

DESCRIPTION

TITLE OF INVENTION:

5 Distributed Power Source Management Apparatus and Power Distribution
System

TECHNICAL FIELD

[0001] The present disclosure relates to a distributed power source management
apparatus and a power distribution system, and more particularly to a method of
generating a control command value to be given to each distributed power source in
10 interconnection with an alternating-current (AC) power distribution system, of one or
more distributed power sources having drooping characteristics, for example, as in
implementation of virtual synchronous generator control. In the present disclosure, a
plurality of distributed power sources encompass energy creation equipment to create
energy by utilizing renewable energy, such as a solar cell, and/or energy storage
15 equipment such as a fuel cell or a storage battery.

BACKGROUND ART

[0002] In order to reduce environmental burdens, introduction of a power generation
system utilizing natural energy, such as a solar cell that does not emit carbon dioxide,
has recently been accelerated. In addition, in order to cope with electricity shortage or
20 the like after the Great East Japan Earthquake, a system equipped with a storage
battery, a system where an electric vehicle is utilized as a storage battery, a system
where a solar cell and a storage battery are combined, or the like has been
commercialized. A static inverter is adopted in each of the systems above.

[0003] Power generation cost including management cost of thermal power stations as
25 reserve, on the other hand, becomes high with increase in amount of power generation
with renewable energy, and hence accelerated closing of them in the future is predicted.
A synchronous generator used for thermal power generation or the like potentially
performs a function to suppress fluctuation of a system frequency (which will be
referred to as inertia, synchronization power, or the like) when it occurs. Therefore,

when decrease in synchronous generators proceeds as a result of closing of the thermal power stations, it becomes difficult to secure stability of the system.

[0004] In order to solve the problem above, various companies have developed a virtual synchronous generator control technique to enable a static inverter to perform the function of the synchronous generator.

[0005] For example, Japanese Patent Laying-Open No. 2019-176584 (PTL 1) discloses a method of setting a control parameter for a distributed power source (more particularly, a static inverter) where the virtual synchronous generator control technique is implemented. Specifically, this literature describes a static inverter for

interconnection of a distributed power source with a power system based on one of a requested inertia value requested by a system operator and a virtual inertia value calculated based on specifications and an operating state of the distributed power source.

[0006] More specifically, a total virtual inertia value J_{opt} which is the sum of virtual inertia in individual static inverters is set as below. Initially, a grid-interconnection control device receives a virtual inertia value J_{req} requested to the distributed power source by the system operator. The grid-interconnection control device then sets an upper limit value $J_{max,i}$ of virtual inertia for each static inverter and a lower limit value $D_{min,i}$ of a virtual attenuation constant during operations at upper limit value $J_{max,i}$ of the virtual inertia based on an operating state of a renewable energy system and specification data of the renewable energy system. The grid-interconnection control device then determines whether or not a total value $\Sigma J_{max,i}$ of upper limit values $J_{max,i}$ is smaller than requested virtual inertia value J_{req} . The grid-interconnection control device sets total virtual inertia value J_{opt} suitable for the renewable energy system to $J_{opt} = \Sigma J_{max,i}$ when total value $\Sigma J_{max,i}$ of $J_{max,i}$ is smaller than requested virtual inertia value J_{req} . The grid-interconnection control device, on the other hand, is configured to set $J_{opt} = J_{req}$ when total value $\Sigma J_{max,i}$ of $J_{max,i}$ is larger than requested virtual inertia value J_{req} . According to PTL 1, a total virtual attenuation constant value $D_{optimal}$ (that is, an optimal value) suitable for the renewable energy

system can also be set with a similar method.

CITATION LIST

PATENT LITERATURE

[0007] PTL 1: Japanese Patent Laying-Open No. 2019-176584

5 SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0008] In the case of PTL 1, the control parameter (that is, the total virtual inertia value and the total virtual attenuation constant value) for virtual synchronous generator control of the static inverter where a virtual synchronous generator control function is implemented is calculated and set with the method described above. According to this method, though inertia capability of the system intended by a system manager is secured, a problem below arises when a load varies and when an amount of power generation varies.

[0009] Specifically, when the load varies or when the amount of power generation varies, each distributed power source bears electric power excess or shortage in accordance with virtual synchronous generator characteristics (that is, drooping characteristics) thereof. More specifically, each distributed power source (more particularly, the static inverter) performs an operation to simulate the synchronous generator based on the drooping characteristics such as virtual synchronous generator control, so that each distributed power source supplies electric power that is excessive or short due to fluctuation of the load or variation in amount of power generation. At that time, each distributed power source determines a frequency of a system AC voltage outputted thereby in accordance with a difference between a power command value from a higher-order energy management system (EMS) and electric power outputted thereby. A frequency of the system AC voltage, on the other hand, is managed by a large-capacity synchronous generator connected to a bulk power system. In other words, the large-capacity synchronous generator is dominant over the frequency of the system AC voltage. Supply of electric power that is excessive or short in accordance with the drooping characteristics, by the distributed power source

provided at the power distribution system where virtual synchronous generator control is implemented hardly affects the frequency of the system AC voltage. The frequency of the AC system voltage that can be covered by the distributed power source where virtual synchronous generator control is implemented is determined by the drooping characteristics and the power command value from the higher-order EMS. In general, the frequency of the bulk power system varies approximately by ± 0.2 Hz with respect to a rated frequency. The distributed power source (that is, the distributed power source having the drooping characteristics and operating as a voltage source) where virtual synchronous generator control is implemented restricts upper and lower limit frequencies of the AC system voltage covered thereby for a stable operation, and a frequency range that can be taken by the bulk power system is wider than a range of those frequencies. Therefore, when the frequency of the AC system voltage is out of the frequency range that can be covered by the distributed power source where virtual synchronous generator control is implemented, the distributed power source where virtual synchronous generator control is implemented disadvantageously stops.

[0010] The present disclosure was made to solve the problem as described above, and relates to a distributed power source management apparatus (that is, a higher-order EMS). An object of the present disclosure is generation of a control command value by a distributed power source management apparatus such that static inverters having virtual synchronous generator characteristics (more generally, drooping characteristics) can keep operating without stopping, without departure from a frequency range that can be managed by the static inverters based on the drooping characteristics even when a frequency of an AC system voltage varies due to fluctuation or abrupt change of an amount of consumption by a load or fluctuation or abrupt change of electric power generated by equipment for creation of energy such as renewable energy in a power system provided with a plurality of static inverters where a virtual synchronous generator control scheme is implemented.

SOLUTION TO PROBLEM

[0011] In one aspect of the present disclosure, a distributed power source management

apparatus to manage one or more distributed power sources is provided. Each of the one or more distributed power sources is connected to a power system and operates as a voltage source. Relation between a frequency and electric power of each of the one or more distributed power sources has drooping characteristics and is adjusted such that a frequency command value and a power command value correspond to each other.

The distributed power source management apparatus includes an AC frequency collector to collect information on an AC frequency of the power system and to determine a representative value of the AC frequency based on the collected information on the AC frequency and a frequency command value generator to generate the frequency command value for each of the one or more distributed power sources based on the representative value of the AC frequency.

[0012] In another aspect of the present disclosure, a distributed power source management apparatus to manage one or more distributed power sources is provided. Each of the one or more distributed power sources is connected to a power system and operates as a voltage source. Relation between a frequency and electric power of each of the one or more distributed power sources has drooping characteristics and is adjusted such that a frequency command value and a power command value correspond to each other. The distributed power source management apparatus includes an AC frequency collector to collect information on an AC frequency of the power system and to determine a representative value of the AC frequency based on the collected information on the AC frequency and a power command value corrector to correct the power command value for each of the one or more distributed power sources based on the representative value of the AC frequency.

ADVANTAGEOUS EFFECTS OF INVENTION

[0013] According to the present disclosure, a frequency command value or a power command value to be given to each distributed power source is determined based on an actually measured AC frequency of a power system. Thus, even when a frequency of an AC system voltage varies due to fluctuation or abrupt change of electric power generated by equipment for creation of energy such as renewable energy to be supplied

to the power system due to fluctuation or abrupt change of power consumption by a load or abrupt change of solar radiation, without the frequency of the AC system voltage being out of a frequency range managed by a static inverter where virtual generator control characteristics (more generally, drooping characteristics) or the like are implemented, the distributed power source can keep operating without stopping.

BRIEF DESCRIPTION OF DRAWINGS

[0014] Fig. 1 is a block diagram showing a configuration of a distributed power source management apparatus according to a first embodiment and a power distribution system including a plurality of distributed power sources controlled thereby.

Fig. 2 is a block configuration diagram of a CEMS shown in Fig. 1.

Fig. 3 is a block configuration diagram of an operation plan creation circuit within the CEMS shown in Fig. 2.

Fig. 4 is a block configuration diagram of an AC frequency collection circuit within the CEMS shown in Fig. 2.

Fig. 5 is a block configuration diagram of a storage battery power conversion device shown in Fig. 1.

Fig. 6 is a block diagram illustrating a configuration of a first control circuit to control a first DC/DC conversion circuit of the storage battery power conversion device shown in Fig. 5.

Fig. 7 is a block diagram illustrating a configuration of a second control circuit to control a first DC/AC conversion circuit of the storage battery power conversion device shown in Fig. 5.

Fig. 8 is a block diagram illustrating a configuration of an AC frequency detection circuit shown in Fig. 7.

Fig. 9 is a block diagram illustrating a configuration of an inverter current control circuit shown in Fig. 7.

Fig. 10 is a block diagram illustrating a configuration of an inverter voltage control circuit shown in Fig. 7.

Fig. 11 is a block diagram illustrating a configuration of a virtual synchronous

generator control circuit shown in Fig. 7.

Fig. 12 is a block diagram illustrating a configuration of a governor control circuit shown in Fig. 11.

5 Fig. 13 is a block diagram illustrating a configuration of a mass point system computing circuit shown in Fig. 11.

Fig. 14 is a diagram showing a region covered by virtual synchronous generator control implemented in the storage battery power conversion device.

Fig. 15 is a diagram showing exemplary drooping characteristics of virtual synchronous generator control shown in the present first embodiment.

10 Fig. 16 is a diagram showing an exemplary result of actual measurement for twenty-five hours in one-second cycles, of a frequency of a power distribution system voltage.

15 Fig. 17 is a diagram showing exemplary drooping characteristics of the storage battery power conversion device in the power distribution system in the first embodiment.

Fig. 18 is a diagram for illustrating a method of creating a frequency command value in the distributed power source management apparatus in the first embodiment.

Fig. 19A is a diagram showing the frequency command value when drooping characteristics in a comparative example are used.

20 Fig. 19B is a diagram showing the frequency command value when drooping characteristics in the present first embodiment are used.

Fig. 20 is a sequence diagram in normal operations of a distributed power source management system, with the CEMS shown in Fig. 1 being centered.

Fig. 21 is a flowchart showing control processing in the CEMS shown in Fig. 1.

25 Fig. 22 is a flowchart showing detailed operations in operation plan creation processing in step S105 in the flowchart shown in Fig. 21.

Fig. 23 is a flowchart showing a procedure of generation of the frequency command value.

Fig. 24 is a diagram showing exemplary drooping characteristics of the storage

battery power conversion device in the distributed power source management system in the present first embodiment.

Fig. 25 is a flowchart showing a procedure of generation of the frequency command value in step S10574 in Fig. 23.

5 Fig. 26 is a diagram for illustrating a procedure of modification of the frequency command value.

Fig. 27 is a flowchart showing a procedure of determination as to whether or not modification of an operation plan is required.

10 Fig. 28 is a flowchart showing a procedure of modification of the operation plan.

Fig. 29 is a flowchart mainly showing operations of a second control circuit.

Fig. 30 is a flowchart showing a procedure of control of a first DC/AC conversion circuit.

Fig. 31 is a block configuration diagram of the CEMS in a second embodiment.

15 Fig. 32A is a diagram for illustrating a method of generating a power command value in the CEMS in the second embodiment (before modification of the power command value).

Fig. 32B is a diagram for illustrating the method of generating the power command value in the CEMS in the second embodiment (after modification of the power command value).

20 Fig. 33A is a diagram showing a frequency range of an inverter when drooping characteristics in a comparative example are used.

Fig. 33B is a diagram showing a power command value and a frequency of the inverter when the drooping characteristics in the second embodiment are used.

25 Fig. 34 is a flowchart showing detailed operations in operation plan creation processing in step S105 in Fig. 21 in the second embodiment.

Fig. 35 is a flowchart showing a procedure of generation of the power command value.

Fig. 36 is a diagram showing exemplary drooping characteristics of the storage

battery power conversion device in the distributed power source management system in the second embodiment.

Fig. 37 is a flowchart showing a procedure of generation of the power command value in step S10580 in Fig. 35.

5 Fig. 38 is a diagram for illustrating a procedure of modification of the power command value.

Fig. 39 is a flowchart showing a procedure of modification of an operation plan in the distributed power source management apparatus in the second embodiment.

10 Fig. 40A is a diagram showing exemplary linear drooping characteristics when the storage battery power conversion device performs charging and discharging.

Fig. 40B is a diagram showing exemplary linear drooping characteristics including a dead band when the storage battery power conversion device performs charging and discharging.

15 Fig. 40C is a diagram showing exemplary curved drooping characteristics when the storage battery power conversion device performs charging and discharging.

Fig. 40D is a diagram showing exemplary linear drooping characteristics including the dead band when the storage battery power conversion device performs only discharging.

20 Fig. 40E is a diagram showing exemplary curved drooping characteristics when the storage battery power conversion device performs only discharging.

Fig. 40F is a diagram showing exemplary linear drooping characteristics including the dead band when the storage battery power conversion device performs only charging.

25 Fig. 40G is a diagram showing exemplary curved drooping characteristics when the storage battery power conversion device performs only charging.

Fig. 41A is a diagram showing exemplary linear drooping characteristics when the storage battery power conversion device performs charging and discharging.

Fig. 41B is a diagram showing exemplary linear drooping characteristics when the storage battery power conversion device performs only charging.

Fig. 41C is a diagram showing exemplary linear drooping characteristics including the dead band when the storage battery power conversion device performs only discharging.

5 Fig. 41D is a diagram showing exemplary linear drooping characteristics including the dead band when the storage battery power conversion device performs only charging.

Fig. 42 is a diagram schematically representing a governor function.

Fig. 43 is a block configuration diagram shown for calculation of a transfer function $F(s)$ of a virtual synchronous generator control circuit 4093 shown in Fig. 11.

10 DESCRIPTION OF EMBODIMENTS

[0015] Each embodiment will be described in detail below with reference to the drawings. The same or corresponding elements in the drawings have the same reference characters allotted below and description thereof will not be repeated in principle.

15 [0016] First Embodiment.

[Exemplary Configuration of Distributed Power Source Management Apparatus and Power Distribution System]

Fig. 1 is a block diagram showing a configuration of a distributed power source management apparatus according to a first embodiment and a power distribution
20 system including a plurality of distributed power sources controlled thereby. Though a three-phase system will be described by way of example of a power distribution system in the present first embodiment, the distributed power source management apparatus in the first embodiment may naturally be applied to a single-phase system.

[0017] Referring to Fig. 1, a power distribution system 1 includes a substation 20, a
25 main electricity distribution line 24m drawn from substation 20, branch electricity distribution lines 24a to 24d branched from main electricity distribution line 24m, and a plurality of automatic voltage regulators 23 arranged in series at main electricity distribution line 24m. In the present first embodiment, a step voltage regulator (SVR) is employed as automatic voltage regulator 23. Automatic voltage regulator 23 will

also be denoted as SVR 23 below. Main electricity distribution line 24m and branch electricity distribution lines 24a to 24d will also collectively be denoted as an electricity distribution line 24. As shown in Fig. 1, a consumer such as a building 102, an apartment 103, a town A 100a, a town B 100b, a town C 100c, and a town D 100d, and a factory 101, a mega-solar power conversion device 27, storage battery power conversion devices 41a, 41b, and 41c, and synchronous generators 30a and 30b are connected to electricity distribution line 24. A utility-scale solar power plant (hereinafter also referred to as a "mega-solar power plant") 26 is connected to a power conversion device 27 for utility-scale solar power plant 26 (also referred to as "mega-solar power conversion device 27"), and storage batteries 40a, 40b, and 40c are connected to storage battery power conversion devices 41a, 41b, and 41c, respectively. [0018] Furthermore, power distribution system 1 includes a plurality of voltmeters 22 (22a to 22x) connected to main electricity distribution line 24m, a power distribution automation system 21, and a community energy management system (CEMS) 31. Power distribution automation system 21 will also be denoted as a distribution system operator (DSO) 21 below. CEMS 31 corresponds to the distributed power source management apparatus in the present disclosure. CEMS 31, inclusive of DSO 21, a storage battery power conversion device 41, voltmeter 22, and the like, will be referred to as a distributed power source management system. [0019] In the present embodiment, each voltmeter 22 calculates an effective voltage value and a frequency of an AC system voltage based on measured voltage information of electricity distribution line 24 of power distribution system 1. Each voltmeter 22 notifies DSO 21 and CEMS 31 of the calculated effective voltage value and frequency in predetermined cycles (for example, one-minute cycles). [0020] In addition, in the present embodiment, each SVR 23 notifies power distribution automation system (DSO) 21 of tap positional information, primary-side voltage information, and secondary-side voltage information in predetermined cycles. Furthermore, SVR 23 irregularly notifies power distribution automation system (DSO) 21 of tap positional information, primary-side voltage information, and secondary-side

voltage information at the time of tap switching.

[0021] CEMS 31 collects information on various measurement results such as power consumption from a smart meter (not shown) provided at each consumer (that is, town A 100a, town B 100b, town C 100c, town D 100d, building 102, apartment 103, and factory 101) in predetermined cycles (for example, in one-minute cycles).

Furthermore, CEMS 31 collects information on various measurement results such as electric power generated by each piece of energy creation equipment from mega-solar power conversion device 27, synchronous generators 30a and 30b, and storage battery power conversion devices 41a, 41b, and 41c in predetermined cycles (for example, in one-minute cycles). At that time, CEMS 31 notifies DSO 21 of the collected data based on a request from DSO 21. In the case of the present first embodiment, cycles of communication between CEMS 31 and DSO 21 are set to thirty-minute cycles.

[0022] Though the cycles of communication between DSO 21 and CEMS 31 are set to thirty-minute cycles in the above example, the cycles are not limited thereto. For example, the cycles may naturally be fifteen-minute cycles or one-hour cycles. The cycles of communication between each voltmeter 22, storage battery power conversion device 41, and the like and CEMS 31 are not limited to one-minute cycles either. The cycles may naturally be, for example, one-second cycles, ten-second cycles, thirty-second cycles, two-minute cycles, or the like.

[0023] Fig. 2 is a block configuration diagram of CEMS 31 shown in Fig. 1.

Referring to Fig. 2, CEMS 31 includes a communication circuit 311, a storage circuit 312, an AC frequency collection circuit 313, an operation plan creation circuit 314, a frequency command value generation circuit 315, a distributed power source drooping characteristic management circuit 316, a transmission data generation circuit 317, and an in-CEMS control circuit 318.

[0024] Communication circuit 311 communicates through communication line 25 with DSO 21, each voltmeter 22, each SVR 23, each consumer (that is, town A 100a, town B 100b, town C 100c, town D 100d, building 102, apartment 103, town 100, and factory 101), mega-solar power conversion device 27, synchronous generators 30a and

30b, and storage battery power conversion devices 41a, 41b, and 41c.

[0025] In storage circuit 312, various types of information obtained through communication circuit 311, that is, measurement results, status information of each distributed power source, and the like are stored.

5 [0026] AC frequency collection circuit 313 generates a representative value (F_{measure}) of a measured frequency of an AC system voltage based on a result of measurement of the frequency of the AC system voltage received from voltmeter 22, results of measurement of the frequency of the AC system voltage received from storage battery power conversion devices 41a, 41b, and 41c, and a result of measurement of the
10 frequency of the AC system voltage received from mega-solar power conversion device 27. In the present first embodiment, AC frequency collection circuit 313 calculates as the representative value, an average value of frequencies at points of the AC system voltages measured by voltmeters 22a to 22x and outputs the representative value.

Measurement errors of voltmeters 22 are thus averaged.

15 [0027] A method of generating the representative value of the frequency at AC frequency collection circuit 313 is not limited to the above. For example, output of a single voltmeter 22 may be used as the representative value, or a result of measurement of the frequency of the AC system voltage measured by storage battery power conversion device 41 or another distributed power source may naturally be used to
20 determine the representative value. In an example where power distribution system 1 is an isolated system, a calculated value of an AC frequency collected from a distributed power source maximum in power capacity among a plurality of distributed power sources or a distributed power source corresponding to a power command value largest among power command values generated by a later-described storage battery
25 operation plan generation circuit 3141 of operation plan creation circuit 314 may be employed as the representative value of the AC frequency.

[0028] Operation plan creation circuit 314 creates an operation plan of storage battery power conversion devices 41a, 41b, and 41c based on a control command from DSO
21. In the present first embodiment, operation plan creation circuit 314 generates the

operation plan for twenty-four hours every thirty minutes. Furthermore, operation plan creation circuit 314 determines whether or not modification of the operation plan is required, based on information such as results of measurement of storage battery power conversion devices 41a, 41b, and 41c collected per one minute or a state of charge (SOC). When operation plan creation circuit 314 determines that modification of the operation plan is required, it modifies the operation plan for a period until the control command is next given from DSO 21.

