US 20250266708A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2025/0266708 A1**

Ma et al. (43) **Pub. Date: Aug. 21, 2025**

(54) **MULTI-MACHINE PARALLEL ENERGY STORAGE SYSTEM AND A CHARGING AND DISCHARGING CONTROL METHOD THEREOF**

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(21) Appl. No.: **19/194,980**

(22) Filed: **Apr. 30, 2025**

Related U.S. Application Data

(63) Continuation of application No. PCT/CN2023/137873, filed on Dec. 11, 2023.

(30) **Foreign Application Priority Data**

Feb. 14, 2023 (CN) 202310108608.5

Publication Classification

(51) **Int. Cl.**

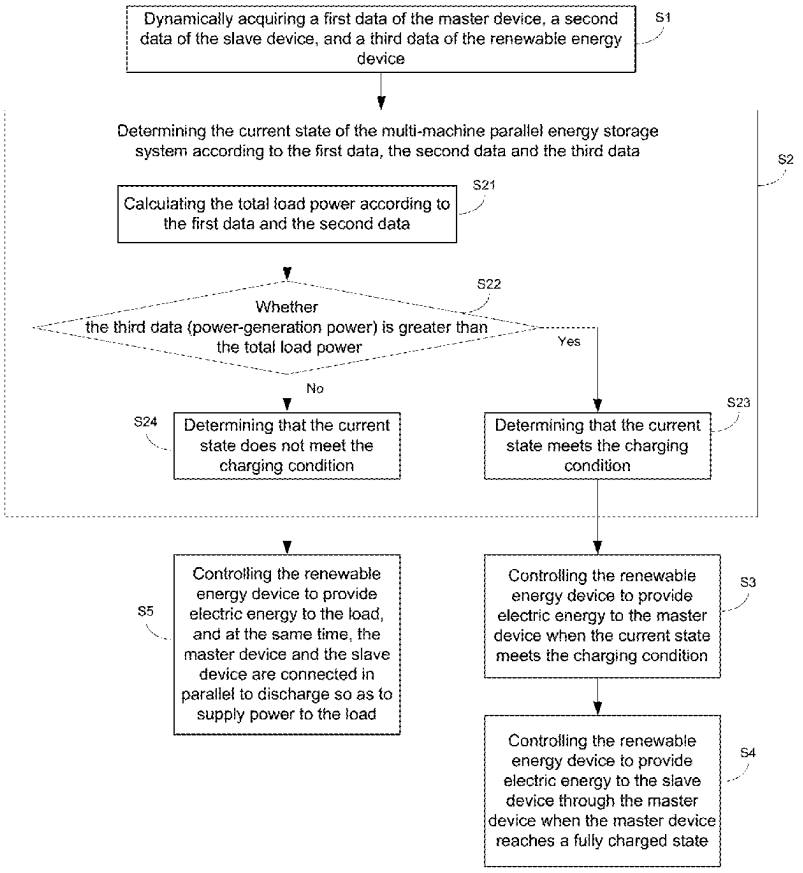
H02J 7/34	(2006.01)
H02J 3/32	(2006.01)
H02J 7/00	(2006.01)
H02J 7/35	(2006.01)

(52) **U.S. Cl.**

CPC ***H02J 7/342*** (2020.01); ***H02J 3/32*** (2013.01); ***H02J 7/0049*** (2020.01); ***H02J 7/0063*** (2013.01); ***H02J 7/007182*** (2020.01); ***H02J 7/35*** (2013.01); *H02J 2207/20* (2020.01)

(57) **ABSTRACT**

A multi-machine parallel energy storage system and a charging and discharging control method thereof are provided. The multi-machine parallel energy storage system includes: a single renewable energy device, at least two energy storage devices, an AC bus and a load. When the renewable energy device is connected to any energy storage device, that device becomes the master while others serve as slaves, and the master device is configured to: dynamically acquire first data, second data and third data; determine the current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data; control the renewable energy device to provide electric energy to the master device when the current state meets the charging condition; and control the renewable energy device to provide electric energy to the slave device when the master device reaches a fully charged state.



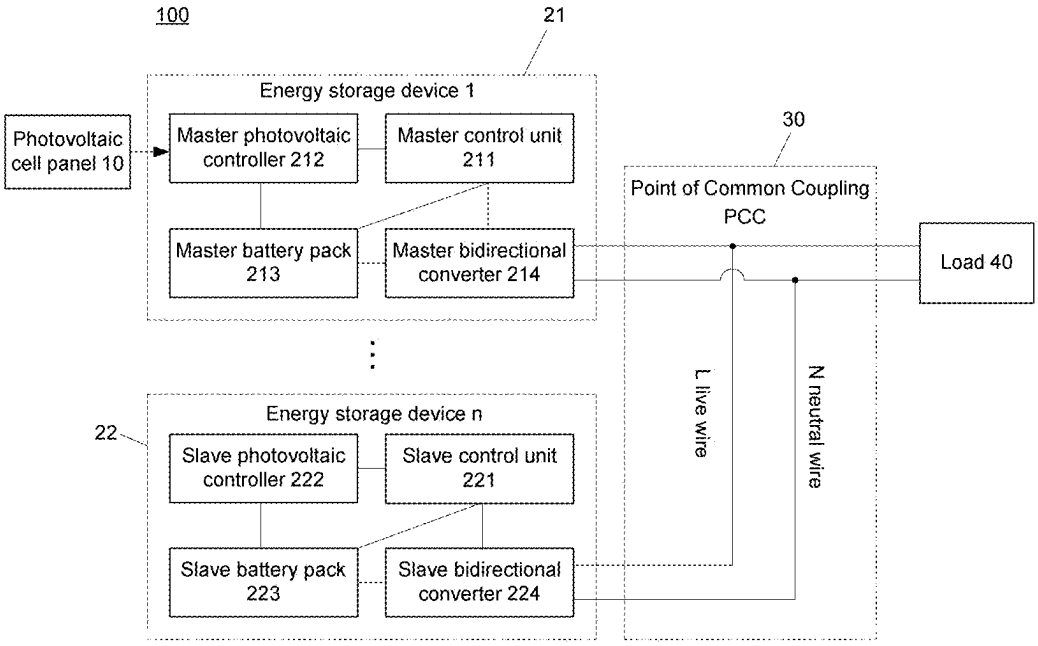

100
21
Energy storage device 1
Photovoltaic cell panel 10
Master photovoltaic controller 212
Master control unit 211
Master battery pack 213
Master bidirectional converter 214
30
Point of Common Coupling PCC
Load 40
L live wire
N neutral wire
Energy storage device n
22
Slave photovoltaic controller 222
Slave control unit 221
Slave battery pack 223
Slave bidirectional converter 224

