Claims

~~1. A method of determining, in a measurement system, a frequency response characteristic within a synchronous area of an electric power grid, electricity flowing in the grid in accordance with a grid frequency, wherein the electric power grid is connected to a first group of one or more power units each arranged to consume electric power from and/or provide electric power to the electric power grid such that a change in power provision and/or consumption by said first group of one or more power units results in a change in power flow in the electric power grid, wherein power flow to and/or from each of the power units is modulated on the basis of a sequence of control signals, thereby modulating the grid frequency to provide a frequency modulated signal according to the sequence of control signals, the method comprising:~~

~~measuring, in the measurement system, a frequency characteristic relating to a frequency of electricity flowing in the electric power grid;~~

~~accessing a database storing data relating to power characteristics of said one or more power units and determining, on the basis thereof, a characteristic relating to said power flow modulation; and~~

~~determining a frequency response characteristic associated with at least one area of said electric power grid on the basis of the measured frequency characteristic and the said determined power flow modulation characteristic.~~

~~2. A method according to claim 1, in which determining the frequency response characteristic comprises correlating the measured frequency characteristic with said power flow modulation characteristic.~~

~~3. A method according to claim 1, in which determining the frequency response characteristic comprises determining a ratio of said power flow modulation characteristic and the measured frequency characteristic.~~

~~4. A method according to any preceding claim in which said power flow modulation characteristic comprises a magnitude characteristic relating to said power flow modulation.~~

~~5. A method according to claim 4, in which said magnitude characteristic comprises an amplitude of the power flow.~~

~~6. A method according to any preceding claim, in which said measured frequency characteristic is measured on the basis of one or more of: a frequency of alternating voltage, a frequency of alternating current, a measured frequency of power flowing in the electric power grid; a rate of change of frequency; a period of alternating current or voltage.~~

~~7. A method according to any preceding claim, in which said measured frequency characteristic comprises a time variation in frequency associated with said modulated signal.~~

~~8. A method according to any preceding claim, in which said frequency response characteristic comprises an inertia characteristic.~~

~~9. A method according to claim 8, in which said inertia characteristic comprises at least one of a rise time and a fall time associated with said frequency modulated signal.~~

~~10. A method according to any of claims 1 to 7, in which said frequency response characteristic comprises a characteristic relating to a magnitude of variation in grid frequency per unit change in power balance.~~

~~11. A method according to any preceding claim, in which of the first group of power units is a distributed group of power units, the method comprising:~~

~~modulating power flow to and/or from each of the first group of power units in accordance with a control pattern, such that the consumption and/or provision of power by the plurality of power units is coordinated to provide a collective frequency modulated signal, having a collective frequency characteristic, that is detectable by the measurement system.~~

12. A method according to claim 11, comprising sending a signal specifying said control pattern to each power unit of the first group of power units.

13. A method according to claim 11 or claim 12, in which the control pattern comprises a repeating pattern, and the method comprises controlling power to and/or from the first group of one or more power units continuously according to the repeating pattern.

14. A method according to any of claim 11 to claim 13, comprising controlling power to and/or from the first group of one or more power units intermittently according to the control pattern.

15. A method according to any of claim 11 to claim 14, in which said collective modulated signal includes an identifier identifying said group of power units, the method comprising:

accessing a database storing one or more identifiers each associated with said first group of one or more power units; and

determining a correspondence between the identifier included in the collective modulated signal and one or more of the identifiers stored in the database, thereby identifying said first group of one or more power units.

16. A method according to claim 15, in which each identifier stored in the database is associated with at least one area of the electric power grid and the method comprises determining an area with which the determined frequency response characteristic is associated on the basis of the determined identifier correspondence.

17. A method according to any preceding claim, in which the electric power grid is connected to a second group of one or more power units arranged to consume power from and/or provide power to the electric power grid, the method comprising:

determining, on the basis of the determined frequency response characteristic, one or more parameters for use in triggering a change in consumption and/or provision of power by the second group of one or more power units; and

~~transmitting said one or more parameters for receipt at said second group of power units.~~

~~18. A method according to claim 17, comprising:~~

~~receiving, at the second group of power units, said one or more parameters;~~

~~deriving, on the basis of the received parameters, a trigger condition;~~

~~determining, based on a measured frequency characteristic of electric power flowing in the grid locally to a second group of power units, whether the trigger condition is satisfied; and~~

~~in response to a determination that the trigger condition is satisfied, changing a power flow to and/or from the second group of power units.~~

~~19. A method according to claim 17 or 18, comprising:~~

~~defining, at the measurement system, a first series of values associated with the frequency characteristic during a first time period and a second series of values associated with the frequency characteristic during a second, later, time period;~~

