

[DESCRIPTION]

[TITLE OF INVENTION]

CONTROL DEVICE AND CONTROL METHOD

[Technical Field]

5 [0001]

The present disclosure relates to a control device and a control method, each for controlling an inverter provided in a power supply.

[Background Art]

[0002]

10 A power system, that supplies alternating current (AC) power from a power supply to a load, controls to maintain an output voltage thereof and a frequency thereof. In such a power system, when the amount of AC power introduced from a renewable energy power source increases to an amount greater than the amount of AC power introduced from a synchronous generator, inertial property of the power supply decreases, thereby making
15 it difficult to maintain the frequency when the supply and demand balance suddenly changes.

[0003]

In contrast, for example, the control device for a distributed power supply of Patent Document 1 operates an inverter, that interconnects the distributed power supply
20 with the system, by virtual synchronous generator (hereinafter, an acronym VSG is used as an abbreviation of virtual synchronous generator.) control, thereby causing the distributed power supply to have an inertial property of the synchronous generator in a pseudo manner. The control device thus reduces or prevents a frequency fluctuation of the system.

25 [Citation List]

[Patent Document]

[0004]

[Patent Document 1]

Japanese Unexamined Patent Application, First Publication No. 2019-176584

5 [Summary of Invention]

[Technical Problem]

[0005]

However, the conventional control device for a distributed power supply has a problem that, when a change occurs in a specification, a configuration, or an operational situation of a device connected to the system, a work for configuration change of the inverter and one for confirmation after the configuration change, are required to exert an effect of reducing or preventing a frequency fluctuation similarly as before the change. This is because the active power output from the inverter, which is an input value of the computation processing related to VSG control, changes by an effect from a device that is the connection destination device (hereinafter referred to simply as the destination device). That is, when a change occurs in a specification, a configuration, or an operational situation of a destination device, gain adjustment of the inverter, for example, is required to compensate for the change in the active power.

[0006]

20 The present disclosure has been made to solve the above problems, and it is an object of the present disclosure to provide a control device and a control method, where the control device is configured to be able to calculate an active power reference value output by an inverter to a destination device in a predetermined reference state, and feeds back a difference between the active power reference value and an active power measurement value, or a difference between a VSG control output based on the active

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power reference value and a VSG control output based on the active power measurement value, to computation processing related to VSG control, and can thereby control the inverter to exert an effect of reducing or preventing a frequency fluctuation as specified by prescribed values, even when a change occurs in a specification, a configuration, or an operational situation of the destination device.

[Solution to Problem]

[0007]

A control device according to the present disclosure is a control device that controls an inverter to cause a frequency of an output voltage of the inverter to have a virtual inertial property on active power supplied to a destination device connected to the inverter. The control device comprises a first virtual synchronous generator controller that calculates a frequency deviation by a transfer function based on an oscillation equation for a synchronous generator, using an active power measurement value supplied to the destination device by the inverter; a first command value generator that generates a frequency command value of the output voltage of the inverter using the frequency deviation calculated by the first virtual synchronous generator controller; and a first error correction controller that determines a gain of the transfer function in the first virtual synchronous generator controller using a first error that is a difference between an active power reference value and the active power measurement value, where the active power reference value is active power to be supplied by the inverter to the destination device in a predetermined reference state.

[0008]

Another embodiment of a control device according to the present disclosure comprises a first virtual synchronous generator controller that calculates a first frequency deviation by a transfer function based on an oscillation equation for a synchronous

generator, using an active power measurement value supplied to a destination device by an inverter; a first command value generator that generates a first frequency command value as a frequency command value of the output voltage of the inverter using the first frequency deviation calculated by the first virtual synchronous generator controller; a
5 second virtual synchronous generator controller that calculates a second frequency deviation by the transfer function using an active power reference value that is active power to be supplied by the inverter to the destination device in a predetermined reference state; and a second error correction controller that feeds back, to the first virtual synchronous generator controller, a second error that is a difference between the first frequency
10 deviation calculated by the first virtual synchronous generator controller and the second frequency deviation calculated by the second virtual synchronous generator controller.

[0009]

A control method according to the present disclosure is a control method for controlling an inverter to cause a frequency of an output voltage of the inverter to have a
15 virtual inertial property on active power supplied to a destination device connected to the inverter. The control method comprises a step of calculating a frequency deviation by a transfer function based on an oscillation equation for a synchronous generator, using an active power measurement value supplied to the destination device by the inverter; a step of generating a frequency command value of the output voltage of the inverter using the
20 frequency deviation; and a step of determining a gain of the transfer function using a first error that is a difference between an active power reference value and the active power measurement value, where the active power reference value is active power to be supplied by the inverter to the destination device in a predetermined reference state.

[0010]

25 Another embodiment of a control method according to the present disclosure

comprises a step of calculating a first frequency deviation by a transfer function based on an oscillation equation for a synchronous generator, using an active power measurement value supplied to the destination device by the inverter; a step of generating a frequency command value of the output voltage of the inverter using the first frequency deviation; a
5 step of calculating a second frequency deviation by the transfer function using an active power reference value that is active power to be supplied by the inverter to the destination device in a predetermined reference state; and a step of feeding back, to the step of calculating a first frequency deviation, a second error that is a difference between the first frequency deviation and the second frequency deviation.

10 [Advantageous Effects of Invention]

[0011]

According to the present disclosure, it is possible to provide a control device and a control method for controlling an inverter to exert an effect of reducing or preventing a frequency fluctuation as specified by prescribed values, even when a change occurs in a
15 specification, a configuration, or an operational situation of a destination device connected to the inverter.

[Brief Description of Drawings]

[0012]

FIG. 1 is a diagram illustrating an exemplary configuration of a microgrid in a
20 first embodiment.

FIG. 2 is a block diagram illustrating a control system comprising a control device and an inverter to be controlled in the first embodiment.

FIG. 3 is a flowchart illustrating control processing performed by the control device in the first embodiment.

25 FIG. 4 is a diagram illustrating a relationship between the inverter to be controlled

and a destination device in the first embodiment.

FIG. 5 is a block diagram illustrating a hardware configuration of a PLC that implements the control device in the first embodiment.

FIG. 6 is a block diagram illustrating a control system comprising the control
5 device and the inverter to be controlled in a second embodiment.

