

POWER DISTRIBUTION SYSTEM

FIELD

The invention relates to the field of power distribution.

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BACKGROUND

Electricity is typically distributed from producers to consumers via an electrical grid, also known as a power grid. Losses are inherent in electricity distribution. To maximise efficiency, it is necessary to minimise these losses.

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Accordingly, systems for minimising losses in power distribution networks are disclosed herein.

BRIEF DESCRIPTION OF THE INVENTION

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Disclosed is a power distribution system including: an energy storage module configured to receive and store energy from a polyphase power supply; an energy management module configured to balance the load on each phase of the polyphase power supply when charging the energy storage module by
20 adjusting the load used to charge the energy storage module on each phase so as to minimise a resultant neutral current for the polyphase power supply; and an output interface configured to output power from the energy storage module.

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The energy management module may include respective charger modules associated with each phase of the polyphase power supply, each charger module configured to charge the energy storage module, when switched on, by drawing power from its associated phase of the polyphase power supply, and adjusting the load used to charge the energy storage module may include switching each
30 charger module on or off.

The energy management module may be configured to determine the resultant neutral current using meter data obtained from a polyphase energy meter connected to the polyphase power supply.

- 5 The energy management module may include at least one communications module configured to receive commands to adjust the load on at least one phase of the polyphase power supply from a remote device, and the energy management module may be further configured to adjust the load on the or each phase of the polyphase power supply according to the received commands.

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The communications module may be configured to operate using a LoRaWAN protocol.

- 15 The energy management module may be configured to convert AC power from the polyphase power supply to DC power for charging the energy storage module.

The output interface may include a DC power output configured to output DC power from the energy storage module.

- 20 The power distribution system may further include a power conversion module configured to convert DC power from the energy storage module to AC power, and the output interface may include an AC power output.

- 25 The energy storage module may be further configured to receive and store energy from a DC power supply.

The power distribution system may further include a solar cell or wind turbine configured to charge the energy storage module.

- 30 The energy storage module may include a lithium iron phosphate battery.

The polyphase power supply may be a three-phase power supply.

Also disclosed is a method of distributing power, including: charging an energy storage module using a polyphase power supply; balancing, using an energy management module, the load on each phase of the polyphase power supply, when charging the energy storage module, by adjusting the load used to charge the energy storage module on each phase so as to minimise a resultant neutral current for the polyphase power supply; and outputting power from the energy storage module through an output interface.

10 Adjusting the load used to charge the energy storage module on each phase may include switching respective charger modules associated with each phase of the polyphase power supply on or off, and the charger modules may be configured to charge the energy storage module.

15 The resultant neutral current may be determined using meter data obtained from a polyphase energy meter connected to the polyphase power supply.

The method may further include receiving from a remote device, using a communications module of the energy management module, a command to adjust the load on at least one phase of the polyphase power supply, and adjusting the load on the or each phase of the polyphase power supply according to the received command.

The communications module may be configured to operate using a LoRaWAN protocol.

The method may further include converting, using the energy management module, AC power from the polyphase power supply to DC power for charging the energy storage module.

30 The output interface may include a DC power output configured to output DC power from the energy storage module.

The method may further include converting, using a power conversion module, DC power from the energy storage module to AC power, and outputting the AC power through an AC power output of the output interface.

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The method may further include charging the energy storage module using a DC power supply.

The method may further include using a solar cell or wind turbine to charge the energy storage module.

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The energy storage module may include a lithium iron phosphate battery.

The polyphase power supply may be a three-phase power supply.

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BRIEF DESCRIPTION OF THE FIGURES

In order that the present disclosure may be more readily understood, preferable embodiments thereof will now be described, by way of example only, with reference to the accompanying drawings, in which:

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Figs. 1-5 are schematic views of parts of a power distribution system according to the present disclosure; and

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Fig. 6 is a view of a flowchart illustrating a method according to the present disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

The present disclosure includes a power distribution system 1 (see e.g. Fig. 1).

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The power distribution system 1 includes an energy storage module 11. The energy storage module 11 is configured to store energy. The energy storage

module 11 may, therefore, include a cell or battery, such as a lithium iron phosphate battery. Alternative battery chemistries, such as for example lithium-ion, lead-acid, and/or sodium-ion, may also be used.

