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10172783.2 13 August 2010 (13.08.2010) EP(71) Applicant (for all designated States except US):
SIEMENS AKTIENGESELLSCHAFT [DE/DE]; Wiltelsbacherplatz 2, 80333 München (DE).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **ANDRESEN, Björn** [DE/DK]; Potmosevej 20, Saby, DK-8752 Ostbirk (DK). **BJERGE, Martin Huus** [DK/DK]; Bjødstrupvej 14 E, DK-7400 Herning (DK). **EGEDAL, Per** [DK/DK]; Krogvejen 37, DK-7400 Herning (DK). **KUMAR, Sathees** [DK/DK]; Liselundvej 14, DK-7400 Herning (DK).(74) Common Representative: **SIEMENS AKTIENGESELLSCHAFT**; Postfach 22 16 34, 80506 München (DE).

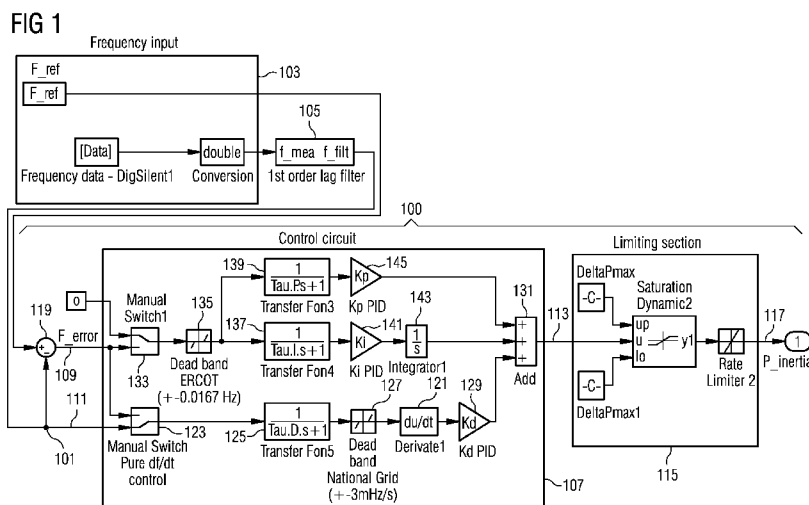
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(54) Title: ARRANGEMENT FOR GENERATING A CONTROL SIGNAL FOR CONTROLLING A POWER OUTPUT OF A POWER GENERATION SYSTEM



(57) Abstract: It is described an arrangement (100, 300) for generating a control signal for controlling a power output of a power generation system (463), in particular a wind turbine, wherein the power output is to be supplied to a utility grid, the arrangement comprising: an input terminal (101) for receiving an input signal (f_filt) indicative of an actual grid frequency of the utility grid; a control circuit (107, 115) for generating the control signal (P_inertia), wherein the control circuit comprises a first circuit (121) for generating a time derivative value of the input signal; and an output terminal (117, 317) to which the control signal is supplied, wherein the control signal depends on the generated time derivative value of the input signal. Further a power generation system is described.

DESCRIPTION

Arrangement for generating a control signal for controlling a power output of a power generation system

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Field of invention

The present invention relates to an arrangement for generating a control signal for controlling a power output of a power generation system and to a power generation system including the arrangement. In particular, the present invention relates to an arrangement for generating a control signal for controlling a power output of a power generation system and to a power generation system, which is adapted to stabilize oscillations of a frequency of a utility grid to which the power generation system is supposed to supply electric energy.

20 Art Background

One or more power generation systems, such as wind turbines, may be connected to a utility grid to supply electric energy to the utility grid. On the other hand, one or more consumers or loads are connected to the utility grid to extract electric energy from the utility grid. The utility grid may deliver the electric energy in form of a AC power stream (or signal or electromagnetic wave) which have a predetermined nominal grid frequency, such as 50 Hz or 60 Hz. Thereby, the grid frequency may highly depend on the balance of generated and consumed power. This balance of generated and consumed power is necessary to keep the frequency stable, but due to outage, generation loss and sudden increase in power a variation in frequency is often observed.

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US 7,345,373 B2 discloses a system and method for utility and wind turbine control, wherein a flow of power through the converter is modulated in response to frequency disturbances

or power swings of the utility system relative to an internal reference frame which is implemented as an integrator that emulates a virtual inertia with a particular magnitude defined by the constant M. Thereby, the internal reference frame has an output that is variable and is the frequency of the internal reference frame. A relative frequency is obtained as a difference of a measured frequency (measured utility system frequency) and the frequency of the internal reference frame. In particular, the frequency of the internal reference frame may differ from the utility system during frequency disturbances.

Summary of the Invention

There may be a need for an arrangement for generating a control signal for controlling a power output of a power generation system and for a power generation system which provides improved control in case of frequency oscillations of the utility grid.

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 an embodiment an arrangement for generating a control signal for controlling a power output of a power generation system, in particular a wind turbine, is provided, wherein the power output is to be supplied to a utility grid, wherein the arrangement comprises an input terminal (such as an electrical input terminal or an input node) for receiving an input signal (such as an electrical signal, such as an analogue signal or a digital signal) indicative of an actual grid frequency (i.e. a momentary frequency of the utility grid, in particular comprising one or more values, in particular at different time points, of the frequency, wherein the one or more values may indicative of a time course of the actual frequency of the utility grid) of the utility grid (to

which the power generation system supplies energy and from which one or more consumers extract electrical energy); a control circuit (in particular comprising one or more integrated circuits, and/or a computer, a computer program being
5 executed on the computer) for generating the control signal (in particular an electrical control signal, such as an analogue signal or a digital signal), wherein the control circuit comprises a first circuit for generating a time derivative value (indicating a change of the input signal with re-
10 spect to time, wherein in particular the input signal may be continuously measured or measured at a number of sample points being spaced in time relative from each other); and an output terminal (or an output node) to which the control signal is supplied, wherein the control signal depends (in par-
15 ticular is based on, in particular changes if the time derivative value of the input signal changes) on the generated time derivative value of the input signal.

The control signal may also be denoted as inertia response
20 signal in the context of the present application. In particular, the control signal may be supplied to a wind turbine controller which in turn generates based on the control signal a power reference signal to be supplied to a converter of the wind turbine for controlling a power output of the con-
25 verter (and thus of the wind turbine) depending on the power reference signal.

In particular, the control signal may be generated to cause an increase of active power output of the power generation
30 system, when the actual grid frequency falls below a certain limit. Further in particular, the control signal may be generated to cause reduction of power production by the power generation system, when the actual grid frequency exceeds the fixed nominal frequency (such as 50 Hz or 60 Hz) of the util-
35 ity grid.

In particular, the wind turbine may be equipped with a full-scale converter, effectively decoupling the rotor side from

the grid. In particular, the wind turbine may comprise a tower, a nacelle mounted on top of the tower, and a rotor rotatably supported within the shaft, wherein at the rotor one or more rotor blades are mounted. The rotor shaft may mechanically be coupled to a generator for generating electric energy when the rotor shaft rotates due to wind impacting on the rotor blades.

In particular, the generator of the wind turbine may generate variable frequency AC power signals (or a AC power stream) which may be supplied to the full-scale converter. The full-scale converter may first convert the variable frequency power signal to a DC power signal and may then convert the DC power signal to a fixed frequency power signal having the frequency of the utility grid under normal conditions, i.e. the nominal grid frequency. In particular, the converter may be capable of controlling a power output of the wind turbine, in particular may be adapted for decoupling the inertia of the rotor from the grid. In particular, the grid may not have a direct link to the inertia of the revolving mass of the rotor.

According to an embodiment kinetic energy, such as rotational energy of the rotor is extracted during a particular grid event, such in case when the actual grid frequency is below the nominal predetermined grid frequency. In particular, an additional active power may be delivered to the utility grid during grid drop events to stabilize the utility grid frequency. In particular, active power of the energy stored in the rotor may be injected into the utility grid in such a way that the frequency decay is pulled towards the nominal grid frequency. According to an embodiment the control signal is generated such that the wind turbine controller finally supplied with a signal based on the control signal controls the wind turbine or the wind turbine converter such as to prevent further declination of the grid frequency.

Taking into account the time derivative value of the input signal facilitates fast response when the grid frequency changes, in particular changes in a rapid way. Thereby, a stabilization of the grid frequency may be achieved. Such a fast response may not be possible with conventional controllers. In particular, the derivative value of the input signal may be obtained as a difference of the input signal at a second time point and the input signal at a first time point, wherein the first time point precedes the second time point. In particular, a time difference between the first time point and the second time point may be adapted according to the particular operational condition or the particular requirements, such as local regulations.

According to embodiments, the time derivative (df/dt) may be controlled instead of the absolute frequency. The purpose of this feature may be to minimize the rate of frequency declination during a frequency drop and reach a quicker break-off. This may be achieved by feeding more active power into the grid in such a way that df/dt goes toward $df/dt=0$.