[0029] Frequency command value generation circuit 315 generates a frequency command value (F_{ref}) based on the representative value ($F_{measure}$) of the result of measurement of the frequency of the AC system voltage outputted from AC frequency collection circuit 313.

[0030] Distributed power source drooping characteristic management circuit 316 stores and manages drooping characteristics of storage battery power conversion devices 41a, 41b, and 41c. In the present first embodiment, distributed power source drooping characteristic management circuit 316 stores and manages a virtual synchronous generator control parameter (that is, a speed adjustment ratio: K_{gd} , a governor time constant: T_g , an inertia constant: M , and a braking coefficient D_g) which will be described later. Distributed power source drooping characteristic management circuit 316 may naturally manage drooping characteristics themselves or may naturally be configured to manage an inclination $\Delta P/\Delta F$ of the drooping characteristics.

Furthermore, the drooping characteristics of the distributed power source are not limited to virtual synchronous generator control, and the drooping characteristics having P (electric power)– F (frequency) characteristics may naturally be applicable. Distributed power source drooping characteristic management circuit 316 may naturally be configured to obtain a control parameter (that is, the drooping characteristics) from a virtual synchronous generator control circuit 4093 of storage battery power conversion device 41 and to manage the same.

[0031] In transmission data generation circuit 317, the operation plan outputted from operation plan creation circuit 314 and the frequency command value (F_{ref}) outputted

from frequency command value generation circuit 315 are stored. Transmission data generation circuit 317 then outputs stored data to communication circuit 311 based on a transmission command from in-CEMS control circuit 318. Communication circuit 311 transmits the data outputted from communication data generation circuit 317 in accordance with a control signal outputted from in-CEMS control circuit 318.

[0032] In-CEMS control circuit 318 controls operations of each of communication circuit 311, storage circuit 312, AC frequency collection circuit 313, operation plan creation circuit 314, frequency command value generation circuit 315, distributed power source drooping characteristic management circuit 316, and transmission data generation circuit 317 provided within CEMS 31.

[0033] Fig. 3 is a block configuration diagram of operation plan creation circuit 314 within CEMS 31 shown in Fig. 2. Referring to Fig. 3, operation plan creation circuit 314 includes a storage battery operation plan generation circuit 3141, a power generation amount prediction circuit 3142, a power consumption prediction circuit 3143, a storage battery operation plan correction circuit 3144, a power command value storage transmission circuit 3145, and a management circuit 3146.

[0034] Storage battery operation plan generation circuit 3141 generates an operation plan (specifically, a frequency command value and a power command value) for twenty-four hours every thirty minutes, of storage battery power conversion devices 41a, 41b, and 41c based on control command information given from DSO 21, a result of prediction of the amount of power generation by mega-solar power plant 26 predicted by power generation amount prediction circuit 3142, and power consumption prediction information of the consumer predicted by power consumption prediction circuit 3143. The control information given from DSO 21 is a planned value (for example, a plan for twenty-four hours every thirty minutes) of electric power (that is, supply electric power supplied from substation 20 to a load side) consumed at the load side of substation 20.

[0035] Power generation amount prediction circuit 3142 obtains weather forecast information for twenty-four hours through communication circuit 311 from a not-

shown weather forecast server. Power generation amount prediction circuit 3142 predicts the amount of power generation by mega-solar power plant 26 based on the obtained weather forecast information, not-shown clock information (day, month, and year, and time) inside CEMS 31, and not-shown database information prepared for prediction of the amount of power generation.

[0036] Power consumption prediction circuit 3143 predicts a total of power consumption by each consumer based on not-shown clock information (that is, day, month, and year, day of the week, and time) within CEMS 31 and not-shown database information prepared for power consumption prediction.

[0037] Storage battery operation plan correction circuit 3144 determines whether or not modification of the operation plan is required based on amounts of charging and discharging power of storage battery power conversion devices 41a, 41b, and 41c collected through communication circuit 311 and given power command value information and generates a modification value of the operation plan when it determines modification as being required.

[0038] In power command value storage transmission circuit 3145, the power command value for each distributed power source generated in storage battery operation plan generation circuit 3141 and storage battery operation plan correction circuit 3144 is stored, and power command value storage transmission circuit 3145 outputs the power command value to frequency command value generation circuit 315 based on a control signal outputted from management circuit 3146 within operation plan creation circuit 314.

[0039] Management circuit 3146 within operation plan creation circuit 314 manages operations of storage battery operation plan generation circuit 3141, power generation amount prediction circuit 3142, power consumption prediction circuit 3143, storage battery operation plan correction circuit 3144, and power command value storage transmission circuit 3145.

[0040] Fig. 4 is a block configuration diagram of AC frequency collection circuit 313 within CEMS 31 shown in Fig. 2. Referring to Fig. 4, AC frequency collection circuit

313 includes an averaging circuit 3131, a multiplier 3132, an adder 3133, a multiplier 3134, and a register 3135. As shown in Fig. 4, in the first embodiment, AC frequency collection circuit 313 is configured to remove a noise component in output of averaging circuit 3131 through a first-order infinite impulse response (IIR) filter and to provide the resultant output.

[0041] Averaging circuit 3131 is notified by in-CEMS control circuit 318 in one-minute cycles, of the frequency of the AC system voltage collected by voltmeter 22. Averaging circuit 3131 calculates an average value of the given frequencies of the AC system voltage. Multiplier 3132 multiplies the average value of the frequencies outputted from averaging circuit 3131 by a multiplication constant k outputted from in-CEMS control circuit 318. Adder 3133 adds output of multiplier 3132 and output of multiplier 3134, and outputs a result of addition to frequency command value generation circuit 315 and register 3135. In register 3135, the result of addition by adder 3133 is stored. Multiplier 3134 multiplies a value in register 3135 by a multiplication constant $(1-k)$ and outputs a result of multiplication to adder 3133.

[0042] Fig. 5 is a block configuration diagram of storage battery power conversion device 41 shown in Fig. 1. Referring to Fig. 5, storage battery power conversion device 41 includes a voltmeter 401, an ammeter 402, a first DC/DC conversion circuit 403, a first control circuit 404, a DC bus 405, a voltmeter 406, an ammeter 407, a first DC/AC conversion circuit 408, a second control circuit 409, a voltmeter 410, an ammeter 411, and a communication interface circuit 412.

[0043] Voltmeter 401 measures a voltage (that is, a DC voltage) outputted from a storage battery 40. Ammeter 402 measures a current (that is, a DC current) outputted from storage battery 40. First DC/DC conversion circuit 403 converts a first DC voltage (DC power) outputted from storage battery 40 to a second DC voltage (DC power). First control circuit 404 controls first DC/DC conversion circuit 403 based on measurement values from voltmeters 401 and 406 and a measurement value from ammeter 402. Through DC bus 405, the second DC voltage outputted from first DC/DC conversion circuit 403 is supplied to first DC/AC conversion circuit 408.

[0044] Voltmeter 406 measures the voltage of DC bus 405. Ammeter 407 measures a DC current outputted from first DC/DC conversion circuit 403. First DC/AC conversion circuit 408 converts DC power outputted from first DC/DC conversion circuit 403 to AC power. Second control circuit 409 controls first DC/AC conversion circuit 408 based on measurement values from voltmeters 406 and 410 and measurement values from ammeters 407 and 411. Voltmeter 410 measures a voltage (that is, an AC voltage) outputted from first DC/AC conversion circuit 408. Ammeter 411 measures a current (that is, an AC current) outputted from first DC/AC conversion circuit 408. Communication interface circuit 412 allows communication between storage battery power conversion device 41 and CEMS 31.

[0045] A known configuration of a DC/DC converter and an inverter can be employed as appropriate for the configuration of first DC/DC conversion circuit 403 and first DC/AC conversion circuit 408. In the configuration in Fig. 5, first DC/AC conversion circuit 408 corresponds to one example of a "static inverter portion." Second control circuit 409 corresponds to one example of a "static inverter controller."

[0046] Fig. 6 is a block diagram illustrating a configuration of first control circuit 404 to control first DC/DC conversion circuit 403 of storage battery power conversion device 41 shown in Fig. 5.

[0047] Referring to Fig. 6, first control circuit 404 includes a charging control circuit 4041, a discharging control circuit 4042, a first switching circuit 4043, and a third control circuit 4044.

[0048] Charging control circuit 4041 generates a control command value for first DC/DC conversion circuit 403 in control of charging of storage battery 40 based on measurement values from voltmeters 401 and 406 and a measurement value from ammeter 402. Discharging control circuit 4042 generates a control command value for first DC/DC conversion circuit 403 in control of discharging from storage battery 40 based on measurement values from voltmeters 401 and 406 and a measurement value from ammeter 402.

[0049] Third control circuit 4044 outputs a control parameter, a control target value

(command value), and the like to charging control circuit 4041 and discharging control circuit 4042 and manages an amount of charging, a charging current, an amount of discharging power, and the like for storage battery 40. Furthermore, third control circuit 4044 outputs a control signal to first switching circuit 4043.

5 [0050] First switching circuit 4043 selectively outputs one of outputs of charging control circuit 4041 and discharging control circuit 4042 as a control command value for first DC/DC conversion circuit 403, in accordance with the control signal from third control circuit 4044. First switching circuit 4043 is controlled to output the control command value generated by charging control circuit 4041 when an instruction for
10 charging of storage battery 40 is given. First switching circuit 4043 is controlled to output the control command value generated by discharging control circuit 4042 when an instruction for discharging from storage battery 40 is given.

[0051] Fig. 7 is a block diagram illustrating a configuration of second control circuit 409 to control first DC/AC conversion circuit 408 of storage battery power conversion
15 device 41 shown in Fig. 5.

[0052] Referring to Fig. 7, second control circuit 409 includes an AC frequency detection circuit 4091, an effective power calculation circuit 4092, virtual synchronous generator control circuit 4093, an inverter current control circuit 4094, an inverter voltage control circuit 4095, a second switching circuit 4096, and a fourth control
20 circuit 4097.

[0053] AC frequency detection circuit 4091 detects a phase and a frequency from an AC voltage waveform measured by voltmeter 410. In the present first embodiment, AC frequency detection circuit 4091 detects a zero cross point from the AC voltage waveform and detects the frequency from a time interval between detected zero cross
25 points. A method of detecting the frequency of the AC voltage is naturally not limited to a method using a result of detection of the zero cross point.

[0054] Effective power calculation circuit 4092 calculates effective power from AC voltage information and AC current information measured by voltmeter 410 and ammeter 411. In the present first embodiment, effective power calculation circuit

4092 calculates effective power by integrating electric power corresponding to one cycle of the AC voltage waveform based on zero cross point detection information and AC frequency information outputted from AC frequency detection circuit 4091. A method of calculating effective power is not limited to the scheme above. For

5 example, in an example where the AC system is a three-phase AC system, effective power may naturally be calculated using dq transformation or the like.

[0055] Virtual synchronous generator control circuit 4093 allows first DC/AC conversion circuit 408 (that is, the static inverter) to have inertia capability, synchronization capability, and braking capability of the synchronous generator, based
10 on the frequency information and AC effective power information of the AC voltage outputted from AC frequency detection circuit 4091 and effective power calculation circuit 4092.

[0056] The virtual synchronous generator control technique will briefly be described below. Functions of the synchronous generator represented by thermal power

15 generation include a function (that is, a governor function) to regulate electric power to be outputted in accordance with the frequency, a function (that is, inertia capability) to maintain an angular velocity, a function (that is, synchronization capability) for synchronization with the AC system voltage, a voltage regulation function (that is, an automatic voltage regulator function: an AVR function) for a bulk power system, a
20 function to continue operations even on the occurrence of instantaneous lowering in AC system voltage that occurs in a system fault or the like, and the like. In the virtual synchronous generator control technique, the functions of the synchronous generator are simulated by controlling transient response of the static inverter. Specifically, three functions of the governor function, a function that simulates a mass point system
25 model (that is, dynamic characteristics of a rotor) based on a swing equation, and the AVR function are simulated.

[0057] In the present first embodiment, in particular the governor function and the function that simulates the mass point system model based on the swing equation will be described. Fig. 42 shows a conceptual diagram for illustrating the virtual

synchronous generator control technique. Since the AVR function of the synchronous generator is the function mainly controlled based on an output voltage command given from a higher-order system (in the first embodiment, CEMS 31) or a reactive power command value, it is not implemented in the first embodiment. The governor function and the function that simulates the mass point system model based on the swing equation will specifically be described below.

[0058] Initially, the governor function will be described. A governor in a power generation plant performs a function to control output of a gas turbine or a steam turbine in thermal power generation or nuclear power generation, a guide vane of a water turbine in hydroelectric power generation, or the like, to thereby control output power of a generator. When demand exceeds supply in an AC power system, the frequency of the AC system voltage lowers. In a thermal power generator and a hydroelectric power generator output from which is controllable, the governor is allowed to have droop characteristics and the generator is controlled to increase generated electric power when the frequency lowers. When supply exceeds demand, on the other hand, the frequency of the AC system voltage increases. In this case as well, similarly in the thermal power generator and the hydroelectric power generator output from which is controllable, the governor is allowed to have droop characteristics and the generator is controlled to decrease generated electric power when the frequency increases.

[0059] Fig. 42 is a diagram schematically representing the governor function. As shown in Fig. 42, with increase in angular velocity ω of the synchronous generator, a valve to regulate inflow of energy moves to the right to decrease energy to be supplied to the synchronous generator. When the angular velocity of the synchronous generator decreases, on the other hand, the valve to regulate inflow of energy moves to the left to increase energy to be supplied to the synchronous generator. Energy outputted from the synchronous generator can thus be controlled independently based on the frequency (that is, the angular velocity of the synchronous generator) of a local AC system voltage. Even when the synchronous generators individually perform the

operation above, the generators can bear burdens in a shared manner, because they are managed based on the frequency of the AC system voltage. A model or the like configured with a first-order lag type as a standard model is provided by the Institute of Electrical Engineers of Japan (IEEJ), as the model of the governor.

5 [0060] In the present first embodiment, operations in an example where the governor is approximated by the model configured with the first-order lag system described above will be described. A transfer function of the governor is expressed in an expression (1) below. In the expression (1), $-1/K_{gd}$ represents a proportional gain (K_{gd} : speed adjustment ratio) of the governor and T_g represents a time constant (T_g : governor time
10 constant) of the first-order lag system.

[0061] [Math. 1]

$$\frac{-1}{K_{gd} \times (1 + s \times T_g)} \quad \dots(1)$$

[0062] The function that simulates the mass point system model based on the swing equation will now be described. The synchronous generator includes a generator rotor having a unit inertia constant M as shown in Fig. 42. For example, when electric
15 power generated by mega-solar power plant 26 abruptly decreases due to abrupt change of solar radiation, under the governor control, shortage in electric power cannot instantaneously be compensated for. The synchronous generator converts rotational energy accumulated in the generator rotor to electric power and outputs electric power to the power system. At that time, the angular velocity (that is, the number of
20 rotations per unit time) of the generator rotor decreases. With decrease in angular velocity of the generator rotor, energy supplied under governor control increases to bear demand and supply. The swing equation that simulates the mass point system model (generator rotor) is expressed in an expression (2) below. In the expression (2) below, energy P is divided by angular velocity ω to convert energy to torque T . In the
25 expression (2), D_g represents the braking coefficient and M represents the inertia constant described above.

[0063] [Math. 2]

$$T_{in} - T_{out} = M \times \frac{d\omega}{dt} + Dg \times \omega \quad \dots(2)$$

[0064] In the present first embodiment, an example where the expression (1) and the expression (2) are incorporated in control of the static inverter (that is, first DC/AC conversion circuit 408) to simulate inertia capability, synchronization capability, and braking capability of the synchronous generator will be described.

5 [0065] Referring back to Fig. 7, inverter current control circuit 4094 generates a control command value in controlling first DC/AC conversion circuit 408 under current control based on outputs of voltmeter 406, ammeter 411, and AC frequency detection circuit 4091. Inverter voltage control circuit 4095 generates the control command value in controlling first DC/AC conversion circuit 408 under voltage control (that is, a control scheme in which the AC system voltage is outputted from first DC/AC conversion circuit 408) based on outputs of voltmeter 410 and AC frequency detection circuit 4091. Second switching circuit 4096 switches between the control command value from inverter current control circuit 4094 and the control command value from inverter voltage control circuit 4095 based on output of fourth control circuit 4097.

10 [0066] Fourth control circuit 4097 collects results of measurement in connection with DC bus 405 outputted from voltmeter 406 and ammeter 407, results of measurement in connection with the AC system outputted from voltmeter 410 and ammeter 411, status information of first DC/DC conversion circuit 403 outputted from first control circuit 404, and the like, and notifies CEMS 31 or the like of the information through communication interface 412.

15 [0067] Fourth control circuit 4097 notifies CEMS 31 or the like through communication interface 412 also of various control parameters for above-described virtual synchronous generator control circuit 4093, inverter current control circuit 4094 (more specifically, a first PI control circuit 40942 and a second PI control circuit 40945), and inverter voltage control circuit 4095 (more specifically, a third PI control circuit 40953 and a first current restriction circuit 40955). Furthermore, fourth control circuit 4097 notifies CEMS 31 through communication interface 412 also of an effective voltage of the AC system measured by a not-shown effective voltage

measurement unit of the AC system and active power and reactive power information measured by a not-shown active and reactive power measurement unit of the AC system. Furthermore, fourth control circuit 4097 notifies also third control circuit 4044 of a result of measurement of the effective voltage, active power, and the like of the AC system.

[0068] Fig. 8 is a block diagram illustrating a configuration of AC frequency detection circuit 4091 shown in Fig. 7. Referring to Fig. 8, AC frequency detection circuit 4091 includes a phase detection circuit 40910, a frequency detection circuit 40911, and a first sinusoidal wave generation circuit 40912.

[0069] Phase detection circuit 40910 detects the zero cross point from the voltage waveform of the AC system outputted from voltmeter 410. Frequency detection circuit 40911 detects the frequency based on a result of detection of the zero cross point by phase detection circuit 40910. A method of detecting the phase by phase detection circuit 40910 is naturally not limited to detection of the zero cross point. In detection of the zero cross point in an actual machine, an error is produced due to an error (mainly an offset error) in detection of a zero point by voltmeter 410, an error (mainly, a linearity error) in amplitude detection by voltmeter 410, an error (for example, in sampling using a microcomputer or the like, variation in time from carrier interruption until actual sampling) in a sampling cycle in sampling of a system AC voltage waveform, or the like. Phase detection circuit 40910 may naturally be configured to correct these errors and to detect the zero cross point.

[0070] First sinusoidal wave generation circuit 40912 generates a sinusoidal wave in synchronization with the AC system voltage based on the result of detection of the zero cross point by phase detection circuit 40910, the result of detection of the frequency by frequency detection circuit 40911, and an amplitude of the system AC voltage outputted from CEMS 31. AC frequency detection circuit 4091 outputs the result of detection of the zero cross point (that is, time of detection of the zero cross point), the result of detection of the frequency, and information on a sinusoidal wave (that is, the voltage, the frequency, the phase, and the sinusoidal waveform).

[0071] Fig. 9 is a block diagram illustrating a configuration of inverter current control circuit 4094 shown in Fig. 7. Referring to Fig. 9, inverter current control circuit 4094 includes a subtractor 40941, first PI control circuit 40942, a multiplier 40943, a subtractor 40944, second PI control circuit 40945, and a first PWM conversion circuit 40946.

[0072] Inverter current control circuit 4094 generates the control command value to control first DC/AC conversion circuit 408 based on the DC voltage of DC bus 405 outputted from voltmeter 406. The DC voltage of DC bus 405 outputted from voltmeter 406 is subtracted by subtractor 40941 from a target value of a DC bus voltage outputted from fourth control circuit 4097 and the result is inputted to first PI control circuit 40942. First PI control circuit 40942 outputs a command value such that the DC voltage of DC bus 405 attains to a prescribed value, based on control parameters (that is, a proportional gain and an integration time period) outputted from fourth control circuit 4097.

[0073] The command value outputted from first PI control circuit 40942 is multiplied by multiplier 40943 by a sinusoidal wave in synchronization with the AC voltage waveform (that is, the sinusoidal waveform) outputted from first sinusoidal wave generation circuit 40912. A current command value is thus generated. The current command value outputted from multiplier 40943 is subtracted by subtractor 40944 from a current value of the AC system measured by ammeter 411 and the result is inputted to second PI control circuit 40945. Second PI control circuit 40945 outputs the control command value to first PWM conversion circuit 40946 such that the result of subtraction outputted from subtractor 40944 is zero, based on the control parameters (that is, the proportional gain and the integration time period) outputted from fourth control circuit 4097. First PWM conversion circuit 40946 subjects the control command value to PWM modulation when the control command value is inputted from second PI control circuit 40945, and outputs the control command value as the command value to first DC/AC conversion circuit 408.

[0074] As described above, fourth control circuit 4097 gives also the control

parameters for first PI control circuit 40942 and second PI control circuit 40945.

[0075] Fig. 10 is a block diagram illustrating a configuration of inverter voltage control circuit 4095 shown in Fig. 7. Referring to Fig. 10, inverter voltage control circuit 4095 includes a second sinusoidal wave generation circuit 40951, a subtractor 40952, third PI control circuit 40953, first current restriction circuit 40955, and a second PWM conversion circuit 40954.