~~determining, at the measurement system, a first polynomial function having a first set of coefficients on the basis of said first series of values and a second polynomial function having a second set of coefficients on the basis of said second series of values; and~~

~~determining, at the measurement system, whether the trigger condition is satisfied on the basis of a difference between the first set of coefficients and the second set of coefficients.~~

~~20. A method according to any of claim 1 to claim 16, in which the electric power grid is connected to a second group of one or more power units arranged to consume power from and/or provide power to the electric power grid, the method comprising:~~

~~determining, based on the determined frequency response characteristic associated with an area associated with the second group of power units, one or more parameters for use in triggering a change in consumption and/or provision of power by the second group of one or more power units;~~

deriving a trigger condition on the basis of the measured frequency response characteristic;

measuring, in an area associated with the second group of power units, a frequency characteristic relating to a frequency of electricity flowing in the electric power grid;

communicating the measured frequency characteristic measured in the area associated with the second group of power units to the measurement system;

determining, based on the communicated measured frequency characteristic, whether the trigger condition is satisfied; and

in response to a determination that the trigger condition is satisfied, sending a request to the second group of power units to change a power flow to and/or from the second group of power units.

21. A method according to any of claim 17 to 20, in which the second group of power units is the same as the first group of power units.

22. A method according to any preceding claim, in which the power modulation comprises modulation of at least one of real power and reactive power.

23. A measurement system for determining a frequency response characteristic within a synchronous area of an electric power grid, wherein electricity flows in the grid in accordance with a grid frequency and the electric power grid is connected to a group of one or more power units each arranged to consume electric power from and/or provide electric power to the electric power grid such that a change in power provision and/or consumption by said power unit results in a change in power flow in the grid, wherein power flow to and/or from each of the power units is modulated on the basis of a sequence of control signals, thereby modulating the grid frequency to provide a frequency modulated signal, the measurement system being arranged to:

measure a frequency characteristic relating to a frequency of electricity flowing in the electric power grid;

~~access a database storing data relating to power characteristics of said one or more power units and determine, on the basis thereof, a characteristic relating to said power flow modulation; and~~

~~determine a frequency response characteristic associated with at least one area of said electric power grid on the basis of the measured frequency characteristic and the said determined power flow modulation characteristic.~~

1~~24~~. A power control device for use with one or more associated power units to provide a response to changes in a frequency of electricity flowing in a synchronous area of an electric power grid, wherein the electric power grid is connected to a measurement system arranged to determine a frequency response characteristic of the grid in said area and to determine one or more trigger parameters on the basis of the measured frequency response characteristic, the power control device being arranged to:

intermittently receive one or more parameters from the measurement system, the one or more parameters being derived from a said determined frequency response characteristic;

derive, on the basis of the received one or more parameters, a trigger condition;

determine, based on a measured frequency characteristic of electric power flowing in the grid, whether the trigger condition is satisfied; and

in response to a determination ~~that~~ that the trigger condition is satisfied, change a power flow to and/or from the power unit,

wherein when the trigger condition being satisfied indicates a rise in grid frequency, changing the power flow comprises increasing a power flow to and/or reducing a power flow from the one or more power units,

and when the trigger condition being satisfied indicates a drop in grid frequency, changing the power flow comprises reducing a power to and/or increasing a power flow from the one or more power units.

2~~25~~. A power control device according to claim 1~~24~~, in which one of the received one or more parameters comprise said trigger condition.

3~~26~~. A power control device according to claim 1~~24~~ or claim 2~~25~~, in which said frequency response characteristic comprises an inertia characteristic.

4~~27~~. A power control device~~method~~ according to claim ~~24~~ 1 or claim ~~25~~2, in which said frequency response characteristic comprises a characteristic relating to a magnitude of variation in grid frequency per unit change in power balance.

5~~28~~. A power control device according to any one of claims 1~~24~~ to 4~~27~~, arranged to:

define a first series of values associated with the frequency characteristic during a first time period and a second series of values associated with the frequency characteristic during a second, later, time period;

determine a first polynomial function having a first set of coefficients on the basis of said first series of values and a second polynomial function having a second set of coefficients on the basis of said second series of values; and

determine whether the trigger condition is satisfied on the basis of a difference between the first set of coefficients and the second set of coefficients.

6~~29~~. A power control device according to claim 5~~28~~, wherein the first and second polynomial functions are second order polynomial functions.