FIG. 1

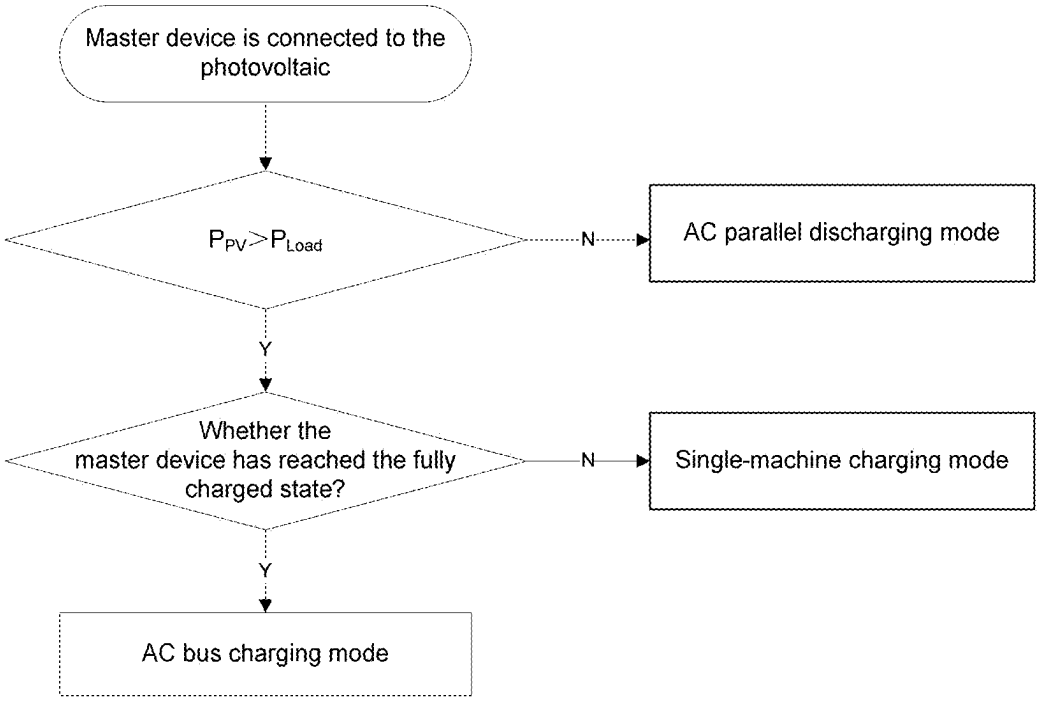

Master device is connected to the photovoltaic
$P_{PV} > P_{Load}$
N
AC parallel discharging mode
Y
Whether the master device has reached the fully charged state?
N
Single-machine charging mode
Y
AC bus charging mode