FIG. 7 is a flowchart illustrating control processing performed by the control device in the second embodiment.

[Description of Embodiments]

[0013]

10 First Embodiment.

A first embodiment will be described in detail with reference to FIG. 1. FIG. 1 is a diagram illustrating an exemplary configuration of a microgrid 1 in a first embodiment. In FIG. 1, a microgrid 1 is a self-sustaining power system that independently generates and consumes power, and comprises a power generation facility 11, a load 12, a storage battery
15 13, a power conversion device 14, and a transducer 15, which are connected to each other by a power transmission and distribution network 21. Among them, operation of the power conversion device 14, that is, operation of supplying an amount of power generated by the power generation facility 11 to the storage battery 13 and operation of supplying an amount of charged power in the storage battery 13 to the load 12 are controlled by an
20 integrated controller 31.

[0014]

The power generation facility 11 is a renewable energy power source whose output is difficult to control, such as a power generation facility of, for example, wind power generation, solar power generation, or hydraulic power generation. The power
25 generation facility 11 comprises an electric energy meter that measures the power

generation amount thereof and a communication device that transmits a measurement value of the amount of power.

[0015]

The load 12 is a device that consumes power, and comprises an electric energy
5 meter that measures the power consumption amount thereof and a communication device that transmits a measurement value of the amount of power.

[0016]

The storage battery 13 is a secondary battery such as a lead storage battery, a
nickel-metal hydride battery, a lithium-ion battery, a sodium sulfur battery, or a redox flow
10 battery, and comprises a communication device for transmitting a state of charge (SOC) and receiving a control command related to charging and discharging.

[0017]

The power conversion device 14 comprises a control device 41, an inverter 42,
and a communication device (not illustrated). In the power conversion device 14, the
15 inverter 42 is an inverter capable of converting an AC into a direct current (DC) and vice versa, specifically, converts a DC voltage output from the storage battery 13 to the transmission and distribution network 21 into an AC voltage when the storage battery 13 is discharged, and converts an AC voltage received by the storage battery 13 from the transmission and distribution network 21 into a DC voltage when the storage battery 13 is
20 charged. The control device 41 controls the above-described AC-DC interconversion performed by the inverter 42, and controls the inverter 42 to cause the frequency of the output voltage of the inverter 42 to have a virtual inertial property on active power supplied to the destination device connected to the inverter. The communication device receives an output command value transmitted from the integrated controller 31. The power
25 conversion device 14 causes the storage battery 13 to act as a voltage source since the

output command value transmitted from the integrated controller 31, and thus functions as a grid forming (GFM) inverter.

[0018]

The transducer 15 measures an active power measurement value P_{measure} , which is
 5 a value of active power actually output from the inverter 42 of the power conversion device 14. The transducer 15 is connected to the control device 41 by a signal line such as, for example, a coaxial cable and outputs the active power measurement value P_{measure} that has been measured, to the control device 41 via the signal line.

[0019]

10 The integrated controller 31 is connected to the power generation facility 11, the load 12, the storage battery 13, and the power conversion device 14, and controls the storage battery 13 and the power conversion device 14 on the basis of information regarding power supply and demand, such as, for example, a power generation amount and a power consumption amount transmitted from the communication device provided in each
 15 applicable device.

Specifically, when the power consumption amount of the load 12 is less than the power generation amount of the power generation facility 11, the integrated controller 31 controls the power conversion device 14 to convert the AC voltage supplied by the power generation facility 11 into a DC voltage to charge the storage battery 13 with the amount
 20 of power generated by the power generation facility 11 and converted into the DC voltage by the power conversion device 14. Alternatively, when the power consumption amount of the load 12 is greater than the power generation amount of the power generation facility 11, the integrated controller 31 discharges the storage battery 13 within a range allowed by the SOC to compensate for a difference between the power generation amount of the power
 25 generation facility 11 and the power consumption amount of the load 12, and controls the

power conversion device 14 to convert the DC voltage supplied by the storage battery 13 into an AC voltage.

In a case of controlling the storage battery 13 and the power conversion device 14 to cause discharge, the integrated controller 31 outputs an active power command value P_{ref} to the power conversion device 14 as an output command value for the power conversion device 14.

[0020]

In this respect, the active power measurement value $P_{measure}$, the active power command value P_{ref} , and the active power described below are values according to a PU system (PU: per unit) unless otherwise specified, and the unit thereof is not watt (W) but pu. For example, active power is divided by the rated output of the inverter 42 and is expressed in the PU system.

[0021]

Here, the integrated controller 31 is implemented in a computer system comprising a computing device such as, for example, a central processing unit (CPU), storage devices, which are, for example, a memory such as a random access memory (RAM) and a storage such as a hard disc drive (HDD), a communication device, and a system bus that connects these devices. Specifically, the storage device stores a program representing the above-described control processing, the computing device executes the above-described program stored in the storage device, and the communication device communicates with the power generation facility 11, the load 12, the storage battery 13, and the power conversion device 14. In addition, the integrated controller 31 is not limited to one implemented in a single computer system, but may be implemented in a plurality of computer systems or in a cloud system.

[0022]

Next, a configuration and operation of the control device 41 will be described in detail with reference to FIGS. 2 and 3. FIG. 2 is a block diagram illustrating a control system comprising the control device 41 and the inverter 42 to be controlled in the first embodiment. FIG. 3 is a flowchart illustrating control processing performed by the control device 41 in the first embodiment.

The control device 41 comprising a subtractor 111, a first virtual synchronous generator controller 101 (hereinafter referred to as first VSG controller 101), a first governor controller 113, a first command value generator 102, a ZOH circuit 116 (ZOH: zero order hold), a reference output calculator 117, a subtractor 118, and a first error correction controller 103. The control device 41 controls the frequency of the output voltage of the inverter 42 on the basis of the active power command value P_{ref} transmitted from the integrated controller 31. An operation of each functional block of the control device 41 will hereinafter be described.

[0023]

The subtractor 111 subtracts an output value of the first governor controller 113 from the active power command value P_{ref} received from the integrated controller 31, and outputs the resulting value to the first VSG controller 101. In this respect, the first governor controller 113 is a functional block that performs calculation simulating a governor (speed governor) for maintaining the rotation speed of the synchronous generator constant. The operation of will be described later.