7~~30~~. A power control device according to claim 5~~28~~ or claim 6~~29~~, in which the frequency change event is identified on the basis of a value of at least one coefficient of the second set of coefficients differing from a corresponding coefficient in the first set of coefficients by more than a predetermined amount.

8~~31~~. A power control device according to any one of claim 5~~28~~ to claim 7~~30~~, arranged to measure said series of values according to a polynomial extrapolation technique and/or conic extrapolation technique.

9~~32~~. A power control device according to any one of claim 1~~24~~ to claim 8~~31~~, comprising a detector (302) for measuring a frequency characteristic.

10. A power control device according to any one of claims 1 to 9, comprising phasor measurement instrumentation arranged to measure said measured frequency characteristic on the basis of a phasor measurement.

1133. A power control device according to claim 1032, in which the phasor measurement instrumentation is arranged to measure a phase associated with a vector of voltage measured in the electric power grid with reference to an absolute time reference.

1234. A power control device according to any one of claim 124 to claim 1133, wherein the measured frequency characteristic includes one or more of: a frequency of alternating voltage, a frequency of alternating current, a frequency of power flowing in the electric power grid; a rate of change of frequency; and a period of alternating current.

1335. A power control device according to any one of claim 24 1 to claim 1234, arranged to receive a signal, said signal indicating a time period during which power flow may be controlled.

1436. A power control device according to any one of claims 124 to 1335, in which the power modulation comprises modulation of at least one of real power and reactive power.

15. A power control device according to any one of claims 1 to 14, in which said trigger condition is a level of the measured frequency characteristic or is based on one or more parameters relating to a fitting function applied to the measured frequency characteristic, or changes to the one or more parameters.

1637. A system for responding to changes of frequency in an electric power grid, the system comprising:

a distributed plurality of power control devices according to any one of claim ~~24~~ 1 to claim ~~36~~15, each controlling a respective power unit connected to the electric power grid; and

a measurement system for transmitting one or more trigger parameters to each of the plurality of distributed power control devices.

17~~38~~. A system according to claim 16~~37~~, wherein the measurement system is arranged to:

define, a plurality of groups of power control devices from said distributed plurality of power control devices;

assign different respective trigger conditions to each of the plurality of groups; and

transmit, to each of power control devices a trigger condition assigned to the group to which it is assigned.

18~~39~~. A system according to claim 17~~38~~, wherein the measurement system is arranged to:

access a power unit database storing profile information relating to the consumption and/or provision of power by the power units associated with the power control devices; and

define said plurality of groups on the basis of the accessed profile information.

19~~40~~. A system according to claim 16~~37~~, wherein the measurement system is arranged to:

receive data indicative of a polynomial function representative of a measured frequency characteristic;

extrapolate, based on said polynomial function, future expected values associated with the measured frequency characteristic; and

determine, on the basis of the extrapolated future expected values, an expected power flow requirement for responding to the frequency change event.

2041. A system according to claim 1940, wherein the measurement system is arranged to:

access a power unit database comprising profile information relating to the consumption and/or provision of power by the power units;

define, on the basis of the expected power flow requirement and said profile information, one or more groups of one ~~of~~ or more power units for responding to the frequency change event.

2142. A system according to claim 2041, wherein the measurement system is arranged to transmit one or more requests, for receipt at the power control devices of the defined groups, to control consumption and/or provision of electrical power by the power units associated with power control devices, thereby varying a net consumption of electrical energy in said area.

~~43. A power control device for use with one or more associated power units to provide a response to changes in a frequency of electricity flowing in an electric power grid, wherein electricity flows in the electric power grid in accordance with a grid frequency, the power control device comprising a frequency measurement device and being arranged to:~~

~~monitor, using said frequency measurement device, changes in said grid frequency at the power control device;~~

~~based at least partly on said monitoring, determine a trigger condition;~~

~~determine, based on a measured frequency characteristic of electric power flowing in the grid, whether the trigger condition is satisfied; and~~

~~in response to a determination that that the trigger condition is satisfied, change a power flow to and/or from the power unit.~~

~~44. A power control device according to claim 43, arranged, responsive to the measured frequency characteristic crossing a threshold value, to:~~

~~perform an analysis of the measured frequency characteristic at times preceding said threshold value being crossed; and~~

~~determine said trigger condition at least partly on the basis of said analysis.~~

~~45. A power control device according to claim 43 or claim 44, arranged to:~~

~~monitor, using said frequency measurement device, changes in the grid frequency at the power control device subsequent to the derivation of said trigger condition, and~~

~~based on the subsequent monitoring, derive an updated trigger condition.~~

~~46. A power control device according to claim 45, in which the derivation of the updated trigger condition is based in part on said first trigger condition.~~