FIG. 2

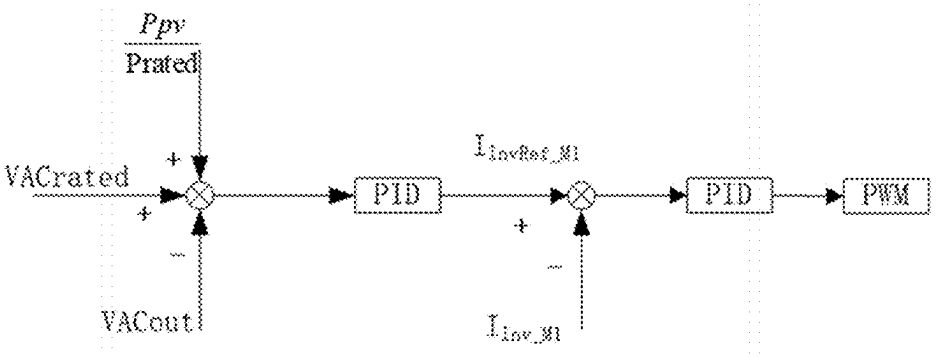


FIG. 3

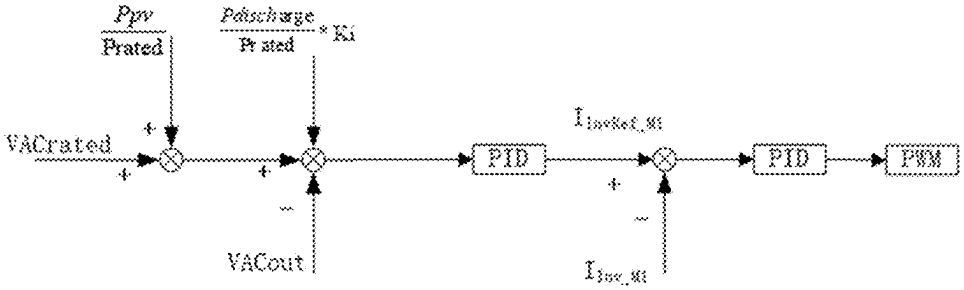


FIG. 4

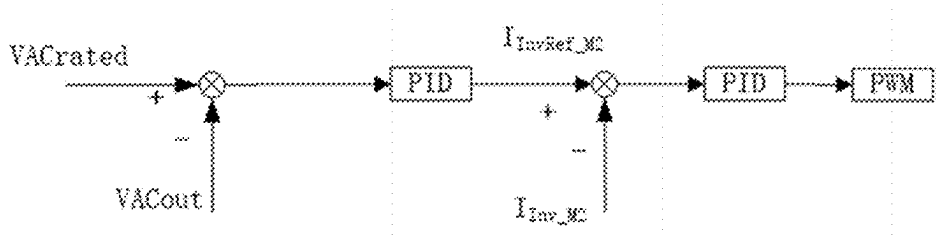


FIG. 5

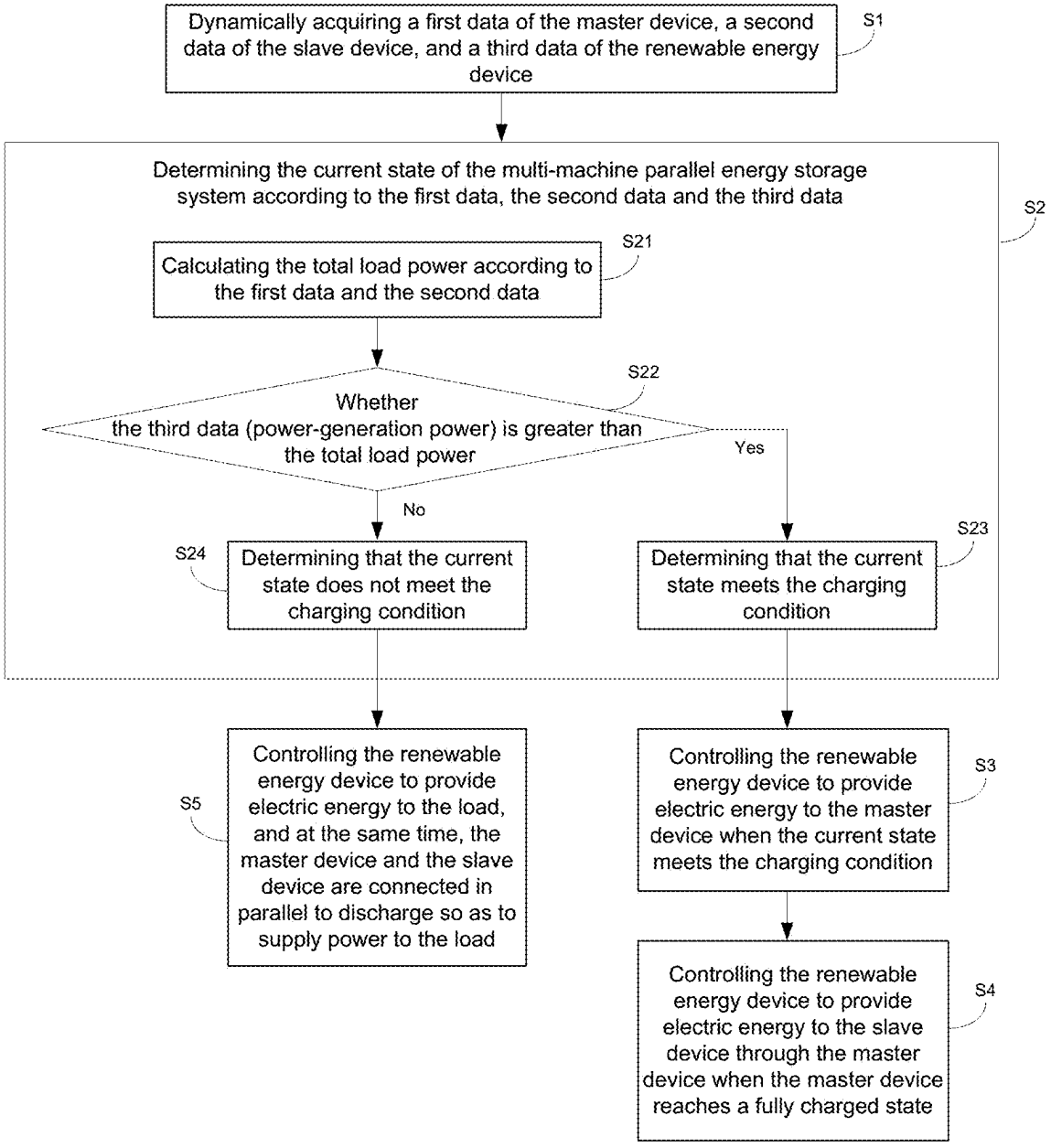

Dynamically acquiring a first data of the master device, a second data of the slave device, and a third data of the renewable energy device
S1
Determining the current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data
S2
Calculating the total load power according to the first data and the second data
S21
Whether the third data (power-generation power) is greater than the total load power
S22
Yes
No
Determining that the current state does not meet the charging condition
S24
Determining that the current state meets the charging condition
S23
Controlling the renewable energy device to provide electric energy to the load, and at the same time, the master device and the slave device are connected in parallel to discharge so as to supply power to the load
S5
Controlling the renewable energy device to provide electric energy to the master device when the current state meets the charging condition
S3
Controlling the renewable energy device to provide electric energy to the slave device through the master device when the master device reaches a fully charged state
S4

FIG. 6

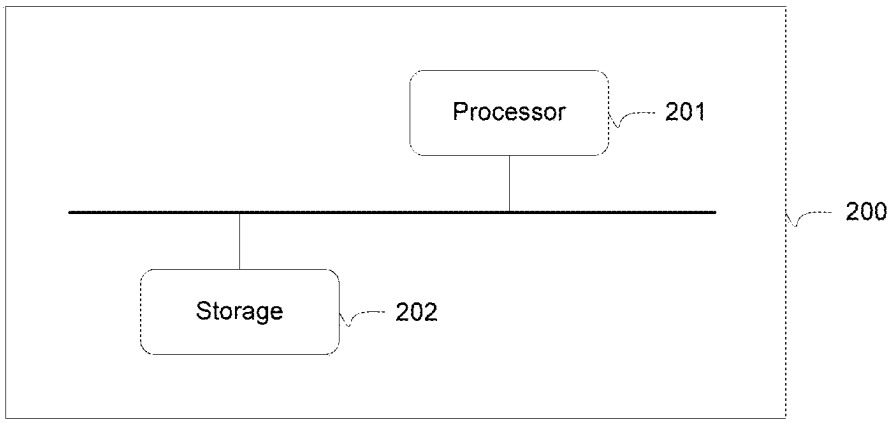


FIG. 7

MULTI-MACHINE PARALLEL ENERGY STORAGE SYSTEM AND A CHARGING AND DISCHARGING CONTROL METHOD THEREOF

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to and benefit of Chinese Patent Application No. 202310108608.5, filed with the Chinese Patent Office on Feb. 14, 2023 and entitled "A MULTI-MACHINE PARALLEL ENERGY STORAGE SYSTEM AND A CHARGING AND DISCHARGING CONTROL METHOD THEREOF", the entirety of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present application relates to the technical field of energy storage power supplies, and in particular, relates to a multi-machine parallel energy storage system and a charging and discharging control method thereof.

BACKGROUND

[0003] With the development of the photovoltaic (PV) industry and the craze for outdoor travel, industries related to photovoltaic energy storage are also developing rapidly, and the application scenarios of photovoltaic energy storage products are increasing. In the face of the ever-increasing load power demands, usually multiple energy storage devices are connected in parallel to output electric power for high-power loads.

[0004] The AC sides of independent energy storage devices are connected together and the AC sides thereof can only realize the control of output and load driving. Since the battery sides and DC charging sides of the independent energy storage devices are independent, each of the energy storage devices needs to be connected to a photovoltaic (solar) cell panel separately in order to be charged through solar energy. However, users often only have one set of solar photovoltaic panels, which requires users to manually connect the photovoltaic cell panels to individual energy storage devices one by one for charging. Not only is the work tedious, but the repeated connection of the photovoltaic cell panels to the respective energy storage devices also poses a safety hazard.

SUMMARY

[0005] A technical solution adopted by the embodiments of the present application is to provide a multi-machine parallel energy storage system which includes: a single renewable energy device, at least two energy storage devices, an AC bus and a load, wherein the renewable energy device is configured to be connected to one of the at least two energy storage devices, and AC output terminals of the at least two energy storage devices are connected to the load through the AC bus;

[0006] when the renewable energy device is connected to any one of the at least two energy storage devices, the energy storage device connected to the renewable energy device is determined as a master device, and the energy storage device not connected to the renewable energy device is determined as a slave device, the master device is configured to:

[0007] dynamically acquire first data of the master device, second data of the slave device, and third data of the renewable energy device;

[0008] determine the current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data;

[0009] control the renewable energy device to provide electric energy to the master device when the current state meets the charging condition; and control the renewable energy device to provide electric energy to the slave device when the master device reaches a fully charged state.

[0010] Preferably, the operation of determining the current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data includes: calculating a total load power of the multi-machine parallel energy storage system according to the first data and the second data; determining whether the third data is greater than the total load power, the third data including the power-generation power of the renewable energy device; when the third data is greater than the total load power, determining that the current state meets the charging condition; and when the third data is less than or equal to the total load power, determining that the current state does not meet the charging condition.

[0011] Further preferably, the master device is further configured to: after determining that the current state does not meet the charging condition, controlling the renewable energy device to provide electric energy to the load, and at the same time, the master device and the slave device are connected in parallel to discharge so as to supply power to the load.

[0012] Preferably, the system adopts a dual-loop control mode of an AC output voltage outer loop and an inverter current inner loop.

[0013] Further preferably, the master device introduces photovoltaic power-generation power and battery discharge power into the AC output voltage outer loop of the dual-loop control mode as feedforward control, and the AC output target voltage of the master device is expressed as the following equation:

$$VAC_{Ref_M1} = VAC_{rated} + \frac{P_{PV}}{P_{rated}} \times (1 + \Delta U)$$

$$\Delta U = -\frac{P_{discharge}}{P_{rated}} \times Ki$$

wherein VAC_{Ref_M1} is the AC output voltage target value of the master device; VAC_{rated} is the AC rated output voltage of the system; P_{PV} is the current power-generation power of the renewable energy device; P_{rated} is the rated power of the system; AU is the adjustment amount of the AC output voltage, which is related to the battery pack discharge power of the master device; $P_{discharge}$ is the battery pack discharge power of the master device, Ki is the output voltage adjustment coefficient corresponding to the battery pack discharge power of the master device, which is adjusted according to the dynamic response demand occasion of the actual load; and $0<Ki\leq1$, wherein the larger the Ki is, the faster the response to the sudden change of load will be, and the shorter the time to adjust the output voltage will be; and the smaller the Ki is, the longer the time to adjust the output voltage will be, and the smoother the adjustment process will be.