[0024]

The first VSG controller 101 comprises a subtractor 121, a multiplier 122, and a first-order delay circuit 123. The first VSG controller 101 performs VSG control for stabilizing the power system by causing the output voltage of the inverter 42 to have an inertial property caused by the inertia moment of the rotor in the synchronous generator in

a pseudo manner. The phrase “stabilizing the power system” refers to mitigating a frequency fluctuation in the p-f drooping characteristic, in which the frequency of the output voltage of the power supply decreases when the load applied to the AC power supply increases, whereas the frequency of the output voltage increases when the load decreases. In a case of a synchronous generator, which is an example, a rotor having large mass and thus strongly subjected to an inertial property, for example, is characterized in that a load fluctuation has a small effect on the rotation speed of the rotor. Due to synchronization between the rotational speed of the rotor of the synchronous generator and the frequency of the output voltage, a rotor having a large inertia moment will be subjected to a gradual change of the frequency of the output voltage under a load increase. In VSG control, the change of the frequency of the output voltage is mitigated under a fluctuation of the active power corresponding to the load fluctuation, thus stabilizing the power system, by simulating the inertia property of the rotor in such a manner.

[0025]

In step S11 illustrated in FIG. 3, the first VSG controller 101 calculates a frequency deviation $\Delta\omega_1$ using the active power measurement value P_{measure} .

Specifically, in the first VSG controller 101, the subtractor 121 calculates an active power deviation ΔP_1 by subtracting, from the output value of the subtractor 111, a signal value indicating the active power measurement value P_{measure} , zero-order held by the ZOH circuit 116. The subtractor 121 then outputs the active power deviation ΔP_1 calculated, to the multiplier 122. In this respect, the term zero-order hold refers to holding a signal value at a constant value until a next sampling time.

[0026]

In the first VSG controller 101, the multiplier 122 multiplies the active power deviation ΔP_1 by a gain $(1/D)$ and outputs the product to the first-order delay circuit 123.

Subsequently, the first-order delay circuit 123 multiplies the output value of the multiplier 122 by a transfer function $\{1/(1+sM/D)\}$ including an inertia constant M and a damping constant D to calculate a frequency deviation $\Delta\omega_1$, and outputs the frequency deviation $\Delta\omega_1$ to the first governor controller 113 and to the first command value generator 102, where the symbol s is a Laplace operator in the transfer function.

[0027]

The transfer function that the first VSG controller 101 applies to the input value thereof will be described later. As described above, the first VSG controller 101 performs control to simulate the inertia property caused by the inertia moment of the rotor in the synchronous generator. This control is based on the oscillation equation of the rotor in a synchronous generator, expressed by Equation (1-1). Here, Equation (1-1) is expressed in the PU system, where M is an inertia constant (unit is s) of the rotor, D is a damping constant (no unit), and ω is a rotational speed (unit is pu) of the rotor.

[0028]

15 [Equation 1]

$$\Delta P(t) = M \frac{d}{dt} \omega(t) + D\{\omega(t) - 1\} \quad (1-1)$$

[0029]

Equation (1-1) is transformed using Equation (1-2), and then obtained Laplace transform thereof, yielding a transfer function from ΔP to $\Delta\omega$, as expressed by Equation (1-3). In view of the illustration of FIG. 2, it can be seen that the transfer function applied to the input value by the first VSG controller 101 corresponds to the transfer function expressed by Formula (1-3). In addition, ΔP and $\Delta\omega$ in Equation (1-3) respectively correspond to ΔP_1 and $\Delta\omega_1$ in the present embodiment.

[0030]

[Equation 2]

$$\Delta\omega(t) = \omega(t) - 1 \quad (1 - 2)$$

$$\Delta P(s) = sM\Delta\omega(s) + D\Delta\omega(s) = \{sM + D\}\Delta\omega(s)$$

$$\Delta\omega(s) = \frac{1}{sM + D}\Delta P(s) = \frac{1}{D} \cdot \frac{1}{1 + sM/D}\Delta P(s) \quad (1 - 3)$$

[0031]

Returning to FIG. 2, the first governor controller 113 performs an operation of the
 5 governor in the synchronous generator in a pseudo manner. Specifically, the first governor
 controller 113 multiplies the frequency deviation $\Delta\omega_1$ output from the first VSG controller
 101 by a transfer function $\{K/(1+sT)\}$, and outputs the resulting value to the subtractor
 111. Here, T is a time constant corresponding to the integration time, and K is a gain of the
 governor.

10 [0032]

In step S12 illustrated in FIG. 3, the first command value generator 102 generates
 a frequency command value f_v of the output voltage as a control command value for the
 inverter 42 using the frequency deviation $\Delta\omega_1$ calculated by the first VSG controller 101.
 The first command value generator 102 then outputs the generated frequency command
 15 value f_v to the inverter 42 and to the reference output calculator 117. The first command
 value generator 102 comprises, as illustrated in FIG. 2, a constant multiplier 114a, a ZOH
 circuit 114b, and an adder 115.

[0033]

In the first command value generator 102, the constant multiplier 114a multiplies
 20 the frequency deviation $\Delta\omega_1$ by a rated frequency f_n (unit is hertz (Hz)) to convert the unit
 into Hz, and outputs the product to the ZOH circuit 114b as a frequency deviation df_1 . The
 ZOH circuit 114b outputs a signal value resulting from zero-order holding of the frequency
 deviation df_1 , to the adder 115. The adder 115 adds the rated frequency f_n to the signal

value output from the ZOH circuit 114b to thus calculate the frequency command value f_v , and outputs the frequency command value f_v to the inverter 42 and to the reference output calculator 117 as the control command value for the inverter 42.

In this respect, in Japan, the rated frequency f_n is, for example, a system frequency prescribed to be 50 Hz in eastern Japan and 60 Hz in western Japan.

