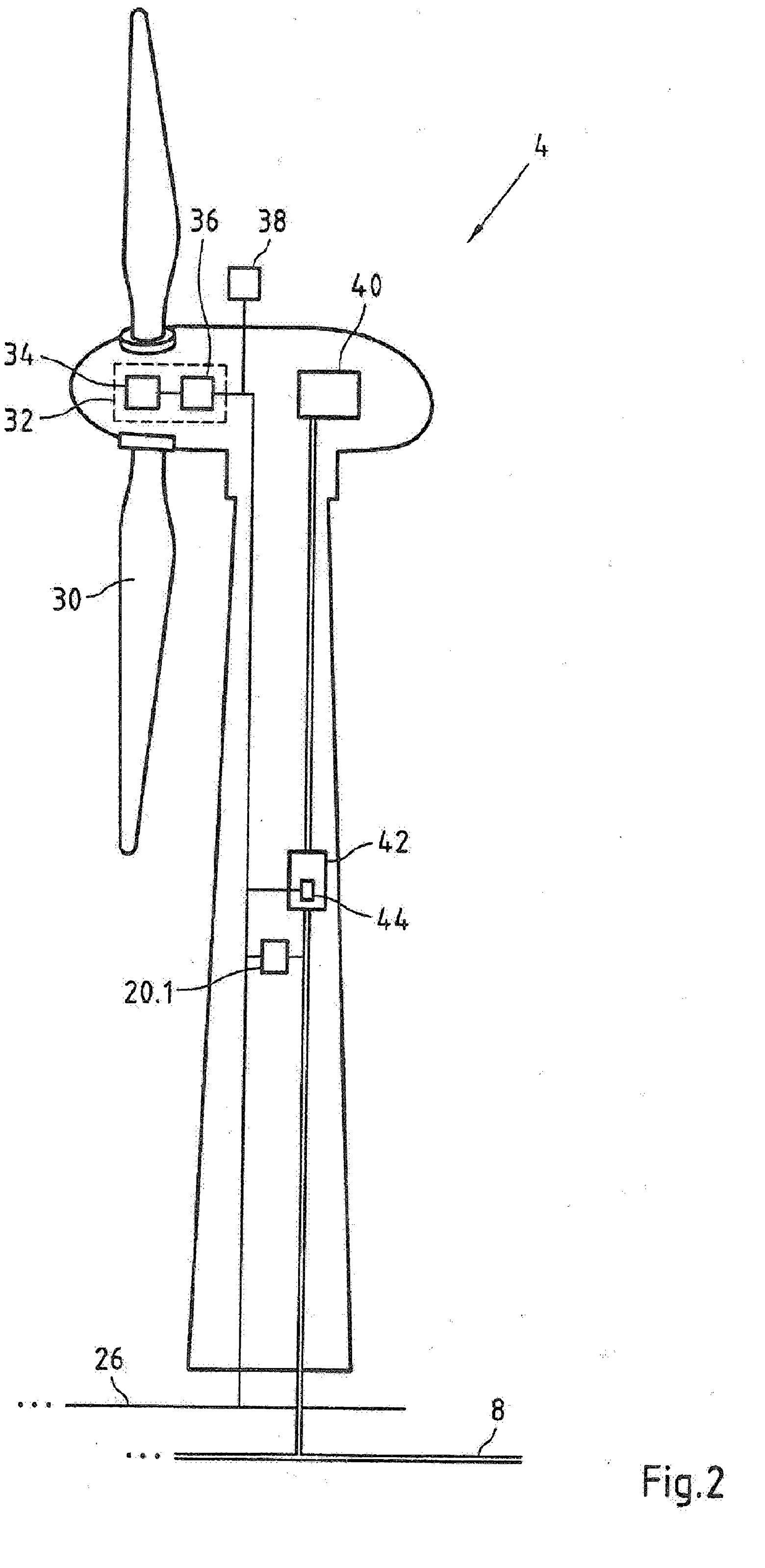

Fig.2

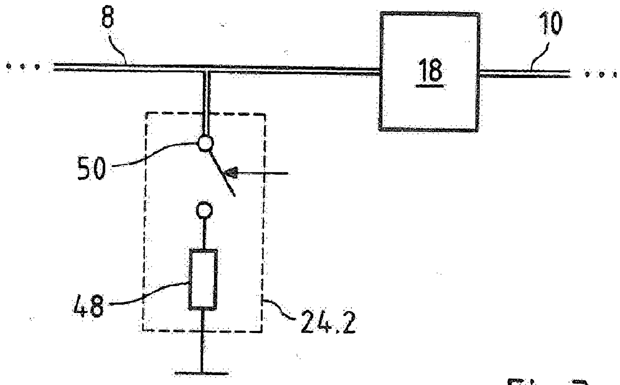

Fig.3

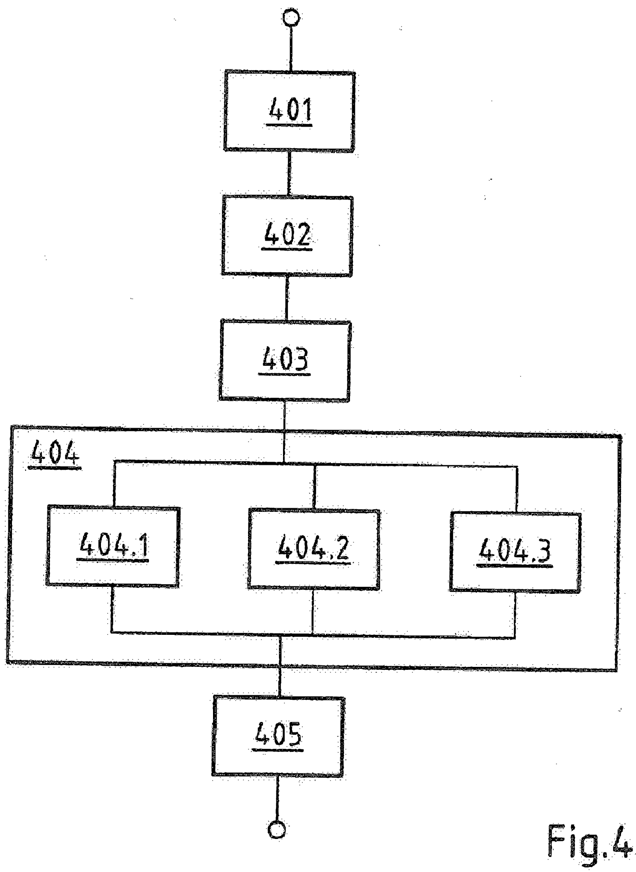

Fig.4