[0076] Inverter voltage control circuit 4095 outputs a control command value to control first DC/AC conversion circuit 408 based on frequency and phase information outputted from virtual synchronous generator control circuit 4093 details of which will be described later and amplitude information (in the present first embodiment, inputted via first sinusoidal wave generation circuit 40912) of the AC system voltage outputted from fourth control circuit 4097.

[0077] Sinusoidal wave information (that is, the frequency, phase, and amplitude information) from AC frequency detection circuit 4091 and frequency and phase information from virtual synchronous generator control circuit 4093 are inputted to second sinusoidal wave generation circuit 40951. In the present first embodiment, the amplitude is not controlled because QV control (reactive power – voltage control) is not carried out in virtual synchronous generator control circuit 4093. Second sinusoidal wave generation circuit 40951 generates a target value of the AC system voltage outputted from first DC/AC conversion circuit 408 based on the inputted frequency, phase, and amplitude information.

[0078] Subtractor 40952 subtracts the voltage measured by voltmeter 410 from output of second sinusoidal wave generation circuit 40951 and outputs a result of subtraction to third PI control circuit 40953. Third PI control circuit 40953 generates a voltage command under PI control such that the inputted result of subtraction attains to zero and outputs the generated voltage command to first current restriction circuit 40955. Control parameters (that is, the control gain and the integration time period) for the third PI control circuit are outputted from fourth control circuit 4097. First current restriction circuit 40955 restricts the command value outputted from third PI control

circuit 40953 based on the result of measurement by ammeter 411 inputted via fourth control circuit 4097. The command value outputted from first current restriction circuit 40955 is subjected to PWM modulation in second PWM conversion circuit 40954 and the modulated command value is outputted to first DC/AC conversion circuit 408.

[0079] Fig. 11 is a block diagram illustrating a configuration of virtual synchronous generator control circuit 4093 shown in Fig. 7. Referring to Fig. 11, virtual synchronous generator control circuit 4093 includes a subtractor 40932, a governor control circuit 40933, an adder 40935, a subtractor 40936, and a mass point system computing circuit 40937.

[0080] Subtractor 40932 subtracts the frequency command value (Fref) outputted from fourth control circuit 4097 from a result of actual measurement of the frequency.

Output of subtractor 40932 is inputted to governor control circuit 40933. Detailed operations of governor control circuit 40933 will be described later. Adder 40935 generates a control power target value (command value) of mass point system computing circuit 40937 by adding an offset value to be added to the power target value (command value) outputted from governor control circuit 40933 and a power command value (Pref) outputted from fourth control circuit 4097.

[0081] Subtractor 40936 subtracts effective power outputted from effective power calculation circuit 4092 from the control power target value (command value) outputted from adder 40935. Output of subtractor 40936 is inputted to mass point system computing circuit 40937. Though details will be described later, mass point system computing circuit 40937 calculates the frequency and the phase of the AC system voltage outputted from storage battery power conversion device 41 such that output of subtractor 40936 attains to zero. In the present first embodiment, control parameters (speed adjustment ratio K_{gd} , governor time constant T_g , inertia constant M , and braking coefficient D_g) for governor control circuit 40933 and mass point system computing circuit 40937 given from CEMS 31 are given via fourth control circuit 4097.

[0082] Fig. 12 is a block diagram illustrating a configuration of governor control circuit 40933 shown in Fig. 11. Referring to Fig. 12, governor control circuit 40933 includes a multiplier 409331, a first-order lag system model (in the figure, denoted as $1/(1+s \times T_g)$) 409332, and a limiter circuit 409333.

5 [0083] Multiplier 409331 multiplies output of subtractor 40932 by a proportional gain (denoted as $-1/K_{gd}$ in the figure) outputted from fourth control circuit 4097. Output of multiplier 409331 is outputted to first-order lag system model 409332. In the present first embodiment, an example where a standard model of the first-order lag type presented by the Institute of Electrical Engineers of Japan (IEEJ) is employed as
10 governor control will be described. Therefore, the first-order lag system model (that is, $1/(1+s \times T_g)$) is implemented as first-order lag system model 409332 as shown in Fig. 12. Output of first-order lag system model 409332 is subjected to limiter processing in limiter circuit 409333 and resultant output is provided.

[0084] Fig. 13 is a block diagram illustrating a configuration of mass point system
15 computing circuit 40937 shown in Fig. 11. Referring to Fig. 13, mass point system computing circuit 40937 includes a subtractor 409371, an integrator (denoted as $1/(M \times s)$ in the figure) 409372, a multiplier 409373, a divider 409374, an adder 409375, and a phase calculation circuit 409376.

[0085] Subtractor 409371 subtracts output of multiplier 409373 from output (that is, a
20 result of subtraction of actually measured effective power from the power command value (command value)) of subtractor 40936 in Fig. 11. A result of subtraction is inputted to integrator 409372. Integrator 409372 generates a differential value ($\Delta\omega$) between an angular velocity of the generator rotor and an angular velocity command value for the generator rotor shown in Fig. 42 by multiplying output of subtractor
25 409371 by $1/M$ time for integration. In the present first embodiment, the frequency command value is set to 60 [Hz]. Therefore, the angular velocity command value is $2 \times \pi \times 60$ [rad/s]. Output of integrator 409372 is inputted to multiplier 409373, and multiplier 409373 multiplies the output by braking coefficient D_g outputted from fourth control circuit 4097. As a result of subtraction by subtractor 409371, of output of

multiplier 409373 from output of subtractor 40936, mass point system computing circuit 40937 simulates braking capability of the synchronous generator in control of first DC/AC conversion circuit 408.

[0086] Output ($\Delta\omega$) of integrator 409372 is converted to frequency difference

5 information (Δf) by being divided by $2\times\pi$ by divider 409374. The frequency difference information (Δf) is converted to the frequency of the generator rotor (rotation frequency) by being added to a frequency target value (60 Hz) in adder 409375.

Output of adder 409375 is inputted to phase calculation circuit 409376, where the phase of the generator rotor is calculated based on information (that is, zero cross

10 detection information, frequency detection information, a new grid connection start instruction, or the like) from fourth control circuit 4097.

[0087] The transfer function of a swing equation portion of mass point system computing circuit 40937 will now be described. The transfer function of the swing equation portion can be expressed by a first-order lag system having a proportional

15 gain: $1/D_g$ and a time constant: M/D_g , as shown in an expression (3) below. The governor time constant (T_g) and a mass point system computing unit time constant (M/D_g) in virtual synchronous generator control circuit 4093 are determined based on a response speed required in the system.

[0088] [Math. 3]

$$\frac{\frac{1}{M \times s}}{1 + \frac{D_g}{M} \times \frac{1}{s}} = \frac{1}{D_g} \times \frac{1}{1 + \frac{M}{D_g} \times s} \quad \dots(3)$$

20 [0089] Fig. 43 is a block configuration diagram shown for calculation of a transfer function $F(s)$ of virtual synchronous generator control circuit 4093 shown in Fig. 11.

Transfer function $F(s)$ (that is, $\Delta f/\Delta P$) in the block configuration diagram shown in Fig. 43 is expressed in an expression (4) below.

[0090] [Math. 4]

$$F(s) = \frac{1 + s \times T_g}{2\pi \times \left[M \times T_g \times s^2 + (M + D_g \times T_g) \times s + D_g + \frac{1}{2\pi \times K_{gd}} \right]} \quad \dots(4)$$

[0091] Therefore, based on the final value theorem, an expression (5) below holds.

The expression (5) corresponds to an inclination (that is, $1/(2 \times \pi \times D_g + 1/K_{gd})$) of the drooping characteristics of the virtual synchronous generator controller.

[0092] [Math. 5]

$$\Delta F = \Delta P \times \frac{1}{2\pi \times D_g + \frac{1}{K_{gd}}} \quad \dots(5)$$

5 [0093] [Overview of Operations of Distributed Power Source Management Apparatus]

Overview of operations of the distributed power source management apparatus in the present first embodiment will now be described with reference to Figs. 14 to 19.

[0094] Fig. 14 is a diagram showing a region covered by virtual synchronous generator control implemented in storage battery power conversion device 41. In Fig. 14, the

10 abscissa represents response time and the ordinate represents a demand fluctuation range. As shown in the figure, in virtual synchronous generator control implemented in the static inverter, minor fluctuation from several ten milliseconds to several minutes and short-cycle fluctuation are covered. Control for several minutes or longer is carried out by load frequency control (LFC) or economic load dispatching control (EDC). Therefore, in the present first embodiment, description will continue with response performance of virtual synchronous generator control circuit 4093 being defined as one second or shorter.

[0095] Fig. 15 is a diagram showing exemplary drooping characteristics of virtual

synchronous generator control shown in the present first embodiment. The abscissa in

20 Fig. 15 represents the frequency, and the frequency command value (F_{ref}) is shown.

In the present disclosure, a difference between an actually measured frequency

($F_{measure}$) and the frequency command value will be referred to as a Δ frequency

($F_{measure} - F_{ref}$). The ordinate in Fig. 15 represents a difference (Δ electric power)

between the power command value (P_{ref}) and actually measured effective power

(P_{measure}). The expression (5) expresses an inclination of drooping characteristics shown in Fig. 15. This figure shows an example where the power command value (P_{ref}) is set to "zero" for the sake of brevity of description. The drooping characteristics are adjusted to obtain the power command value (P_{ref}) at the frequency command value (F_{ref}).

[0096] The drooping characteristics of the power distribution system (that is, the drooping characteristics of the bulk power system) will now briefly be described. In general, upper and lower limit values of the frequency of the AC system voltage of the bulk power system are approximately 1 to 2% of the system frequency (that is, the rated frequency). Therefore, in an example where the system frequency is 60 Hz, the upper limit frequency is approximately from 61.2 to 60.6 Hz and the lower limit frequency is approximately from 59.4 to 58.8 Hz. The frequency of the power distribution system is converted from time to time within the frequency range.

[0097] Fig. 16 is a diagram showing an exemplary result of actual measurement for twenty-five hours in one-second cycles, of the frequency of the power distribution system voltage. As shown in the figure, constant fluctuation by ± 0.2 Hz around 60 Hz can be observed.

[0098] Fig. 17 is a diagram showing exemplary drooping characteristics of storage battery power conversion device 41 in power distribution system 1 in the present first embodiment. In the figure, the abscissa represents the frequency of the AC system voltage and the ordinate represents electric power. F_{max} on the abscissa represents a maximum frequency that can be taken by storage battery power conversion device 41 and F_{min} represents a minimum frequency that can be taken by storage battery power conversion device 41. A frequency 60.1 Hz represents the maximum frequency that can be taken by the power distribution system voltage and a frequency 59.9 Hz represents the minimum frequency that can be taken by the power distribution system voltage. A frequency range that can be taken by the power distribution system voltage will also be referred to as a rated frequency range below. F_{ref} represents the frequency command value in virtual synchronous generator control and P_{ref} represents

the power command value. In the present first embodiment, upper and lower limit values of the frequency of the power distribution system voltage are defined as ± 0.1 Hz. In the present first embodiment, for the sake of brevity of description, storage battery power conversion device 41 is described as performing only discharging. The upper and lower limit values of the frequency of the power distribution system voltage are not limited to ± 0.1 Hz. For example, ± 0.2 Hz aimed by a major electric utility, frequency upper and lower limit values (for example, ± 0.15 Hz) determined by a microgrid power distribution system business entity in construction of the microgrid, or the like may naturally be applicable.

[0099] In an example where the static inverter (that operates as the voltage source) where virtual synchronous generator control is implemented is interconnected with the bulk power system, in an example where a plurality of static inverters (each of which operates as the voltage source) where virtual synchronous generator control is implemented are interconnected in the isolated system, or in an example where a plurality of types of main power sources (that operate as voltage sources) such as the synchronous generators are interconnected in the isolated system, for stable operation of the static inverter (that operates as the voltage source) where virtual synchronous generator control is implemented, braking coefficient D_g should be increased. With increase in braking coefficient D_g , a frequency range ΔF that can be covered by the drooping characteristics of virtual synchronous generator control becomes narrower as shown in the expression (5). Thus, as shown in Fig. 16, the frequency range (F_{min} to F_{max}) covered by the drooping characteristics of virtual synchronous generator control becomes narrower than the rated frequency range (in the present first embodiment, 59.9 Hz to 60.1 Hz) of the AC system voltage. Consequently, when the frequency of the system AC voltage becomes lower than F_{min} or becomes higher than F_{max} , storage battery power conversion device 41 can no longer maintain operation and stops. For example, in an example where F_{min} is 59.95 Hz and the frequency of the system AC voltage is 59.94 Hz, a voltage phase is shifted by a difference between the frequency of the AC system voltage that can be outputted by storage battery power conversion

device 41 and the frequency of the system AC voltage, and hence storage battery power conversion device 41 disadvantageously stops for protection.

[0100] Fig. 18 is a diagram for illustrating a method of creating the frequency

command value (F_{ref}) in the distributed power source management apparatus in the

5 present first embodiment. Though details will be described later, in the present first

embodiment, when CEMS 31 creates frequency command value F_{ref} for each storage

battery power conversion device 41, operation plan creation circuit 314 shown in Fig. 2

creates power command value P_{ref} (that is, operation plan power command value

information) for each storage battery power conversion device 41. When CEMS 31

10 completes creation of power command value P_{ref} , it creates drooping characteristics on

the assumption that frequency command value F_{ref} is equal to the rated frequency (for

example, 60 Hz) of the bulk power system as shown in a portion A in Fig. 18. Then,

for example, when $F_{measure}$ is lower than F_{min} based on comparison with the result

($F_{measure}$) of actual measurement of the frequency of the AC system voltage taken by

15 AC frequency collection circuit 313, with the current drooping characteristics, storage

battery power conversion device 41 stops as described above. In the present first

embodiment, in such a case, for example, CEMS 31 sets frequency command value

F_{ref} to the result ($F_{measure}$) of actual measurement as shown in a portion B in the

figure and notifies storage battery power conversion device 41 of the command value,

20 although details will be described later. In this case, since the drooping characteristics

move to the left as shown in the figure, storage battery power conversion device 41 can

keep operating.

[0101] An effect of the method of creating the frequency command value above will

now be described with reference to Figs. 19A and 19B. Fig. 19A is a diagram

25 showing the frequency command value when drooping characteristics in a comparative

example are used. The figure shows an example where the load becomes less and the

frequency of the AC system voltage ramps up with lapse of time. As shown in the

figure, when the frequency command value (F_{ref}) is constant at the rated frequency (60

Hz) of the bulk power system, an inner side of bold dashed lines is the frequency range

(which will also be referred to as a frequency management range) of storage battery power conversion device 41 (inverter). With gradual increase in frequency of the system voltage as shown in the figure, the frequency of the system voltage goes out of the frequency range of the inverter controllable by storage battery power conversion device 41 (inverter) (an NG region in the figure), and hence virtual synchronous generator control (VSG control) fails and storage battery power conversion device 41 stops.

[0102] Fig. 19B, on the other hand, is a diagram showing the frequency command value when drooping characteristics in the present first embodiment are used. As shown in the figure, the frequency command value (Fref) is controlled based on a result of actual measurement of the frequency of the AC system voltage. Specifically, in the present first embodiment, the frequency of the AC system voltage is measured in one-minute cycles and the frequency command value (Fref) is controlled based on a result of measurement, although details will be described later. As shown in the figure, the frequency command value (Fref) is appropriately controlled based on the frequency of the AC system voltage. Therefore, interconnected operation can continue without the actually measured system frequency being out of the frequency management range of storage battery power conversion device 41 (inverter) even when the frequency of the system voltage gradually increases.

[0103] As described above, in an example where the power conversion device including the static inverter where drooping characteristics (that is, droop characteristics) represented by virtual synchronous generator control are implemented is connected to the AC system, the distributed power source management apparatus is configured to generate the frequency command value (Fref) in the drooping characteristics (droop characteristics) based on the frequency of the AC system voltage. Thus, even when the frequency of the bulk power system deviates from the rated frequency (for example, 60 Hz), the power conversion device can effectively be controlled without the actually measured system frequency going out of the frequency management range of the power conversion device including the static inverter where

the drooping characteristics (that is, droop characteristics) are implemented.

[0104] [Details of Operations of Distributed Power Source Management Apparatus (CEMS)]

Operations of the distributed power source management apparatus (CEMS 31) in the present first embodiment will now be described in detail with reference to Figs. 1 to 30. Referring again to Fig. 1, the power distribution system to which the distributed power source management apparatus according to the first embodiment is connected will be described. In the first embodiment, power distribution system 1 includes three SVRs 23 connected in series at electricity distribution line 24m between substation 20 and mega-solar power conversion device 27 (or storage battery power conversion device 41a or town D 100d) in order to control the power distribution system voltage outputted from substation 20 to be between prescribed voltages. Storage battery power conversion device 41a is provided near mega-solar power conversion device 27. In the present first embodiment, storage battery power conversion device 41a operates as the voltage source and mega-solar power conversion device 27 operates as a current source. Mega-solar power conversion device 27 also adjusts an amount of fluctuation of electric power generated by mega-solar power plant 26 by causing virtual synchronous generator control circuit 4093 to operate.

[0105] Town A 100a, town B 100b, town C 100c, town D 100d, factory 101, building 102, and apartment 103 are provided as loads. Electric power supplied from substation 20, electric power generated by mega-solar power plant 26, and electric power supplied from storage batteries 40a to 40c are supplied to these loads. For emergency, synchronous generator 30a is arranged in factory 101 and synchronous generator 30b is arranged in building 102.

[0106] Operations of the power distribution system for control of electric power supplied from substation 20, electric power generated by mega-solar power plant 26, and discharging power outputted from storage batteries 40a to 40c will be described below.

[0107] Fig. 20 is a sequence diagram in normal operations of the distributed power

source management system, with CEMS 31 shown in Fig. 1 being centered. As shown in the figure, processing in a steady state of the distributed power source management system includes two kinds of processing of processing P1 performed in thirty-minute cycles and processing P2 performed in one-minute cycles.

5 [0108] As thirty-minute cycle processing P1 is started in the figure, DSO 21 issues to CEMS 31 through communication line 25, an output request to output collected measurement data (F1). When CEMS 31 receives the request from DSO 21, it transmits the output request to output the measurement data to storage battery power conversion device 41, voltmeter 22, and each consumer (including mega-solar power conversion device 27) (F2, F4) and collects most recent measurement information (F3, 10 F5). CEMS 31 then calculates an amount of power consumption by each consumer, an amount of electric power generated by mega-solar power plant 26, and an amount of charging and discharging power of storage battery 40 for thirty minutes by summing data collected thirty times in one-minute cycles and transmits the amounts to DSO 21 together with information on a state of charge (SOC) or the like of storage battery 40 15 (F6).

[0109] When DSO 21 receives the result of measurement, it creates a demand plan (that is, total supply electric power to be supplied to power distribution system 24 through substation 20 for thirty minutes) for twenty-four hours in thirty-minute cycles 20 necessary for creation of the operation plan of storage battery 40 and notifies CEMS 31 of a result of creation (F7). When CEMS 31 receives the information to be used for creation of the operation plan of the storage battery, it creates the operation plan of storage battery 40 and control parameters (that is, the power command value (Pref), the frequency command value (Fref), or the like) based on SOC information collected 25 previously, state-of-health (SOH) information of storage battery 40, generated electric power prediction information (details of which will be described later) of mega-solar power plant 26, and demand prediction information (details of which will be described later) of the consumer (F8). A method of creating the operation plan and the control parameters will be described later. When CEMS 31 has completed creation of the

operation plan of storage battery 40 and the control parameters, it transmits the operation plan and the control parameters to each storage battery power conversion device 41 (F9) and quits thirty-minute cycle processing P1.

[0110] CEMS 31 issues a request to output measurement data to each storage battery

5 power conversion device 41 and voltmeter 22 in processing P2 performed in one-minute cycles (F10, F12) to collect measurement data therefrom (F11, F13). CEMS 31 then checks a result of collection, a difference between the power command value (Pref) and actual charging and discharging power, and further a difference between frequency command value Fref and an actually measured frequency (Fmeasure) of the
10 power distribution system voltage, and determines whether or not modification of the operation plan and/or the control parameters (Pref, Fref, or the like) is required (F14). In the case of the present first embodiment, CEMS 31 re-calculates the operation plan and/or the control parameters (Pref, Fref, or the like) when the difference is equal to or larger than a predetermined value (F15) and notifies each storage battery power
15 conversion device 41 of a result of re-calculation (F16). A specific re-calculation processing method will be described later.

[0111] Detailed operations of CEMS 31 will now be described with reference to Fig.

21. Fig. 21 is a flowchart showing control processing in CEMS 31 shown in Fig. 1.

When a process is started in the figure, in step S101, CEMS 31 checks whether or not it
20 has received from DSO 21, the transmission request to transmit measurement data.

When CEMS 31 has received the output request (YES in step S101), in next step S102, it transmits the output request to output the measurement data to storage battery power conversion device 41, voltmeter 22, and each consumer (including mega-solar power conversion device 27) to collect most recent measurement information therefrom.