[0034]

The inverter 42 outputs active power on the basis of the frequency command value f_v output from the first command value generator 102. When the frequency command value f_v fluctuates, the active power output from the inverter 42 changes according to, for example, the voltage, the frequency, and/or the like on the destination device connected to the inverter 42. The relationship between the frequency command value f_v , which is the control command value for the inverter 42, and the active power output from the inverter 42 will next be described in detail with reference to FIG. 4. FIG. 4 is a diagram illustrating a relationship between the inverter 42 to be controlled and the destination device connected to the inverter 42. FIG. 4 schematically illustrates the inverter 42 controlled by the control device 41 and a destination device such as, for example, the load 12 (hereinafter referred to simply as destination device) connected to the inverter 42 via a line reactance L . In this respect, the destination device is not limited to the load 12, For example, when a plurality of storage batteries 13 and a plurality of power conversion devices 14 are connected, these devices may also be regarded as destination devices.

[0035]

In FIG. 4, in regard to the AC voltage output from the inverter 42 denoted by v_v , the line reactance of the transmission and distribution network 21 denoted by L , the current flowing through the transmission and distribution network 21 denoted by i , and the AC voltage on the destination device denoted by v_o , the relational expression of these values

is expressed as the following Equation (1-4), where f_v is the frequency of the AC voltage output from the inverter 42, f_o is the frequency of the AC voltage on the destination device, and θ_o is the phase difference between the current i and the voltage v_o on the destination device.

5 [0036]

[Equation 3]

$$\begin{aligned} L \frac{di(t)}{dt} &= v_v - v_o \\ L \frac{di(t)}{dt} &= V_v e^{j2\pi f_v t} - V_o e^{j(2\pi f_o t + \theta_o)} \end{aligned} \quad (1-4)$$

[0037]

Furthermore, introducing Equation (1-5) to facilitate subsequent equation
10 deformation and then solving Equation (1-4) for the current i yields Equation (1-6) below.
In addition, considering that the apparent power S is expressed as Equation (1-7), the active power P output from the inverter 42 is expressed as Equation (1-8), where Q is reactive power output from the inverter 42.

[0038]

15 [Equation 4]

$$\Delta f = f_v - f_o \quad (1-5)$$

$$\begin{aligned} L \frac{di(t)}{dt} &= V_v e^{j2\pi f_v t} - V_o e^{j\{2\pi(f_v - \Delta f)t + \theta_o\}} \\ i(t) &= \frac{V_v}{j2\pi f_v L} e^{j2\pi f_v t} - \frac{V_o}{j2\pi(f_v - \Delta f)L} e^{j\{2\pi(f_v - \Delta f)t + \theta_o\}} \\ &= -j \frac{V_v}{2\pi f_v L} e^{j2\pi f_v t} + j \frac{V_o}{2\pi(f_v - \Delta f)L} e^{j2\pi f_v t} e^{j(\theta_o - 2\pi \Delta f t)} \\ &= -j \frac{V_v}{2\pi f_v L} e^{j2\pi f_v t} + j \frac{V_o \{\cos(\theta_o - 2\pi \Delta f t) + j \sin(\theta_o - 2\pi \Delta f t)\}}{2\pi(f_v - \Delta f)L} e^{j2\pi f_v t} \\ &= -\frac{V_o \sin(\theta_o - 2\pi \Delta f t)}{2\pi(f_v - \Delta f)L} e^{j2\pi f_v t} + j \left\{ \frac{V_o \cos(\theta_o - 2\pi \Delta f t)}{2\pi(f_v - \Delta f)L} - \frac{V_v}{2\pi f_v L} \right\} e^{j2\pi f_v t} \quad (1-6) \end{aligned}$$

$$S = P + jQ = \bar{v}_v i \quad (1-7)$$

$$\begin{aligned} P = \text{Re}(S) &= \text{Re}(\bar{v}_v i) = V_v e^{-j2\pi f_v t} \left\{ -\frac{V_o \sin(\theta_o - 2\pi \Delta f t)}{2\pi(f_v - \Delta f)L} e^{j2\pi f_v t} \right\} = \frac{V_v V_o \sin(2\pi \Delta f t - \theta_o)}{2\pi(f_v - \Delta f)L} \\ &= \frac{V_v V_o \sin\{2\pi(f_v - f_o)t - \theta_o\}}{2\pi f_o L} \quad (1-8) \end{aligned}$$

[0039]

Equation (1-8) expressing the active power P has two controllable parameters, which are an amplitude V_v of the AC voltage output from the inverter 42 and the frequency
 5 command value f_v of the AC voltage output from the inverter 42. Among these parameters, the amplitude V_v of the AC voltage depends on the Q-v drooping characteristic, which is the relationship between the reactive power Q and the voltage v in the synchronous generator in the VSG control; in the present embodiment, accordingly, only the frequency
 10 command value f_v of the AC voltage is controlled to change the active power P output from the inverter 42.

[0040]

Besides, the active power P expressed by Equation (1-8) depends on variables that are the voltage amplitude V_o , the frequency f_o , the phase difference θ_o , and the line reactance L on the destination device. These values depend on which of the inverter 42,
 15 another inverter 42, and another storage battery 13, all of which are connected to the load

12. That is, the active power P output from the inverter 42 changes under an effect of, for example, the device specification, configuration, operational situation, and the like of the destination device.

[0041]

5 Back to FIG. 2, the reference output calculator 117 calculates active power to be output from the inverter 42, when the load 12 in a predetermined reference state is connected, on the basis of the frequency command value f_v output from the first command value generator 102, and outputs the calculated active power to the subtractor 118 as an active power reference value P_{st} .

10 Specifically, the reference output calculator 117 calculates the active power reference value P_{st} according to Equation (1-8a) using the frequency command value f_v output from the adder 115. In Equation (1-8a), the voltage amplitude V_s , the frequency f_s , the phase difference θ_s , and the line reactance L_s are constants representing conditions of the destination device in the reference state. In this respect, the term reference state refers
15 to a prescribed condition of the control device 41 to be used when the power conversion device 14 determines an inertial property to be provided by the VSG control. That is, when the destination device is in a state represented by the voltage amplitude V_s , the frequency f_s , the phase difference θ_s , and the line reactance L_s , the control device 41 may affect the power conversion device 14 to reduce or prevent a frequency fluctuation as specified by
20 prescribed values.

[0042]

[Equation 5]

$$P_{st} = \frac{V_v V_s \sin\{2\pi(f_v - f_s)t - \theta_s\}}{2\pi f_s L_s} \quad (1 - 8 a)$$

[0043]

Subsequently, the subtractor 118 subtracts the active power measurement value P_{measure} from the active power reference value P_{st} output from the reference output calculator 117 to calculate a first error dP_1 , and outputs the first error dP_1 to the first error correction controller 103.

