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(54) Benævnelse: **Vindenergiinstallation og fremgangsmåde til styring af udgangseffekten fra en vindenergiinstallation**

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**WO-A-01/86143**

# DESCRIPTION

**[0001]** The present invention relates to a wind energy installation, i.e. a single wind turbine or a wind farm comprising a number of wind turbines. The invention further relates to a method of controlling the output power from such a wind energy installation to an electrical grid for which a nominal grid frequency is specified.

**[0002]** Many wind energy installations are not stand alone installations provided for a single user but feed the generated electrical power into a grid which distributes the power to a large number of different users. As the power consuming devices of the users require electrical power within a certain parameter range, e.g., a specified nominal voltage and a specified nominal grid frequency, measures are necessary to ensure the stability of these grid parameters.

**[0003]** The grid parameters depend on a balance between the power fed into the grid by electrical power generating installations and the power consumed by the consumers. If the produced electrical power fed to the grid is less than the consumed power, the grid frequency drops. On the other hand, if the consumed power is less than the power fed into the grid, the grid frequency increases which could lead to malfunctions of the consumer's electrical devices.

**[0004]** As long as the fraction of electrical power generated by wind energy installations was relatively small compared to the fraction of electrical power generated by other power generating installations, it was not necessary for wind farms to react to variations in the grid frequency. However, as the fraction of electrical power fed into electrical grids by wind energy installations increases it becomes more and more important that these installations are capable of reacting to variations in the grid frequency.

**[0005]** EP 1 282 774 B1 describes controlling the output power of a wind energy generating plant such that it is constant as long as the grid frequency lies in the range between the nominal grid frequency and a threshold frequency which is at least 3 per mill higher than the nominal grid frequency. When the grid frequency increases above the threshold value the output power of the plant is continuously reduced.

**[0006]** EP 1 467 463 A1 describes a wind farm and a method of operating the same. The wind farm is driven at a fixed power output, e.g., maximum total power output, while the grid frequency stays within a predetermined frequency range. If, however, the grid frequency exceeds an upper boundary value of said frequency range, the power output of the wind farm is reduced. If, on the other hand, the grid frequency undershoots a lower boundary value of the predetermined frequency range, the power output is increased. In addition, a procedure of operating a wind farm is described in which the wind farm is operated at partial load. If, in this operation mode, the grid frequency rises from its set point, or drops, the output power of the wind farm will be reduced or increased, respectively.

**[0007]** It is an objective of the present invention to provide a method of controlling the,output power from a wind energy installation and a wind energy installation which allow an improved reaction to changes of the grid frequency.

**[0008]** This objective is solved by a method of controlling the output power from a wind energy installation as claimed in claim 1 and by a wind energy installation, e.g., a single wind turbine or a wind farm comprising a number of wind turbines, as claimed in claim 5.

**[0009]** In the inventive method of controlling the output power from a wind energy installation, e.g. a single windmill or a wind farm comprising a number of windmills, to a utility grid having a specified nominal frequency the output power is controlled depending on the actual grid frequency in the utility grid such that the output power is reduced when the grid frequency exceeds the nominal grid frequency. The output power is reduced as soon as any increase of the grid frequency above the predetermined value is detected.

**[0010]** The inventive method reduces the so-called "dead band", i.e. the frequency range above the nominal frequency in which the output power is kept constant. This allows for an earlier reaction to increasing output power than it is possible in the state of the art. According to the invention, no dead zone at all is present so that the output power will be reduced as soon as the actual grid frequency deviates from the nominal grid frequency. In contrast thereto, the state of the art control mechanisms include dead bands which are as large as possible while maintaining the ability to react to large deviations of the grid frequency from the nominal frequency so that the amount of output power which is lost due to the controlling is reduced. In these state of the art methods, output power is only lost outside the dead band. Although the inventive method slightly increases the output power loss due to the reduced dead band and, in particular, due to not having a dead band at all, this loss is counterweighted by the increased ability to quickly react to deviations of the actual grid frequency from the nominal grid frequency. In particular if the grid frequency increases rapidly such an early reaction can prevent the utility grid from becoming unstable.