- 5 The capacity of the energy storage module 1 may vary depending on user requirements in different use cases; the present disclosure is not limited to any particular capacity. In some versions of the technology, the energy storage module 1 may have a capacity of around 1-1,000 kWh, for example. Other versions may use capacities of over 1 MWh, for example.

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- The energy storage module 1 may additionally or alternatively include other energy storage means, such as a mechanical storage unit (e.g. spring, flywheel, or solid mass gravitational storage unit), an electrical storage unit (e.g. capacitor), and/or a thermal storage unit. The energy storage module 11 may
15 include a corresponding means for converting electrical energy into stored energy (e.g. using a motor in the case of a mechanical storage unit or heater in the case of a thermal storage unit) and back to electrical energy for outputting (e.g. using a turbine).

- 20 The energy storage module 11 may be connected in electrical communication with one or more of an energy management module 12, a power conversion module 13, an input interface 14, an output interface 15, a DC output module 16, an AC output module 17, a polyphase power supply 21, and/or a DC power supply 22.

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The energy storage module 11 may be configured to be charged (i.e. to store energy) using the polyphase power supply 21 and/or DC power supply 22.

- The DC power supply 22 may include a connection to one or more DC power
30 generators, such as one or more renewable energy generators, such as one or more solar cells or wind turbines, which may therefore be configured to charge the energy storage module 11. The DC power supply 22 may include a

connection to one or more batteries, which may be configured to charge the energy storage module 11. Energy may, therefore, be stored in an external battery, and supplied from that external battery to the energy storage module 11 (which may, in some versions, also include a battery).

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The DC power supply 22 and/or energy storage module 11 may include a controller 221 (see Fig. 5) configured to control the input of energy from the DC power supply 22 to the energy storage module 11. The controller may, therefore, be configured to charge the energy storage module 11 according to a predefined charging profile, which may include a maximum charging rate and a maximum charge capacity, for example.

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The DC power supply 22 may be connected to the energy storage module 11 via the input interface 14. The input interface 14 may, therefore, include at least one DC input port configured to be connected to a DC power supply (e.g. the DC power supply 22).

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The polyphase power supply 21 may include a mains power supply, which may be supplied by a power grid. The mains power supply may be a polyphase power supply, such as a two-, three-, or four-phase power supply. It will be appreciated that power grids often use a three-phase power supply. The mains power may be generated using one or more power plants, such as a fossil fuel power plant, nuclear power plant, or other power plant.

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The energy storage module 11 may, therefore, be configured to be charged using a polyphase power supply 21, which may be a three-phase power supply 21.

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The energy management module 12 may be configured to balance the load on each phase of the polyphase power supply 21 when charging the energy storage module 11. This load balancing may be performed by adjusting the load used to charge the energy storage module 11 on each phase of the

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polyphase power supply. The loads may be adjusted so as to minimise a resultant neutral current for the polyphase power supply.

The resultant neutral current, I_N , for a three-phase power supply may be
 5 determined as follows:

$$I_N = \sqrt{[0.866(M_{I_{L2}} - M_{I_{L3}})]^2 + [M_{I_{L1}} - 0.5(M_{I_{L2}} + M_{I_{L3}})]^2}$$

where $M_{I_{L1}}$ is the measured line current for a first of the three phases, $M_{I_{L2}}$ is the measured line current for a second of the three phases, and $M_{I_{L3}}$ is the measured line current for a third of the three phases.

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The power distribution system 1 may include a polyphase energy meter 30 connected to, or configured to be connected to, the polyphase power supply 21 (see e.g. Fig. 3). The polyphase energy meter 30 may measure power consumption for each phase of the polyphase power supply 21. The associated
 15 line currents for each phase of the polyphase power supply 21 may, therefore, be determined from the measured power consumption data. The polyphase energy meter 30 may in some versions be configured to measure the line current for each phase of the polyphase power supply 21 directly.

20 The polyphase energy meter 30 may output meter data for each phase of the polyphase power supply 21. The meter data may include the power consumption and/or line current data, for example. The meter data may be output to the energy management module 12, which may therefore include a corresponding processing unit 120 which may be configured to process the
 25 meter data.

The energy management module 12 may, therefore, be configured to determine the resultant neutral current using the meter data.