25 CEMS 31 then calculates the amount of power consumption by each consumer, the amount of electric power generated by mega-solar power plant 26, and the amount of charging and discharging power of storage battery 40 for thirty minutes from the measurement data collected thirty times in one-minute cycles, and has the calculated various amounts of electric power stored in storage circuit 312. The data stored in

storage circuit 312 corresponds to the measurement data transmission of which is requested by DSO 21 in step S101. In next step S103, CEMS 31 transmits the measurement data stored in storage circuit 312 to DSO 21 through communication circuit 311, together with information on the SOC or the like of storage battery 40.

5 [0112] After CEMS 31 transmits the measurement data to DSO 21 in step S103 or when it has not received from DSO 21, the transmission request to transmit the measurement data in step S101 (No in step S101), it has the process proceed to step S104. In step S104, CEMS 31 checks whether or not it has received a demand plan notification from DSO 21. When CEMS 31 has received the demand plan, it creates
10 the operation plan in next step S105. In the present first embodiment, DSO 21 notifies CEMS 31 of a plan for twenty-four hours, for supply and demand of electric power to be supplied from the bulk power system to power distribution system 1 in thirty-minute cycles. Details of operation plan creation processing will be described below with reference to Fig. 22.

15 [0113] Fig. 22 is a flowchart showing detailed operations in operation plan creation processing in step S105 in the flowchart shown in Fig. 21. In Fig. 22, when creation of the operation plan is started, CEMS 31 initially predicts in step S1051, the amount of power generation by mega-solar power plant 26. Specifically, referring again to Figs. 2 and 3, when in-CEMS control circuit 318 receives a notification of the demand plan
20 (storage battery operation plan) from DSO 21, it instructs management circuit 3146 within operation plan creation circuit 314 to create the operation plan. When management circuit 3146 receives the instruction, it instructs via storage battery operation plan generation circuit 3141, power generation amount prediction circuit 3142 to predict electric power generated by mega-solar power plant 26. When power
25 generation amount prediction circuit 3142 receives the instruction, it obtains weather forecast for twenty-four hours from a not-shown weather forecast server arranged on the Internet. Power generation amount prediction circuit 3142 predicts the amount of power generation for twenty-four hours based on an obtained result of the weather forecast and data in a not-shown database for prediction of the amount of power

generation managed by generated electric power prediction circuit 3142. The not-shown database for prediction of the amount of power generation is constructed, for example, based on an actual amount of power generation by mega-solar power plant 26, actual weather information, and time information (day, month, and year, time
5 information) collected in thirty-minute cycles. Since details of a method of constructing the database is irrelevant to the key factor in the present application, description thereof will not be given.

[0114] When prediction of the amount of power generation by mega-solar power plant 26 in step S1051 described above ends, CEMS 31 predicts power consumption by the
10 consumer in step S1052 in Fig. 22. Specifically, referring again to Fig. 3, when management circuit 3146 within operation plan creation circuit 314 receives a result of prediction of the amount of power generation by mega-solar power plant 26 from power generation amount prediction circuit 3142, it instructs via storage battery
15 operation plan generation circuit 3141, power consumption prediction circuit 3143 to predict power consumption by the consumer. When power consumption prediction circuit 3143 receives the instruction, it predicts power consumption by the consumer for twenty-four hours based on data in a not-shown database for prediction of power consumption managed by power consumption prediction circuit 3143. The not-shown
20 database for prediction of power consumption is constructed based, for example, on power consumption by the consumer collected in thirty-minute cycles, day, month, and year, time information, and weather information. Since details of a method of constructing the database is irrelevant to the key factor in the present application, description thereof will not be given. Either of steps S1051 and S1052 may be performed first, or they may be performed in parallel.

25 [0115] When prediction of power consumption by the consumer in step S1052 described above ends, CEMS 31 starts creation of the demand plan in step S1053 in Fig. 22. Specifically, referring again to Fig. 3, when storage battery operation plan generation circuit 3141 within operation plan creation circuit 314 receives a result of prediction of power consumption by the consumer from power consumption prediction

circuit 3143, it calculates a total value of charging and discharging power every thirty minutes, of storage batteries 40a to 40c based on the result of prediction by power generation amount prediction circuit 3142, of the amount of power generation by mega-solar power plant 26, a result of prediction by power consumption prediction circuit 3143, of power consumption by the consumer, and the demand plan given from DSO 21. As described above, in the case of the present first embodiment, the demand plan given from DSO 21 is an electric power supply plan (that is, the electric power supply plan every thirty minutes) for twenty-four hours planned for power distribution system 1 located at a load side relative to substation 20.

[0116] When CEMS 31 has completed creation of the demand plan in step S1053 in Fig. 22, it draws up charging and discharging power of storage batteries 40a to 40c in next step S1054. Specifically, referring again to Figs. 2 and 3, operation plan creation circuit 314 determines (proportionally distributes) charging and discharging power from respective storage batteries every thirty minutes based on SOC information of storage batteries 40a to 40c collected in storage circuit 312 via communication circuit 311 and storage battery capacities of storage batteries 40a to 40c.

[0117] In the first embodiment, in the operation plan for the storage battery for twenty-four hours, operation plan creation circuit 314 draws up the operation plan such that SOC of storage batteries 40a to 40c substantially simultaneously attain to zero or the storage batteries are in a chargeable and dischargeable state simultaneously in twenty-four hours, for reasons below. For example, an example in which clouds flow over mega-solar power plant 26 (for example, 10 MW) and generated electric power lowers, for example, for approximately five minutes (lowers from 10 MW to 4 MW) is assumed. Furthermore, the capacities of the static inverters of storage battery power conversion devices 41a to 41c are assumed as 8 MW, 4 MW, and 2 MW, respectively. It is assumed that storage battery 40a is in a standstill state with the SOC being zero, and the storage battery operation plan has been given to have storage batteries 40b and 40c discharge 1 MW and 0.5 MW, respectively. In this case, due to abrupt change of solar radiation, storage batteries 40b and 40c are merely able to additionally output

discharging power of 3 MW and 1.5 MW under virtual synchronous generator control, respectively, and shortage of 6 MW cannot be covered. When storage batteries 40a to 40c are operating, on the other hand, discharging up to 14 MW at the maximum can be performed, and a range of electric power covered by virtual synchronous generator control is wider than in the previous example of 6 MW. Therefore, in creation of the operation plan of storage battery 40 by CEMS 31, such an operation plan that the SOCs of storage batteries 40a to 40c substantially simultaneously attain to zero or the storage batteries are substantially simultaneously fully charged should be created.

[0118] When drawing up of charging and discharging power of storage batteries 40a to 40c in step S1054 in Fig. 22 ends, in next step S1055, AC frequency collection circuit 313 within CEMS 31 obtains the frequency of the power distribution system voltage and calculates an average value (F_{measure}) as the representative value. As described above, in the present first embodiment, voltmeters 22a to 22x calculate the frequency at each point from the measured AC system voltage and AC frequency collection circuit 313 calculates and outputs the average value of the frequencies.

[0119] When collection of the frequency of the power distribution system voltage and calculation of the representative value (F_{measure}) have been completed in step S1055 in Fig. 22, in next step S1056, in-CEMS control circuit 318 checks whether or not the control parameters (that is, the power command value and the frequency command value) for all storage battery power conversion devices 41 have been generated. When determination as NO is made in step S1056, in next step S1057, in-CEMS control circuit 318 generates the frequency command value (F_{ref}). A flow of generation of the frequency command value (F_{ref}) in step S1057 will be described below with reference to Fig. 23.

[0120] Fig. 23 is a flowchart showing a procedure of generation of the frequency command value (F_{ref}). When the flow of generation of the frequency command value (F_{ref}) is started in Fig. 23, in initial step S10571, frequency command value generation circuit 315 shown in Fig. 2 instructs in-CEMS control circuit 318 to obtain the control parameter (that is, the drooping characteristics) for storage battery power conversion

device 41 for which the frequency command value (F_{ref}) should presently be generated.

[0121] When in-CEMS control circuit 318 receives the instruction from frequency command value generation circuit 315, it obtains the drooping characteristics from distributed power source drooping characteristic management circuit 316. In the present first embodiment, in-CEMS control circuit 318 obtains, as the control parameters, the speed adjustment ratio (K_{gd}), the governor time constant (T_g), the inertia constant (M), and the braking coefficient (D_g) for virtual synchronous generator control and the capacity (inverter capacity) of first DC/AC conversion circuit 408.

Drooping characteristic information is not limited to the above. Table data indicating relation between ΔP (that is, the power command value (P_{ref}) – $P_{measure}$ (actually measured active power value)) outputted from first DC/AC conversion circuit 408 and outputted ΔF (that is, the frequency command value (F_{ref}) – the actually measured value ($F_{measure}$) of the AC system voltage), an inclination of the drooping characteristics, or the like may naturally be applicable. In other words, the drooping characteristic information may be a shape of the drooping characteristics or a parameter that determines the shape of the drooping characteristics.

[0122] When step S10571 ends, in next step S10572, frequency command value generation circuit 315 instructs in-CEMS control circuit 318 to generate the upper limit value and the lower limit value of the frequency of the AC system voltage determined by the drooping characteristics. An example where virtual synchronous generator control is used as the drooping characteristics will be described in the present first embodiment. Under virtual synchronous generator control, ΔF can be obtained from the expression (5) described above. Therefore, in the present first embodiment, upper limit value F_{max} of the frequency and lower limit value F_{min} of the frequency can be calculated by substituting speed adjustment ratio K_{gd} , braking coefficient D_g , and a minimum value and a maximum value of ΔP into the expression (5). In the present first embodiment, the minimum value of ΔP is calculated as the power command value (P_{ref}) – maximum discharging power. The maximum value of ΔP , on the other hand,

is calculated as the power command value (P_{ref}) – 0, on the assumption that first DC/AC conversion circuit 408 does not perform charging.

[0123] When generation of the upper and lower limit values of the frequency of the AC system voltage in the drooping characteristics in step S10572 ends, in next step S10573, frequency command value generation circuit 315 checks whether or not the actually measured frequency of the AC system voltage is within a frequency reference range (see Fig. 24) determined by the upper and lower limit frequencies in the drooping characteristics. Operations in step S10573 will be described below with reference to Fig. 24.

[0124] Fig. 24 is a diagram showing exemplary drooping characteristics of storage battery power conversion device 41 in the distributed power source management system in the present first embodiment. In the figure, the abscissa represents the frequency of the power distribution system voltage and the ordinate represents discharging power outputted from storage battery power conversion device 41. In the first embodiment, for the sake of brevity of description, storage battery power conversion device 41 is assumed as not performing charging. F_{max} and F_{min} in the figure represent the upper and lower limit frequencies in the drooping characteristics. In the present first embodiment, a range at the inner side of upper limit frequency F_{max} and lower limit frequency F_{min} by a frequency offset F_{offset} is defined as the frequency reference range determined by upper and lower limit frequencies F_{max} and F_{min} . Naturally, frequency offset F_{offset} may be different in value between an upper limit side and a lower limit side, or may be variable in value in accordance with a value of the power command value (P_{ref}).

[0125] In Fig. 24, when the representative value ($F_{measure}$) of the actually measured frequency outputted from AC frequency collection circuit 313 is out of the frequency reference range determined by the upper and lower limit frequencies (*1 in the figure), frequency command value generation circuit 315 selects NO in step S10573, and when the representative value ($F_{measure}$) of the actually measured frequency is within the frequency reference range determined by the upper and lower limit frequencies (*2 in

the figure), it selects YES.

[0126] When determination as YES is made in step S10573, in next step S10575, frequency command value generation circuit 315 sets the frequency command value (Fref) to the rated frequency (for example, 60 Hz) of the power system and quits the process for generating the frequency command value (Fref). When determination as NO is made in S10573, on the other hand, in next step S10574, frequency command value generation circuit 315 generates the frequency command value (Fref).

Operations in step S10574 will be described below with reference to Fig. 25.

[0127] Fig. 25 is a flowchart showing a procedure of generation of the frequency command value (Fref) in step S10574 in Fig. 23. In initial step S105741 in Fig. 25, frequency command value generation circuit 315 generates the drooping characteristics with Fref being defined as $F_{ref} = F_{measure}$ and calculates the upper and lower limit frequencies of the frequency of the AC system voltage based on the generated drooping characteristics. Specifically, the upper and lower limit frequencies can be calculated as in step S10572 in Fig. 23. Specifically, frequency command value generation circuit 315 calculates upper limit value F_{max} of the frequency and lower limit value F_{min} of the frequency by substituting speed adjustment ratio K_{gd} , braking coefficient D_g , the minimum value of ΔP , and the maximum value of ΔP into the expression (5) (corresponding to a portion B in Fig. 26). As described previously, in the present first embodiment, the minimum value of ΔP is calculated as the power command value (Pref) – maximum discharging power. In the present first embodiment, the maximum value of ΔP is equal to the power command value (Pref) on the assumption that first DC/AC conversion circuit 408 does not perform charging.

[0128] When step S105741 ends, in next step S105742, frequency command value generation circuit 315 checks whether or not the upper and lower limit frequencies in the drooping characteristics are between the upper and lower limit values of the frequency of the AC system voltage (that is, within the predetermined rated frequency range). In the present first embodiment, the upper and lower limit values of the frequency of the AC system voltage are defined as 60.1 Hz and 59.9 Hz. When

determination as YES is made in step S105742, frequency command value generation circuit 315 quits the procedure of calculation of the frequency command value (Fref), with the frequency command value being defined as the frequency command value (Fref) = Fmeasure. When determination as NO is made in step S105742, on the other hand, in next step S105743, frequency command value generation circuit 315 modifies the frequency command value (Fref). Operations in step S105743 will be described below with reference to Fig. 26.

[0129] Fig. 26 is a diagram for illustrating a procedure of modification of the frequency command value. As shown in a portion A in Fig. 26, it is assumed that the representative value (Fmeasure) of the frequency of the actually measured AC system voltage is 59.915 Hz in an example where the frequency command value (Fref) is 60 Hz. In this case, when the drooping characteristics are generated with the representative value (Fmeasure) of the actually measured frequency being set to the frequency command value (Fref), as shown with the portion B in Fig. 26, the lower limit frequency in the drooping characteristics becomes lower than the lower limit value (59.9 Hz) of the frequency of the AC system voltage. Therefore, frequency command value generation circuit 315 modifies the frequency command value (Fref) such that the lower limit frequency in the drooping characteristics matches with 59.9 Hz which is the lower limit value of the frequency of the AC system voltage as shown in a portion C in Fig. 26. Specifically, in the drooping characteristics modified such that the lower limit frequency in the drooping characteristics matches with the lower limit value of the frequency of the AC system voltage, the frequency at which output electric power attains to the power command value (Pref) is set as the frequency command value (Fref).

[0130] This is also applicable to an example where the upper limit frequency in the drooping characteristics exceeds the upper limit value of the frequency of the AC system voltage. In this case, frequency command value generation circuit 315 modifies the frequency command value (Fref) such that the upper limit frequency in the drooping characteristics matches with the upper limit value of the frequency of the AC

system voltage. Specifically, in the drooping characteristics modified such that the upper limit frequency in the drooping characteristics matches with the upper limit value of the frequency of the AC system voltage, the frequency at which output electric power attains to the power command value (Pref) is set as the frequency command value (Fref). When step S105743 in Fig. 25 ends, in-CEMS control circuit 318 quits calculation (step S10574 in Fig. 23) of the frequency command value (Fref).

[0131] Referring back to Fig. 22, when step S1057 ends, in-CEMS control circuit 318 has the process return to step S1056, and thereafter repeats step S1057 until determination as YES is made in step S1056, that is, calculation of frequency command values Fref for all storage battery power conversion devices 41 is completed.

[0132] Referring back to Fig. 21, when in-CEMS control circuit 318 quits generation of the operation plan in step S105, in next step S110, it notifies each storage battery power conversion device 41 of the generated operation plan (that is, power command value Pref and frequency command value Fref). In next step S111, in-CEMS control circuit 318 determines whether or not to stop operations of CEMS 31. When determination as YES is made in step S111, in-CEMS control circuit 318 stops operations of CEMS 31. When determination as NO is made in step S111, on the other hand, in-CEMS control circuit 318 has the process return to step S101 and repeats the flow described above.

[0133] An example where determination as NO is made in step S104 in Fig. 21 will now be described. In this case, in-CEMS control circuit 318 checks in step S106 whether or not time to start one-minute cycle processing has come. When determination as NO is made in step S106, in-CEMS control circuit 318 has the process return to step S101 and repeats the flow described above. When determination as YES is made in step S106, on the other hand, in-CEMS control circuit 318 has the process proceed to next step S107.

[0134] In step S107, in-CEMS control circuit 318 collects measurement data from voltmeter 22, measurement data from storage battery power conversion device 41, measurement data from mega-solar power conversion device 27, measurement data

from the consumer, or the like. When in-CEMS control circuit 318 has completed collection of the measurement data in step S107, in next step S108, it determines whether or not modification of the operation plan is required. By way of example, in the present first embodiment, when the SoC given from storage battery power conversion device 41 is out of a predetermined range, in-CEMS control circuit 318 determines that modification of the operation plan is required. For example, in the present first embodiment, when the SoC exceeds 0.9 in charging or when the SoC is lower than 0.05 in discharging, in-CEMS control circuit 318 determines that modification of the operation plan is required. The SoC at 1.0 is defined as full charge. In another example, when the representative value (Fmeasure) of the frequency of the actually measured system voltage outputted from AC frequency collection circuit 313 is out of the predetermined range, in-CEMS control circuit 318 determines that modification of the operation plan is required. Step S108 in Fig. 21 will be described in further detail below with reference to Fig. 27.

[0135] Fig. 27 is a flowchart showing a procedure of determination as to whether or not modification of the operation plan is required. When a process for determining whether or not modification of the operation plan is required is started, in step S1081, in-CEMS control circuit 318 clears an operation plan modification flag. When the operation plan modification flag has been set, in step S108 in Fig. 21, in-CEMS control circuit 318 determines that modification of the operation plan is required, and when the operation plan modification flag has been cleared, it determines that modification of the operation plan is not required. In the present first embodiment, the operation plan modification flag is prepared for each storage battery power conversion device 41.

[0136] When step S1081 ends, in next step S1082, in-CEMS control circuit 318 obtains representative value Fmeasure of the frequency of the actually measured system voltage outputted from AC frequency collection circuit 313.

[0137] In next step S1083, the in-CEMS control circuit obtains charging and discharging power and the SoC from each storage battery power conversion device 41. Furthermore, in step S1084, in-CEMS control circuit 318 obtains the virtual

synchronous generator control parameter (drooping characteristics) for each storage battery power conversion device 41 from distributed power source drooping characteristic management circuit 316.

5 [0138] In next step S1085, in-CEMS control circuit 318 calculates the upper and lower limit frequencies in the drooping characteristics, from the drooping characteristics collected in step S1084, in a manner described with reference to step S10572 in Fig. 23 and step S105741 in Fig. 25.

[0139] When step S1085 ends, in next step S1086, in-CEMS control circuit 318 checks whether or not the SoC is within the predetermined range. When the SoC is out of the
10 predetermined range, in-CEMS control circuit 318 has the process proceed to step S1088, and in step S1088, it sets the operation plan modification flag.

[0140] When the SoC is within the predetermined range (YES in S1086), in next step S1087, in-CEMS control circuit 318 checks whether or not the representative value (F_{measure}) of the actually measured frequency of the power distribution system
15 voltage is within the frequency reference range determined by the upper and lower limit frequencies in the drooping characteristics. The frequency reference range is the same as that described with reference to step S10573 in Fig. 23 and with reference to Fig. 24. When the representative value (F_{measure}) of the actually measured system frequency is out of the frequency reference range determined by the drooping characteristics (NO in
20 step S1087), in-CEMS control circuit 318 has the process proceed to step S1088, and in step S1088, it sets the operation plan modification flag.

[0141] When the operation plan modification flag has been set in step S1088 or when it is confirmed in step S1087 that the actually measured system frequency (F_{measure}) is within the frequency range determined by the drooping characteristics (YES in step
25 S1087), the process proceeds to step S1089. In step S1089, in-CEMS control circuit 318 checks whether or not it has determined whether or not setting of the modification flag is required for all storage battery power conversion devices 41, and when determination as to whether or not setting of the modification flag is required has been completed for all storage battery power conversion devices 41 (YES in step S1089), it

quits the process for determining whether or not modification of the operation plan is required. When determination as NO is made in step S1089, on the other hand, in-CEMS control circuit 318 has the process return to step S1083 and repeats the procedure above.

5 [0142] Referring back to Fig. 21, when in-CEMS control circuit 318 determines in step S108 that modification of the operation plan is not required (that is, the operation plan modification flags of all storage battery power conversion devices 41 are set to "0") (NO in step S108), in-CEMS control circuit 318 has the process return to initial step S101 and repeats the process described above. When in-CEMS control circuit 318
10 determines in step S108 that modification of the operation plan is required (that is, even one of the operation plan modification flags is set to "1") (YES in step S108), in next step S109, it modifies the operation plan. Details of step S109 will be described below with reference to Fig. 28.

[0143] Fig. 28 is a flowchart showing a procedure of modification of the operation
15 plan. When the flow of modification of the operation plan is started, in step S1091, in-CEMS control circuit 318 checks whether or not the operation plan modification flag has been set. As described above, in the present first embodiment, the operation plan modification flag is provided for each storage battery power conversion device 41, and the frequency command value (Fref) and/or the power command value (Pref) are/is
20 newly generated for one requiring modification of the operation plan.