[0014] Further preferably, the slave device adopts a constant voltage control mode in the AC output voltage outer loop of the dual-loop control mode, and the AC output target voltage of the slave device is expressed as the following equation:

$$VAC_{Ref_M2}=VAC_{rated}$$

wherein VAC_{Ref_M2} is the AC output voltage target value of the slave device; and VAC_{rated} is the AC rated output voltage of the system.

[0015] Further preferably, in a case where the number of the energy storage devices is at least three, the slave devices comprises at least two devices and the master device is further configured to: when the master device reaches the fully charged state, determine the charging sequence of the slave devices according to a predetermined rule and control the renewable energy device to provide electric energy to the slave devices through the master device according to the charging sequence.

[0016] Another technical solution adopted by the embodiments of the present application is to provide a charging and discharging control method for a multi-machine parallel energy storage system, which is applied to the multi-machine parallel energy storage system. The multi-machine parallel energy storage system includes: a single renewable energy device, at least two energy storage devices, an AC bus, and a load, wherein the renewable energy device is connected to the energy storage devices, and AC output terminals of the at least two energy storage devices are connected to the load via the AC bus; when the renewable energy device is connected to any one of the at least two energy storage devices, the energy storage device connected to the renewable energy device is determined as a master device, and the energy storage device not connected to the renewable energy device is determined as a slave device, and the charging and discharging control method for the system includes: dynamically acquiring first data of the master device, second data of the slave device, and third data of the renewable energy device; determining the current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data; controlling the renewable energy device to provide electric energy to the master device when the current state meets the charging condition; and controlling the renewable energy device to provide electric energy to the slave device when the master device reaches a fully charged state.

[0017] Preferably, the charging and discharging control method for the system includes: enabling the system to adopt a dual-loop control mode of an AC output voltage outer loop and an inverter current inner loop; the master device introduces photovoltaic power-generation power and battery discharge power into the AC output voltage outer loop of the dual-loop control mode as feedforward control, and the AC output target voltage of the master device is expressed as the following equation:

$$VAC_{Ref_M1} = VAC_{rated} + \frac{P_{PV}}{P_{rated}} \times (1 + \Delta U)$$

$$\Delta U = -\frac{P_{discharge}}{P_{rated}} \times Ki$$

[0018] wherein VAC_{Ref_M1} is the AC output voltage target value of the master device; VAC_{rated} is the AC rated output voltage of the system; P_{PV} is the current power-generation power of the renewable energy device; Prated is the rated power of the system; AU is the AC adjustment amount of the output voltage, which is related to the battery pack discharge power; $P_{discharge}$ is the battery pack discharge power of the master device, Ki is the output voltage adjustment coefficient corresponding to the battery pack discharge power of the master device, which is adjusted according to the dynamic response demand occasion of the actual load; and $0<Ki\leq 1$, wherein the larger the Ki is, the faster the response to the sudden change of load will be, and the shorter the time to adjust the output voltage will be; and the smaller the Ki is, the longer the time to adjust the output voltage will be, and the smoother the adjustment process will be.

[0019] The slave device adopts a constant voltage control mode in the AC output voltage outer loop of the dual-loop control mode, and the AC output target voltage of the slave device is expressed as the following equation:

$$VAC_{Ref_M2}=VAC_{rated}$$

wherein VAC_{Ref_M2} is the AC output voltage target value of the slave device; and VAC_{rated} is the AC rated output voltage of the system.

[0020] The present application further provides an electronic device, which includes: at least one processor, and a storage in communication connection with the at least one processor; wherein the storage stores instructions that can be executed by the at least one processor, and the instructions are executed by the at least one processor to enable the at least one processor to execute the charging and discharging control method for the multi-machine parallel energy storage system as described above.

[0021] The present application further provides a non-volatile computer storage medium in which computer executable instructions are stored, and the computer executable instructions, when executed by one or more processors, may enable the one or more processors to execute the charging and discharging control method for the multi-machine parallel energy storage system as described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] One or more embodiments are illustrated by corresponding attached drawings, and this does not constitute limitation on the embodiments. Elements with the same reference numerals in the attached drawings are indicated as similar elements, and the pictures in the attached drawings do not constitute scale limitation unless otherwise stated particularly.

[0023] FIG. **1** is a schematic structural diagram of a multi-machine parallel energy storage system according to an embodiment of the present application.

[0024] FIG. **2** is a block diagram of a working mode of a multi-machine parallel energy storage system according to an embodiment of the present application.

[0025] FIG. **3** is a block diagram of the AC output control of a master device in the non-discharging state of a multi-machine parallel energy storage system according to an embodiment of the present application.

[0026] FIG. **4** is a block diagram of the AC output control of the master device in the discharging state of the multi-machine parallel energy storage system according to an embodiment of the present application.

[0027] FIG. **5** is a block diagram of charging control for a slave device of a multi-machine parallel energy storage system according to an embodiment of the present application.

[0028] FIG. **6** is a schematic flowchart diagram of charging and discharging control of a multi-machine parallel energy storage system according to an embodiment of the present application.

[0029] FIG. **7** is a schematic structural diagram of an electronic device according to an embodiment of the present application.

DETAILED DESCRIPTION

[0030] In order to make objectives, technical solutions and advantages of the present application clearer, the present application will be further described in detail hereinafter with reference to attached drawings and embodiments. It shall be appreciated that, the specific embodiments described herein are only used to explain the present application, and are not intended to limit the present application.

[0031] It shall be noted that, various features in the embodiments of the present application may be combined with each other without conflict, and all the combinations are within the scope claimed in the present application. In addition, although functional module division is made in the schematic diagrams of the device and logical sequences are shown in the flowchart diagrams, in some cases, the steps shown or described may be executed with module division and sequences different from those in the schematic diagrams of the device and the flowchart diagrams.

[0032] Unless otherwise defined, all technical and scientific terms used in this specification have the same meanings as commonly understood by those skilled in the art of the present application. The terms used in the specification of the present application are only for the purpose of describing specific embodiments, and are not intended to limit the present application. The term "and/or" used in this specification includes any and all combinations of one or more associated items listed.

[0033] Energy storage devices refer to energy storage and conversion devices which are composed of energy conversion units (such as bidirectional converters), energy storage units (energy storage batteries), energy management units and safety systems or other important components. The energy storage batteries can be charged through photovoltaic/mains power, and the energy storage devices can supply power to loads (refrigerators, TVs, power tools, smart terminals, etc.) in the off-grid state. The energy storage devices themselves can work independently.

[0034] Renewable energy devices include photovoltaic/wind/hydroelectric power generation devices, such as photovoltaic cell panels, wind turbines or the like. The following description is made by taking the photovoltaic cell panel as an example.

[0035] Reference is made to FIG. **1** for a multi-machine parallel energy storage system **100** provided according to an embodiment of the present application. The multi-machine parallel energy storage system **100** includes: a photovoltaic cell panel **10**, at least two energy storage devices (which exemplarily include energy storage devices **1** to n in FIG. **1**, where $n \geq 2$), an AC bus **30** and a load **40**. The photovoltaic cell panel **10** is used to be connected to one of the energy storage devices (the energy storage device **1** is exemplarily selected to be connected to the photovoltaic cell panel **10** in FIG. **1**), and the at least two energy storage devices are connected to the load **40** through the AC bus **30**. The AC bus **30** includes a power line, and the power line includes a live wire and a neutral wire for power connection between respective energy storage devices. Data is exchanged between the energy storage devices through wired or wireless communication (not shown in the figure), such as through the Controller Area Network (CAN), WIFI (the wireless network communication technology), Bluetooth, serial interface and other communication modes.