5 In this respect, the first error dP_1 calculated by the subtractor 118 represents the magnitude relationship of the active power measurement value P_{measure} with respect to the active power reference value P_{st} , and affects the effect of reducing or preventing a frequency fluctuation. Specifically, when the first error dP_1 is a positive value, the effect of reducing or preventing a frequency fluctuation is insufficient, and when the first error
10 dP_1 is a negative value, the effect of reducing or preventing a frequency fluctuation is excessive.

[0044]

In step S13 illustrated in FIG. 3, the first error correction controller 103 determines the gain in the first VSG controller 101 using the first error dP_1 , which affects
15 the effect of reducing or preventing a frequency fluctuation. The first error correction controller 103 comprises, as illustrated in FIG. 2, a first-order delay circuit 124, an adder 125, and a limiter 126.

[0045]

In the first error correction controller 103, the first-order delay circuit 124
20 multiplies the first error dP_1 input from the subtractor 118 by a transfer function $\{K_{\text{obs}}/(1+sT_{\text{obs}})\}$ and outputs the product to the adder 125. The adder 125 adds $1/D$, which is the gain that has been set in the multiplier 122, to the value input from the first-order delay circuit 124, and outputs the sum to the limiter 126, where T_{obs} is the time constant, and K_{obs} is the gain. These values may be determined using a commonly-used control
25 theory such as, for example, ultimate sensitivity method.

[0046]

In the first error correction controller 103, the limiter 126 makes a comparison regarding whether the value input from the adder 125 is greater than a predetermined lower limit value, and sets, as the gain of the multiplier 122, the value when the value is greater than the lower limit value, and the lower limit value when the value is equal to or less than the lower limit value. That is, the limiter 126 changes the gain of the multiplier 122 according to the magnitude relationship between the value input from the adder 125 and the predetermined lower limit value, and the multiplier 122 multiplies the active power deviation ΔP_1 by the gain resulting from the change. In this respect, the lower limit value is a value that is set to prevent the value input from the adder 125 from being 0, and should not be set to 0. If the lower limit value is set to 0 and the value input from the adder 125 is 0 or less, a value of 0 will be set as the gain of the multiplier 122. This will cause the output value of the first VSG controller 101 to be 0, and cause the first VSG controller 101 to malfunction.

[0047]

The first error correction controller 103 sets the gain of the multiplier 122 to compensate for the difference between the active power measurement value P_{measure} and the active power reference value P_{st} . This process therefore acts in such a manner that the first error dP_1 is reduced to a small value regardless of the state of the destination device, specifically, the voltage amplitude V_o , the frequency f_o , the phase difference θ_o , and the line reactance L on the destination device.

[0048]

A hardware configuration of the control device 41 will now be described. The control device 41 is implemented in a programmable logic controller (PLC). A hardware configuration of the PLC will be described with reference to FIG. 5. FIG. 5 is a block

diagram illustrating a hardware configuration of a PLC that implements the control device 41.

Each of the functional blocks of the control device 41 illustrated in FIG. 2 is implemented by execution of a program that describes processing to be performed by the control device 41 on the PLC (hereinafter described as control program). As illustrated in FIG. 5, the PLC comprises a computing device 51, a storage device 52, and a communication device 53, which are connected to each other via a system bus 54. In this respect, the configuration of FIG. 5 is an example, and the configuration of the PLC is not limited to the example of FIG. 5.

[0049]

In the PLC, the computing device 51 is, for example, a processor such as a CPU, and executes a control program. The storage device 52 comprises a volatile memory such as a RAM and a nonvolatile memory such as a flash memory. The storage device 52 stores the control program to be executed by the computing device 51, data obtained during a process of processing, and the like, and is used as a temporary storage area for the program. The communication device 53 is, for example, a set of a receiver and a transmitter that communicate with the integrated controller 31.

In this respect, unlike a computer system having a similar hardware configuration, the PLC does not comprise an operating system (OS), and is characterized in that processing delay or processing failure due to an interrupt of a resident program or for another reason caused by operation of the OS is less likely to occur. In the present embodiment, an example is provided in which the control device 41 is implemented in a PLC in view of these features. However, the control device 41 is not limited to this example, and may be implemented in a computer system.

[0050]

As described above, the configuration is such that the first VSG controller 101 calculates the frequency deviation $\Delta\omega_1$ by the transfer function based on the oscillation equation for the synchronous generator; the first command value generator 102 generates the frequency command value f_v of the output voltage of the inverter 42 using the frequency deviation $\Delta\omega_1$; the reference output calculator 117 calculates, on the basis of the frequency command value f_v , the active power reference value P_{st} to be output from the inverter 42 to the destination device in a predetermined reference state; the subtractor 118 calculates the first error dP_1 by subtracting the active power measurement value $P_{measure}$ from the active power reference value P_{st} ; and the first error correction controller 103 sets the gain of the transfer function of the first VSG controller 101 using the first error dP_1 . The control device 41 can therefore be provided that controls the inverter 42 to exert an effect of reducing or preventing a frequency fluctuation as specified by prescribed values, even when a change occurs in the specification, configuration, or operational situation of the destination device.

[0051]

In the present embodiment, an example has been described in which the first error correction controller 103 determines the gain in first VSG controller 101. However, the first error correction controller 103 is not limited to this example, but may change a value (M/D) corresponding to the time constant of the first VSG controller 101 according to the determined gain. Specifically, the first error correction controller 103 sets the reciprocal of the determined gain as a new value of D, and determines the value of M to thereby enable the transfer function $\{1/(1+sM/D)\}$ using this value of D to provide stability during control. The value of M in this case may be determined using a common control theory such as a Nyquist stability criterion, or may be determined by holding in advance a pattern of values of M in association with values of D and assigning a value from this pattern. This can

prevent oscillation during control when the first error dP_1 , which is the difference between the active power measurement value P_{measure} and the active power reference value P_{st} , is a large value, providing a large value as the gain to be set in the multiplier 122.