**[0011]** In the inventive method, the loss of output power due to the early reaction can be reduced by varying the rate of reducing the output power depending on the magnitude of the deviation of the actual grid frequency from the nominal grid frequency. Moreover, a threshold value could be additionally present for the grid frequency. The threshold value would be higher than the nominal grid frequency. Then, the reduction of output power could, e.g. be proportional to the deviation of the grid frequency from the nominal grid frequency. The constant of proportionality in the frequency range between the nominal grid frequency and the threshold value could differ from the constant of proportionality in the frequency range above the threshold value. This offers the opportunity to only slightly reduce the output power as long as the frequency is in the range between the nominal grid frequency and the threshold value. As a consequence, only a minor fraction of the output power is lost for controlling reasons in this frequency range, which is an acceptable trade-off for increasing the ability to react to frequency deviations. For example, the threshold value could be set as the threshold values for the dead bands in the state of the art, e.g. 3 per mill above the nominal grid frequency. Above the threshold value the reduction of output power could then be carried out as it is, e.g., described in EP 1 282 774 B1. However, as also in the range between the nominal grid frequency and the threshold value the output power has been reduced, the reduction for frequencies above the threshold value would start at an already lower level of output power than in the state of the art so that the reduction in the frequency range outside the threshold value could be less steep than in the state of the art. This reduces the requirements for the electronics by which the reduction of output power is controlled.

**[0012]** Alternatively, to the linear reduction with different constants of proportionality in at least two different frequency ranges, the inventive method can also be implemented with the reduction of output power being a non-linear function of the deviation of the grid frequency from the nominal frequency. In this case, no threshold value would be necessary. If the non-linear function was, e.g., a polynomial like a quadratic or cubic function, only a slight reduction of the output power would result as long as the deviation of the grid frequency from the nominal grid frequency is small. With increasing deviation the reduction of the output power per given frequency interval would also increase. In other words, the higher the deviation from the nominal frequency, the higher the reduction rate of output power. With higher order of the polynomial the reduction rate for the output power at low frequency deviations becomes less while the reduction rate at high frequency deviation increases.

**[0013]** Instead of giving a functional relationship between the reduction of output power and the deviation of the grid frequency the reduction of output power could also be defined by a transfer function.

**[0014]** An inventive wind energy installation,is adapted to be connected to a utility grid for delivering output power to the utility grid. It comprises at least one wind driven generator, a generator electronics, a frequency sensor and a control unit. The frequency sensor is designed and arranged such as to be able to measure the grid frequency present in the utility grid and to output a frequency signal representing the grid frequency. The control unit is connected to the generator electronics for delivering a control signal and to the frequency sensor for receiving the frequency signal. It is adapted to calculate to the control signal depending on the grid frequency such that the output power is reduced as soon as any increase of the frequency above the nominal grid frequency is detected.

**[0015]** In the inventive wind energy installation the control unit is adapted to calculate the control signal depending on the grid frequency such that the rate of reduction in the output power varies with the magnitude of the deviation of the grid frequency from the nominal frequency. This could, in a first alternative, be implemented by adapting the control unit to include at least one threshold value for the grid frequency which is higher than the nominal grid frequency. The control unit would then be further adapted to reduce the output power proportionally to the deviation of the grid frequency from the nominal grid frequency. In addition, it would include two constants of proportionality with the constant of proportionality for reducing the output power in the frequency range between the nominal grid frequency and the threshold value being different from the constant of proportionality for reducing the output power and the frequency range above the threshold value. In an alternative implementation, the control unit would be adapted to reduce the output power as a non-linear function of the deviation of the grid frequency from the nominal frequency. Such a non-linear function could either be given by a direct functional relationship between the reduction of output power and the deviation of the grid frequency, e.g. in form of a polynomial, or by a transfer function.

**[0016]** The inventive wind energy installation is adapted for performing the inventive control method. The advantages described with respect to the inventive method therefore are also provided by the inventive wind energy installation.