The input signal which is indicative of the actual grid frequency may in particular represent for example as an electrical value the actual grid frequency or may alternatively represent a deviation of the actual grid frequency from a fixed nominal grid frequency. In particular, the input terminal of the arrangement may comprise a first input terminal for receiving a first input signal representing the actual grid frequency and the arrangement or the input terminal may further comprise a second input terminal for receiving a second input signal representative or representing a deviation of the actual grid frequency from the fixed nominal grid frequency.

The actual grid frequency may in particular be measured to generate a measurement signal which may then be transformed in an appropriate way (for example digitized) and/or filtered

for finally obtaining the input signal for the control arrangement.

According to an embodiment the arrangement further comprises
5 a first filter (such as a cut-off filter for filtering the input signal regarding frequency components comprised in the input signal) connected between the input terminal and the first circuit (such that the first circuit is supplied with a first filtered version of the input signal), wherein the
10 first filter is adapted to attenuate a frequency component of the input signal having a frequency higher than a first threshold frequency. In particular, the input signal may be supplied to the first filter and the first filter may output a first filtered input signal, wherein in the filtered input
15 signal frequency components above the first threshold frequency are attenuated (such as by between 50% and 100%) compared to the same frequency components in the not filtered input signal.

20 In particular, the input signal may be based on measurements of the grid frequency, wherein these measurements may contain errors, such as noise. In particular, the noise in the measurements may comprise relatively high frequency components. Thereby, in particular the noise due to inaccurate measurements
25 of the grid frequency may be reduced in the first filtered input signal compared to the unfiltered input signal. Thereby, the influence of inaccuracy of the measurements of the actual grid frequency and thus the influence of noise in the input signal may be reduced by supplying the first filtered input signal to the first circuit. In particular, the
30 first circuit may be sensitive to noise.

Filtering the input signal using the first filter having a cut-off frequency at the first threshold frequency may be accompanied by a first delay time interval being a time delay
35 of the first filtered input signal, wherein the first time delay interval may be equal to the inverse of the first threshold frequency. In particular, the first delay time in-

terval may amount to between 5 s and 10 s. In turn, the first threshold frequency may be relatively low.

In particular, the first threshold frequency may be determined based on an accuracy of the actual utility grid frequency measurements. For example, the unfiltered input signal may comprise large spikes of the measured actual grid frequency which are due to measurement errors and which spikes may be reduced in the first filtered input signal. Thereby, the control signal may be generated in a more accurate way.

According to an embodiment, the input signal is indicative of a deviation of the actual grid frequency from a fixed nominal grid frequency, wherein the arrangement in particular comprises a comparator such as a logic circuit for determining the frequency deviation of the actual grid frequency from the fixed nominal grid frequency. Including a comparator for determining the frequency deviation may allow generating the control signal based on the frequency deviation. This in particular may allow inclusion of further control elements into the arrangement which are sensitive to the absolute value of the input signal.

According to an embodiment, the control circuit comprises a second circuit (also called a second control element) for generating a time integrative value (e.g. obtained by forming an integral or a sum of the input signal over a particular time interval) of the input signal, wherein the control signal further depends on the generated time integrative value (in particular obtained by forming a sum or integral of the input signal from a first time point to a second time point, in particular comprising forming a sum of a plurality of input signals associated to the actual grid frequency at a plurality of time points). In particular, in this case the input signal may represent the deviation of the actual grid frequency from the fixed nominal grid frequency.

Thus in particular the deviation of the actual grid frequency from the fixed nominal grid frequency may be considered as an error signal and the control signal may be generated such that the error signal is reduced or even minimized. Inclusion
5 of the second circuit for generating the time integrative value of the input signal may further improve the control of the power output of the power generation system to stabilize the actual grid frequency.

10 According to an embodiment, the arrangement further comprises a second filter (such as a cut-off filter, in particular an analogue filter) connected between the input terminal and the second circuit (such that from the input signal a second filtered input signal is generated and supplied to the second
15 circuit), wherein the second filter is adapted to attenuate a frequency component of the input signal having a frequency higher than a second threshold frequency, wherein in particular the second threshold frequency is greater than the first threshold frequency. In particular, the second filter may allow to reduce measurement errors in the input signal.
20 Thereby, the stabilization of the grid frequency may be improved.

In particular, the filtering by the second filter to output
25 the second filtered input signal may be accompanied by delaying the second filter input signal relative to the input signal by a second delay time interval, which may in particular correspond to an inverse of the second threshold frequency.

30 According to an embodiment, the control circuit comprises a third circuit (also referred to as third control element) for generating a proportional value of the input signal, wherein the control signal further depends on the generated proportional value (being a value formed by a product of the input
35 signal and a factor, wherein the factor may be constant) of the input signal. Thereby, the generating the control signal may be performed such that the controlled power output leads to an improved stabilization of the grid frequency.

According to an embodiment, the arrangement further comprises a third filter (in particular a cut-off filter) connected between the input terminal and the third circuit (such that
5 from the input signal a third filtered input signal is generated and supplied to the third circuit), wherein the third filter is adapted to attenuate a frequency component of the input signal having a frequency higher than a third threshold frequency, wherein the third threshold frequency is in particular
10 greater than the first threshold frequency. In particular, in the third filtered input signal, frequency components greater than the third threshold frequency may be reduced in amplitude compared to the same frequency components in the unfiltered input signal. In particular, filtering the
15 input signal using the third filter to output the third filtered input signal may be accompanied by delaying the third filtered input signal by a third delay time interval which may be related to the third threshold frequency, which may in particular be the inverse of the third threshold frequency.
20 In particular, also the third filter may reduce measurement errors in the input signal to output the third filtered input signal to be supplied to the third circuit.

In particular the second delay time interval and/or the third
25 delay time interval may amount to between 100 ms and 2 s, in particular between 500 ms and 1 s. Further, the second threshold frequency and/or the third threshold frequency may depend on the particular application, the particular requirements and/or local regulations.

30 According to an embodiment, at least one of the first filter, the second filter and the third filter comprises a low pass filter, in particular a first order analogue filter. In particular, a first order low pass filter may have a gain slope
35 with respect to angular frequency of -20 dB/decade. In particular, the first order filter may reduce the signal amplitude by half every time the frequency doubles. The cut-off frequency may be defined as the frequency at the intersection

point of the line (of the filter characteristics) having the slope -20 dB/decade and the line having a constant gain (in particular having gain 0 dB) in the passband. In particular, the gain of the first order filter drops by 20 dB when the frequency increases from a first frequency at or above the cut-off frequency to a second frequency which equals 10 times the first frequency.

According to an embodiment, the control signal is based on a weighted sum of the proportional value, the time integrative value and the time derivative value of the input signal. Thus in particular a PID controller may be provided comprised in the arrangement for generating the control signal. The relative weights of the proportional value, the time integrative value and the time derivative value may be determined by simulation or may be determined by trial and error and/or training data. In particular, the relative weights may be determined such that the deviation of the actual grid frequency from the predetermined fixed nominal grid frequency is reduced under a number of operational conditions. In particular, the relative weights may be determined in an iterative way.

According to an embodiment, the arrangement is selectively operable in a first mode and in a second mode, wherein in the first mode a weight of the proportional value of the input signal and a weight of the time integrative value of the input signal are both below a weight threshold (in particular are essentially zero), while the weight of the time derivative value of the input signal is one. In particular, in the first mode only the derivative value of the input signal is taken into account to generate the control signal but not the proportional value and not the integrative value of the input signal. Thus, from the proportional value, the integrative value and the derivative value of the input signal exclusively the derivative value of the input signal is taken into account for generation of the control signal. In particular, it may be manually switched into the first mode under par-

ticular requirements or conditions, in particular depending on local regulations.

5 In the second mode all three, the proportional value, the integrative value and the derivative value of the input signal are taken into account for generation of the control signal.

10 According to an embodiment, the arrangement further comprises a limiting circuit connected between the control circuit and the output terminal for limiting the control signal to be below a predetermined change per time (such that a change of the control signal within a particular time interval is below a change threshold) and/or to be in a predetermined range (a range of values of the control signal), wherein the predetermined range is 0.0 to 0.2, in particular 0.0 to 0.1, times a nominal power output (also referred to as a rated power output, i.e. a power output of the power generation system, in particular the wind turbine, for continuous operation or normal operation) of the power generation system. Thereby it may be avoided that the power generation system is operated under conditions the power generation system is not designed to operate in. Thereby, a lifetime of the power generation system may be increased.

25 According to an embodiment, the predetermined range depends on an actual power supplied by the power generation system to the utility grid and/or on a kinetic energy of the mechanical portion of the power generation system. Thereby, it may be possible to make inertial response deliveries more efficient as the inertia response signal (or control signal) may depend on how much power the turbine is delivering (pre-frequency dip) and how much kinetic energy is stored in the generator rotor.

35 Alternatively, the static limiting circuit may be a simple implementation how much active power the turbine is able to provide which may highly depend on the active power delivered

to the grid (just before the inertial response) and the generator rotational speed.