[0144] When the operation plan modification flag has not been set (NO in step S1091), the process proceeds to step S1098. Processing in step S1098 will be described later. When the operation plan modification flag has been set (YES in step S1091), on the other hand, the process proceeds to steps S1092 to S1094. In step S1092, in-CEMS
25 control circuit 318 obtains data (charging and discharging power, the SoC) measured in storage battery power conversion device 41, in step S1093, it obtains the frequency command value (Fref) and the power command value (Pref), and further in step S1094, it obtains the representative value (Fmeasure) of the frequency of the actually measured AC voltage outputted from AC frequency collection circuit 313.

[0145] When steps S1092 to S1094 end, in next step S1095, in-CEMS control circuit 318 checks whether or not the SoC is within the predetermined range. In the present first embodiment, as described above, the SoC being out of the predetermined range refers to a case where the SoC exceeds 0.9 in charging and a case where the SoC is lower than 0.05 in discharging. The SoC at 1.0 is defined as full charge. The SoC being out of the predetermined range is not limited to this case. For example, in an example where a lead acid battery is employed, the storage battery quickly deteriorates by overdischarging, and the lower limit value of the SoC in discharging is set, for example, to 0.3. In the example of the lead acid battery, deterioration does not quickly proceed by overcharging, and the upper limit value of the SoC in charging may naturally be set to 1.0 or more. The upper limit value and the lower limit value of the SoC may thus be determined in accordance with characteristics of the storage battery.

[0146] When the SoC of the storage battery is not within the predetermined range (NO in step S1095), in next step S1096, in-CEMS control circuit 318 changes the power command value (Pref). In the present first embodiment, a not-shown data table that determines the power command value in accordance with a value of the SoC is stored in CEMS 31, and in-CEMS control circuit 318 determines the power command value (Pref) based on that information. A method of determining the power command value is not limited to the method based on the data table. For example, the power command value may be changed to a value at which overdischarging or overcharging does not occur at the time when a notification of the demand plan is next given from DSO 21 based on a time period until time of reception of the demand plan next given from DSO 21, the value of the SoC, and the current power command value.

[0147] When the SoC of the storage battery is within the predetermined range (YES in step S1095) or when generation of the power command value (Pref) ends in step S1096, the process proceeds to step S1097. In step S1097, in-CEMS control circuit 318 checks whether or not the representative value (Fmeasure) of the actually measured frequency of the power distribution system voltage is within the frequency reference range determined by the upper and lower limit frequencies in the drooping

characteristics. The frequency reference range is the same as that described with reference to step S10573 in Fig. 23 and with reference to Fig. 24.

[0148] When the representative value (Fmeasure) of the actually measured frequency of the power distribution system voltage is not within the frequency reference range (NO in step S1097), in next step S10910, in-CEMS control circuit 318 calculates the frequency command value (Fref). Since step S10910 in Fig. 28 is the same as step S10574 in Fig. 23 and more specifically the same as the flowchart in Fig. 25, description thereof will not be repeated.

[0149] When the operation plan modification flag has not been set (NO in step S1091), when calculation of the frequency command value (Fref) in step S10910 has been completed, or when the representative value (Fmeasure) of the actually measured frequency of the power distribution system voltage is within the frequency reference range (YES in step S1097), the process proceeds to step S1098. In step S1098, in-CEMS control circuit 318 checks whether or not it has generated the control parameters (Pref, Fref) for all storage battery power conversion devices 41 that should be modified. When generation of all control parameters has been completed (YES in step S1098), in-CEMS control circuit 318 quits the flow of modification of the operation plan. When generation of the control parameters for all storage battery power conversion devices 41 that should be modified has not been completed (NO in step S1098), on the other hand, in step S1099, in-CEMS control circuit 318 changes a processing target to next storage battery power conversion device 41, and thereafter returns to initial step S1091 and performs again the process described above.

[0150] Referring back to Fig. 21, when modification of the operation plan in step S109 described above is completed or when creation of the operation plan in step S105 described above is completed, in next step S110, in-CEMS control circuit 318 notifies each storage battery power conversion device 41 of the created operation plan (the power command value (Pref) and the frequency command value (Fref)). Then, in next step S111, in-CEMS control circuit 318 determines whether or not to quit operations of CEMS 31. When operations of CEMS 31 are to end (YES in step S111), CEMS 31

stops. When operations of CEMS 31 are not to end (NO in step S111), on the other hand, the process returns to initial step S101 and the process described above is performed again.

[0151] As described above, the present first embodiment is configured to generate, in creation of the operation plan (that is, the power command value (Pref) and the frequency command value (Fref)) for storage battery power conversion device 41, the frequency command value (Fref) based on the drooping characteristics of the static inverter within storage battery power conversion device 41, the created power command value, and the actually measured frequency (Fmeasure) of the AC system voltage. Consequently, even when generated electric power or the like supplied from energy creation equipment to the power distribution system, such as renewable energy, fluctuates (abruptly varies) and the frequency of the AC system voltage varies due to fluctuation (abrupt change) of power consumption by the load and/or abrupt change of solar radiation, without the frequency of the AC system voltage being out of a frequency range managed by the static inverter where the virtual generator control characteristics (drooping characteristics) or the like are implemented, the distributed power source can effectively keep operating without stopping.

[0152] [Detailed Operations of Storage Battery Power Conversion Device]

Details of operations of storage battery power conversion device 41 will now be described with reference to Figs. 5 to 13, 29, and 30. In the present first embodiment, since virtual synchronous generator control is implemented in storage battery power conversion device 41, first DC/AC conversion circuit 408 operates as the voltage source (that is, voltage control). Therefore, first control circuit 404 controls the voltage of DC bus 405 to attain to a constant value. Operations of first control circuit 404 will be described below with reference to Fig. 6. The voltage of DC bus 405 is measured by voltmeter 406 and inputted to charging control circuit 4041, discharging control circuit 4042, and third control circuit 4044.

[0153] Charging control circuit 4041 controls charging power to storage battery 40 to attain to a target voltage outputted from third control circuit 4044 when the voltage of

DC bus 405 is higher than the target voltage. When the voltage of DC bus 405 is lower than the target voltage outputted from third control circuit 4044, on the other hand, discharging control circuit 4042 controls discharging power of storage battery 40 to increase. Switching between output of charging control circuit 4041 and output of discharging control circuit 4042 is made by first switching circuit 4043. Third control circuit 4044 outputs a switch control signal to first switching circuit 4043 based on a voltage value of DC bus 405 measured by voltmeter 406.

[0154] Operations of second control circuit 409 will now be described with reference to Figs. 7 to 13, 29, and 30. Fig. 29 is a flowchart mainly showing operations of second control circuit 409. When operations of storage battery power conversion device 41 are started in Fig. 29, in step S201, second control circuit 409 initializes various control parameters to predetermined initial values.

[0155] When initialization of the various control parameters is completed, in next step S202, fourth control circuit 4097 collects measurement voltages measured by voltmeters 401, 406, and 410, measured currents measured by ammeters 402, 407, and 411, and status information (for example, the SOC or the like) of storage battery 40. Since a result of measurement by voltmeter 410 is the AC voltage, fourth control circuit 4097 calculates an effective voltage thereof to define the effective voltage as the measured voltage. Similarly, since a result of measurement by ammeter 411 is an AC current, fourth control circuit 4097 calculates an effective current thereof to define the effective current as the measured current. Furthermore, in the present first embodiment, a not-shown charging and discharging power calculation circuit within third control circuit 4044 in Fig. 6 calculates charging and discharging power and an amount of charging and discharging power of storage battery 40 based on collected data.

[0156] In step S203 in Fig. 29, an AC voltage waveform of power distribution system 24 measured by voltmeter 410 is inputted to AC frequency detection circuit 4091 shown in Figs. 7 and 8 and the zero cross point of the AC voltage is detected. Specifically, referring to the block diagram of AC frequency detection circuit 4091 in

Fig. 8, a result of measurement by voltmeter 410 is inputted to phase detection circuit 40910 and the zero cross point is detected. In the present first embodiment, phase detection circuit 40910 detects as zero cross point information, a point and time at which the AC voltage waveform measured by voltmeter 410 switches from negative to positive. The zero cross point information detected by phase detection circuit 40910 is inputted also to frequency detection circuit 40911. Frequency detection circuit 40911 calculates a cycle of the AC voltage based on time information of the zero cross point detected previously by phase detection circuit 40910 and time information of the presently detected zero cross point, and calculates the AC system frequency based on a result of calculation. First sinusoidal wave generation circuit 40912 outputs the zero cross point information detected by phase detection circuit 40910 and frequency information of the AC voltage detected by frequency detection circuit 40911, as sinusoidal wave information. The zero cross point detection information and the frequency detection information are outputted to inverter current control circuit 4094, inverter voltage control circuit 4095, virtual synchronous generator control circuit 4093, and fourth control circuit 4097.

[0157] Referring back to Fig. 29, when fourth control circuit 4097 detects the zero cross point in step S203, in next step S204, it sets a zero cross point detection flag. When setting of the detection flag has been completed in step S204 or when the zero cross point has not been detected (NO in step S203), in next step S205, third control circuit 4044 controls first DC/DC conversion circuit 403. In the present first embodiment, as described above, third control circuit 4044 controls charging and discharging of storage battery 40 such that the voltage of DC bus 405 attains to a predetermined value. When step S205 ends, in next step S206, fourth control circuit 4097 controls first DC/AC conversion circuit 408.

[0158] Fig. 30 is a flowchart showing a procedure of control of first DC/AC conversion circuit 408. Referring to Figs. 7 and 30, when control of first DC/AC conversion circuit 408 is started, in step S2061 in Fig. 30, effective power calculation circuit 4092 calculates an electric power value based on measurement information from voltmeter

410 and ammeter 411. In next step S2062, effective power calculation circuit 4092 integrates the measured electric power value by using an integrator. When the zero cross point detection flag has been set (YES in step S2063), effective power calculation circuit 4092 calculates an effective power value corresponding to one cycle of the AC voltage. Effective power calculation circuit 4092 has the calculated effective power value stored in a not-shown storage circuit within fourth control circuit 4097 (step S2064) and initializes the integrator to zero (step S2065). After initialization of the integrator in step S2065 ends or when the zero cross point detection flag has not been set (NO in step S2063), in next S2066, inverter voltage control circuit 4095 generates a command value for first DC/AC conversion circuit 408.

[0159] Control of first DC/AC conversion circuit 408 will be described below with reference to Figs. 7, 10, and 30. Since virtual synchronous generator control is implemented in storage battery power conversion device 41 as described above, first DC/AC conversion circuit 408 is controlled as the voltage source (that is, voltage control). Therefore, when electric power supplied to power distribution system 24 is insufficient, electric power to be outputted is increased, and when supply electric power is much, electric power to be outputted is decreased.

[0160] Operations of inverter voltage control circuit 4095 will be described below with reference to Fig. 10. Inverter voltage control circuit 4095 outputs a control command value to control first DC/AC conversion circuit 408 based on frequency and phase information outputted from virtual synchronous generator control circuit 4093 and amplitude information (inputted via first sinusoidal wave generation circuit 40912 in the present first embodiment) of the AC system voltage outputted from fourth control circuit 4097. Sinusoidal wave information (that is, the frequency, phase, and amplitude information) from AC frequency detection circuit 4091 and frequency and phase information calculated by virtual synchronous generator control circuit 4093 are inputted to second sinusoidal wave generation circuit 40951.

[0161] Second sinusoidal wave generation circuit 40951 generates a target value of the AC system voltage to be outputted from first DC/AC conversion circuit 408 based on

such inputted information, that is, the frequency and phase information calculated by virtual synchronous generator control circuit 4093 and the amplitude information outputted from fourth control circuit 407. Subtractor 40952 subtracts the voltage measured by voltmeter 410 from an AC voltage target value outputted from second sinusoidal wave generation circuit 40951 and inputs a result of subtraction to third PI control circuit 40953. Third PI control circuit 40953 generates a voltage command under PI control such that the inputted result of subtraction attains to zero and outputs the generated voltage command to first current restriction circuit 40955.

[0162] First current restriction circuit 40955 restricts a command value outputted from third PI control circuit 40953 based on the result of measurement by ammeter 411 inputted via fourth control circuit 4097. Specifically, in the present first embodiment, the current is restricted when a current exceeding a current capacity of first DC/AC conversion circuit 408 flows, and the current that flows in first DC/AC conversion circuit 408 is controlled to a predetermined current value (that is, the current capacity of first DC/AC conversion circuit 408). First current restriction circuit 40955 monitors the current that flows in first DC/AC conversion circuit 408 and controls (specifically, restricts) the current value such that the current does not exceed the current capacity of first DC/AC conversion circuit 408. Output of first current restriction circuit 40955 is inputted to second PWM conversion circuit 40954.

Control parameters (that is, a control gain and an integration time period) for third PI control circuit 40953 and first current restriction circuit 40955 are outputted from fourth control circuit 4097.

[0163] Second PWM conversion circuit 40954 subjects a voltage command value outputted from first current restriction circuit 40955 to PWM modulation and outputs the voltage command value subjected to PWM modulation to second switching circuit 4096. Second switching circuit 4096 in Fig. 7 selects one of a control command value for inverter current control circuit 4094 and a control command value for inverter voltage control circuit 4095 based on a control signal (that is, a switching signal) outputted from the fourth control circuit and outputs the selected control command

value to first DC/AC conversion circuit 408.

[0164] Though operations of inverter current control circuit 4094 are not used in the present first embodiment, they will also be described with reference to Fig. 9. Inverter current control circuit 4094 generates the control command value to control first

5 DC/AC conversion circuit 408 based on a DC voltage of DC bus 205 outputted from voltmeter 406. Specifically, subtractor 40941 subtracts the DC voltage of DC bus 405 outputted from voltmeter 406 from a target value of the DC bus voltage outputted from fourth control circuit 4097 and inputs a result of subtraction to first PI control circuit 40942. First PI control circuit 40942 generates a command value under PI control
10 such that a result of subtraction attains to zero and outputs the generated command value to multiplier 4094. The control parameters (the proportional gain and the integration time period) for first PI control circuit 40942 are outputted from fourth control circuit 4097.

[0165] Multiplier 40943 then multiplies the command value outputted from first PI control circuit 40942 by a sinusoidal wave in synchronization with the AC voltage waveform outputted from first sinusoidal wave generation circuit 40912 within AC frequency detection circuit 4091. The current command value is thus generated.

Subtractor 40944 subtracts the current value of the AC system measured by ammeter 411 from the current command value outputted from multiplier 40943 and inputs a
20 result of subtraction to second PI control circuit 40945. Second PI control circuit 40945 generates the control command value such that the result of subtraction inputted from subtractor 40944 attains to zero and outputs the generated control command value to first PWM conversion circuit 40946. The control parameters (the proportional gain and the integration time period) for the second PI control circuit are inputted from
25 fourth control circuit 4097. First PWM conversion circuit 40946 subjects the control command value inputted from second PI control circuit 40945 to PWM modulation and outputs the control command value subjected to PWM modulation to first DC/AC conversion circuit 408.

[0166] Referring back to Fig. 29, when control (more specifically, generation of the

command value for first DC/AC conversion circuit 408 in step S2066 in Fig. 30) of first DC/AC conversion circuit 408 in step S206 ends, in next step S207, fourth control circuit 4097 checks whether or not it has received from CEMS 31, a transmission request to transmit the measurement information. When fourth control circuit 4097 has received the transmission request to transmit the measurement information from CEMS 31 (YES in step S207), in next step S208, it notifies CEMS 31 through communication interface circuit 412 of various results of measurement stored in a not-shown memory.

[0167] When fourth control circuit 4097 has not received from CEMS 31, the transmission request to transmit the measurement information (NO in step S207) or when it has completed notification of the various results of measurement in step S208, in next step S209, it checks whether or not it has received control information from CEMS 31. When fourth control circuit 4097 has received the control information from CEMS 31 (YES in step S209), in next step S210, it sets a reception flag. When fourth control circuit 4097 has not received the control information from CEMS 31 (NO in step S209) or when setting of the reception flag has been completed in step S210, in next step S211, it checks whether or not the zero cross point detection flag has been set. When the zero cross point detection flag has not been set (NO in step S211), fourth control circuit 4097 has the process return to step S202 and performs again processing in step S202 or later.

[0168] When the zero cross point detection flag has been set (YES in step S211), on the other hand, in next step S212, fourth control circuit 4097 takes in the representative value of the frequency and a result of detection of the phase of the AC system voltage outputted from AC frequency detection circuit 4091. When obtainment of a result of detection of the AC frequency and the phase in step S212 has been completed, in next step S213, fourth control circuit 4097 controls the virtual synchronous generator. In the present first embodiment, one cycle of the AC system voltage is defined as a control cycle. The control cycle may naturally be an integral multiple of the cycle of the AC system voltage or a predetermined cycle such as one-second cycles.

[0169] Control of the virtual synchronous generator in step S213 in Fig. 29 will be described below with reference to the block configuration diagram of second control circuit 409 shown in Fig. 7, the block configuration diagram of virtual synchronous generator control circuit 4093 shown in Fig. 11, the block configuration diagram of governor control circuit 40933 shown in Fig. 12, and the block configuration of mass point system computing circuit 40937 shown in Fig. 13. Initially, when fourth control circuit 4097 in Fig. 7 determines that timing to control the virtual synchronous generator has come as a result of the passage of the control cycle, it instructs virtual synchronous generator control circuit 4093 to generate the frequency and phase information to be used for voltage control. In the present first embodiment, second sinusoidal wave generation circuit 40951 within inverter voltage control circuit 4095 updates, for each zero cross point, the target value of the frequency and the phase of the AC voltage. Therefore, in the present first embodiment, the control cycle is the cycle of the zero cross point detected by AC frequency detection circuit 4091.

[0170] Referring to Fig. 11, subtractor 40932 subtracts the frequency (Fref): for example, 60 Hz) of a reference AC voltage outputted from fourth control circuit 4097, from the representative value of the frequency of the actually measured AC system voltage outputted from frequency detection circuit 40911 and inputs a result of subtraction to governor control circuit 40933.

[0171] Referring to Fig. 12, multiplier 409331 of governor control circuit 40933 multiplies output of subtractor 40932 in Fig. 11 by the control parameter $(-1/K_{gd})$ given from fourth control circuit 4097 and inputs a result of multiplication to first-order lag system model 409332. The speed adjustment ratio and the governor time constant given from CEMS 31 are set and used in a not-shown register via fourth control circuit 4097, as speed adjustment ratio K_{gd} and governor time constant T_g to be used by governor control circuit 40933.

[0172] First-order lag system model 409332 performs computation to simulate a first-order lag system $(1/(1+s \times T_g))$ by using time constant T_g given from fourth control circuit 4097 as described above and inputs a result of computation to limiter circuit

409333. Limiter circuit 409333 restricts data inputted from first-order lag system model 409332. Specifically, limiter circuit 409333 restricts output of governor control circuit 40933 so as not to exceed the power capacity of first DC/AC conversion circuit 408.

5 [0173] Referring back to Fig. 11, adder 40935 adds output of governor control circuit 40933 and the power command value (Pref) outputted from fourth control circuit 4097 and outputs a result of addition to subtractor 40936. The power command value given from CEMS 31 is outputted from fourth control circuit 4097 as described above.

10 Subtractor 40936 subtracts actually measured effective power outputted from effective power calculation circuit 4092 from output of adder 40935 and inputs a result of subtraction to mass point system computing circuit 40937.

[0174] Operations of mass point system computing circuit 40937 will be described below with reference to Fig. 13. Subtractor 409371 of mass point system computing circuit 40937 subtracts output of multiplier 409373 from output of subtractor 40936 in Fig. 11 and inputs a result of subtraction to integrator 409372. Integrator 409372 divides the result of subtraction outputted from subtractor 409371 by inertia constant M outputted from fourth control circuit 4097 and integrates a result of division. A result of integration by integrator 409372 represents a differential value $\Delta\omega$ from the angular velocity ($2\times\pi\times 60$ Hz) of the AC system frequency. Integrator 409372 inputs the

15 result of integration to multiplier 409373 and divider 409374. Multiplier 409373 multiplies output $\Delta\omega$ of integrator 409372 by braking coefficient Dg outputted from fourth control circuit 4097 and outputs a result of multiplication to subtractor 409371 described previously. Divider 409374 converts $\Delta\omega$ to a differential value Δf from the AC system frequency (60 Hz) by dividing output $\Delta\omega$ of integrator 409372 by $2\times\pi$.

20 Adder 409375 adds output Δf of divider 409374 to Fref representing the frequency command value for the AC system voltage. The frequency in voltage control by inverter voltage control circuit 4095 is thus generated. The inertia constant and the braking coefficient generated and given by CEMS 31 as described above are set and used in a not-shown register via fourth control circuit 4097, as inertia constant M and

braking coefficient Dg to be used within mass point system computing circuit 40937.

[0175] The frequency information outputted from adder 409375 is inputted to phase calculation circuit 409376. Operations of phase calculation circuit 409376 will be described below. In the first embodiment, the frequency information outputted from adder 409375 is integrated by phase calculation circuit 409376 and outputted as the phase information of the frequency of the power distribution system voltage in voltage control by inverter voltage control circuit 4095. The phase information and the frequency information outputted from mass point system computing circuit 40937 are inputted to second sinusoidal wave generation circuit 40951 within inverter voltage control circuit 4095 in Fig. 10 via first sinusoidal wave generation circuit 40912 within AC frequency detection circuit 4091 in Fig. 8. Second sinusoidal wave generation circuit 40951 generates the target value of the AC system voltage outputted from storage battery power conversion device 41 based on inputted sinusoidal wave information.