[0036] When the photovoltaic cell panel **10** is connected to any of the at least two energy storage devices, the energy storage device connected to the photovoltaic cell panel **10** is determined as the master device **21**, and the energy storage device not connected to the photovoltaic cell panel **10** is determined as the slave device **22**. Specifically, when the photovoltaic cell panel **10** is connected to the energy storage device **1**, it is detected by the energy storage device **1** that the PV voltage signal of the PV port meets the first voltage range (for example, 50V to 200V, 10V to 150V, etc., and the first voltage range may be determined according to actual conditions), then the energy storage device **1** is automatically determined as the master device **21** and it communicates with other energy storage devices at the same time so that the energy storage devices **2** to n are determined as the slave devices **22**.

[0037] The energy storage devices have the same structures and functions no matter they serve as the master device or the slave devices. Specifically, each of the energy storage devices includes: a photovoltaic controller, a battery pack, a control unit and a bidirectional converter, and the control unit is connected to the photovoltaic controller, the battery pack and the bidirectional converter respectively. The photovoltaic controller is one of the core components of the photovoltaic power generation system, and it is mainly used to detect the connection of photovoltaic cell panels and realize the charging of the current energy storage device by solar energy through the MPPT maximum power tracking algorithm. The photovoltaic controller also has the following functions: 1) preventing overcharging or over-discharging of the battery pack and extending the life of the battery pack; 2) preventing the reverse polarity connection of the photovoltaic cell panel array and the storage battery; 3) providing breakdown protection caused by lightning stroke. The battery pack is used to store or release electric energy. The control unit is used for control of respective units/modules in the energy storage device and communication with other energy storage devices; the control unit includes one or more processors, storages and one or more programs therein; and the control unit for each energy storage device is the same, except that the program and/or function called by each energy storage device vary depending on whether the energy storage device serves as the master device or the slave device. The bidirectional converter is used for conversion including DC to AC and AC to DC.

[0038] Specifically, as shown in FIG. **1**, the master device **21** includes a master control unit **211**, a master photovoltaic controller **212**, a master battery pack **213** and a master bidirectional converter **214**. The slave device **22** includes a slave control unit **221**, a slave photovoltaic controller **222**, a slave battery pack **223** and a slave bidirectional converter **224**.

[0039] The input end of the master photovoltaic controller **212** is connected to the photovoltaic cell panel **10**, the output

end of the master photovoltaic controller **212** is connected to the first end of the master battery pack **213**, the second end of the master battery pack **213** is connected to the first end of the master bidirectional converter **214**, the second end of the master bidirectional converter **214** is connected to the load **40** through the AC bus **30**, and the master control unit **211** is respectively connected to the master photovoltaic controller **212**, the master battery pack **213** and the master bidirectional converter **214**. The master control unit **211** is used for data transmission with the slave control unit **221** and control the working state of the master photovoltaic controller **212**, the master battery pack **213** and the master bidirectional converter **214**.

[0040] The first end of the slave bidirectional converter **224** is connected to the second end of the slave battery pack **223**, the second end of the slave bidirectional converter **224** is connected to the load **40** through the AC bus **30**, and the first end of the slave battery pack **223** is connected to the slave photovoltaic controller **222**. The slave control unit **221** is connected to the slave photovoltaic controller **222**, the slave battery pack **223** and the slave bidirectional converter **224** respectively; the slave control unit **221** is used for data transmission with the master control unit **211** and control the working states of the slave photovoltaic controller **222**, the slave battery pack **223** and the slave bidirectional converter **224**.

[0041] The master control unit **211** in the master device is used to first dynamically acquire the first data of the master device, the second data of the slave device **22**, and the third data of the photovoltaic cell panel **10**. Then, the current state of the multi-machine parallel energy storage system **100** is determined according to the first data, the second data, and the third data. Next, when the current state meets the charging conditions, the photovoltaic cell panel **10** is controlled to provide electric energy to the master device **21**. When the master device **21** reaches a fully charged state, the photovoltaic cell panel **10** is controlled to provide electric energy to the slave device **22** through the master device **21**. That is, the photovoltaic cell panel **10** is controlled to provide electric energy to the master device **21**, and at the same time, the master device **21** is controlled to provide electric energy to the slave device **22**.

[0042] In some embodiments, the first data of the master device **21** includes the battery capacity and load power or the like of the master device **21**, the second data of the slave device **22** includes the battery capacity and load power or the like of the slave device **22**, and the third data of the photovoltaic cell panel **10** includes the power-generation power P_{pv}.

[0043] The total load power P_{Load} of the master device and the slave device is calculated according to the first data and the second data. Then, the working mode of the multi-machine parallel energy storage system **100** is determined according to the total load power P_{Load}, the power-generation power P_{pv} of the third data and the battery capacity SOC of the master device.

[0044] Referring to FIG. **2**, there is shown a block diagram of a working mode of a multi-machine parallel energy storage system provided according to an embodiment of the present application. After the photovoltaic cell panel **10** is connected to the master device **21**, the master device **21** dynamically acquires the first data of the master device **21**, the second data of the slave device **22** and the third data of the photovoltaic cell panel **10**, and then calculates to obtain the total load power P_{Load} and the power-generation power P_{pv}. It is determined whether $P_{pv}>P_{Load}$; if not, then it is determined that the current state does not meet the charging condition, and thus the system enters the AC parallel discharge mode, that is, the photovoltaic cell panel **10** is controlled to provide electric energy to the load while the master device **21** and the slave device **22** are discharged together to provide electric energy for use by the load; and if yes, then it is determined that the current state meets the charging conditions, and it is further determined whether the master device **21** reaches the fully charged state. If the master device does not reach the fully charged state, then it enters a single-machine charging mode, that is, the photovoltaic cell panel **10** is controlled to provide electric energy to the master device **21**. If the master device reaches the fully charged state, then it enters an AC bus charging mode, that is, the photovoltaic cell panel **10** is controlled to provide electric energy to the master device **21**, and at the same time, the master device **21** is controlled to provide electric energy to the slave device **22**.

[0045] In the AC parallel discharge mode, the total output power of the multi-machine parallel energy storage system **100** is the total load power P_{Load} minus the current PV power-generation power P_{Pv}, that is, $P_{Load}-P_{Pv}$.

[0046] The essence for the single-machine charging mode and the AC bus charging mode after the current state meets the charging condition as described above is to charge the energy storage devices on the principle of first the master device and then the slave device. The basis for determining whether the master device has reached the fully charged state is to determine whether the battery capacity of the master device exceeds the set threshold. For example, when the battery capacity of the master device **21** exceeds 80% or 100%, it is considered that the master device **21** has reached the fully charged state, and otherwise, it is considered that the master device **21** has not reached the fully charged state. After the master device reaches the fully charged state, the photovoltaic cell panel **10** is controlled to charge the slave device **22** through the master device **21**. The power at which the photovoltaic cell panel **10** charges the master device or the slave device is equal to the power-generation power P_{Pv} of the photovoltaic cell panel **10** minus the total load power P_{Load}, that is, $P_{Pv}-P_{Load}$.

[0047] When the system has at least three energy storage devices, that is, the system has multiple slave devices, the respective slave devices are charged in sequence according to the predetermined rules. The predetermined rules may be based on the ascending order of the electricity quantity of the slave devices, or the descending order of the electricity quantity of the slave devices, or the sequence of the address sizes of the slave devices or the like.