30 In some versions the polyphase energy meter 30 may be configured to determine the resultant neutral current and to output the determined resultant

neutral current to the energy management module 12. The meter data output to the energy management module 12 may, therefore, include the resultant neutral current, in some versions.

5 The energy management module 12 may include respective charger modules 121 associated with each phase of the polyphase power supply 21 (see e.g. Fig. 2). In the case of a three-phase power supply 21, therefore, as illustrated in Fig. 3, the energy management module 12 may include a first charger module 121a associated with a first phase 211 of the three-phase power supply
10 21, a second charger module 121b associated with a second phase 212 of the three-phase power supply 21, and a third charger module 121c associated with a third phase 213 of the three-phase power supply 21. Each charger module 121 may, therefore, be connected in electrical communication with its corresponding phase of the polyphase power supply 21. Each charger module
15 121 may also be connected in electrical communication with a neutral line 214, as illustrated in Fig. 3.

Each charger module 121 may also, therefore, have a corresponding output to the energy storage module 11. For example, as illustrated in Fig. 3, the first
20 charger module 121a may have a first output 111 to the energy storage module 11, the second charger module 121b may have a second output 112 to the energy storage module 11, and the third charger module 121c may have a third output 113 to the energy storage module 11. In some versions, the charger modules 121 may share a common output to the energy storage module 11.

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Each charger module 121 may be configured to charge the energy storage module 11, when switched on, by drawing power from its associated phase of the polyphase power supply 21. Each charger module 121 may, therefore, be configured to convert power drawn from the polyphase power supply 21 into a
30 form compatible with the energy storage module 11. For example, each charger module 121 may be configured to convert AC power into DC power for charging the energy storage module 11. Each charger module 121 may also be

configured to charge the energy storage module 11 according to a predefined charging profile, which may include a maximum charging rate and a maximum charge capacity, for example. Each charger module 121 may, therefore, be configured to output power to the energy storage module 11 within predefined
5 voltage and/or current limits, for example.

The energy management module 12 may be configured to adjust the load used to charge the energy storage module 11 on each phase of the polyphase power supply 21 using the charger modules 121. In particular, each charger module
10 121 may be configured to draw an adjustable amount of power from the polyphase power supply 21 to charge the energy storage module 11, and the energy management module 12 may be configured to control the charger modules 121 to balance the load on the polyphase power supply 21 (and this may be by minimising the resultant neutral current as described).

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The energy management module 12 may, therefore, include a controller 122 configured to control the charger modules 121. In some versions, the processing unit 120 and controller 122 may be combined. The controller 122 may, in particular, control the amount of power drawn from the polyphase power
20 supply 21 by each charger module 121 to charge the energy storage module 11.

The energy management module 12 may be configured to adjust the amount of power drawn by each charger module 121 to charge the energy storage module
25 11 to balance the load on the polyphase power supply 21. The energy management module 12 may, therefore, be configured to increase, decrease, or maintain the amount of power drawn by each charger module 121 in order to balance the load on the polyphase power supply 21. The power drawn by each charger module 121 may, as described, be adjusted so as to minimise the
30 resultant neutral current.

In some versions the energy management module 12 may be configured to adjust the load on each phase of the polyphase power supply 21 by switching each charger module 121 on or off. Each charger module 121 may be configured to draw a fixed amount of power from the polyphase power supply 21 when switched on, and switching each charger module on or off may, therefore, provide a simple way to balance the load on the polyphase power supply 21. In some versions, the load may be balanced both by switching each charger module 121 on or off and by adjusting the amount of power drawn from the polyphase power supply 21 by the charger modules 121 that are switched on.

The energy management module 12 may be configured to communicate with a remote device 6 by a wired or wireless communications link. The energy management module 12 may be configured to receive commands from the remote device 6. The commands may include commands to control the charger modules 121. The energy management module 12 may, therefore, control the charger modules 121 according to the received commands. In particular, the energy management module 12 may adjust the amount of power drawn from the polyphase power supply 21 by each charger module 121 according to a command from the remote device 6. The remote device 6 may control the operation of the controller 122 and/or processing unit 120 (e.g. by providing instructions for execution by the controller 122 and/or processing unit 120). The remote device 6 may, therefore, control the operation of the charger modules 121.