[0176] Referring back to Fig. 29, when the processing for controlling the virtual synchronous generator has been completed in step S213, in next step S214, fourth control circuit 4097 resets the zero cross point detection flag, and in next step S215, it checks whether or not the reception flag has been set. When the reception flag has not been set (NO in step S125), fourth control circuit 4097 has the process return to step S202 and performs again the processing in step S202 or later. When the reception flag has been set (YES in step S215), on the other hand, in next step S216, fourth control circuit 4097 sets the frequency command value (Fref) and the power command value (Pref) given from CEMS 31 in a not-shown register within fourth control circuit 4097, and then in next step S217, it resets the reception flag. Thereafter, fourth control circuit 4097 has the process return to step S202 and performs again subsequent processing.

[0177] [Effects of First Embodiment]

As set forth above, the distributed power source management apparatus and the distributed power source management system in the present first embodiment are

configured to generate the frequency command value (F_{ref}) based on the drooping characteristics of the static inverter within storage battery power conversion device 41, the created power command value, and the actually measured frequency ($F_{measure}$) of the AC system voltage, in creation of the operation plan (that is, the power command value (P_{ref}) and the frequency command value (F_{ref})) for storage battery power conversion device 41. Therefore, even when the frequency of the AC system voltage varies due to fluctuation (abrupt change) of power consumption by the load or fluctuation (abrupt change) due to abrupt change of solar radiation, of generated electric power from equipment for creation of energy such as renewable energy to be supplied to the system, the frequency of the AC system voltage does not go out of the frequency range managed by the static inverter where the virtual generator control characteristics (drooping characteristics) or the like are implemented. Consequently, the static inverter can effectively keep operating without the distributed power source being stopped.

[0178] Though the example in which the power conversion device including the static inverter where the drooping characteristics (droop characteristics) represented by virtual synchronous generator control are implemented is connected to the AC system is described in the present first embodiment, the present disclosure is not limited to this case. The power conversion device is configured to generate the frequency command value (F_{ref}) based on the result ($F_{maesure}$) of actual measurement of the frequency of the AC system voltage, the power command value (P_{ref}), and the drooping characteristics (that is, droop characteristics) of the static inverter. Therefore, even when the frequency of the bulk power system deviates from the rated frequency (for example, 60 Hz), the power conversion device including the static inverter where the drooping characteristics (that is, droop characteristics) are implemented can effectively be controlled without the frequency being out of the frequency management range thereof.

[0179] Though the example in which the power conversion device having the drooping characteristics is connected to the interconnected system (that is, electric power is

supplied from the bulk power system) is described in the first embodiment, the present disclosure is not limited to this case. With such a configuration that the frequency command value (F_{ref}) is generated also in the isolated system based on the drooping characteristics of the static inverter, the created power command value, and the actually measured frequency ($F_{measure}$) of the AC system voltage that has actually been measured, even when the frequency of the isolated system deviates from the rated frequency (for example, 60 Hz), as in interconnection, control of the frequency of the isolated system without departure from the frequency management range of the power conversion device including the static inverter where the drooping characteristics (droop characteristics) are implemented can effectively be achieved.

[0180] Though the example in which, in the discharging operation of storage battery power conversion device 41, power consumption by the load or the like increases and the frequency of the power distribution system voltage lowers as shown in Figs. 18, 24, and 26 is described in the present first embodiment, the present disclosure is not limited to this case. For example, also when the power consumption by the load decreases and the frequency of the power distribution system voltage increases in the discharging operation or when the load fluctuates and the frequency of the power distribution system voltage increases or decreases in a charging operation, the similar effect is achieved by controlling the frequency command value (F_{ref}) based on the result ($F_{measure}$) of actual measurement of the frequency of the power distribution system voltage.

[0181] Second Embodiment.

Though control of the frequency command value (F_{ref}) based on the result ($F_{measure}$) of actual measurement of the frequency of the AC system voltage is described in the first embodiment, in a second embodiment, an example in which the power command value (P_{ref}) is controlled (modified) based on the result ($F_{measure}$) of actual measurement of the frequency of the AC system voltage will be described. The present second embodiment will be described below, with operations of a portion different from those in the first embodiment being focused on.

[0182] [Configuration of CEMS in Second Embodiment]

Fig. 31 is a block configuration diagram of CEMS 31 in the present second embodiment. As shown in Fig. 31, CEMS 31 in the second embodiment includes communication circuit 311, storage circuit 312, AC frequency collection circuit 313, operation plan creation circuit 314, a power command value correction circuit 320, distributed power source drooping characteristic management circuit 316, transmission data generation circuit 317, and a second in-CEMS control circuit 321. In other words, CEMS 31 in the second embodiment is different from CEMS 31 in the first embodiment shown in Fig. 2 in that power command value correction circuit 320 is provided instead of frequency command value generation circuit 315 and second in-CEMS control circuit 321 is provided instead of in-CEMS control circuit 318. The configuration above different from the first embodiment will mainly be described below.

[0183] [Overview of Operations of Distributed Power Source Management Apparatus]

Figs. 32A and 32B are each a diagram for illustrating a method of generating a power command value in CEMS 31 in the present second embodiment. Fig. 32A shows drooping characteristics before modification of the power command value (Pref) and Fig. 32B shows drooping characteristics after modification of the power command value (Pref). Operation principles of CEMS 31 in the present second embodiment will be described below with reference to Figs. 32A and 32B.

[0184] In the present second embodiment, CEMS 31 generates the power command value (Pref) for each storage battery power conversion device 41 in two stages. Specifically, when CEMS 31 starts generation of the power command value (Pref), operation plan creation circuit 314 shown in Fig. 31 creates a demand plan based on the result of prediction of electric power generated by mega-solar power plant 26 and the result of prediction of power consumption by the consumer as in the first embodiment. CEMS 31 then creates a yet-to-be-modified power command value (Pref) for each storage battery power conversion device 41, that is, operation plan power command value information, based on the created demand plan.

[0185] When CEMS 31 completes creation of the yet-to-be-modified power command value (Pref), it creates the drooping characteristics on the assumption that frequency command value Fref is equal to the rated frequency (for example, 60 Hz) of the bulk power system (see Fig. 32A). Then, when the frequency range of the drooping characteristics is compared with the result (Fmeasure) of actual measurement of the frequency of the AC system voltage collected by AC frequency collection circuit 313 and the measured system frequency is, for example, lower than Fmin, with the current drooping characteristics, storage battery power conversion device 41 may stop on the occurrence of fluctuation of the load or abrupt change of generated electric power as described above as in the first embodiment. In such a case, CEMS 31 in the present second embodiment generates a power command value (Pref') to be outputted to storage battery power conversion device 41 such that electric power at the yet-to-be-modified power command value (Pref) described above is outputted at the actually measured value (Fmeasure) of the frequency of the AC system voltage as shown, for example, in Fig. 32B, although details will be described later. In the example in Fig. 32B, change to drooping characteristics (a chain dotted line in the figure) which are translation to the left of the drooping characteristics (a solid line in the figure) before modification of the power command value is made. In the case of the first embodiment, similar change of the drooping characteristics has been made by outputting the actually measured system frequency (Fmeasure) as the frequency command value (Fref) to storage battery power conversion device 41. In the second embodiment, the drooping characteristics are changed by modifying the power command value (Pref). Specifically, in the example shown in Fig. 32B, the drooping characteristics are translated to the left by decreasing the power command value (Pref) created by operation plan creation circuit 314. Consequently, as shown in Fig. 32B, even when the actually measured value (Fmeasure) of the frequency of the power distribution system voltage is out of the frequency range covered by the original drooping characteristics of storage battery power conversion device 41, CEMS 31 sends the modified power command value (Pref') to each storage battery power

conversion device 41. Then, the drooping characteristics move to the left as shown in Fig. 32B, and hence storage battery power conversion device 41 can keep operating.

[0186] Effects of the method of creating the power command value above will now be described with reference to Figs. 33A and 33B. Fig. 33A is a diagram showing a

5 frequency range of an inverter when drooping characteristics in a comparative example are used. In Fig. 33A, the abscissa represents time and the ordinate represents the frequency of the AC system voltage. The figure shows an example where the load becomes less and the frequency of the AC system voltage ramps up with lapse of time.

As shown in the figure, when the frequency command value (F_{ref}) is constant at the

10 rated frequency (60 Hz) and when the constant value generated by operation plan creation circuit 314 is used as the power command value (P_{ref}), the inner side of bold dashed lines is the frequency range (which will also be referred to as the frequency management range) of storage battery power conversion device 41 (inverter). As

shown in the figure, with gradual increase in frequency of the system voltage, the

15 frequency of the system voltage goes out of the frequency range of the inverter controllable by storage battery power conversion device 41 (inverter) (the NG region in the figure), virtual synchronous generator control (VSG control) fails, and storage battery power conversion device 41 stops.

[0187] Fig. 33B, on the other hand, is a diagram showing a power command value and

20 a frequency of the inverter when the drooping characteristics in the present second embodiment are used. As shown in the figure, the power command value (P_{ref}')

which is the power command value (P_{ref}) modified based on the result of actual measurement of the frequency of the AC system voltage is outputted to storage battery power conversion device 41. Specifically, in the present second embodiment, as in

25 the first embodiment, the frequency of the AC system voltage is measured in one-minute cycles. The power command value (P_{ref}') is then controlled based on the result of measurement of the frequency of the AC system voltage. In Fig. 33B, the abscissa represents time and the ordinate represents the power command value (P_{ref}') and the frequency of the power distribution system voltage to be given to storage

battery power conversion device 41. As shown in the figure, the power command value (Pref) is appropriately controlled based on the frequency of the AC system voltage. Therefore, even when the frequency of the system voltage gradually increases, the frequency range (which is also referred to as the frequency management range) controllable by storage battery power conversion device 41 (inverter) based on virtual synchronous generator control (drooping characteristics) can appropriately be controlled. Consequently, interconnected operation can continue without the frequency of the power distribution system voltage being out of the frequency management range of storage battery power conversion device 41 (inverter).

[0188] As described above, the distributed power source management apparatus is configured to generate the power command value (Pref) based on the result of actual measurement of the frequency of the AC system voltage, the power command value (Pref) created by operation plan creation circuit 314, and the drooping characteristics (droop characteristics) in the example where the power conversion device including the static inverter where the drooping characteristics (droop characteristics) represented by virtual synchronous generator control are implemented is connected to the AC system. Thus, even when the frequency of the bulk power system deviates from the rated frequency (for example, 60 Hz), the power conversion device can effectively be controlled without departure from the frequency management range of the power conversion device including the static inverter where the drooping characteristics (droop characteristics) are implemented.

[0189] [Details of Operations of Distributed Power Source Management Apparatus (CEMS)]

Operations of the distributed power source management apparatus (CEMS 31) in the present second embodiment will now be described in detail with reference to Figs. 31 to 38. In the description below, operations of a portion different from those in the first embodiment will be described. Since the power distribution system to which CEMS 31 is connected is identical to that in the first embodiment, description will not be repeated. Since the configuration and the operations of storage battery

power conversion device 41 managed by CEMS 31 are also similar to those in the first embodiment, description will not be repeated. In the second embodiment, storage battery power conversion device 41 is notified by CEMS 31 of the modified power command value (Pref) and frequency command value (specifically, a reference value of the frequency (that is, the rated frequency) of the power distribution system voltage, such as 60 Hz).

[0190] As in the first embodiment, electric power supplied from substation 20, electric power generated by mega-solar power plant 26 (mega-solar power conversion device 27 operating as the current source), and discharging power outputted from storage batteries 40a to 40c are supplied to the load of power distribution system 1. A sequence in normal operations of the distributed power source management system with a focus on CEMS 31 is composed of thirty-minute cycle processing and one-minute cycle processing shown in Fig. 20, as in the first embodiment. Contents of processing by the distributed power source management apparatus are also basically similar, and only the method of generating the power command value and the frequency command value is different.

[0191] Detailed operations of CEMS 31 will be described below with reference to the block configuration diagram of CEMS 31 in Fig. 31 and Figs. 21 and 34 to 39. When processing in CEMS 31 is started, second in-CEMS control circuit 321 performs processing basically in accordance with the flow shown in Fig. 21. Since the flowchart shown in Fig. 21 is basically similar to that in the first embodiment, steps common to those in the first embodiment will only briefly be described and detailed description will not be repeated.

[0192] When the process is started in Fig. 21, in step S101, CEMS 31 checks whether or not it has received from DSO 21, a transmission request to transmit measurement data. When CEMS 31 has received the transmission request (YES in step S101), in next step S102, it collects most recent measurement information from storage battery power conversion device 41, voltmeter 22, and each consumer (including mega-solar power conversion device 27). CEMS 31 then calculates the amount of power

consumption by each consumer, the amount of electric power generated by mega-solar power plant 26, and the amount of charging and discharging power of storage battery 40 for thirty minutes, based on measurement data collected thirty times in one-minute cycles. CEMS 31 transmits the calculated various amounts of electric power to DSO 21 through communication circuit 311, together with information on the SOC or the like of storage battery 40 (S103). When transmission of data in step S103 is completed or when there is no transmission request from DSO 21 to transmit the measurement data (NO in S101), in next step S104, CEMS 31 checks whether or not it has received a notification of the demand plan from DSO 21. When CEMS 31 has received the notification of the demand plan (YES in step S104), in next step S105, it creates the operation plan. In the present second embodiment, as in the first embodiment, DSO 21 notifies CEMS 31 in thirty-minute cycles, of a twenty-four-hour plan for supply and demand of electric power to be supplied from the bulk power system to power distribution system 24.

[0193] Fig. 34 is a flowchart showing detailed operations in operation plan creation processing in step S105 in Fig. 21 in the present second embodiment. When creation of the operation plan is started in Fig. 34, initially in step S1051, CEMS 31 predicts the amount of power generation by mega-solar power plant 26. Specifically, referring again to Figs. 31 and 3, when second in-CEMS control circuit 321 receives the notification of the demand plan (specifically, the storage battery operation plan) from DSO 21, it instructs management circuit 3146 within operation plan creation circuit 314 to create the operation plan. When management circuit 3146 receives the instruction, it instructs via storage battery operation plan generation circuit 3141, power generation amount prediction circuit 3142 to predict electric power generated by mega-solar power plant 26. When power generation amount prediction circuit 3142 receives the instruction, it obtains weather forecast for twenty-four hours from a not-shown weather forecast server arranged on the Internet. Power generation amount prediction circuit 3142 predicts the amount of power generation for twenty-four hours based on an obtained result of the weather forecast and data in a not-shown database for prediction

of the amount of power generation managed by power generation amount prediction circuit 3142. Since an exemplary database has been described in connection with the flowchart in Fig. 22, description will not be repeated.

[0194] When prediction of the amount of power generation in step S1051 in Fig. 34

5 described above ends, in next step S1052, CEMS 31 predicts power consumption by the consumer. Specifically, referring again to Fig. 3, when management circuit 3146 within operation plan creation circuit 314 receives a result of prediction of the amount of power generation by mega-solar power plant 26 from power generation amount prediction circuit 3142, it instructs via storage battery operation plan generation circuit 10 3141, power consumption prediction circuit 3143 to predict power consumption by the consumer. When power consumption prediction circuit 3143 receives the instruction, it predicts power consumption by the consumer for twenty-four hours based on data in the not-shown database for power consumption prediction managed by power consumption prediction circuit 3143. Since the exemplary database has been 15 described in connection with the flowchart in Fig. 22, description will not be repeated.

[0195] When prediction of power consumption by the consumer in step S1052 in Fig. 34 ends, CEMS 31 starts creation of the demand plan in step S1053 in Fig. 34.

Specifically, referring again to Fig. 3, when storage battery operation plan generation circuit 3141 within operation plan creation circuit 314 receives the result of prediction 20 of power consumption by the consumer from power consumption prediction circuit 3143, it calculates a total value of charging and discharging power every thirty minutes, of storage batteries 40a to 40c based on the result of prediction by power generation amount prediction circuit 3142, of the amount of power generation by mega-solar power plant 26, the result of prediction by power consumption prediction circuit 3143, 25 of power consumption by the consumer, and the demand plan given from DSO 21. As described above, in the case of the present second embodiment, the demand plan given from DSO 21 is an electric power supply plan for twenty-four hours (that is, the electric power supply plan every thirty minutes) planned for power distribution system 1 located at a side of the load relative to substation 20.

[0196] When creation of the demand plan in step S1053 in Fig. 34 ends, in next step S1054, CEMS 31 draws up charging and discharging power of storage batteries 40a to 40c. Specifically, referring again to Figs. 31 and 3, operation plan creation circuit 314 determines (proportionally distributes) charging and discharging power from respective storage batteries every thirty minutes based on SOC information of storage batteries 40a to 40c collected in storage circuit 312 via communication circuit 311 and storage battery capacities of storage batteries 40a to 40c. In the second embodiment, as in the first embodiment, the operation plan is created such that the SOC's of storage batteries 40a to 40c are substantially simultaneously zero or the storage batteries are in a chargeable or dischargeable state in twenty-four hours in the operation plan of the storage battery for twenty-four hours.

[0197] When drawing up of charging and discharging power of storage batteries 40a to 40c in step S1054 in Fig. 34 ends, in next step S1055, AC frequency collection circuit 313 within CEMS 31 obtains the frequency of the power distribution system voltage. As described above, in the present second embodiment, as in the first embodiment, voltmeters 22a to 22x measure the frequency at each point from the measured AC system voltage and AC frequency collection circuit 313 calculates and outputs the average value of the frequencies as the representative value (F_{measure}).

[0198] When collection of the frequency of the power distribution system voltage and calculation of the representative value (F_{measure}) in step S1055 in Fig. 34 have been completed, in next step S1056, second in-CEMS control circuit 321 checks whether or not it has generated control parameters (that is, the power command value and the frequency command value (Pref)) for all storage battery power conversion devices 41. When determination as NO is made in step S1056, in next step S1060, second in-CEMS control circuit 321 generates the power command value (Pref). A flow of generation of the power command value (Pref) in step S1060 will be described below with reference to Fig. 35.

[0199] Fig. 35 is a flowchart showing a procedure of generation of the power command value (Pref). When generation of the power command value (Pref) is started in Fig.

35, in initial step S10571, power command value correction circuit 320 shown in Fig. 31 instructs second in-CEMS control circuit 321 to obtain the control parameter (that is, the drooping characteristics) for virtual synchronous generator control circuit 4093 of storage battery power conversion device 41 for which the power command value (Pref) is to presently be generated (that is, the power command value (Pref) for which is to be modified).

[0200] When second in-CEMS control circuit 321 receives the instruction from power command value correction circuit 320, it obtains the drooping characteristics from distributed power source drooping characteristic management circuit 316. In the present second embodiment, second in-CEMS control circuit 321 obtains the speed adjustment ratio (Kgd), the governor time constant (Tg), the inertia constant (M), and the braking coefficient (Dg) for virtual synchronous generator control and the capacity (inverter capacity) of first DC/AC conversion circuit 408 as the control parameters, as in the first embodiment. Drooping characteristic information is not limited to the above. A data table showing relation between ΔP (that is, the power command value (Pref) – an actually measured active power value (Pmeasure)) outputted from first DC/AC conversion circuit 408 and outputted ΔF (that is, the frequency command value (Fref) – the actually measured value (Fmeasure) of the frequency of the AC system voltage) or data on an inclination of the drooping characteristics or the like may naturally be applicable.

[0201] When step S10571 ends, in next step S10572, power command value correction circuit 320 instructs second in-CEMS control circuit 321 to generate the upper limit value and the lower limit value of the frequency of the AC system voltage determined by the drooping characteristics. In the present second embodiment, an example in which virtual synchronous generator control is used as the drooping characteristics as in the first embodiment will be described. Under virtual synchronous generator control, ΔF can be obtained based on the expression (5) described above. Specifically, in the present second embodiment, upper limit value F_{max} of the frequency and lower limit value F_{min} of the frequency can be calculated by

substituting speed adjustment ratio K_{gd} , braking coefficient D_g , and the minimum value and the maximum value of ΔP into the expression (5). In the present second embodiment, the minimum value of ΔP is calculated as the power command value (Pref) – maximum discharging power. The maximum value of ΔP , on the other hand, is calculated as the power command value (Pref) – 0, on the assumption that first DC/AC conversion circuit 408 does not perform charging.

[0202] When generation of the upper and lower limit values of the frequency of the AC system voltage in the drooping characteristics in step S10572 ends, in next step S10573, power command value correction circuit 320 checks whether or not the actually measured frequency of the AC system voltage is within the frequency reference range (see Fig. 36) determined by the upper and lower limit frequencies in the drooping characteristics. Operations in S10573 will be described below with reference to Fig. 36.