**[0017]** Further features, properties and advantages of the present invention will become clear from the following description of embodiments of the invention in conjunction with the accompanying drawings.

Figure 1 schematically shows a first embodiment of an inventive wind energy installation.

Figure 2 shows the output power of the wind energy installation as a function of the grid frequency's deviation from the nominal grid frequency.

Figure 3 shows a second embodiment of an inventive wind energy installation.

**[0018]** The wind energy installation shown in Figure 1 comprises a number of wind turbines two of which are exemplary shown in the figure. The wind turbines 1, 3 produce electrical output power and are connected via an internal node 5 to an external utility grid 7. Although the first embodiment comprises more than one wind turbine, it can also be implemented for a single wind turbine.

**[0019]** The wind turbines 1, 3 are variable speed wind turbines, i.e., the rotational speed of the rotor 9, 11 is allowed to vary depending on the wind conditions.

**[0020]** Each wind turbine 1, 3 comprises a rotor 9, 11 with a shaft 13, 15 transmitting the torque of the wind driven turning rotor 9, 11 to an AC generator 17, 19 which transforms the mechanical power provided by the rotation of the shaft 13, 15 into electrical power. Although not shown in the Figure, the shaft 13, 15 may be divided into a rotor shaft extending from the rotor to an optional gearbox and an output shaft extending from the gearbox to the generator 17, 19. With the gearbox, a transmission of the rotor shafts' rotation speed to a different rotation speed of the output shaft can take place with a certain transmission ratio.

**[0021]** The AC generator 17, 19 comprises a generator electronics and may either by a synchronous generator or an asynchronous generator. In a synchronous generator, a rotor rotates with the same rotational frequency as the rotating magnetic field produced by a stator of the generator, or with an integer relationship with the frequency of the rotating magnetic field, depending on the number of pole pairs present in the rotor. In contrast thereto, in an asynchronous generator the rotational frequency of the stator's magnetic field is more or less independent from the rotational frequency of the rotor. The difference in rotational frequency of the rotor and the stator is described by the slip of the asynchronous generator.

**[0022]** In the embodiment depicted in Figure 1, synchronous generators are used in the wind turbines 1, 3 for producing the electrical power. The wind turbines 1, 3 are connected to the internal node 5 via frequency converters 21, 23 which are part of the generator electronics and which convert the frequency of the electrical power delivered by the generators 17, 19 into an electrical power having a fixed frequency which corresponds to the frequency of the grid 7. Each frequency converter 21, 23 comprises a rectifier 25, 27 which converts the amplifying current delivered by the generator 17, 19 into a direct current and an inverter which converts the direct current back into an amplifying current with the frequency of the grid 7.

**[0023]** Control units 33, 35 are present which are connected to a frequency sensor 37, 39 for receiving a frequency signal and to the inverter 29, 31 for delivering the control signal. The frequency sensor is present in the grid so as to allow the measurement of the actual grid frequency of the external grid 7. Although the frequency sensor 37, 39 is shown to be placed directly behind the output of the frequency converter 21, 23, it could also be placed behind the internal node 5 or even in the external grid 7. However, as the frequency at the internal node 5 matches the frequency in the external grid 7 the frequency measured by the frequency sensor 37, 39 at the output of the frequency converter 21, 23 is identical to the frequency in the external grid 7.

**[0024]** The control unit 33, 35 is adapted to produce a control signal depending on the measured grid frequency. The control signal represents the output power, in particular the active output power, to be output by the inverter 21, 23. In addition, the control signal can also be adapted to represent a special power factor which is a measure for the ratio of active power to the sum of active and reactive power.

**[0025]** In the present invention, the control unit 33, 35 is adapted to provide a control signal such that the output power P is reduced as soon as the grid frequency exceeds the nominal grid frequency. In a comparative example, the predetermined value is defined by a deviation Δf of the measured grid frequency f from the nominal grid frequency $f_N$ by 2 per mill. In an embodiment of the invention, the output power P is already reduced as soon as the grid frequency rises above the nominal grid frequency $f_N$.