[0048] During the operation of the above-mentioned multi-machine parallel energy storage system **100**, the master device monitors the working status of all the energy storage devices and the photovoltaic cell panel **10**. When the connection status of the photovoltaic cell panel, the power of photovoltaic power generation and the load **40** vary, the operating status of the multi-machine parallel energy storage system **100** is adjusted in time to ensure the power supply requirements first.

[0049] The above multi-machine parallel energy storage system **100** adopts a dual-loop control mode of an AC output voltage outer loop and an inverter current inner loop. For the

AC output voltage outer loop, the master device and the slave device are respectively as follows.

[0050] Referring to FIG. **3** and FIG. **4**, FIG. **3** is a block diagram of the AC output control of a master device in the non-discharging state of a multi-machine parallel energy storage system provided according to an embodiment of the present application, and FIG. **4** is a block diagram of the AC output control of the master device in the discharging state of a multi-machine parallel energy storage system provided according to an embodiment of the present application. For the energy storage device **1** (i.e., the master device **21**) connected to the photovoltaic cell panel **10** in the multi-machine parallel energy storage system, photovoltaic power-generation power and battery discharge power as feedforward control are introduced into the AC output voltage outer loop of the dual-loop control mode thereof to realize photovoltaic charging-AC parallel discharging power control.

[0051] After the master device **21** is connected to the photovoltaic cell panel **10**, the maximum power tracking MPPT control is performed, and meanwhile, the AC output voltage of the master device **21** is adjusted according to the photovoltaic power, and the AC output target voltage of the master device is expressed as the following equation:

$$VAC_{Ref_M1} = VAC_{rated} + \frac{P_{PV}}{P_{rated}} \times (1 + \Delta U) \quad \text{Equation (1)}$$

[0052] wherein VAC_{Ref_M1} is the AC output voltage target value of the master device; VAC_{rated} is the AC rated output voltage of the system; P_{PV} is the current power-generation power of the renewable energy device, Prated is the rated power of the system; AU is the adjustment amount of the AC output voltage, which is related to the battery pack discharge power of the master device.

$$\Delta U = -\frac{P_{discharge}}{P_{rated}} \times Ki \quad \text{Equation (2)}$$

[0053] wherein $P_{discharge}$ is the battery pack discharge power of the master device, Ki is the output voltage adjustment coefficient corresponding to the battery pack discharge power of the master device, which is adjusted according to the dynamic response demand occasion of the actual load; and $0<Ki\leq 1$, wherein the larger the Ki is, the faster the response to the sudden change of load will be, and the shorter the time to adjust the output voltage will be; and the smaller the Ki is, the longer the time to adjust the output voltage will be, and the smoother the adjustment process will be.

[0054] Referring to FIG. **3**, the Equation (1) and the Equation (2), the current power-generation power P_{pv} of the renewable energy device meets the current charging and load driving power requirements of the multi-machine parallel energy storage system, and the battery pack of the master device (i.e., the master battery pack **213**) is in a non-discharging state. At this time, $P_{discharge}=0$ W, then $\Delta U=0$, and the AC output voltage of the master device gradually increases with the increase of the current power-generation power P_{pv} of the renewable energy device. Referring to FIG. **4**, the Equation (1) and the Equation (2), the current power-generation power P_{pv} of the renewable energy device is lower than the current charging and load driving power requirements of the multi-machine parallel energy storage system, and the battery pack of the master device (i.e., the master battery pack **213**) enters the discharging state. At this time, $P_{discharge}>0$ W, and as can be known from Equation (2), $\Delta U<0$ W, and the AC output voltage of the master device gradually decreases with the discharge power of the battery pack of the master device.

[0055] Referring to FIG. **5**, there is shown a block diagram of charging control for a slave device of a multi-machine parallel energy storage system provided according to an embodiment of the present application. For the energy storage devices **2** to n (i.e., the slave devices **22**) connected to the photovoltaic cell panel **10** in the multi-machine parallel energy storage system, a constant voltage control mode is adopted in the AC output voltage outer loop of the dual-loop control mode thereof to realize AC bus charging. The voltage outer loop target voltage of the slave device, i.e., the AC output target voltage of the slave device, is expressed as the following equation:

$$VAC_{Ref_M2} = VAC_{rated} \quad \text{Equation (3)}$$

[0056] wherein VAC_{Ref_M2} is the AC output voltage target value of the slave device; and VAC_{rated} is the AC rated output voltage of the system.

[0057] Referring to FIG. **1**, as can be known from the Equation (3) and FIG. **5**, when the voltage of the point of common coupling (PCC) of the AC bus is $>VAC_{rated}$, the slave device is charged through the AC bus, and the charging is achieved through the following path: photovoltaic cell panel—master device—AC parallel bus—slave device; and when the voltage of the point of common coupling (PCC) of the AC bus is $<VAC_{rated}$, the battery pack of the slave device (i.e., the slave battery pack **223**) is discharged to drive the load through the AC bus.

[0058] Different from the prior art in which only AC parallel discharge can be achieved when multiple energy storage devices are connected in parallel, the present application achieves AC bus charging through steps of: determining the current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data when the AC sides of multiple energy storage devices are connected in parallel; and when the current state meets the charging condition, charging the energy storage system on the principle of first the master device and then the slave device, while keeping the connection relationship between the renewable energy device and a current energy storage device in the system unchanged. Thus, the function of automatically charging the multiple energy storage devices can be realized simply by connecting one set/single renewable energy devices.

[0059] Referring to FIG. **3** and FIG. **4**, the difference between the AC output target voltage of the master device obtained according to the Equation (1) and the Equation (2) and the AC bus actual voltage VACout is calculated to obtain the voltage error value, which is then subjected to the processing of the proportional-integral regulator to obtain the reference current I_{InvRef_M1} of the inverter current inner loop of the master device, and then the difference between the reference current I_{InvRef_M1} and the actual inverter current I_{Inv_M1} is calculated to obtain the current error value,

which is then subjected to the processing of the proportional-integral regulator to obtain the modulation wave to control the switch of the power electronic controllable element.

[0060] Referring to FIG. **5**, the difference between the AC output target voltage of the slave device obtained according to the Equation (3), i.e., the AC rated output voltage of the system, and the AC bus actual voltage VACout is calculated to obtain the voltage error value, which is then subjected to the processing of the proportional-integral regulator to obtain the reference current I_{InvRef_M2} of the inverter current inner loop of the slave device, and then the difference between the reference current I_{InvRef_M2} and the actual inverter current I_{Inv_M2} is calculated to obtain the current error value, which is then subjected to the processing of the proportional-integral regulator to obtain the modulation wave to control the switch of the power electronic controllable element.

[0061] The working steps of the overall multi-machine parallel energy storage system when the charging conditions are met are as follows.

[0062] 1) When the master device **21** connected to the photovoltaic cell panel **10** has not reached the fully charged state, the system enters the single-machine charging mode for single-machine charging;

[0063] 2) after the master device reaches the fully charged state, the system enters the AC bus charging mode; the master device performs photovoltaic-AC parallel discharge, controls the PV power to output to the AC bus, and the voltage of the point of common coupling (PCC) of the AC bus is increased;

[0064] 3) the slave device initiates the AC constant voltage control, the constant voltage target is $VAC_{Ref_M2}=VAC_{rated}$, the increase in the port voltage is detected, and the AC constant voltage controls the slave device to perform AC parallel charging.