[0052]

5 An example has been described in which the limiter 126 makes a comparison regarding whether the input value is greater than a predetermined lower limit value, and sets the lower limit value in the multiplier 122 when the input value is equal to or less than the lower limit value. However, the limiter 126 is not limited to this example, but may further set an upper limit value, make a comparison regarding whether the input value is
10 less than the upper limit value, and set the upper limit value in the multiplier 122, when the input value is equal to or greater than the upper limit value. This can prevent setting of an excessive gain and occurrence of oscillation during control.

[0053]

Second Embodiment.

15 A second embodiment will be described in detail with reference to FIGS. 6 and 7. FIG. 6 is a block diagram illustrating a control system comprising the control device 41 and the inverter 42 to be controlled in the second embodiment. FIG. 7 is a flowchart illustrating control processing performed by the control device 41 in the second embodiment. Among the elements illustrated in FIG. 6, elements indicated by reference
20 numbers the same as those in FIG. 2 indicate the same or equivalent parts, and description thereof will be omitted. The configuration of the microgrid 1 in the second embodiment is similar to that in the first embodiment, and illustration and description thereof will be omitted.

[0054]

25 In the second embodiment, the control device 41 comprises a subtractor 111a, a

first VSG controller 101a (hereinafter referred to as first VSG controller 101a), the first governor controller 113, the first command value generator 102, the ZOH circuit 116, a subtractor 211, a second VSG controller 201, a second governor controller 213, a second command value generator 202, the reference output calculator 117, a ZOH circuit 216, a subtractor 217, and a second error correction controller 218. An operation of each functional block of the control device 41 in the second embodiment will hereinafter be described.

[0055]

The subtractor 111a subtracts the output value of the first governor controller 113 from the sum of the active power command value P_{ref} received from the integrated controller 31 and a second error dP_2 output from the second error correction controller 218, which will be described in detail later, and outputs the resulting value to the first VSG controller 101a.

[0056]

The first VSG controller 101a is similar to the first VSG controller 101 in the first embodiment in comprising the subtractor 121, a multiplier 122a, and the first-order delay circuit 123, and in performing VSG control to cause the power conversion device 14 to have an inertial property of the synchronous generator in a pseudo manner. On the other hand, the multiplier 122a is different from a corresponding one of the first embodiment in that a gain $(1/D)$, by which the input value thereof, is multiplied is a fixed value.

[0057]

In step S21 illustrated in FIG. 7, the first VSG controller 101a calculates a first frequency deviation $\Delta\omega_1$ using the active power measurement value $P_{measure}$.

Specifically, in the first VSG controller 101a, the multiplier 122a multiplies the active power deviation ΔP_1 calculated by the subtractor 121 by the gain $(1/D)$ and outputs

the product to the first-order delay circuit 123. Subsequently, the first-order delay circuit 123 multiplies the output value of the multiplier 122a by the transfer function $\{1/(1+sM/D)\}$ to calculate the first frequency deviation $\Delta\omega_1$, and outputs the first frequency deviation $\Delta\omega_1$ to the first governor controller 113, to the first command value generator 102, and to the subtractor 217.

[0058]

The first governor controller 113 is the same functional block as that of the first embodiment, multiplies the first frequency deviation $\Delta\omega_1$ output from the first VSG controller 101a by the transfer function $\{K/(1+sT)\}$, and outputs the resulting value to the subtractor 111a, where the time constant T and the gain K are the same as those in the first embodiment.

[0059]

In step S22 illustrated in FIG. 7, the first command value generator 102 uses the first frequency deviation $\Delta\omega_1$ calculated by the first VSG controller 101a to generate a first frequency command value f_{v1} , which is the frequency command value of the output voltage, as the control command value for the inverter 42. The first command value generator 102 then outputs the generated first frequency command value f_{v1} to the inverter 42. Similarly to the first embodiment, the first command value generator 102 comprises the constant multiplier 114a, the ZOH circuit 114b, and the adder 115.

Specifically, the constant multiplier 114a multiplies the first frequency deviation $\Delta\omega_1$ by the rated frequency f_n to calculate the frequency deviation $df1$, and outputs the frequency deviation $df1$ to the ZOH circuit 114b. The ZOH circuit 114b outputs a signal value resulting from zero-order holding of the frequency deviation $df1$, to the adder 115. The adder 115 adds the rated frequency f_n to the signal value output from the ZOH circuit 114b to thus calculate the first frequency command value f_{v1} , and outputs the first

frequency command value f_{v1} to the inverter 42 as the control command value for the inverter 42.

[0060]

The inverter 42 outputs active power on the basis of the first frequency command value f_{v1} output from the first command value generator 102. As described above, the control for the active power output from the inverter 42 by the frequency command value is similar to that in the first embodiment.

[0061]

In the second embodiment, the active power command value P_{ref} output from the integrated controller 31 is input also to the subtractor 211. The subtractor 211 subtracts an output value of the second governor controller 213 from the active power command value P_{ref} , and outputs the resulting value to the second VSG controller 201.

[0062]

In step S23 illustrated in FIG. 7, the second VSG controller 201 calculates a second frequency deviation $\Delta\omega_2$ using the active power reference value P_{st} , which is the active power to be supplied from the inverter 42 to the destination device in the predetermined reference state. The second VSG controller 201 comprises, as illustrated in FIG. 6, the subtractor 121, the multiplier 122a, and the first-order delay circuit 123, which are the same functional blocks as those of the first VSG controller 101a; performs the same computation processing as the processing of the first VSG controller 101a to calculate the second frequency deviation $\Delta\omega_2$, and outputs the second frequency deviation $\Delta\omega_2$ to the second governor controller 213, to the second command value generator 202, and to the subtractor 217.

In this respect, the gain $(1/D)$ and the transfer function $\{1/(1+sM/D)\}$ by which the input values are multiplied by the second VSG controller 201, and the inertia constant

M and the damping constant D included therein are the same as those of the first VSG controller 101a.

[0063]

Similarly to the first governor controller 113, the second governor controller 213
 5 multiplies the second frequency deviation $\Delta\omega_2$ output from the second VSG controller 201 by the transfer function $\{K/(1+sT)\}$, and outputs the resulting value to subtractor 211. Here, the time constant T and the gain K are the same as those of the first governor controller 113.