**[0026]** The dependency of the output power P from the deviation of the grid frequency Δf for the comparative example is represented in Figure 2 by curve A. Curve B shows the dependency according to the state of the art. As can be seen from curve A, the output power P starts being reduced as soon as the deviation of the grid frequency f from the nominal grid frequency $f_N$ reaches 2 per mill. Before that value is reached, the output power P is kept constant (A1). When the frequency deviation Δf rises above 2 per mill, which represents the predetermined value in the comparative example, the output power P is reduced linearly with a first (negative) coefficient of proportionality (A2). As soon as a threshold value is reached, which is 6 per mill frequency deviation in the comparative example, the coefficient of proportionality changes, i.e. it becomes more negative, so that the linear reduction of the output power becomes steeper above 6 per mill frequency deviation. The reduction can be such that the output power becomes zero as soon as the measured grid frequency f exceeds the nominal grid frequency $f_N$ by a given value, e.g. by 20 per mill, i.e. 2%.

**[0027]** Figure 2 also shows, for comparison reasons, the reduction of output power according to the state of the art (B). In the state of the art, as in Figure 1 of EP 1 282 774 B1, the output power is not reduced until a deviation of the measured grid frequency f from the nominal grid frequency $f_N$ of 6 per mill is reached. Then, after reaching 6 per mill, the output power P is linearly reduced until it is zero for a deviation of the measured grid frequency f from the nominal grid frequency $f_N$ of 20 per mill.

**[0028]** Although, according to the comparative example, the reduction of the output power begins as soon as the frequency deviation Δf reaches 2 per mill, i.e. the predetermined value is 2 per mill, the predetermined value could as well be less than a deviation of 2 per mill and, according to a first embodiment of the invention, the nominal grid frequency $f_N$ itself. In this case, the linear reduction of output power A2 would already begin at Δf=0. Furthermore, the threshold value could be different to the 6 per mill value given in the comparative example.

**[0029]** In a second embodiment of the invention the output power P is reduced according to a non-linear function of the grid frequency deviation Δf. In the present embodiment, this function is chosen such that the output power P becomes zero as soon as the frequency deviation Δf reaches 20 per mill. The output power P is reduced as soon as the measured grid frequency f exceeds the nominal grid frequency and is, e.g. a negative quadratic or cubic function of the frequency deviation Δf. Note that although the output power is a negative quadratic or cubic function of the frequency deviation in the present embodiment, the output power could be any non-linear function reducing the output power with increasing frequency deviation Δf, in particular, any negative polynomial. Furthermore, a non-linear function could, e.g., be represented by a transfer function. Another possibility would be to combine linear and non-linear functions, e.g. defining a linear function for a first frequency range and a non-linear function for another frequency range.

**[0030]** A second embodiment of the inventive wind energy installation is shown in Figure 3. Each wind turbine 1, 3 of the second embodiment corresponds substantially to the wind turbines described with respect to the first embodiment, shown in Figure 1. The only substantial difference from the first embodiment is that not each single wind turbine 1, 3 is equipped with a control unit for controlling the output power as a function of the frequency deviation Δf from the nominal grid frequency $f_N$ in the utility grid 7. Instead, a central control unit 133 is present at the wind farm which delivers individual control signals for each wind turbine 1, 3 of the wind farm on the basis of the measured frequency deviation Δf. Furthermore, the frequency sensor 137 is placed at the output node of the wind farm rather than at the inverter outputs.

**[0031]** The control method performed by the central controller 133 is the same as the control method performed by the controllers 33, 35 of the first embodiment and will not be described again. However, the centralised control unit 133 offers the possibility for differently reducing the output power of different wind turbines as a reaction of e.g. an increasing grid frequency. If, for example, the grid frequency increases and, as a consequence, the output power of the wind farm is reduced by the controller 133, it is possible to reduce output power of only some of the wind turbines and not reducing the output power of the other wind turbines. This could be useful if, e.g. some wind turbines operate at rated output power and other wind turbines operate at an output power which is lower than the rated output power. In this case, wear of the wind turbines which operate at rated output power is usually higher than the wear of wind turbines which are operated at a lower output power than rate output power. Therefore, in order to reduce the output power of the wind farm, it becomes possible with the second embodiment to only reduce the output power of those wind turbines which are operated at the rated output power. By this measure the wear of these wind turbines can be reduced.