[0065] The master device connected to the photovoltaic cell panel **10** adopts photovoltaic power feedforward control. When the photovoltaic output power increases/decreases, the discharge output voltage of the AC port of the master device increases/decreases, and the charging power of the slave device is increased/decreased through the AC bus.

[0066] The master device connected to the photovoltaic cell panel **10** also adopts the master battery pack discharge power feedforward control at the same time. The discharge of the master battery pack actively reduces the discharge output voltage of the AC port of the master device. The charging power of the master device is reduced through the AC bus, and under the condition of keeping the connection relationship between the renewable energy device and a current energy storage device in the system unchanged, the energy storage system is charged on the principle of first the master device and then the slave device.

[0067] As shall be appreciated, the above embodiments only take the photovoltaic power generation device-photovoltaic cell panel as an example, and other renewable energy devices such as wind/hydroelectric power generation devices are also possible.

[0068] Referring to FIG. **6**, there is shown a schematic flowchart diagram of a charging and discharging control method for a multi-machine parallel energy storage system provided according to an embodiment of the present application. The charging and discharging control method is applied to the multi-machine parallel energy storage system **100** as described above, and the method includes:

[0069] Step S**1**. dynamically acquiring first data of the master device, second data of the slave device, and third data of the renewable energy device;

[0070] Step S**2**. determining the current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data;

[0071] Step S**3**. controlling the renewable energy device to provide electric energy to the master device **21** when the current state meets the charging condition;

[0072] Step S**4**. controlling the renewable energy device to provide electric energy to the slave device through the master device when the master device reaches a fully charged state.

[0073] The step S**2** includes:

[0074] Step S**21**. calculating the total load power of the multi-machine parallel energy storage system according to the first data and the second data;

[0075] Step S**22**. determining whether the third data is greater than the total load power, wherein the third data includes the power-generation power of the renewable energy device;

[0076] Step S**23**. when the third data is greater than the total load power, determining that the current state meets the charging condition;

[0077] Step S**24**. when the third data is less than or equal to the total load power, determining that the current state does not meet the charging condition.

[0078] When it is determined that the current state does not meet the charging condition, the method further includes: Step S**5**. controlling the renewable energy device to provide electric energy to the load, and at the same time, the master device and the slave device are connected in parallel to discharge so as to supply power to the load.

[0079] In the control method as described above, the system adopts a dual-loop control mode of an AC output voltage outer loop and an inverter current inner loop.

[0080] The master device introduces photovoltaic power-generation power and battery discharge power into the AC output voltage outer loop of the dual-loop control mode as feedforward control, and the AC output target voltage of the master device is expressed as the following equation:

$$VAC_{Ref_M1} = VAC_{rated} + \frac{P_{PV}}{P_{rated}} \times (1 + \Delta U) \quad \text{Equation (1)}$$

$$\Delta U = -\frac{P_{discharge}}{P_{rated}} \times Ki \quad \text{Equation (2)}$$

[0081] wherein VAC_{Ref_M1} is the AC output voltage target value of the master device; VAC_{rated} is the AC rated output voltage of the system; P_{PV} is the current power-generation power of the renewable energy device; P_{rated} is the rated power of the system; ΔU is the adjustment amount of the AC output voltage, which is related to the battery pack discharge power of the master device; $P_{discharge}$ is the battery pack discharge power of the master device, Ki is the output voltage adjustment coefficient corresponding to the battery pack discharge power of the master device, which is adjusted according to the dynamic response demand occasion of the actual load, and $0<Ki\leq 1$.

[0082] The slave device adopts a constant voltage control mode in the AC output voltage outer loop of the dual-loop control mode, and the AC output target voltage of the slave device is expressed as the following equation:

$$VAC_{Ref_M2}=VAC_{rated}$$

[0083] wherein VAC_{Ref_M2} is the AC output voltage target value of the slave device; and VAC_{rated} is the AC rated output voltage of the system.

[0084] For technical details not fully described in the charging and discharging control method for a multi-machine parallel energy storage system, reference may be made to the multi-machine parallel energy storage system provided in the above embodiments of the present application.

[0085] When multiple energy storage devices are connected in parallel, the multi-machine parallel energy storage system and the charging and discharging control method thereof provided in the embodiments of the present application can realize the function of automatically charging the multiple energy storage devices simply by connecting one set/single renewable energy devices.

[0086] FIG. **7** is a schematic structural diagram of an electronic device **200** provided according to an embodiment of the present application. As shown in FIG. **7**, the electronic device **200** includes: one or more processors **201** and a storage **202**. One processor **201** is taken as an example in FIG. **7**.

[0087] The processor **201** and the storage **202** may be connected via a bus or by other means, and FIG. **7** takes the connection via a bus as an example.

[0088] As a non-volatile computer readable storage medium, the storage **202** may be used to store non-volatile software programs, non-volatile computer executable programs and modules. The processor **201** runs the non-volatile software programs, instructions and units stored in the storage **202** to execute various functions and data processing of the electronic device **200**, i.e., to implement a charging and discharging control method for the multi-machine parallel energy storage system of the above embodiments.

[0089] The storage **202** may include a program storing area and a data storing area, wherein the program storing area may store the operating system and the application program required by at least one function, and the data storing area may store data created according to the use of the electronic device **200**. Additionally, the storage **202** may include a high-speed random access memory, and may also include a non-volatile storage, e.g., at least one disk storage device, a flash memory device or other non-volatile solid state storage devices. In some embodiments, the storage **202** may optionally include storages disposed remotely from the processor **201**, and these remote storages may be connected to the electronic device **200** via the network. Examples of the aforesaid network include but are not limited to the Internet, an intranet, a local area network (LAN), a mobile communication network or combinations thereof.

[0090] The one or more units are stored in the storage **202**, and when they are executed by the one or more processors **201**, a charging and discharging control method for the multi-machine parallel energy storage system of any of the embodiments of the method described above is executed.

[0091] The aforesaid electronic device **200** can execute a charging and discharging control method for the multi-machine parallel energy storage system provided in the embodiment of the present application, and has program modules and beneficial effects corresponding to the execution of the method. For technical details not fully described in the embodiment of the electronic device **200**, reference may be made to a charging and discharging control method for the multi-machine parallel energy storage system provided in the embodiment of the present application.

[0092] The electronic device of the embodiment of the present application exists in various forms, including but not limited to:

[0093] (1) Ultra-mobile personal computer devices which fall into the category of personal computers, have computing and processing capabilities, and generally also have mobile Internet accessing characteristics. These terminals include: PDA, MID and UMPC devices or the like, such as iPad;

[0094] (2) servers which are devices that provide computing services, and the servers are composed of a processor, a hard disk, an internal storage, a system bus or the like. The servers are similar to the general computer architecture, but they have higher requirements in terms of processing power, stability, reliability, security, scalability, and manageability because they are required to provide highly reliable services; and

[0095] (3) other electronic devices.

[0096] It should be noted that, the embodiments of the device described above are only for illustrative purpose, wherein the units illustrated as separate components may be or may not be physically separated, and components displayed as units may be or may not be physical units. That is, these units and components may be located in one place or distributed over multiple network units. Some or all of the modules may be selected according to actual needs to achieve the objective of the solution of the embodiment.