[0064]

10 The second command value generator 202 comprises a constant multiplier 214a, a ZOH circuit 214b, and an adder 215, and generates and outputs a second frequency command value f_{v2} as a frequency command value, similarly to the first command value generator 102. Specifically, the constant multiplier 214a calculates a frequency deviation $df2$ by computation processing similar to that of the constant multiplier 114a, and outputs
 15 the frequency deviation $df2$ to the ZOH circuit 214b. The ZOH circuit 214b outputs a signal value resulting from zero-order holding of the frequency deviation $df2$, to the adder 215. The adder 215 adds the rated frequency f_n to the signal value output from the ZOH circuit 214b to thus calculate the second frequency command value f_{v2} , and outputs the second frequency command value f_{v2} to the reference output calculator 117.

20 [0065]

The reference output calculator 117 calculates the active power to be output from the inverter 42 when the load 12 in a predetermined reference state is connected, on the basis of the second frequency command value f_{v2} output from the second command value generator 202, and outputs the calculated active power, to the ZOH circuit 216 as the active
 25 power reference value P_{st} . Specifically, the reference output calculator 117 calculates the

active power reference value P_{st} by assigning $f_v=f_{v2}$ in Equation (1-8a).

[0066]

The subtractor 217 subtracts the first frequency deviation $\Delta\omega_1$ output by the first VSG controller 101a from the second frequency deviation $\Delta\omega_2$ output by the second VSG controller 201 to calculate a difference value of the frequency deviation. The subtractor 217 then outputs the difference value of the calculated frequency deviation, to the second error correction controller 218.

[0067]

In step S24 illustrated in FIG. 7, the second error correction controller 218 calculates the second error dP_2 from a difference between the first frequency deviation $\Delta\omega_1$ calculated by the first VSG controller 101a and the second frequency deviation $\Delta\omega_2$ calculated by the second VSG controller 201, and feeds back the second error dP_2 to the first VSG controller 101a.

Specifically, the second error correction controller 218 functions as an integrator; multiplies the difference value of the frequency deviation output from the subtractor 217 by the transfer function (K_s/s) to calculate the second error dP_2 , and outputs the second error dP_2 to the subtractor 111a. The second error dP_2 is a value generated depending on the difference between the active power measurement value $P_{measure}$ and the active power reference value P_{st} . Accordingly, feeding back this value enables the difference between the active power measurement value $P_{measure}$ and the active power reference value P_{st} to be reduced to a small value. In this respect, K_s in the transfer function (K_s/s) is an integral gain in the second error correction controller 218. The value thereof may be determined using a common-used control theory to keep the entire control system comprising the second error correction controller 218 in a stable condition during control. The symbol s denotes a Laplace operator.

[0068]

As described above, the configuration is such that the first VSG controller 101a calculates the first frequency deviation $\Delta\omega_1$ by the transfer function based on the oscillation equation for the synchronous generator using the active power measurement value P_{measure} output from the inverter 42; the second VSG controller 201 calculates the second frequency deviation $\Delta\omega_2$ by the transfer function based on the oscillation equation for the synchronous generator using the active power reference value P_{st} to be output from the inverter 42 to the destination device in the predetermined reference state; the first command value generator 102 generates, using the first frequency deviation $\Delta\omega_1$, the first frequency command value f_{v1} as the frequency command value of the output voltage of the inverter 42 and outputs the first frequency command value f_{v1} to the inverter 42; the second command value generator 202 generates, using the second frequency deviation $\Delta\omega_2$, the second frequency command value f_{v2} as the frequency command value of the output voltage of the inverter 42 and outputs the second frequency command value f_{v2} to the reference output calculator 117; the reference output calculator 117 calculates, on the basis of the second frequency command value f_{v2} , the active power reference value P_{st} to be output from the inverter 42 to the destination device in the predetermined reference state; and the second error correction controller 218 calculates the second error dP_2 using the first frequency deviation $\Delta\omega_1$ and the second frequency deviation $\Delta\omega_2$ and feeds back the second error dP_2 to the first VSG controller 101a. The control device 41 can therefore be provided that controls the inverter 42 to exert an effect of reducing or preventing a frequency fluctuation as specified by prescribed values even when a change occurs in the specification, configuration, or operational situation of the destination device.

[0069]

Note that, in the first and second embodiments, an example has been described

with reference to FIG. 1 in which the plurality of power generation facilities 11 and the plurality of loads 12 are present. However, the configuration is not limited to this example, but may be such that only one of the power generation facilities 11 and one of the loads 12 are present. In addition, an example has been described with reference to FIG. 1 in which
5 one storage battery 13 is present. However, the configuration is not limited to this example, but a plurality of storage batteries 13 may be present, and the plurality of storage batteries 13 may be a combination of a plurality of types of secondary batteries.

[0070]

Moreover, in a case where a plurality of power generation facilities 11 are present
10 in the first and second embodiments, the plurality of power generation facilities 11 may be a combination of a plurality of types of renewable energy power sources. Furthermore, the electric energy meter comprised in the power generation facility 11 and the communication device that transmits a measurement value of the electric energy meter provided for a single power generation facility 11 do not each need to be one or more in number, and in a case
15 where a plurality of power generation facilities 11 are present, it is sufficient that these devices are configured to allow a total power generation amount to be measured and transmitted. Similarly, the electric energy meter included in the load 12 and the communication device that transmits a measurement value of the amount of power provided for a single load 12 do not each need be one or more in number, and in a case
20 where a plurality of loads 12 are present, it is sufficient that these devices are configured to allow a total power consumption to be measured and transmitted.

[0071]

In addition, an example has been described in the first and second embodiments in which the microgrid 1 comprises the power generation facility 11, the load 12, the
25 storage battery 13, the power conversion device 14, and the transducer 15. However, the

microgrid 1 is not limited to this example, but may further comprise power receiving and distributing facilities such as a circuit breaker, a disconnector, and/or a transformer. Moreover, the microgrid 1 may be connected to another power system via the transmission and distribution network 21, that is, may be interconnected with another power system, and may comprise, for example, a circuit breaker, a disconnector, a transformer, and the like as interconnection equipment between the microgrid 1 and the other power system.