[0203] Fig. 36 is a diagram showing exemplary drooping characteristics of storage battery power conversion device 41 in the distributed power source management system in the present second embodiment. In the figure, the abscissa represents the frequency of the power distribution system voltage and the ordinate represents discharging power outputted from storage battery power conversion device 41. In the second embodiment, as in the first embodiment, for the sake of brevity of description, storage battery power conversion device 41 is assumed as not performing charging. F_{max} and F_{min} in the figure represent the upper and lower limit frequencies in the drooping characteristics. In the present second embodiment, as in the first embodiment, the range at the inner side by frequency offset F_{offset} , of upper limit frequency F_{max} and lower limit frequency F_{min} is defined as the frequency reference range determined by the upper and lower limit frequencies. Naturally, frequency offset F_{offset} may be different in value between the upper limit side and the lower limit side, or may be variable in value in accordance with a value of the power command value (Pref) generated by operation plan creation circuit 314.

[0204] In Fig. 36, when the representative value ($F_{measure}$) of the actually measured

frequency outputted from AC frequency collection circuit 313 is out of the frequency reference range determined by the upper and lower limit frequencies (*1 in the figure), power command value correction circuit 320 selects NO in step S10573, and when the actually measured frequency (F_{measure}) is within the frequency reference range

5 determined by the upper and lower limit frequencies (*2 in the figure), it selects YES in step S10573.

[0205] When determination as YES is made in step S10573, in next step S10581, power command value correction circuit 320 quits the process for generating the power command value (P_{ref}), with the power command value (P_{ref}) given as the operation plan from operation plan creation circuit 314 being set to the power command value (P_{ref}) to be outputted to storage battery power conversion device 41 (step S10581).

10 When determination as NO is made in S10573, on the other hand, in next step S10580, power command value correction circuit 320 calculates the power command value (P_{ref}). Operations in step S10580 will be described below with reference to Fig. 37.

15 [0206] Fig. 37 is a flowchart showing a procedure of generation of the power command value (P_{ref}) in step S10580 in Fig. 35. In initial step S105750 in Fig. 37, power command value correction circuit 320 generates the drooping characteristics assuming F_{ref} as $F_{\text{ref}} = F_{\text{measure}}$ as in the first embodiment, and calculates the upper and lower limit frequencies of the frequency of the AC system voltage based on the generated drooping characteristics. Specifically, as in step S10572 in Fig. 35, the upper and lower limit frequencies can be calculated. In other words, power command value correction circuit 320 calculates upper limit value F_{max} of the frequency and lower limit value F_{min} of the frequency by substituting speed adjustment ratio K_{gd} , braking coefficient D_{g} , the minimum value of ΔP , and the maximum value of ΔP into the expression (5) (see a portion B in Fig. 38).

25 [0207] Furthermore, in step S105750, power command value correction circuit 320 sets the value of electric power at frequency command value F_{ref} (for example, 60 Hz in Fig. 38) at the current time point to a tentative power command value P_{ref} , based on the generated drooping characteristics.

[0208] When step S105750 ends, in next step S105751, power command value correction circuit 320 checks whether or not the upper and lower limit frequencies in the drooping characteristics are between the upper and lower limit values of the frequency of the AC system voltage. In the present second embodiment, as in the first embodiment, the upper and lower limit values of the frequency of the AC system voltage are defined as 60.1 Hz and 59.9 Hz. Furthermore, power command value correction circuit 320 checks whether or not tentative power command value Pref" is within a range of the power capacity of storage battery power conversion device 41, that is, whether or not an absolute value of tentative power command value Pref" is equal to or smaller than maximum discharging power and equal to or smaller than maximum charging power.

[0209] When determination as YES is made in step S105751, power command value correction circuit 320 quits the process with tentative power command value (Pref") being set as the finalized power command value (Pref). When determination as NO is made in step S105751, on the other hand, in next step S105752, power command value correction circuit 320 finalizes the power command value (Pref) by modifying the tentative power command value (Pref"). Operations in step S105752 will be described below with reference to Fig. 38.

[0210] Fig. 38 is a diagram for illustrating a procedure of modification of the power command value. As shown with a portion A in Fig. 38, it is assumed that the representative value (Fmeasure) of the actually measured frequency of the AC system voltage is 59.915 Hz in an example where the frequency command value (Fref) is 60 Hz. In this case, as shown in the portion B in Fig. 38, power command value correction circuit 320 calculates the tentative power command value (Pref") at the frequency command value (Fref = 60 Hz) such that output electric power from storage battery power conversion device 41 when the frequency of the power distribution system voltage is set to Fmeasure attains to the power command value (Pref) created by operation plan creation circuit 314. In this example, however, as shown in the portion B in Fig. 38, the lower limit frequency (that is, the frequency at maximum discharging

power) in the drooping characteristics is lower than the lower limit value (59.9 Hz) of the frequency of the AC system voltage. In the case of Fig. 38, the tentative power command value (P_{ref}'') is within the range of the power capacity of storage battery power conversion device 41. Therefore, as shown in a portion C in Fig. 38, power command value correction circuit 320 finalizes the power command value (P_{ref}') by modifying the tentative power command value (P_{ref}'') at the frequency command value ($F_{ref} = 60$ Hz) such that the lower limit frequency in the drooping characteristics matches with the lower limit value of the frequency of the AC system voltage.

[0211] In an example where the power command value (P_{ref}'') at the frequency command value ($F_{ref} = 60$ Hz) is calculated such that output electric power from storage battery power conversion device 41 when the frequency of the power distribution system voltage is set to $F_{measure}$ attains to the power command value (P_{ref}) created by operation plan creation circuit 314, on the other hand, when lower limit frequency F_{min} and upper limit frequency F_{max} in the drooping characteristics are within the rated frequency range (59.9 Hz to 60.1 Hz) of the AC system, power command value correction circuit 320 outputs the tentative power command value (P_{ref}'') as the final power command value (P_{ref}') to storage battery power conversion device 41.

[0212] This is also applicable to an example where the upper limit value frequency in the drooping characteristics exceeds the upper limit value of the frequency of the AC system voltage. In this case, power command value correction circuit 320 generates the power command value (P_{ref}') at the frequency command value ($F_{ref} = 60$ Hz) such that the upper limit value frequency in the drooping characteristics matches with the upper limit value of the frequency of the AC system voltage.

[0213] When the tentative power command value (P_{ref}'') at the frequency command value ($F_{ref} = 60$ Hz) is out of the range of the power capacity of storage battery power conversion device 41, the power command value (P_{ref}') is generated to be within the range of the power capacity. A specific example in this case will be described later with reference to Fig. 41A. When step S105752 in Fig. 37 ends, second in-CEMS

control circuit 321 quits calculation (S10580 in Fig. 35) of the power command value (Pref').

[0214] Referring back to Fig. 34, when step S1060 ends, second in-CEMS control circuit 321 has the process return to step S1056 and thereafter repeats step S1060 until
5 determination as YES is made in step S1056, that is, until calculation of the power command value (Pref') for all storage battery power conversion devices 41 is completed.

[0215] Referring back to Fig. 21, when second in-CEMS control circuit 321 quits generation of the operation plan in step S105, in next step S110, it notifies each storage
10 battery power conversion device 41 of the generated operation plan (power command value Pref' and frequency command value Fref (60 Hz)). In next step S111, second in-CEMS control circuit 321 determines whether or not to stop CEMS 31. When determination as YES is made in step S111, second in-CEMS control circuit 321 stops CEMS 31. When determination as NO is made in S111, on the other hand, second in-
15 CEMS control circuit 321 returns to step S101 and repeats the flow described above.

[0216] An example where determination as NO is made in step S104 in Fig. 21 will now be described. In this case, in step S106, second in-CEMS control circuit 321 checks whether or not time to start one-minute cycle processing has come. When determination as NO is made in step S106, second in-CEMS control circuit 321 has the
20 process return to step S101 and repeats the flow described above. When determination as YES is made in step S106, on the other hand, second in-CEMS control circuit 321 has the process proceed to next step S107.

[0217] In step S107, second in-CEMS control circuit 321 collects measurement data from voltmeter 22, measurement data from storage battery power conversion device 41,
25 measurement data from mega-solar power conversion device 27, measurement data from the consumer, or the like. When second in-CEMS control circuit 321 has completed collection of the measurement data in step S107, in next step S108, it determines whether or not modification of the operation plan is required. In the present second embodiment, as in the first embodiment, when the SoC given from

storage battery power conversion device 41 is out of the predetermined range or when output (F_{measure}) of AC frequency collection circuit 313 is out of the predetermined range, the second in-CEMS control circuit determines that modification is required.

Since operations in determining in step S108 whether or not modification of the

5 operation plan is required are the same as those in the flowchart shown in Fig. 27 in the first embodiment, detailed description will not be repeated.

[0218] When second in-CEMS control circuit 321 determines in step S108 that

modification of the operation plan is not required (that is, the operation plan modification flags for all storage battery power conversion devices 41 are "0") (NO in

10 step S108), second in-CEMS control circuit 321 has the process return to initial step S101 and repeats the process described above. When second in-CEMS control circuit

321 determines in step S108 that modification of the operation plan is required (that is, even one of the operation plan modification flags is "1") (YES in step S108), on the

15 other hand, it modifies the operation plan in next step S109. Details of step S109 will be described below with reference to Fig. 39.

[0219] Fig. 39 is a flowchart showing a procedure of modification of the operation plan in the distributed power source management apparatus in the second embodiment.

When a flow of modification of the operation plan is started, in step S1091, second in-CEMS control circuit 321 checks whether or not the operation plan modification flag

20 has been set. As described above, in the present second embodiment, as in the first embodiment, the operation plan modification flag is provided for each storage battery power conversion device 41, and the power command value (Pref or Pref') is newly generated for the operation plan that should be modified.

[0220] When the operation plan modification flag has not been set (NO in step S1091),

25 the process proceeds to step S1098. Processing in step S1098 will be described later.

When the operation plan modification flag has been set (YES in step S1091), on the other hand, the process proceeds to steps S1092 to S1094. In step S1092, second in-

CEMS control circuit 321 obtains data (charging and discharging power, the SoC)

measured in storage battery power conversion device 41, in step S1093, it obtains the

frequency command value (Fref) and the power command value (Pref), and further in step S1094, it obtains the representative value (Fmeasure) of the actually measured frequency of the AC voltage outputted from AC frequency collection circuit 313.

[0221] When steps S1092 to S1094 end, in next step S1095, second in-CEMS control circuit 321 checks whether or not the SoC is within the predetermined range. In the present second embodiment, as in the first embodiment, the SoC being out of the predetermined range refers to a case where the SoC exceeds 0.9 in charging and a case where the SoC is lower than 0.05 in discharging. The SoC at 1.0 is defined as full charge. The SoC being out of the predetermined range is naturally not limited to this case, as in the first embodiment.

[0222] When the SoC of the storage battery is not within the predetermined range (NO in step S1095), in next step S1096, second in-CEMS control circuit 321 changes the power command value (Pref). In the present second embodiment, a not-shown data table for determination of the power command value in accordance with a value of the SoC is stored in CEMS 31 and second in-CEMS control circuit 321 determines the power command value (Pref) based on that information. As described with reference to Fig. 28 in the first embodiment, the method of determining the power command value is naturally not limited to the method based on the data table.

[0223] When the SoC of the storage battery is within the predetermined range (YES in step S1095) or when generation of the power command value (Pref) ends in step S1096, the process proceeds to step S1097. In step S1097, second in-CEMS control circuit 321 checks whether or not the representative value (Fmeasure) of the actually measured frequency of the power distribution system voltage is within the frequency reference range. The frequency reference range is the same as described with reference to step S10573 in Fig. 35 and with reference to Fig. 36.

[0224] When the representative value (Fmeasure) of the actually measured frequency of the power distribution system voltage is not within the frequency reference range (NO in step S1097), in next step S10911, second in-CEMS control circuit 321 calculates the power command value (Pref). Since step S10911 in Fig. 39 is the same

as step S10580 in Fig. 35 and more specifically the same as the flowchart in Fig. 37, description will not be repeated.

[0225] When the operation plan modification flag has not been set (NO in step S1091), when calculation of the power command value (Pref) in step S10911 is completed, or
5 when the representative value (Fmeasure) of the measured frequency of the power distribution system voltage is within the frequency reference range (YES in step S1097), the process proceeds to step S1098. In step S1098, second in-CEMS control circuit 321 checks whether or not it has generated the control parameters (Pref, Pref) for all storage battery power conversion device 41 that should be modified. When
10 second in-CEMS control circuit 321 has completed generation of all control parameters (YES in step S1098), it quits the flow of modification of the operation plan. When second in-CEMS control circuit 321 has not completed generation of the control parameters for all storage battery power conversion devices 41 that should be modified (NO in step S1098), on the other hand, in step S1099, it changes a processing target to
15 next storage battery power conversion device 41, and thereafter returns to initial step S1091 and performs again the process described above.

[0226] Referring back to Fig. 21, when modification of the operation plan in step S109 described above has been completed or when creation of the operation plan in step S105 described above has been completed, in next step S110, second in-CEMS control
20 circuit 321 notifies each storage battery power conversion device 41 of the created operation plan (the power command value (Pref or Pref) and the frequency command value (Fref: 60 Hz)). In next step S111, second in-CEMS control circuit 321 determines whether or not to quit the operations of CEMS 31. When operations of CEMS 31 are to end (YES in step S111), CEMS 31 stops. When operations of CEMS
25 31 are not to end (NO in step S111), on the other hand, the process returns to initial step S101 and the process described above is performed again. Since operations of storage battery power conversion device 41 are identical to those in the first embodiment, description will not be repeated.

[0227] [Effects of Second Embodiment]

As described above, the distributed power source management apparatus (CEMS 31) in the present second embodiment is configured to calculate the power command value (P_{ref}) by modifying the power command value (P_{ref}) created by operation plan creation circuit 314 based on the drooping characteristics of the static inverter within storage battery power conversion device 41, the power command value (P_{ref}) created by operation plan creation circuit 314, and the actually measured frequency ($F_{measure}$) of the AC system voltage, in creation of the operation plan (including the power command value (P_{ref})) for storage battery power conversion device 41. Therefore, even when the frequency of the AC system voltage varies due to fluctuation or abrupt change of power consumption by the load and fluctuation or abrupt change of generated electric power from equipment for creation of energy such as renewable energy to be supplied to the power system due to abrupt change of solar radiation, without departure from the frequency range managed by the static inverter where the virtual generator control characteristics (that is, the drooping characteristics) or the like are implemented, the distributed power source can effectively keep operating without stopping.

[0228] [Other Exemplary Drooping Characteristics]

Though an example in which the drooping characteristics of the virtual synchronous generator shown in Figs. 15 and 17 are used as exemplary drooping characteristics to be implemented in storage battery power conversion device 41 is described in the first and second embodiments, the drooping characteristics are not limited to characteristics of the virtual synchronous generator. In addition, though the example in which storage battery power conversion device 41 performs only the discharging operation is described in the first and second embodiments for the sake of brevity of description, operations of storage battery power conversion device 41 are not limited to discharging alone and operations may be charging alone or both of charging and discharging. Exemplary drooping characteristics to be applied to the distributed power source management apparatus in the first embodiment will be described below with reference to Figs. 40A to 40G and other exemplary drooping characteristics to be

applied to the distributed power source management apparatus in the second embodiment will be described below with reference to Figs. 41A to 41D.

[0229] Fig. 40A is a diagram showing exemplary linear drooping characteristics when storage battery power conversion device 41 performs charging and discharging. As shown in Fig. 40A, in the case of the first embodiment, frequency command value F_{ref} is changed from the original value (60 Hz) to representative value $F_{measure}$ (for example, the average value) of the frequency of the actually measured system voltage.

[0230] Fig. 40B is a diagram showing exemplary linear drooping characteristics including a dead band when storage battery power conversion device 41 performs charging and discharging. As shown in Fig. 40B, in the case of the first embodiment, frequency command value F_{ref} is changed from the original value (60 Hz) to representative value $F_{measure}$ of the frequency of the actually measured system voltage.

[0231] Fig. 40C is a diagram showing exemplary curved drooping characteristics when storage battery power conversion device 41 performs charging and discharging. As shown in Fig. 40C, in the case of the first embodiment, frequency command value F_{ref} is changed from the original value (60 Hz) to representative value $F_{measure}$ of the frequency of the actually measured system voltage.

[0232] Fig. 40D is a diagram showing exemplary linear drooping characteristics including the dead band when storage battery power conversion device 41 performs only discharging. As shown in Fig. 40D, in the case of the first embodiment, frequency command value F_{ref} is changed from the original value (60 Hz) to representative value $F_{measure}$ of the frequency of the actually measured system voltage.

[0233] Fig. 40E is a diagram showing exemplary curved drooping characteristics when storage battery power conversion device 41 performs only discharging. As shown in Fig. 40E, in the case of the first embodiment, frequency command value F_{ref} is changed from the original value (60 Hz) to representative value $F_{measure}$ of the frequency of the actually measured system voltage.

[0234] Fig. 40F is a diagram showing exemplary linear drooping characteristics including the dead band when storage battery power conversion device 41 performs only charging. As shown in Fig. 40F, in the case of the first embodiment, frequency command value F_{ref} is changed from the original value (60 Hz) to representative value $F_{measure}$ of the frequency of the actually measured system voltage.

[0235] Fig. 40G is a diagram showing exemplary curved drooping characteristics when storage battery power conversion device 41 performs only charging. As shown in Fig. 40G, in the case of the first embodiment, frequency command value F_{ref} is changed from the original value (60 Hz) to representative value $F_{measure}$ of the frequency of the actually measured system voltage.

[0236] Fig. 41A is a diagram showing exemplary linear drooping characteristics when storage battery power conversion device 41 performs charging and discharging. As shown in Fig. 41A, in the case of the second embodiment, tentative power command value P_{ref}' at frequency command value F_{ref} (60 Hz) is provisionally determined to obtain power command value P_{ref} according to the operation plan, at actually measured system frequency $F_{measure}$. In this case, however, tentative power command value P_{ref}' has exceeded a capacity of a DC/AC converter, and hence power command value P_{ref} is finally set to match with maximum charging power of the DC/AC converter.

[0237] Fig. 41B is a diagram showing exemplary linear drooping characteristics when storage battery power conversion device 41 performs only charging. As shown in Fig. 41B, in the case of the second embodiment, tentative power command value P_{ref}' at frequency command value F_{ref} (60 Hz) is provisionally determined to obtain power command value P_{ref} according to the operation plan, at actually measured system frequency $F_{measure}$. In this case, however, the lower limit frequency in the drooping characteristics (that is, the frequency at maximum discharging power) is lower than the lower limit value (59.9 Hz) of the frequency of the AC system voltage. Power command value P_{ref}' at frequency command value F_{ref} (60 Hz) is then finally set such that the lower limit frequency in the drooping characteristics matches with the lower limit value of the frequency of the AC system voltage.

[0238] Fig. 41C is a diagram showing exemplary linear drooping characteristics including the dead band when storage battery power conversion device 41 performs only discharging. As shown in Fig. 41C, in the case of the second embodiment, power command value P_{ref} at frequency command value F_{ref} (60 Hz) is determined to obtain power command value P_{ref} according to the operation plan, at actually measured system frequency $F_{measure}$.

[0239] Fig. 41D is a diagram showing exemplary linear drooping characteristics including the dead band when storage battery power conversion device 41 performs only charging. As shown in Fig. 41D, in the case of the second embodiment, power command value P_{ref} at frequency command value F_{ref} (60 Hz) is set to obtain power command value P_{ref} according to the operation plan, at actually measured system frequency $F_{measure}$.

[0240] [Modification]

A modification of the first and second embodiments will be described below.

In an example where a plurality of static inverters each having drooping characteristics are controlled by the distributed power source management apparatus (that is, CEMS 31 (higher-order EMS)), the static inverters may be controlled to generate the drooping characteristics (specifically, frequency command value F_{ref}) such that the maximum frequencies in the drooping characteristics of these static inverters substantially match with one another and the minimum frequencies therein substantially match with one another. According to such control, even when fluctuation of the load or abrupt change of the amount of power generation by energy creation equipment occurs, the frequency range is controlled such that all static inverters where the drooping characteristics are implemented can operate as following the frequency of the power distribution system voltage. Therefore, the frequency of the AC system voltage effectively does not go out of the frequency range managed by the drooping characteristics and the distributed power source can effectively keep operating without stopping. In consideration of an error of a voltage sensor or the like, so long as an amount of deviation is within 5 to 10% of frequency deviation (that is, a difference

between the maximum frequency and frequency command value F_{ref} or a difference between the minimum frequency and frequency command value F_{ref}), the maximum frequencies in the drooping characteristics of the plurality of static inverters may be regarded as substantially matching with one another and the minimum frequencies therein may be regarded as substantially matching with one another.

[0241] Though the example in which virtual synchronous generator control is implemented in storage battery power conversion device 41 is described in the first and second embodiments, an object where virtual synchronous generator control is implemented is not limited thereto. For example, virtual synchronous generator control and the drooping characteristics described above may be implemented in energy creation equipment such as a wind power generator, energy creation equipment such as a fuel cell, a power conversion device for charging and discharging of electric power within a battery mounted on an electric vehicle and a fuel cell vehicle, or the like. In such a case as well, by control by the distributed power source management apparatus (CEMS 31), of the drooping characteristics of each distributed power source based on the result ($F_{measure}$) of actual measurement of the frequency of the power distribution system voltage, even when the frequency of the power distribution system voltage is out of the rated frequency (for example, 60 Hz), the frequency range is controlled such that the static inverter where the drooping characteristics such as the virtual generator control characteristics or the like are implemented can operate as following the frequency of the power distribution system voltage. Therefore, the frequency of the AC system voltage effectively does not out of the frequency range managed by the static inverter and the distributed power source can effectively keep operating without stopping.