According to an embodiment, the arrangement is adapted to
5 communicate with a power generation plant controller (such as
a wind farm controller HPPP) controlling a plurality of power
generation systems, including the power generation system,
regarding their power outputs (such that the power generation
10 plant controller in a normal operation transmits control sig-
nals to the power generation systems to control their power
output), wherein in particular the control signal is communi-
cated to the power generation plant controller. Thereby, it
is enabled that the power generation plant controller may
take the control signal into account which may prevent the
15 power generation plant controller to counteract.

In particular, as an example, a wind farm may be set to pro-
duce 50 MW at a point of common connection (PCC). Suddenly, a
frequency drop may occur and the wind turbines may inject
20 more power into the utility grid resulting in an increase in
power at the PCC, such as an increase to 54 MW. The wind farm
controller (also referred to as power generation plant con-
troller) may detect this increased power at the PCC and may
determine that the power at the PCC is 4 MW above the rated
25 power. Further, the wind farm controller may reduce its power
reference set point to the turbine. To avoid such an unwanted
scenario the opportunity of communication between the wind
turbine and the wind farm controller is provided according to
an embodiment.

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According to an embodiment, the arrangement further comprises
a load determination unit (in particular comprising measure-
ment equipment, a computer and/or a computer program running
on the computer) for determining, (a) based on the control
35 signal and/or (b) based on both a power output and a nominal
power output of the power generation system, a load (in par-
ticular a mechanical load and/or an electrical load) of the
power generation system (the load for example comprising a

load in a gear or a bearing of the rotor shaft), wherein in particular the load determination unit comprises a counter for counting a number of times the control signal caused an increase of the power output of the power generation system (or wherein the counter is also adapted for measuring a time interval or a plurality of time intervals the control signal caused an increase of the power output of the power generation system), in particular for counting a number of times the control signal caused an increase of the power output of the power generation system above the nominal power output (wherein in particular the counter is also adapted for measuring a time interval or a plurality of time intervals the control signal caused an increase of the power output of the power generation system above the nominal power output, wherein the nominal power output may also be referred to as rated power output defining a power output during normal continuous operation of the power generation system).

In particular, the load determination unit may allow to estimate or measure an accumulated load the power production system or wind turbine system is subjected to. Further, the load determination unit may allow estimation or measuring of an expected lifetime of the power generation system, in particular the wind turbine. Further, the measurements or estimations of the load determination unit may be taken into account for generating the control signal. Thus, the control signal may be generated also to be based on a load determined by the load determination unit. Thereby, the control of the power generation system regarding its power output may be improved.

According to an embodiment, a power generation system, in particular a wind turbine system, for supplying electrical power to a utility grid is provided, wherein the power generation system comprises an arrangement for generating a control signal for controlling a power output of the power generation system according to one of the above described embodiments; and a generator and/or converter arranged to re-

ceive the control signal (or a signal generated based on the control signal, e.g. using a further wind turbine controller) and to adapt the power output in dependence of the control signal. In particular, the control signal may be supplied to
5 an additional wind turbine controller which in turn supplies a signal, in particular a power reference signal, to the generator and/or the converter.

In particular, the control signal may be used by the converter to trigger conducting states of one or more semiconductor switches, such as IGBTs, which control the flow of power through the converter. In particular, the converter may receive a variable frequency AC power signal from the generator (which may be mechanically coupled to the rotor shaft
15 having rotor blades fixed thereto) to a DC power signal using one or more semiconductor switches, such as isolated gate bipolar transistors (IGBTs). The DC power signal may then be converted by the converter using one or more IGBTs to a fixed frequency AC power signal having a frequency close to the
20 fixed nominal grid frequency. Controlling the conducting states of the IGBTs comprised in the converter may allow controlling flow of power through the IGBT into the utility grid. Thereby, the frequency oscillations in the utility grid may be decreased.

25 According to an embodiment, the control signal is generated such that the power generation system is caused to increase its power supply to the utility grid (thus to increase the power output of the power generation system), when the actual
30 grid frequency is below the nominal grid frequency, in particular longer than a predetermined time interval and/or such that the power generation system is caused due to decrease the power output of the power generation system to the utility grid, when the actual grid frequency is above the nominal
35 grid frequency, in particular longer than a further predetermined time interval.

It should be understood that features (individually or in any combination) disclosed, described, used for or mentioned in respect to the description of an embodiment of an arrangement for generating a control signal for controlling a power output of a power generation system may also be (individually or
5 in any combination) applied, used for, or employed for a method for generating a control signal for controlling a power output of a power generation system.

10 According to an embodiment a method for generating a control signal for controlling a power output of a power generation system, in particular a wind turbine, is provided, wherein the power output is to be supplied to a utility grid, wherein the method comprises: (a) receiving an input signal indica-
15 tive of an actual grid frequency of the utility grid; (b) generating the control signal using a control circuit, wherein the control circuit comprises a first circuit for generating a time derivative value of the input signal; and (c) supplying the control signal at an output terminal,
20 wherein the control signal depends on the generated time derivative value of the input signal.

It has to be noted that embodiments of the invention have been described with reference to different subject matters.

25 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
30 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
35 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.

5

Brief Description of the Drawings

Embodiments of the present invention are now described with reference to the accompanying drawings to which the invention
10 is not limited.

Fig. 1 schematically illustrates an arrangement for generating a control signal for controlling a power output of a power generation system according to an embodiment;

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Fig. 2 illustrates a graph illustrating generating a time derivative value to be used in the arrangement illustrated in Fig. 1 according to an embodiment;

20 Fig. 3 schematically illustrates a control operation unit according to an embodiment for controlling a converter for converting electrical energy;

Fig. 4 schematically illustrates a portion of a power generation plant including a power generation system controlled by
25 the arrangement illustrated in Fig. 1;

Fig. 5 illustrates a graph of an actual grid frequency according to a conventional method and according to an embodiment of a method for generating a control signal for controlling a power output of a power generation system; and
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Fig. 6 illustrates a characteristics of a filter comprised in the arrangement illustrated in Fig. 1;

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Fig. 7 schematically illustrates a part of the arrangement of Fig. 1 for generating a control signal for controlling a

power output of a power generation system according to an embodiment;

Fig. 8 schematically illustrates a part of the arrangement of Fig. 1 for generating a control signal for controlling a power output of a power generation system according to an embodiment;

Fig. 9 schematically illustrates a park layout of a wind farm;

Figs. 10 and 11 schematically illustrate adjustment curves provided by the wind park controller of Fig. 9.

Detailed Description

The illustration in the drawings is in schematic form. It is noted that in different figures, similar or identical elements are provided with the same reference signs or with reference signs, which are different from the corresponding reference signs only within the first digit.

In Fig. 9, a common park layout of a wind farm 900 is shown.

In this wind farm, the frequency control is controlled on park level. That means that the grid frequency is monitored at the Point Of Common Coupling (PCC) and an active power production is controlled by the wind farm controller 901. Decrease or increase of active power depends on the droop characteristic parameter in the wind farm controller. The actual frequency f_{pcc} and the actual power P_{pcc} measured at the PCC are provided to the wind farm controller 901. The controller is adapted to send a control signal $P_{ref_turbine}$ to each wind turbine 902. The wind turbines will then change the production of active power in accordance with the control signal, i.e. increase the production when the frequency falls below a certain limit and reduce the power production if the frequency raises above a certain limit.

The wind farm in Fig. 9 has three PCC points. The frequency is measured at these points and sent to the wind farm controller. The wind farm controller is taking the frequency measurement from PCC and corresponding active power references are distributed to the wind turbines. If the frequency is too low the reference power $P_{ref_turbine}$ send to the turbines will increase and while the reference power $P_{ref_turbine}$ is reduced if the frequency is too high.

The wind farm controller may adjust according to the curves shown in Figs. 10 and 11. Two different setups may be possible with the wind farm controller shown in Fig. 9: Frequency Limited Mode FLM (Fig. 10) and Frequency Sensitive Mode FSM (Fig. 11). The FLM only reacts on frequency increase above 50.4 Hz (graph 1010) for example while FSM reacts on both frequency fall and rise as shown with graph 1110. The slope dP/df is defined by the droop factor which determines the amount of active power increase or decrease due to grid frequency changes.

Fig. 1 schematically illustrates an arrangement 100, according to an embodiment, for generating a control signal (also referred to as $P_{inertia}$) for controlling a power output of a not illustrated power generation system, in particular a wind turbine. The arrangement 100 comprises an input terminal 101 for receiving an input signal indicative of an actual grid frequency f_{mea} of the utility grid. In particular, the actual grid frequency is measured using a measurement unit 103 which generates a grid frequency measurement signal f_{mea} which is filtered using a first order lag filter 105 to provide the filtered grid frequency signal f_{filt} to the input terminal 101.

The arrangement 100 further comprises a control circuit 107 to which the filtered grid frequency signal f_{filt} is supplied and to which also a deviation of the filtered signal f_{filt} of the actual grid frequency signal f_{mea} from a fre-

quency reference F_{ref} is supplied, wherein the reference frequency F_{ref} corresponds to the nominal fixed (i.e. not variable) grid frequency, such as 50 Hz or 60 Hz.