# REFERENCES CITED IN THE DESCRIPTION

**Patent documents cited in the description**

- EP1282774B1 [0005] [0011] [0027]

- EP1467463A1 [0006]

## Patentkrav

**1.** Fremgangsmåde til styring af udgangseffekten fra en vindenergiinstallation til et forsyningsnet (7) med en foreskrevet nominel frekvens ($f_N$), hvor udgangseffekten (P) styres afhængigt af den gældende netfrekvens (f) i forsyningsnettet (7), således at udgangseffekten (P) reduceres, når netfrekvensen (f) overstiger den nominelle frekvens ($f_N$), og at udgangseffekten (P) reduceres, så snart der detekteres en forøgelse af netfrekvensen (f) over den nominelle frekvens ($f_N$),
**kendetegnet ved, at**
raten af reduktion af udgangseffekten (P) øges, når størrelsen af netfrekvensens (f) afvigelse ($\Delta f$) fra den nominelle frekvens ($f_N$) tiltager.

**2.** Fremgangsmåde ifølge krav 1, **kendetegnet ved, at**
- der findes mindst en tærskelværdi, som er højere end den nominelle frekvens ($f_N$), for netfrekvensen;
- reduktionen af udgangseffekten (P) er proportional med netfrekvensens (f) afvigelse ($\Delta f$) fra den nominelle frekvens ($f_N$); og
- proportionalitetskonstanten i frekvensområdet mellem den nominelle frekvens ($f_N$) og tærskelværdien er mindre end proportionalitetskonstanten i frekvensområdet over tærskelværdien.

**3.** Fremgangsmåde ifølge krav 1,
**kendetegnet ved, at** reduktionen af udgangseffekten (P) er en ikke-lineær funktion af netfrekvensens (f) afvigelse ($\Delta f$) fra den nominelle frekvens ($f_N$).

**4.** Fremgangsmåde ifølge et af kravene 1 til 3,
**kendetegnet ved, at** reduktionen af udgangseffekten (P) som en funktion af netfrekvensens (f) afvigelse ($\Delta f$) fra den nominelle frekvens ($f_N$) defineres ved hjælp af en overførselsfunktion.

**5.** Vindenergiinstallation, som er tilpasset således, at den forbindes med et forsyningsnet (7) med henblik på at tilføre forsyningsnettet (7) udgangseffekt (P), omfattende:
- mindst en vinddrevet generator (17, 19);

- en generatorelektronik (21, 23);
- en frekvenssensor (37, 39), som er udformet og anbragt således, at den kan måle den netfrekvens (f), der findes i forsyningsnettet (7), og afgive et frekvenssignal, der repræsenterer netfrekvensen (f); og
- en styreenhed (33, 35), som er forbundet med generatorelektronikken (21, 23) med henblik på at levere et styresignal og med frekvenssensoren (37, 39) med henblik på at modtage frekvenssignalet, og som er tilpasset til at beregne styresignalet afhængigt af netfrekvensen (f), således at udgangseffekten (P) reduceres, så snart der detekteres en forøgelse af netfrekvensen (f) over den nominelle frekvens ($f_N$),

**kendetegnet ved, at**

styreenheden (33, 35) er tilpasset til at beregne styresignalet afhængigt af netfrekvensen (f), således at raten af reduktion af udgangseffekten (P) øges, når størrelsen af netfrekvensens (f) afvigelse ($\Delta f$) fra den nominelle frekvens ($f_N$) tiltager.