[0242] Since a motor is rotated by a propeller in the wind power generator, a generator side has inertia capability. Therefore, a similar effect is naturally achieved.

[0243] Though the example where the power distribution system provided with the static inverter where the drooping characteristics are implemented (storage battery power conversion device 41) is interconnected to the bulk power system is described in

the first and second embodiments, without being limited as such, a similar effect is naturally achieved also in the isolated system. At that time, in addition to the distributed power source such as a storage battery, a wind power generator, a photovoltaic power generation system, or a fuel cell, where the static inverter is implemented within the isolated system, a system where an emergency generator (synchronous generator) or the like is further provided may be applicable. As the drooping characteristics of the static inverter where the drooping characteristics are implemented are controlled based on the frequency (F_{measure}) of the AC system voltage in such an isolated system as shown in the first and second embodiments, the frequency range is controlled such that the static inverter can operate as following the frequency of the power distribution system voltage. Therefore, without the frequency of the AC system voltage being out of the frequency range managed in accordance with the drooping characteristics, the distributed power source can effectively keep operating without stopping.

[0244] Though the rated frequency range of the AC system is set to the rated frequency range (see, for example, Fig. 17: 59.9 Hz to 60.1 Hz) of the bulk power system in the first and second embodiments, limitation to this frequency range is not intended. In interconnection with the bulk power system, the rated frequency range should only be set to the rated frequency range (for example, ± 0.2 Hz or the like) arranged by a power transmission and distribution business entity in the bulk power system. Alternatively, in the case of the isolated system, the frequency range (for example, ± 0.15 Hz or the like) determined by a business entity in the isolated system, the frequency range determined by the drooping characteristics of the synchronous generator the drooping characteristics of which cannot be changed from CEMS 31, or the frequency range that can be taken in the drooping characteristics of the static inverter largest in capacity within the isolated system may be applicable. With such a frequency range, even in the isolated system, the frequency range is controlled such that the static inverter where the drooping characteristics such as virtual generator control characteristics are implemented can operate as following the frequency of the power distribution system

voltage. Therefore, without the frequency of the AC system voltage being out of the frequency range managed by the drooping characteristics, the distributed power source can effectively keep operating without stopping. In particular, in an example where the synchronous generator the drooping characteristics of which cannot be changed
5 from CEMS 31 is provided, the frequency of the isolated system can naturally effectively be stabilized by controlling the drooping characteristics of other distributed power sources within the frequency range that can be taken by the synchronous generator.

[0245] Though the power distribution system of interest is described as the three-phase
10 AC system in the first and second embodiments, limitation as such is not intended. For example, the power distribution system may naturally be a single-phase system (including a single-phase three-wire system) or a power distribution system of three or more phases. Furthermore, even in an example where a storage battery power conversion device (three-phase AC) and a household storage battery system (single-
15 phase AC) are both present, as in the first and second embodiments, a similar effect is naturally obtained by generating the power command value (Pref) or the frequency command value (Fref) for the static inverter having the drooping characteristics.

[0246] Though the first and second embodiments are configured to measure the frequency at each point from the AC system voltages measured by voltmeters 22a to 22
20 x, to calculate the average value as the representative value in AC frequency collection circuit 313, and to average measurement errors of voltmeters 22 in obtaining a result of actual measurement of the frequency of the power distribution system voltage, limitation as such is not intended as described previously. A result of measurement at a single representative point or an average value of results of measurement by storage
25 battery power conversion devices 41 may naturally be used. Though a noise component contained in output of averaging circuit 3131 is removed by a first-order IIR filter, a filter does not particularly have to be provided. The filter is not limited to the first-order IIR filter, and a high-order IIR filter or an FIR filter may naturally be applicable.

[0247] Though the drooping characteristics to be used in virtual synchronous generator control shown in Figs. 15 and 17 or the drooping characteristics shown in Figs. 40 and 41 are exemplified in the first and second embodiments as exemplary drooping characteristics to be implemented in storage battery power conversion device 41, limitation thereto is not intended. Furthermore, the drooping characteristics are not limited to characteristics of virtual synchronous generator control. Furthermore, a manner of definition of the drooping characteristics is not particularly limited. For example, naturally, the data table showing relation between ΔP (that is, the power command value (P_{ref}) – $P_{measure}$ (actually measured active power value)) outputted from first DC/AC conversion circuit 408 and outputted ΔF (that is, the frequency command value (F_{ref}) – the actually measured value ($F_{measure}$) of the AC system voltage) may be applicable, data such as the inclination of the drooping characteristics may be applicable, or in characteristics of a bar graph as shown in Fig. 40B, the drooping characteristics may be defined by coordinate information of a start point of the bar, an end point of the bar, and each peak of the bar. Though an example in which the drooping characteristics of each storage battery power conversion device 41 are managed at CEMS 31 is described in the first and second embodiments, without being limited as such, a similar effect is naturally achieved by such a configuration that CEMS 31 obtains the drooping characteristics which each storage battery power conversion device 41 originally has and manages them within distributed power source drooping characteristic management circuit 316. Distributed power source drooping characteristic management circuit 316 may naturally be configured to obtain the control parameter (that is, the drooping characteristics) from virtual synchronous generator control circuit 4093 of storage battery power conversion device 41 and to manage the same.

[0248] Though the range at the inner side by frequency offset F_{offset} , of upper limit frequency F_{max} and lower limit frequency F_{min} determined by the drooping characteristics is defined as the frequency reference range to be used in determination as to whether or not to generate the frequency command value (F_{ref}) or the power

command value (Pref) as described with reference to Figs. 24 and 36 in the first and second embodiments, limitation as such is not intended as described previously. For example, an upper-limit-side frequency offset F_offset_up and a lower-limit-side frequency offset F_offset_down may have values different from each other, or the value may be changed based on the value of the power command value (Pref) created by operation plan creation circuit 314 or the value of the result (Fmeasure) of actual measurement of the frequency of the power distribution system voltage. For example, as the power command value is closer to an inverter capacity, the value of frequency offset F_offset may be made smaller or the like.

[0249] Though a model based on the first-order lag system shown in Fig. 12 is employed as governor control circuit 40933 for virtual synchronous generator control to be implemented in storage battery power conversion device 41 in the first and second embodiments, limitation thereto is not intended. For example, a second-order lag system model, another model recommended by the Institute of Electrical Engineers of Japan (IEEJ), or the like may naturally be applicable. Though a model based on the swing equation shown in Fig. 13 is employed as mass point system computing circuit 40937, without being limited thereto, modeling, for example, by the first-order lag system, the second-order lag system, an LPF, or the like may naturally be applicable. Furthermore, though VQ control that is often carried out in virtual synchronous generator control is not mentioned in the present first and second embodiments for the sake of brevity of description, a similar effect is naturally obtained by adopting the scheme in the present disclosure in the power conversion device where VQ control is implemented as virtual synchronous generator control.

[0250] Though the cycle of communication between DSO 21 and CEMS 31 is set to thirty minutes in the first and second embodiments, limitation thereto is not intended as described previously. The communication cycle may naturally be set, for example, to fifteen-minute cycles or one-hour cycles. In addition, the cycle of communication with voltmeter 22, storage battery power conversion device 41, and the like is not limited to one minute either as described previously. The communication cycle may

naturally be, for example, one-second cycles, ten-second cycles, thirty-second cycles, two-minute cycles, or the like.

[0251] Though the zero cross point is detected from the AC voltage waveform and the frequency is detected from a time interval between detected zero cross points in

5 detection of the phase from the AC voltage waveform measured by voltmeter 410 in the first and second embodiments, a method of detecting the frequency of the AC voltage is naturally not limited to the method using the result of detection of the zero cross point. For example, in the case of three-phase AC, dq transformation or the like may naturally be used to calculate the frequency of the power distribution system

10 voltage.

[0252] Though the first and second embodiments are configured to store in CEMS 31, a not-shown data table to determine the power command value in accordance with the value of the SoC and to determine the power command value (Pref) based on that information when the SoC is out of a prescribed range and the power command value is

15 to be changed, the method of determining the power command value is not limited to table data as described previously. For example, the power command value may be changed to a value at which overdischarging or overcharging does not occur until the next demand plan is given from DSO 21, based on time until time of reception of the demand plan given next from DSO 21, the value of the SoC, and the current power
20 command value.

[0253] Though the example in which several power conversion devices to be used for such a large-capacity storage battery as storage battery 40 for the power distribution system are connected to the power distribution system is described in the first and second embodiments, virtual synchronous generator control may be implemented in a
25 power conversion device for a household storage battery and a power conversion device for an electric vehicle, and control similar to that by CEMS 31 may naturally be carried out. In this case, several hundred power conversion devices are connected to power distribution system 24. Furthermore, a similar effect is naturally achieved even when a large capacity storage battery (for example, several hundred kilowatts to several

megawatts) such as storage battery 40 for the power distribution system and a small capacity storage battery (several kilowatts) such as a household storage battery are connected to an identical power distribution system.

[0254] Though storage battery power conversion device 41 is described in the present

5 first and second embodiments, limitation thereto is not intended. A similar effect is naturally obtained also when virtual synchronous generator control is implemented in such a system as supplying electric power generated, for example, by a solar cell

(which may be a household solar cell without being limited to the mega-solar power plant), a wind power generator, or a fuel cell to the system, the system controlling the

10 static inverter as the voltage source, by configuring the system to generate the control parameter for a virtual synchronous generator controller as in the first and second embodiments. Furthermore, a storage battery mounted on a vehicle such as an electric vehicle (EV), a plug-in hybrid electric vehicle (PHEV), or a fuel cell vehicle (FCV) can also be employed.

15 [0255] Though the example where each functional block of the control circuit of storage battery power conversion device 41 is configured with hardware (H/W) as shown in Figs. 5 to 13 and each functional block of the configuration of CEMS 31 is configured with hardware (H/W) as shown in Figs. 2 to 4 is described in the present first and second embodiments for facilitated understanding of the description, limitation
20 as such is not intended. A similar control function can be realized also when a function of at least one functional block is realized by software (S/W) implemented on a central processing unit (CPU). Alternatively, a similar control function can also be realized by division of functions of software and hardware.

[0256] [Summary of Effects of First and Second Embodiments]

25 As described above, the distributed power source management apparatus in the present disclosure is configured to generate the frequency command value (Fref) or the power command value (Pref) in the drooping characteristics (that is, droop characteristics) based on the result (Fmeasure) of actual measurement of the frequency of the AC system voltage in the example where the power conversion device including

the static inverter where the drooping characteristics (that is, droop characteristics) represented by virtual synchronous generator control are implemented is connected to the AC system. Therefore, even when the frequency of the bulk power system deviates from the rated frequency (for example, 60 Hz), control of the frequency of the bulk power system without departure from the frequency management range of the power conversion device including the static inverter where the drooping characteristics (droop characteristics) are implemented can effectively be achieved.

[0257] It should be understood that the embodiments disclosed herein are illustrative and non-restrictive in every respect. The scope of the present disclosure is defined by the terms of the claims rather than the description above and is intended to include any modifications within the scope and meaning equivalent to the terms of the claims.

REFERENCE SIGNS LIST

[0258] 20 substation; 21 power distribution automation system (DSO); 22 voltmeter; 23 automatic voltage regulator (SVR); 24 power distribution system; 25 communication line; 26 mega-solar power plant; 27 mega-solar power conversion device; 28 switch; 30 synchronous generator; 31 CEMS; 40 storage battery; 41 storage battery power conversion device; 100 town; 101 factory; 102 building; 103 apartment; 401, 406, 410 voltmeter; 402, 407, 411 ammeter; 311 communication circuit; 312 storage circuit; 313 AC frequency collection circuit; 314 operation plan creation circuit; 315 frequency command value generation circuit; 316 distributed power source drooping characteristic management circuit; 317 transmission data generation circuit; 318 in-CEMS control circuit; 320 power command value correction circuit; 321 second in-CEMS control circuit; 403 first DC/DC conversion circuit; 404 first control circuit; 405 DC bus; 408 first DC/AC conversion circuit; 409 second control circuit; 412 communication interface; 3131 averaging circuit; 3132 multiplier; 3133 adder; 3134 multiplier; 3135 register; 3141 storage battery operation plan generation circuit; 3142 power generation amount prediction circuit; 3143 power consumption prediction circuit; 3144 storage battery operation plan correction circuit; 3145 power command value storage transmission circuit; 3146 management circuit; 4041 charging control

circuit; 4042 discharging control circuit; 4043 first switching circuit; 4044 third control circuit; 4091 AC frequency detection circuit; 4092 effective power calculation circuit; 4093 virtual synchronous generator control circuit; 4094 inverter current control circuit; 4095 inverter voltage control circuit; 4096 second switching circuit; 4097
5 fourth control circuit; 40910 phase detection circuit; 40911 frequency detection circuit; 40912 first sinusoidal wave generation circuit; 40932 subtractor; 40933 governor control circuit; 40935 adder; 40936 subtractor; 40937 mass point system computing circuit; 40941 subtractor; 40942 first PI control circuit; 40943 multiplier; 40944 subtractor; 40945 second PI control circuit; 40946 first PWM converter; 40951 second
10 sinusoidal wave generation circuit; 40952 subtractor; 40953 third PI control circuit; 40954 second PWM conversion circuit; 40955 first current restriction circuit; 409331 multiplier; 409332 first-order lag system model; 409333 limiter circuit; 409371 subtractor; 409372 integrator; 409373 multiplier; 409374 divider; 409375 adder; 409376 phase calculation circuit.

15

CLAIMS

[Claim 1] A distributed power source management apparatus to manage one or more distributed power sources, each of the one or more distributed power sources being connected to a power system and operating as a voltage source, relation between a frequency and electric power of each of the one or more distributed power sources having drooping characteristics and being adjusted such that a frequency command value and a power command value correspond to each other, the distributed power source management apparatus comprising:

an AC frequency collector to collect information on an AC frequency of the power system and to determine a representative value of the AC frequency based on the collected information on the AC frequency; and

a frequency command value generator to generate the frequency command value for each of the one or more distributed power sources based on the representative value of the AC frequency.

[Claim 2] The distributed power source management apparatus according to claim 1, further comprising a drooping characteristic manager to manage as drooping characteristic information, a shape of the drooping characteristics or a parameter to determine the shape of the drooping characteristics, the drooping characteristic information corresponding to each of the one or more distributed power sources, wherein

the frequency command value generator generates the frequency command value for each of the one or more distributed power sources based on the corresponding drooping characteristic information managed by the drooping characteristic manager, in addition to the representative value of the AC frequency.

[Claim 3] The distributed power source management apparatus according to claim 2, further comprising an operation plan creator to create an operation plan

corresponding to each of the one or more distributed power sources and to generate the power command value corresponding to each of the one or more distributed power sources based on the corresponding operation plan, wherein

5 the frequency command value generator generates the frequency command value for each of the one or more distributed power sources based on the corresponding power command value generated by the operation plan creator, in addition to the representative value of the AC frequency and the corresponding drooping characteristic information stored in the drooping characteristic manager.

10 [Claim 4] The distributed power source management apparatus according to claim 3, wherein

 the frequency command value generator determines a maximum frequency and a minimum frequency that can be taken by each of the one or more distributed power sources, based on a power capacity corresponding to each of the one or more
15 distributed power sources, and

 the frequency command value generator changes the frequency command value to a value based on the representative value of the AC frequency at a current time point, when the representative value of the AC frequency at the current time point is not included in a frequency reference range based on the maximum frequency and the
20 minimum frequency.

 [Claim 5] The distributed power source management apparatus according to claim 4, wherein

 when the frequency command value generator changes the frequency command value for a first distributed power source among the one or more distributed power sources, the frequency command value generator

 (i) calculates the maximum frequency and the minimum frequency that can be taken by the first distributed power source on an assumption that the frequency command value for the first distributed power source has been set to be equal to the

representative value of the AC frequency at the current time point and actually sets the frequency command value to be equal to the representative value of the AC frequency at the current time point when a first condition is satisfied, the first condition being a condition that the calculated maximum frequency and minimum frequency are within a predetermined rated frequency range based on a rated frequency of the power system, and

(ii) sets, when the first condition is not satisfied, the frequency command value to a value shifted from the representative value of the AC frequency at the current time point to satisfy the first condition.

[Claim 6] The distributed power source management apparatus according to any one of claims 3 to 5, wherein

a plurality of distributed power sources are connected to the power system as the one or more distributed power sources, and

the frequency command value generator generates the frequency command value for each of the plurality of distributed power sources such that maximum frequencies that can be taken by the plurality of distributed power sources substantially match with one another and minimum frequencies that can be taken by the plurality of distributed power sources substantially match with one another.

[Claim 7] A distributed power source management apparatus to manage one or more distributed power sources, each of the one or more distributed power sources being connected to a power system and operating as a voltage source, relation between a frequency and electric power of each of the one or more distributed power sources having drooping characteristics and being adjusted such that a frequency command value and a power command value correspond to each other, the distributed power source management apparatus comprising:

an AC frequency collector to collect information on an AC frequency of the power system and to determine a representative value of the AC frequency based on the

collected information on the AC frequency; and

a power command value corrector to correct the power command value for each of the one or more distributed power sources based on the representative value of the AC frequency.

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[Claim 8] The distributed power source management apparatus according to claim 7, further comprising a drooping characteristic manager to manage as drooping characteristic information, a shape of the drooping characteristics or a parameter to determine the shape of the drooping characteristics, the drooping characteristic information corresponding to each of the one or more distributed power sources, wherein

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the power command value corrector corrects the power command value for each of the one or more distributed power sources based on the corresponding drooping characteristic information managed by the drooping characteristic manager, in addition to the representative value of the AC frequency.

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[Claim 9] The distributed power source management apparatus according to claim 8, further comprising an operation plan creator to create an operation plan corresponding to each of the one or more distributed power sources and to generate the power command value for each of the one or more distributed power sources based on the corresponding operation plan, wherein

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the power command value corrector corrects the power command value generated by the operation plan creator based on the representative value of the AC frequency and the corresponding drooping characteristic information stored in the drooping characteristic manager.

25

[Claim 10] The distributed power source management apparatus according to claim 9, wherein

the power command value corrector determines a maximum frequency and a

minimum frequency that can be taken by each of the one or more distributed power sources, based on a power capacity corresponding to each of the one or more distributed power sources, and

5 the power command value corrector corrects the power command value to a value based on the representative value of the AC frequency at a current time point, when the representative value of the AC frequency at the current time point is not included in a frequency reference range based on the maximum frequency and the minimum frequency.

10 [Claim 11] The distributed power source management apparatus according to claim 10, wherein

when the power command value corrector corrects the power command value of a first distributed power source among the one or more distributed power sources, the power command value corrector

15 (i) calculates the maximum frequency and the minimum frequency that can be taken by the first distributed power source on an assumption that the power command value corresponding to the frequency command value has been corrected to a first value such that a value of electric power at the representative value of the AC frequency at the current time point is equal to the power command value generated by the operation
20 plan creator and actually corrects the power command value corresponding to the frequency command value to the first value when a first condition is satisfied, the first condition being a condition that the calculated maximum frequency and minimum frequency are within a predetermined rated frequency range based on a rated frequency of the power system and the first value is a value within a power source capacity of the
25 first distributed power source, and

 (ii) corrects, when the first condition is not satisfied, the power command value corresponding to the frequency command value to a value shifted from the first value to satisfy the first condition.

[Claim 12] The distributed power source management apparatus according to any one of claims 9 to 11, wherein

a plurality of distributed power sources are connected to the power system as the one or more distributed power sources, and

5 the power command value corrector corrects the power command value for each of the plurality of distributed power sources such that maximum frequencies that can be taken by the plurality of distributed power sources substantially match with one another and minimum frequencies that can be taken by the plurality of distributed power sources substantially match with one another.

10

[Claim 13] The distributed power source management apparatus according to any one of claims 2 to 6 and 8 to 12, wherein

each of the one or more distributed power sources carries out virtual synchronous generator control to simulate an operation of a synchronous generator, and

15 the drooping characteristic manager stores, as the drooping characteristic information, a governor time constant, a speed adjustment ratio, an inertia constant, and a braking coefficient which are control parameters in carrying out the virtual synchronous generator control.

20 [Claim 14] The distributed power source management apparatus according to any one of claims 3 to 6 and 9 to 12, wherein

a plurality of distributed power sources are connected to the power system as the one or more distributed power sources,

25 each of the plurality of distributed power sources calculates the AC frequency based on a voltage of the power system, and

the AC frequency collector collects, as information on the AC frequency, a calculated value of the AC frequency from at least one of the plurality of distributed power sources.

[Claim 15] The distributed power source management apparatus according to claim 14, wherein

the power system is an isolated system, and

the representative value of the AC frequency is a calculated value of the AC
5 frequency collected from a distributed power source maximum in power capacity
among the plurality of distributed power sources or a distributed power source
corresponding to a power command value largest among power command values
generated by the operation plan creator.

10 [Claim 16] A power distribution system comprising:

one or more distributed power sources each of which operates as a voltage
source, relation between a frequency and electric power of each of the one or more
distributed power sources having drooping characteristics and being adjusted such that
a frequency command value and a power command value correspond to each other; and

15 the distributed power source management apparatus according to any one of
claims 1 to 15, the distributed power source management apparatus managing the one
or more distributed power sources.