- 5 The deviation F_{error} of the filtered actual grid frequency from the nominal grid frequency is supplied via a signal line 109 and the filtered actual grid frequency signal is supplied via a signal line 111 to the control circuit 107.
- 10 Based on the input signal (which may be either the measured actual grid frequency or a filtered signal of the actual measured grid frequency or a deviation thereof from the nominal frequency) the control circuit determines and generates a preliminary control signal at a control line 113 which pre-
- 15 liminary control signal is input to a limiting section 115 which is also comprised in the arrangement 100. The limiting section 115 (also referred to as limiting circuit) outputs the control signal at an output terminal 117. The control signal is also referred to as $P_{inertia}$ or inertial response
- 20 signal.

The deviation of the actual grid frequency from the nominal grid frequency is determined by a comparator 119 which provides the deviation F_{error} of the actual grid frequency from

25 the predetermined fixed nominal grid frequency at the signal line 109 to the control circuit 107.

In Fig. 1 the control circuit 107 is illustrated in a first mode, wherein the input signal is only applied to a first

30 circuit 121 connected between the input terminal 101 and the output terminal 117. In particular, in the first mode a switch 123 connects the input terminal 101 to a first filter 125 which provides a first filtered input signal to a dead band element 127 which in turn provides the filtered input

35 signal to the first circuit 121. The first circuit 121 derives a derivative value of the input signal which is then multiplied using a multiplier 129 and is supplied to an adder 131.

In particular, a delay accompanied by filtering the input signal using the first filter 125 amounts to between 5 s and 10 s. The filter 125 reduces the noise in the input signal, wherein the noise may be due to the measurement process of the grid frequency. In particular, the filter 125 attenuates a frequency component of the input signal having a frequency higher than a first threshold frequency which may be related to a reverse of the delay introduced by the filter 125.

In a second mode of operation of the arrangement 100 the switch 123 connects the first filter 125 to the signal line 109 providing the input signal indicative of a deviation F_{error} of the actual grid frequency from the fixed predetermined nominal grid frequency. Further, the switch 133 also connects the input signal applied at signal line 109 to a dead band element 135 which provides its output to a second filter 137 and in parallel to a third filter 139. The second filter 137 generates a second filtered input signal, supplies it to a multiplier 141, wherein the multiplier 141 multiplies the second filtered input signal with a constant K_i and supplies the result to an integrator 143 which integrates the received signal over a certain time interval and supplies the result to the adder 131.

Further, the third filter 139 generates from the input signal a third filtered input signal, supplies it to the multiplier 145 which multiplies the third filtered input signal by a factor K_p and supplies the result to the adder 131.

In particular, the adder 131 forms a weighted sum (weighted by the multiplication factors K_d , K_i and K_p) of a derivative value (wherein the derivative value is generated by the derivative element 121) of the input signal, of the integrative value of the input signal (wherein the integrative value is generated by the integrator 143) and of the proportional value of the input signal (wherein the proportional value is generated by the multiplier 145). The weighted sum of the de-

rivative value, the integrative value and the proportional value of the input signal is supplied via the signal line 113 to the limiting section 115 which ensures that the control signal supplied to the output signal 117 lies within a predetermined range, such as in a range from 0.0 to 0.2 times a nominal control signal and that the rate change (the change with respect to time) of the control signal is also in a particular range.

10 In particular, the nominal grid frequency F_{ref} is a fixed frequency and is not determined based on emulating a synchronous machine. In particular, a wind turbine system may comprise the arrangement 100 as illustrated in Fig. 1, wherein the arrangement 100 controls the power output of the wind
15 turbine. The arrangement 100 enables for controlling the wind turbine to rapidly provide additional power to the utility grid in case the frequency of the utility grid falls below the nominal frequency, in order to stabilize the grid frequency. In particular, the control of the power output at
20 each particular power generation system, in particular wind turbine, may be faster than a control via a central park controller. In particular, the control signal $P_{inertia}$ is generated on the basis of a measured frequency input representing the actual frequency of the utility grid. Further, the
25 actual frequency is filtered using a first order filter 105 before the input signal is supplied to the PID controller 107. In particular, the signal provided by the integrator 143 may be limited in such a way that it does not diverge, for example with anti-wind up which is not illustrated in Fig. 1.
30 Further, the control signal provided at the output terminal 117 is limited by a dynamic or static limiting section 115, as there are limits for the magnitude of the control signal $P_{inertia}$.

35 In particular, the limiting section may be adapted as a static limiter in which case the control signal may be limited to have values between 0 and 0.1 times a nominal power

reference signal or inertial response signal. This may be a very simple implementation.

Alternatively, the limiting section 115 may be adapted as a dynamic limiter, since in some cases the power generation system may be able to provide more active power to the grid than the nominal power. How much active power the turbine is able to provide may highly depend on the active power delivered to the grid and the generator speed. The dynamic limiter makes the inertial response delivery more efficient, as the control signal $P_{inertia}$ may depend on how much power the turbine is delivering and how much kinetic energy is stored in the generator rotor.

Figs. 7 and 8 illustrate schematically the first mode of the arrangement of Fig. 1. In one embodiment, the arrangement may be used for example only in the first mode, wherein the other parts of the arrangement as shown in Fig. 1 might be omitted.

The idea of the first mode is to provide a df/dt controller which reacts with respect to frequency change per second and not the absolute frequency. The objective of the controller is not to drive the frequency back to 50/60 [Hz], but to make $df/dt = 0$ fast as possible.

In Figs. 7 and 8, the arrangement comprises a measurement system 703/803. The measurement system may be adapted for providing any raw measurement data like the actual measured frequency. These measurement data may be provided as input signal to a filter 725/825, for example a first order filter. The filter may be adapted to filter out noise, for instance high frequency noise. In particular, the filter 725/825 may be a low pass filter. The filter comprises an adder 751/851 receiving the input signal and a feedback signal. The output of the adder is supplied to a multiplier 752/852. The output of the multiplier is supplied to an integrator 753/853. The output of the integrator is supplied to a further multiplier

754/854 providing the feedback signal and to a derivative unit 721/821.

5 The derivative unit derives a derivative value of the signal inputted to the derivative unit. Subsequently, the output of the derivative unit, is supplied to a dead band unit 727/827 for filtering out the signal range where no action occurs. The remaining range may be for example 3 to -3 mHz/s. After that, the output signal of the dead band unit is supplied to
10 a multiplier 729/829. In Figs. 7 and 8, the derivative unit and the dead band element are shown in this order, but it could also be possible to rearrange these elements as shown in Fig. 1.

15 The multiplied signal is supplied to a limiting circuit 715/815. The limiting circuit outputs the control signal at an output terminal 717/817. The control signal is also referred to as $P_{inertia}$, ΔP or inertial response signal.

20 In Fig. 7, the limiting circuit 715 is shown as a static limiter. In this case, the signal may be limited to have a value between 0 and $0.1 \cdot P_{nom}$. The saturation may be set to for example 10% as shown in Fig. 7. This is a simple implementation, but it isn't the most efficient solution as the SWT in
25 some cases might be able to provide more active power to the grid. How much active power the turbine is able to provide highly depends on the active power delivered to the grid (just before inertial response) and the generator speed.

30 In Fig. 8, the limiting circuit 815 is shown as a dynamic limiter. This type of limiter may provide the inertial response deliveries more efficient as the $P_{inertia}$ will depend on how much power the turbine is delivering (pre-frequency dip) and how much kinetic energy is stored in the generator
35 rotor. The dynamic saturation may depend on the generator speed and may be adapted dynamically based on the actual measured information. A maximum (ΔP_{max}) and minimum (ΔP_{min}) value may be supplied to the limiting circuit.

Fig. 2 illustrates a graph showing on its abscissa the time t in seconds and showing on its ordinate the actual frequency f of the utility grid in Hertz (Hz). In the illustrated example the nominal grid frequency amounts to 50 Hz, as labelled by reference sign 247. Between a first time point 249 and a second time point 251 the frequency f drops from 50 Hz to a value of 49 Hz, as indicated by reference sign 253. In particular, a derivative value df/dt of the frequency (thus the input signal supplied to the control circuit 107) amounts to $-M$ which is determined by the derivative element 121 illustrated in Fig. 1. Weighted by the factor K_d this derivative value of the input signal contributes to the weighted sum which is formed by the adder 131, as illustrated in Fig. 1. In particular, taking into account the derivative value of the input signal may accelerate controlling the power output of the power generation system compared to a conventional method. Thereby, the grid frequency may be more efficiently stabilized to be close to the nominal grid frequency.

Fig. 3 schematically illustrates controlling a wind turbine converter 344 using a power controller 355. The power controller 355 comprises the arrangement 300 for generating a control signal for controlling a power output of a power generation system, wherein the arrangement 300 may be adapted as the arrangement 100 illustrated in Fig. 1. The control signal $P_{inertia}$ output by the arrangement 300 at the output terminal 317 is supplied to a wind turbine controller 357 to which additional measurement values and parameters are input at an input terminal 349. Taking the control signal $P_{inertia}$ into account the wind turbine controller 357 generates a power reference signal $PowerRef$ at its output terminal 361 to supply the power reference signal to the converter 344 which adapts its power output according to the supplied power reference signal.