[0097] From the description of the above embodiments, those of ordinary skill in the art may clearly appreciate that each embodiment may be realized by means of software plus a general hardware platform, and of course, it may also be realized by hardware. As shall be appreciated by those of ordinary skill in the art, the implementation of all or part of the processes in the embodiments of the method described above may be completed by instructing related hardware through a computer program, the program may be stored in a computer readable storage medium, and the program may include the processes of the embodiments of the method described above when it is executed. The storage medium may be a magnetic disk, an optical disk, a Read-Only Memory (ROM) or a Random Access Memory (RAM) or the like.

[0098] The embodiment of the present application further provides a non-volatile computer-readable storage medium, the non-volatile computer-readable storage medium may be included in the device described in the above embodiments; or it may exist independently without being assembled into the device. The above non-volatile computer-readable storage medium carries one or more programs, and the aforesaid one or more programs, when being executed, implement the method of the embodiment of the present disclosure.

[0099] Finally, it shall be noted that, the above embodiments are only used to illustrate the technical solutions of the present application, and are not intended to limit the present application. Under the idea of the present application, technical features in the above embodiments or different embodiments may also be combined, the steps may be

implemented in any order, and many other variations in different aspects of the present application as described above are possible. For conciseness, these variations are not provided in details. Although the present application has been described in detail with reference to the foregoing embodiments, those of ordinary skill in the art shall appreciate that, the technical solutions described in the foregoing embodiments may still be modified or some of the technical features may be equivalently replaced; and these modifications or replacements do not make the essence of the corresponding technical solutions deviate from the scope of the technical solutions of various embodiments of the present application.

1. A multi-machine parallel energy storage system, comprising: a single renewable energy device, at least two energy storage devices, an AC bus and a load, wherein the renewable energy device is configured to be connected to one of the at least two energy storage devices, and AC output terminals of the at least two energy storage devices are connected to the load through the AC bus;

wherein when the renewable energy device is connected to any one of the at least two energy storage devices, the energy storage device connected to the renewable energy device is determined as a master device, and the energy storage device not connected to the renewable energy device is determined as a slave device;

wherein the master device is configured to:

dynamically acquire a first data of the master device, a second data of the slave device, and a third data of the renewable energy device;

determine a current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data;

control the renewable energy device to provide electric energy to the master device when the current state meets the charging condition; and

control the renewable energy device to provide electric energy to the slave device through the master device when the master device reaches a fully charged state.

2. The multi-machine parallel energy storage system according to claim **1**, wherein the operation of determining the current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data comprises:

calculating a total load power of the multi-machine parallel energy storage system according to the first data and the second data;

determining whether the third data is greater than the total load power, the third data comprising the power-generation power of the renewable energy device;

when the third data is greater than the total load power, determining that the current state meets the charging condition; and

when the third data is less than or equal to the total load power, determining that the current state does not meet the charging condition.

3. The multi-machine parallel energy storage system according to claim **2**, wherein the master device is further configured to:

after determining that the current state does not meet the charging condition, control the renewable energy device to provide electric energy to the load, and at the same time, the master device and the slave device are connected in parallel to discharge so as to supply power to the load.

4. The multi-machine parallel energy storage system according to claim **1**, wherein the system adopts a dual-loop control mode of an AC output voltage outer loop and an inverter current inner loop.

5. The multi-machine parallel energy storage system according to claim **4**, wherein the master device introduces photovoltaic power-generation power and battery discharge power into the AC output voltage outer loop of the dual-loop control mode as feedforward control, and the AC output target voltage of the master device is expressed as the following equation:

$$VAC_{Ref_{M1}} = VAC_{rated} + \frac{P_{PV}}{P_{rated}} \times (1 + \Delta U)$$

$$\Delta U = -\frac{P_{discharge}}{P_{rated}} \times Ki$$

wherein VAC_{Ref_M1} is the AC output voltage target value of the master device; VAC_{rated} is an AC rated output voltage of the system; P_{PV} is a current power-generation power of the renewable energy device; P_{rated} is a rated power of the system; ΔU is an adjustment amount of the AC output voltage, which is related to a battery pack discharge power of the master device; $P_{discharge}$ is the battery pack discharge power of the master device, Ki is an output voltage adjustment coefficient corresponding to the battery pack discharge power of the master device, and $0<Ki\leq 1$.

6. The multi-machine parallel energy storage system according to claim **4**, wherein the slave device adopts a constant voltage control mode in the AC output voltage outer loop of the dual-loop control mode, and the AC output target voltage of the slave device is expressed as the following equation:

$$VAC_{Ref_{M2}} = VAC_{rated}$$

wherein VAC_{Ref_M2} is the AC output voltage target value of the slave device; and VAC_{rated} is the AC rated output voltage of the system.

7. The multi-machine parallel energy storage system according to claim **1**, wherein in a case where the number of the energy storage devices is at least three, the slave devices comprises at least two devices, and the master device is further configured to:

when the master device reaches the fully charged state, determine the charging sequence of the slave devices according to a predetermined rule and control the renewable energy device to provide electric energy to the slave devices through the master device according to the charging sequence.

8. A charging and discharging control method for a multi-machine parallel energy storage system, wherein the charging and discharging control method is applied to the multi-machine parallel energy storage system comprising: a single renewable energy device, at least two energy storage devices, an AC bus, and a load, wherein the renewable energy device is connected to one of the at least two energy storage devices, and AC output terminals of the at least two energy storage devices are connected to the load via the AC bus;

wherein when the renewable energy device is connected to any one of the at least two energy storage devices, the energy storage device connected to the renewable energy device is determined as a master device, and the energy storage device not connected to the renewable energy device is determined as a slave device;

wherein the charging and discharging control method comprises:

dynamically acquiring a first data of the master device, a second data of the slave device, and a third data of the renewable energy device;

determining a current state of the multi-machine parallel energy storage system according to the first data, the second data and the third data;

controlling the renewable energy device to provide electric energy to the master device when the current state meets the charging condition; and

controlling the renewable energy device to provide electric energy to the slave device through the master device when the master device reaches a fully charged state.

9. The charging and discharging control method for the multi-machine parallel energy storage system according to claim **8**, wherein the charging and discharging control method for the system comprises:

enabling the system to adopt a dual-loop control mode of an AC output voltage outer loop and an inverter current inner loop.

10. The charging and discharging control method for the multi-machine parallel energy storage system according to claim **9**, wherein the master device introduces photovoltaic power-generation power and battery discharge power into the AC output voltage outer loop of the dual-loop control mode as feedforward control, and the AC output target voltage of the master device is expressed as the following equation:

$$VAC_{Ref_{M1}} = VAC_{rated} + \frac{P_{PV}}{P_{rated}} \times (1 + \Delta U)$$

$$\Delta U = -\frac{P_{discharge}}{P_{rated}} \times Ki$$

wherein VAC_{Ref_M1} is the AC output voltage target value of the master device; VAC_{rated} is the AC rated output voltage of the system; P_{Pv} is the current power-generation power of the renewable energy device; P_{rated} is the rated power of the system; ΔU is the adjustment amount of the AC output voltage, which is related to the battery pack discharge power of the master device; $P_{discharge}$ is the battery pack discharge power of the master device, Ki is the output voltage adjustment coefficient corresponding to the battery pack discharge power of the master device, and $0<Ki\leq 1$;

the slave device adopts a constant voltage control mode in the AC output voltage outer loop of the dual-loop control mode, and the AC output target voltage of the slave device is expressed as the following equation:

$$VAC_{Ref_{M2}} = VAC_{rated}$$

wherein VAC_{Ref_M2} is the AC output voltage target value of the slave device; and VAC_{rated} is the AC rated output voltage of the system.

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