[0072]

Furthermore, an example has been described in the first and second embodiments in which the microgrid 1 comprises the load 12. However, the microgrid 1 is not limited to this example, and does not need to comprise the load 12. In this case, however, it is noted that the microgrid 1 should comprise a plurality of storage batteries 13. This is because there should be a power draw to consume the power charged in the storage batteries 13. That is, when one of the storage batteries 13 discharges to charge another one of the storage batteries 13, the control device 41 controls the storage battery 13 that discharges power. In this case, charging and discharging of the storage batteries 13 may be controlled by the integrated controller 31.

[0073]

In addition, an example has been described in the first and second embodiments in which the transducer 15 directly measures the active power measurement value P_{measure} . However, the operation is not limited to this example, but may be performed in such a manner that the transducer 15 measures measurement values of the voltage and of the current and outputs these measurement values to the control device 41, and the control device 41 calculates the active power measurement value P_{measure} using the measurement values that have been output. Moreover, the transducer 15 may be connected to the transmission and distribution network 21 via a voltage transformer (VT) and a current

transformer (CT).

[0074]

Furthermore, in the first and second embodiments, the method for connecting the integrated controller 31 to the power generation facility 11, the load 12, the storage battery
5 13, and the power conversion device 14 is not limited in any manner. These components may be connected to each other, for example, by a signal line such as a coaxial cable, by wireless communication, or via the Internet or an intranet.

[0075]

In addition, in the first and second embodiments, the integrated controller 31 may
10 be configured as, for example, a community energy management system (CEMS), an area energy management system (AEMS), a building and energy management system (BEMS), or the like to control, for example, power supply and demand in another power system in parallel.

[0076]

15 A plurality of embodiments has been described above. In addition to the above disclosure contents, arbitrary combination of the embodiments, modification of an arbitrary component of the embodiments, or omission of any of the embodiments can be made as long as not conflicting with the features described in the embodiments. For example, the arrangement order of the constant multiplier 114a and the ZOH circuit 114b
20 may be reversed in each of the first and second embodiments. In the second embodiment, the second error correction controller 218 may output the second error dP_2 , which is the output value thereof, not to the subtractor 111a, but to the subtractor 121.

[Reference Signs List]

[0077]

25 1 Microgrid

	11 Power generation facility
	12 Load
	13 Storage battery
	14 Power conversion device
5	15 Transducer
	21 Transmission and distribution network
	31 Integrated controller
	41 Control device
	42 Inverter
10	101, 101a First VSG controller
	102 First command value generator
	103 First error correction controller
	117 Reference output calculator
	201 Second VSG controller
15	202 Second command value generator
	218 Second error correction controller

[CLAIMS]

[Claim 1]

A control device that controls an inverter to cause a frequency of an output voltage of the inverter to have a virtual inertial property on active power supplied to a destination
5 device connected to the inverter, the control device comprising:

a first virtual synchronous generator controller that calculates a frequency deviation by a transfer function based on an oscillation equation for a synchronous generator, using an active power measurement value supplied to the destination device by the inverter;

10 a first command value generator that generates a frequency command value of the output voltage of the inverter using the frequency deviation calculated by the first virtual synchronous generator controller; and

a first error correction controller that determines a gain of the transfer function in the first virtual synchronous generator controller using a first error, the first error being a
15 difference between an active power reference value and the active power measurement value, the active power reference value being active power to be supplied by the inverter to the destination device in a predetermined reference state.

[Claim 2]

The control device according to claim 1, comprising:

20 a reference output calculator that calculates the active power reference value using the frequency command value generated by the first command value generator.

[Claim 3]

The control device according to claim 1 or 2, wherein the first error correction controller further determines a time constant of the transfer function using the determined
25 gain of the transfer function.

[Claim 4]

The control device according to any one of claims 1 to 3, wherein the first error correction controller sets at least one of an upper limit value or a lower limit value with respect to the gain of the transfer function to be determined.

5 [Claim 5]

A control device that controls an inverter to cause a frequency of an output voltage of the inverter to have a virtual inertial property on active power supplied to a destination device connected to the inverter, the control device comprising:

a first virtual synchronous generator controller that calculates a first frequency
10 deviation by a transfer function based on an oscillation equation for a synchronous generator, using an active power measurement value supplied to the destination device by the inverter;

a first command value generator that generates a first frequency command value
as a frequency command of the output voltage of the inverter using the first frequency
15 deviation calculated by the first virtual synchronous generator controller;

a second virtual synchronous generator controller that calculates a second frequency deviation by the transfer function using an active power reference value, the active power reference value being active power to be supplied by the inverter to the destination device in a predetermined reference state; and

20 a second error correction controller that calculates a second error from a difference between the first frequency deviation calculated by the first virtual synchronous generator controller and the second frequency deviation calculated by the second virtual synchronous generator controller, and feeds back the second error to the first virtual synchronous generator controller.

25 [Claim 6]

The control device according to claim 5, comprising:

a second command value generator that generates a second frequency command value as a frequency command value of the output voltage of the inverter using the second frequency deviation calculated by the second virtual synchronous generator controller; and
5 a reference output calculator that calculates the active power reference value using the second frequency command value generated by the second command value generator.

[Claim 7]

A control method for controlling an inverter to cause a frequency of an output voltage of the inverter to have a virtual inertial property on active power supplied to a
10 destination device connected to the inverter, the control method comprising:

a step of calculating a frequency deviation by a transfer function based on an oscillation equation for a synchronous generator, using an active power measurement value supplied to the destination device by the inverter;

a step of generating a frequency command value of the output voltage of the
15 inverter using the frequency deviation; and

a step of determining a gain of the transfer function using a first error, the first error being a difference between an active power reference value and the active power measurement value, the active power reference value being active power to be supplied by the inverter to the destination device in a predetermined reference state.

20 [Claim 8]

A control method for controlling an inverter to cause a frequency of an output voltage of the inverter to have a virtual inertial property on active power supplied to a destination device connected to the inverter, the control method comprising:

a step of calculating a first frequency deviation by a transfer function based on an
25 oscillation equation for a synchronous generator, using an active power measurement value

supplied to the destination device by the inverter;

a step of generating a frequency command value of the output voltage of the inverter using the first frequency deviation;

5 a step of calculating a second frequency deviation by the transfer function using an active power reference value, the active power reference value being active power to be supplied by the inverter to the destination device in a predetermined reference state; and

a step of calculating a second error from a difference between the first frequency deviation and the second frequency deviation, and feeding back the second error to the step of calculating a first frequency deviation.