Fig. 4 schematically illustrates a portion of a power generation plant including one or more power generation systems 463

(from which only one power generation system is illustrated in Fig. 4), wherein a high performance park pilot or power generation plant controller 465 controls the power generation systems 463. Each power generation system 463, such as a wind turbine system, comprises a controller 457 including a power controller 455 which may be adapted as the power controller 355 illustrated in Fig. 3, wherein the power controller 455 comprises an arrangement 100 for generating a control signal for controlling a power output of the power generation system 463. As is indicated by control and/or communication lines 466 and 467 the power controller 455 and in particular also the arrangement 100 comprised within the power controller 455 is enabled to communicate with the power generation plant controller 465, in order to communicate in particular the control signal $P_{inertia}$ being provided at the output terminal 117 of the arrangement 100. Thereby, the power generation plant controller 465 may take the control signal into account in order not to counteract. Thereby, stabilization of the grid frequency may be achieved more quickly or more accurately. The controller 455 outputs a control signal 477 to the turbine shaft 478 which provides a feed back signal 479 to the controller 455. The power is provided via line 480 to a network bridge 481 which converts the power signal to fixed frequency.

The power generation plant controller 465 receives an input signal from the point of common coupling 482 and outputs a control signal at terminal 483.

Fig. 5 illustrates a graph showing on its abscissa the time t in seconds and on its ordinate the actual frequency f of the utility grids in Hertz. Thereby, a curve 569 depicts the time course of the actual frequency without performing controlling the power output of the power generation system and the curve 571 denotes the time course of the actual grid frequency when the power of the power generation system is controlled according to an embodiment. In particular, the nominal grid frequency (labelled with reference sign 547) amounts to 50

Hz. As can be seen from Fig. 5 a deviation of the actual grid frequency from the nominal grid frequency 547 is lower when the power output of the power generation system is controlled according to an embodiment (corresponding to curve 571) compared to a case where such a controlling is not performed (corresponding to curve 569).

Fig. 6 illustrates a characteristics of a first order low pass filter employed in the arrangement 100 illustrated in Fig. 1. On an abscissa in Fig. 6 the frequency f is indicated, while on an ordinate the gain of the filter in dB is indicated. Up to a cut-off frequency f_0 the gain stays constant at 0 dB. In the range from f_0 to $10 \times f_0$ the gain drops with a rate of -20 dB/decade. For comparison a gain curve 675 of a second order low cut filter is illustrated. As can be seen, frequency components in a signal fed through the filter (such as the filter 125, 137 or 139, as illustrated in Fig. 1) which are above the threshold frequency f_0 are attenuated. The cut-off frequencies of the filters 125, 137 and 139 may be different, as explained above.

It should be noted that the term "comprising" does not exclude other elements or steps and "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:

	100	Arrangement for generating a control signal for controlling a power output of a power generation system
5	101	Input terminal
	103	Measurement system
	105	Leg filter
	107	Control circuit
10	109,113	Signal lines
	115	Limiting section or limiting circuit
	117	Output terminal
	119	Comparator
	121	Derivative element
15	123,133	Switches
	125	First filter
	127	Dead band element
	129,141,145	Multiplier
	131	Adder
20	135	Dead band element
	137	Second filter
	139	Third filter
	143	Integrative element or integrator
	247,547	Nominal grid frequency
25	249,251	Time points
	353	Converter
	355	Power controller
	357	Wind turbine controller
	359	Input terminal of wind turbine controller
30	361	Output terminal of power controller
	463	Power generation system
	466,467	Communication/control lines
	465	Power generation plant controller
	469,471	Actual grid frequency curves
35	673	Gain curve of cut-off filter of first order
	675	Gain curve of second order cut-off filter
	f_0	Cut-off frequency

	700	Part of the arrangement for generating a control signal for controlling a power output of a power generation system in a first mode
	703	Measurement system
5	715	Limiting section or limiting circuit
	717	Output terminal
	721	Derivative element
	725	First filter
	727	Dead band element
10	729	Multiplier
	751	Adder
	752	Multiplier
	753	Integrator
	754	Multiplier
15	800	Part of the arrangement for generating a control signal for controlling a power output of a power generation system in a first mode
	803	Measurement system
	815	Limiting section or limiting circuit
20	817	Output terminal
	821	Derivative element
	825	First filter
	827	Dead band element
	829	Multiplier
25	851	Adder
	852	Multiplier
	853	Integrator
	854	Multiplier
	900	Wind farm
30	901	Wind farm controller
	902	Wind turbine
	1010	Adjusting curve FLM
	1110	Adjusting curve FSM

CLAIMS:

1. Arrangement (100, 300) for generating a control signal for controlling a power output of a power generation system

5 (463), in particular a wind turbine, wherein the power output is to be supplied to a utility grid, the arrangement comprising:

- an input terminal (101) for receiving an input signal (f_{filt}) indicative of an actual grid frequency of the utility grid;
- a control circuit (107, 115) for generating the control signal (P_{inertia}), wherein the control circuit comprises a first circuit (121) for generating a time derivative value of the input signal; and
- 15 • an output terminal (117, 317) to which the control signal is supplied,

wherein the control signal depends on the generated time derivative value of the input signal.

20 2. Arrangement according to claim 1, further comprising:

- a first filter (125) connected between the input terminal and the first circuit, wherein the first filter is adapted to attenuate a frequency component of the input signal having a frequency higher than a first threshold frequency (f_0).

3. Arrangement according to claim 2, wherein the input signal indicative of the actual grid frequency of the utility grid is indicative of a deviation (F_{error}) of the actual grid frequency from a fixed nominal grid frequency (F_{ref}),
30 wherein the arrangement in particular comprises a comparator (119) for determining the frequency deviation of the actual grid frequency from the fixed nominal grid frequency.

35 4. Arrangement according to claim 3, wherein the control circuit comprises a second circuit (143) for generating a time integrative value of the input signal, wherein the control

signal further depends on the generated time integrative value of the input signal.

5. Arrangement according to claim 4, further comprising:

- 5 • a second filter (137) connected between the input terminal and the second circuit, wherein the second filter is adapted to attenuate a frequency component of the input signal having a frequency higher than a second threshold frequency, wherein in particular the second threshold frequency is greater than the first threshold frequency.
- 10

6. Arrangement according to one of claims 3 to 5, wherein the control circuit comprises a third circuit (145) for generating a proportional value of the input signal, wherein the control signal further depends on the generated proportional value of the input signal.

15

7. Arrangement according to claim 6, further comprising:

- 20 • a third filter (139) connected between the input terminal and the third circuit, wherein the third filter is adapted to attenuate a frequency component of the input signal having a frequency higher than a third threshold frequency, wherein the third threshold frequency is in particular greater than the first threshold frequency.

25

8. Arrangement according to one of claims 3 to 7, wherein at least one of the first filter, the second filter and the third filter comprises a low pass filter, in particular a first order analogue filter.

30

9. Arrangement according to claim 7 or 8, wherein the control signal is based on a weighted sum of the proportional value, the time integrative value and the time derivative value of the input signal, wherein in particular the weighted sum is generated by an adder circuit (131).

35

10. Arrangement according to one of claims 7 to 9, wherein the arrangement is selectively operable in a first mode and

in a second mode, wherein in the first mode a weight of the proportional value of the input signal and a weight of the time integrative value of the input value are both below a weight threshold, while the weight of the time derivative value of the input signal is one, wherein in particular from the derivative value, the integrative value and the proportional value exclusively the derivative value is taken into account for generating the control signal.

11. Arrangement according to one of the preceding claims, further comprising:

- a limiting circuit (115) connected between the control circuit and the output terminal for limiting the control signal to be below a predetermined change per time and/or to be in a predetermined range, wherein the predetermined range is 0.0 to 0.2, in particular 0.0 to 0.1, times a nominal power output of the power generation system.

12. Arrangement according to claim 11, wherein the predetermined range depends on an actual power supplied by the power generation system to the utility grid and/or on a kinetic energy of a mechanical portion of the power generation system.

13. Arrangement according to one of the preceding claims, wherein the arrangement is adapted to communicate with a power generation plant controller (465) controlling a plurality of power generation systems (463), including the power generation system, regarding their power outputs, wherein in particular the control signal is communicated to the power generation plant controller.

14. Arrangement according to one of the preceding claims, further comprising:

- a load determination unit for determining, based on the control signal and/or based on both a power output and a nominal power output of the power generation system,

a load of the power generation system,
wherein in particular the load determination unit comprises a
counter for counting a number of times the control signal
caused an increase of the power output of the power genera-
5 tion system,
in particular for counting a number of times the control sig-
nal caused an increase of the power output of the power gen-
eration system above the nominal power output.