**6.** Vindenergiinstallation ifølge krav 5, **kendetegnet ved, at** styreenheden (33, 35) er tilpasset til at

- indbefatte mindst en tærskelværdi for netfrekvensen (f), hvilken tærskelværdi er højere end den nominelle frekvens ($f_N$);
- reducere udgangseffekten (P) proportionalt med netfrekvensens (f) afvigelse ($\Delta f$) fra den nominelle frekvens; og
- indbefatte en proportionalitetskonstant til reduktion af udgangseffekten (P) i frekvensområdet mellem den forudbestemte værdi og tærskelværdien, som er mindre end proportionalitetskonstanten til reduktion af udgangseffekten (P) i frekvensområdet over tærskelværdien.

**7.** Vindenergiinstallation ifølge krav 5, hvor styreenheden (33, 35) er tilpasset til at reducere udgangseffekten (P) som en ikke-lineær funktion af netfrekvensens (f) afvigelse ($\Delta f$) fra den nominelle frekvens ($f_N$).

**8.** Vindenergiinstallation ifølge et af kravene 5 til 7, hvor styreenheden (33, 35) er tilpasset til at reducere udgangseffekten (P) som en funktion af netfrekvensens (f) afvigelse ($\Delta f$) fra den nominelle frekvens ($f_N$) defineret ved hjælp af en overførselsfunktion.

# DRAWINGS

FIG 1

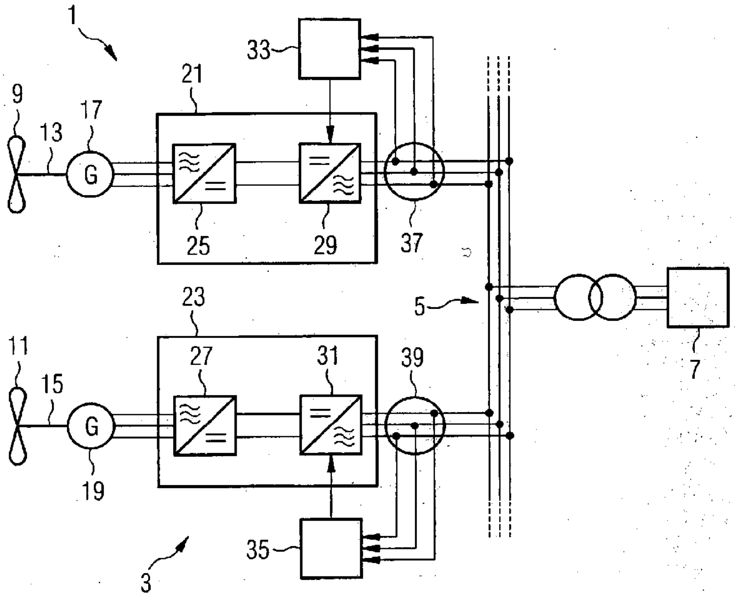

FIG 2

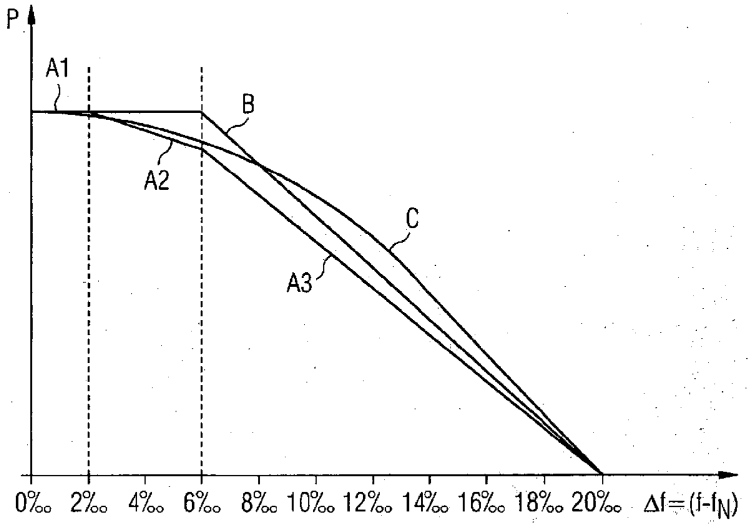

FIG 3