- 10 15. Power generation system, in particular wind turbine sys-
tem, for supplying electrical power to a utility grid, the
power generation system comprising:
- an arrangement for generating a control signal for control-
ling a power output of the power generation system accord-
15 ing to one of the preceding claims; and
 - a generator and/or converter arranged to receive the con-
trol signal and to adapt the power output in dependence of
the control signal.

FIG 1

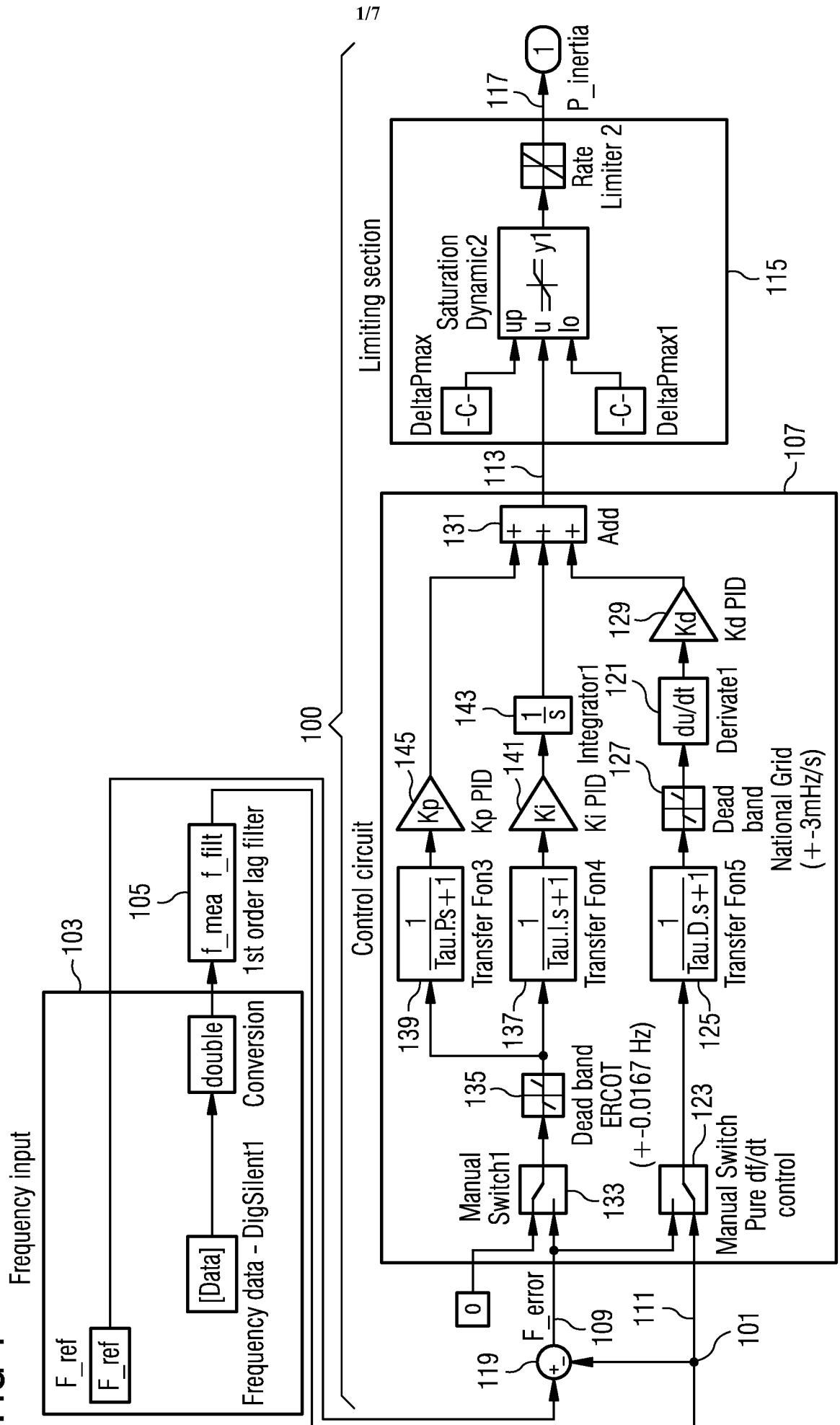


FIG 2

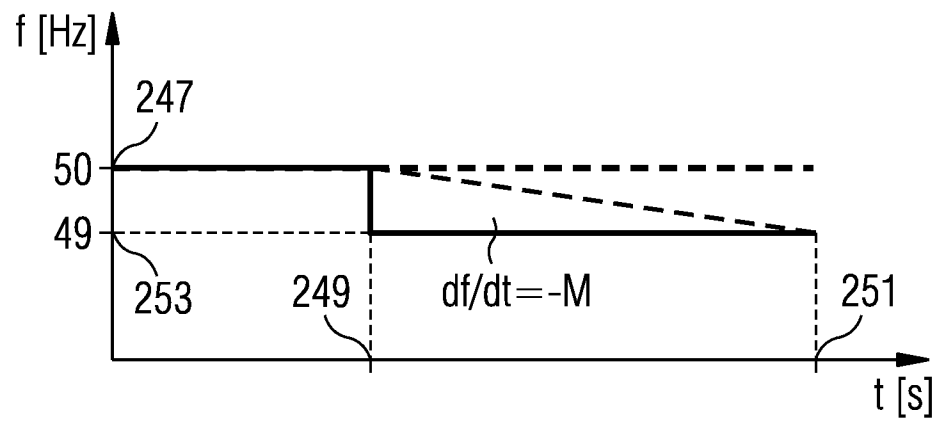


FIG 3

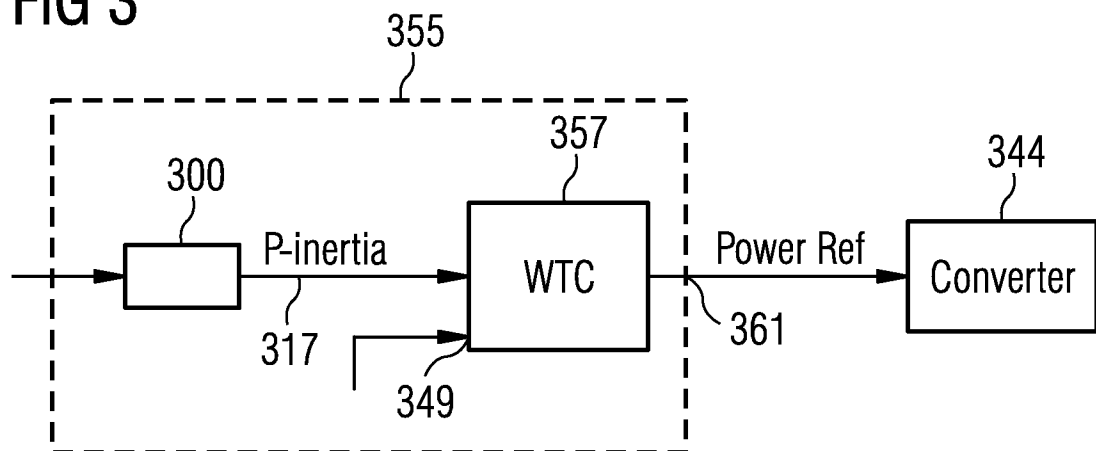


FIG 4

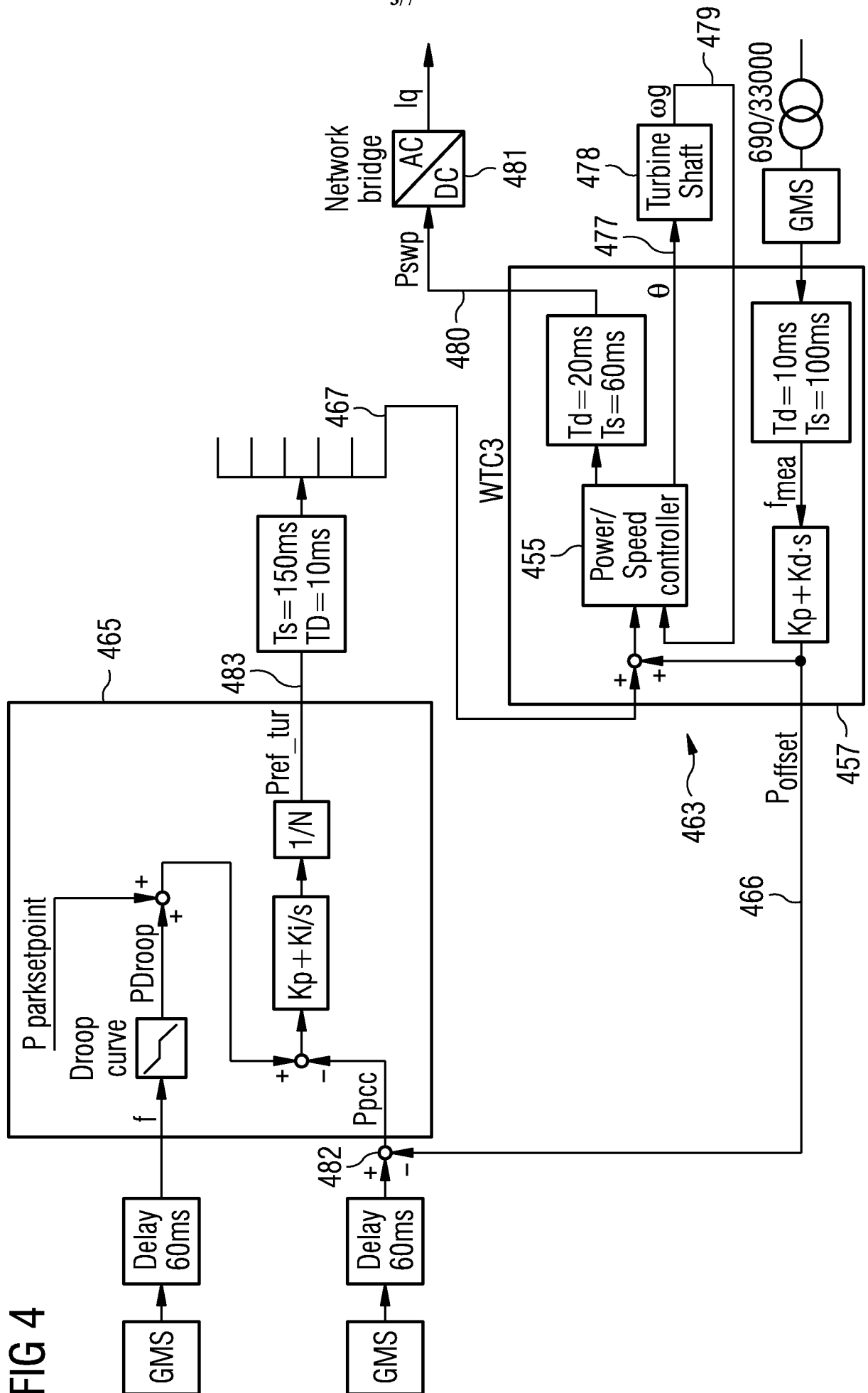


FIG 5

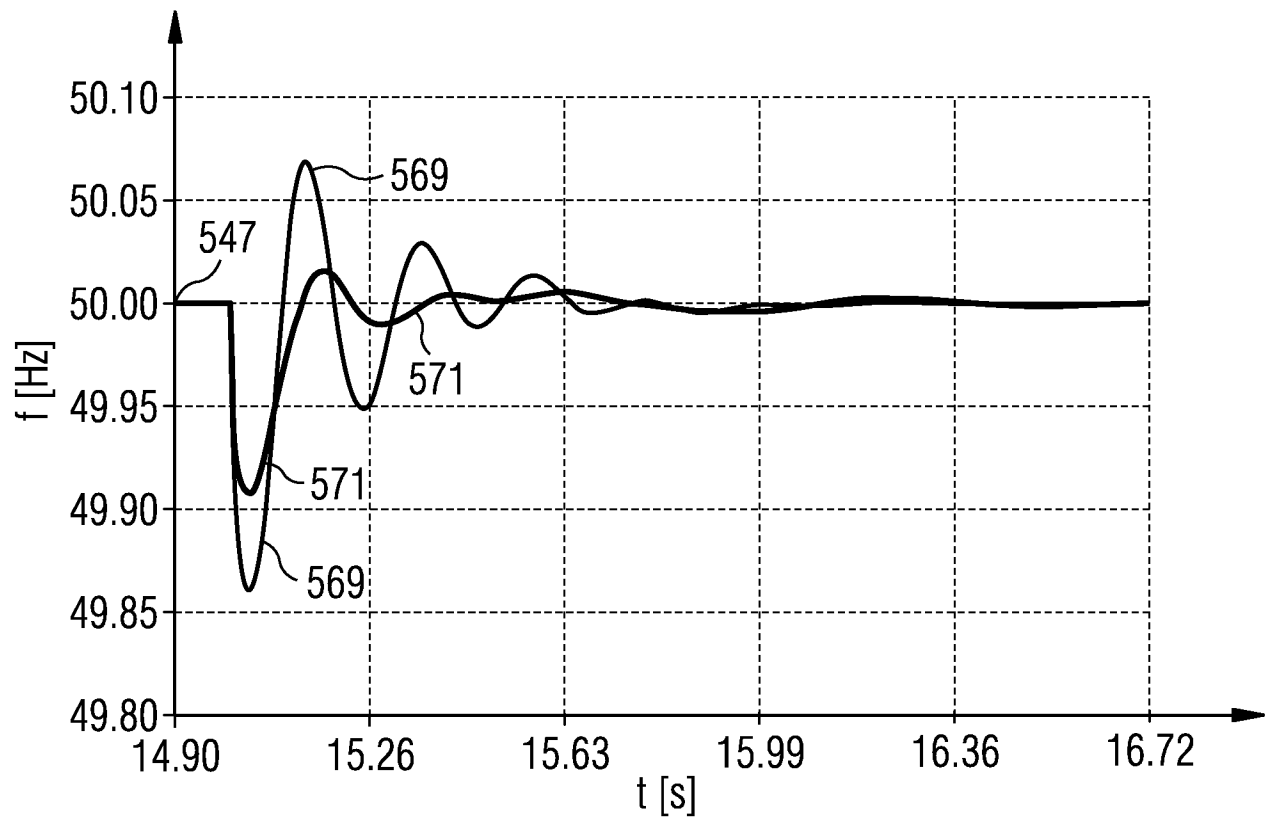


FIG 6

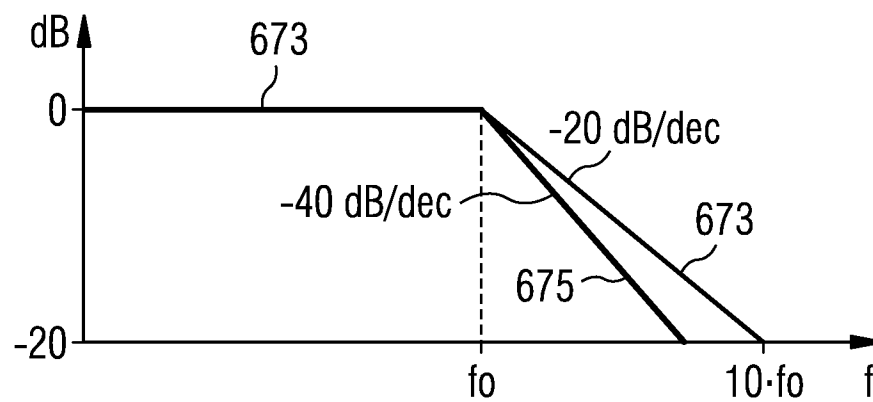


FIG 7

700 ↗

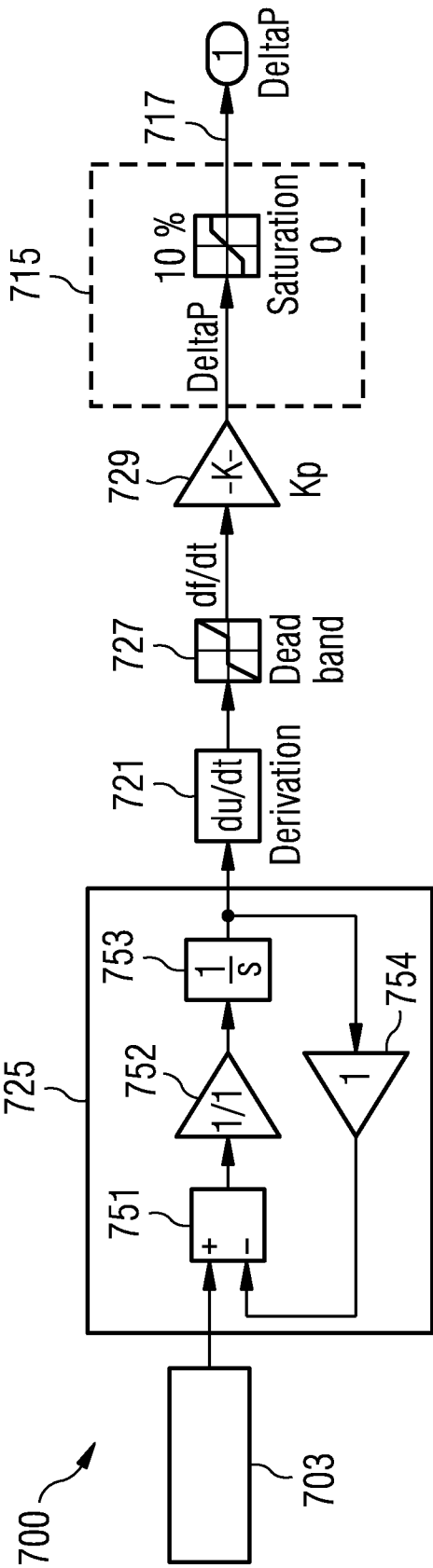
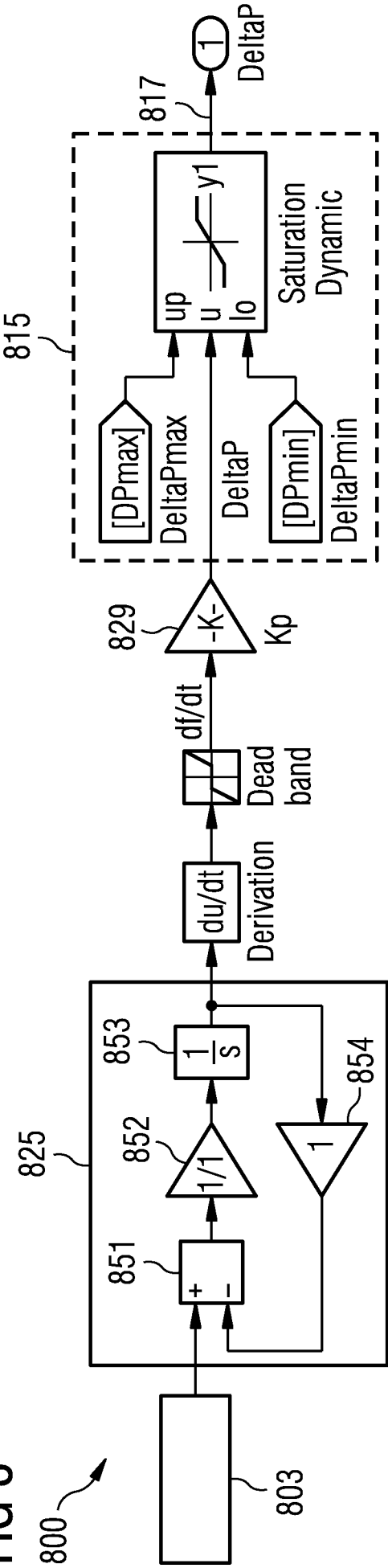


FIG 8

800 ↗



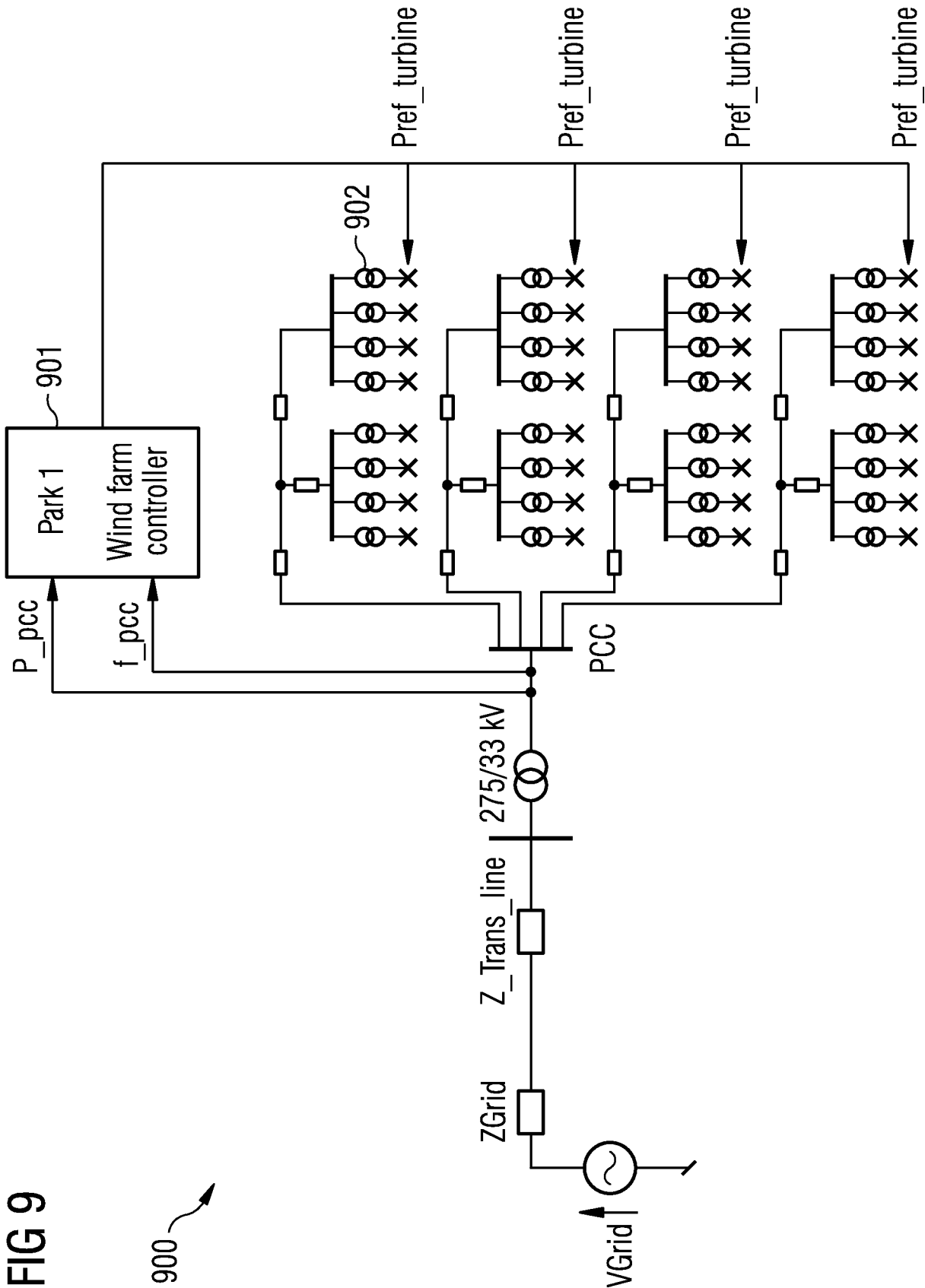


FIG 10

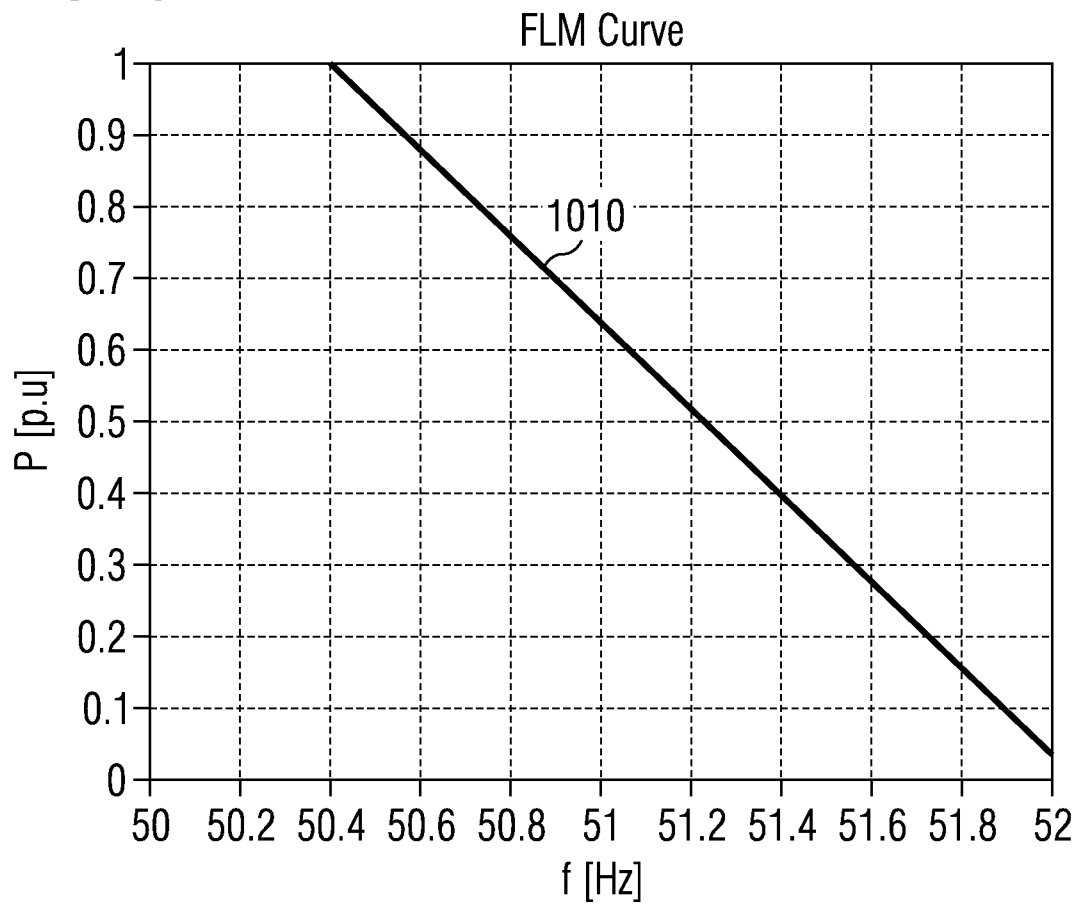


FIG 11