The energy management module 12 may be configured to send data to the remote device 6. For example, the energy management module 12 may be configured to send operation data for the charger modules 121 to the remote device 6. This operation data may include data indicating a current or past state of operation of each charger module 121, such as an on/off state of each charger module 121, and/or an amount of power drawn from the polyphase power supply 21 by each charger module 121. The energy management

module 12 may be configured to maintain a log of the operation of the charger modules 121 and to send the operation data from the log to the remote device 6 periodically.

- 5 The energy management module 12 may include at least one communications module 123, which may be configured to communicate with the remote device 6. The communications module 123 may be configured to operate using a LoRaWAN protocol, for example. The communications module 123 may additionally or alternatively be configured to operate using another protocol,
10 such as WiFi or Bluetooth, for example. The remote device 6 may include a corresponding communications module 63 configured to communicate with the energy management module 12 communications module 123.

The energy management module 12, and specifically the communications
15 module 123, may, for example, include a LoRaWAN relay 124, or LoRaWAN remote power switch 124, associated with each charger module 121a, 121b, 121c (see e.g. Fig. 3), which may be configured to switch each charger module on or off in response to commands from the remote device 6. Accordingly, a simple operation of the power distribution system 1 may be provided.

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The polyphase energy meter 30 may be configured to output meter data, as described herein, to the remote device 6. In some versions, therefore, the remote device 6 may use the meter data to determine the resultant neutral current. The remote device 6 may, therefore, control the operation of the
25 energy management module 12 based on the determined resultant neutral current, and may control the energy management module 12 to minimise the resultant neutral current.

The remote device 6 may, therefore, send commands to the energy
30 management module 12 to switch each charger module 121 on or off (and these commands may be implemented by the processing unit 120, controller 122, or LoRaWAN relay or switch 124, for example). Accordingly, the remote

device 6 may control the operation of the energy management module 12, and in particular the charger modules 121, to balance the load on the polyphase power supply 21. The computation required to determine the control strategy for the energy management module 12 may, therefore, be carried out by the
5 remote device 6, which may simplify the requirements for the energy management module 12.

The remote device 6 may be connected, or configured to be connected, by a wired or wireless communications link, to a plurality of energy management
10 modules 12. Thus, the remote device 6 may control a plurality of energy management modules 12. Accordingly, the remote device 6 may carry out the necessary computation to determine the control strategy for a plurality of energy management modules 12, thereby simplifying the requirements for the plurality of energy management modules 12. The remote device 6 may be cloud-based,
15 for example.

The remote device 6 may be configured to receive meter data from a plurality of polyphase energy meters 30, which may each be associated with a polyphase power supply 21. Accordingly, a plurality of polyphase energy meters 30 may
20 each be configured to send meter data, as described herein, to the remote device 6, which may use the meter data for each polyphase power supply 21 to balance the load on each polyphase power supply 21 by controlling the corresponding energy management modules 12 as described herein.

25 The energy management module 12 may store one or more parameters associated with the energy storage module in a memory 125. These parameters may include a minimum and/or maximum target capacity, a charging profile, maximum charge rate, and the like. The energy management module 12 may, therefore, be configured to charge the energy storage module
30 11 when the energy stored in the energy storage module 11 drops below the maximum target capacity, for example. Similarly, the energy management module 12 may be configured to charge the energy storage module 11 such

that the energy stored in the energy storage module 11 is kept above the minimum target capacity.

5 The energy management module 12 may, as illustrated in Fig. 6, be configured to charge the energy storage module 11 when the cost of input energy is below a predetermined threshold value.

For example, as shown in Fig. 6, the energy management module 12 may be configured to determine the current cost of input energy for the power
10 distribution system 1. This input energy may be from the polyphase power supply 21.

The energy management module 12 may be configured to determine the amount of energy stored in the energy storage module 11 and to compare this
15 amount to a threshold value. If the amount of energy stored in the energy storage module 11 falls below the threshold value, the energy management module 12 may be configured to charge the energy storage module 11, regardless of the cost of input energy.

20 If the amount of energy stored in the energy storage module is above the threshold value, the energy management module 12 may be further configured to compare the cost of input energy to a predetermined threshold value. If the cost of input energy is higher (i.e. more expensive) than the predetermined threshold value, the energy management module 12 may be configured not to
25 charge the energy storage module (when the amount of energy stored in the energy storage module 11 is above the associated threshold value). If the cost of input energy is lower (i.e. cheaper) than the predetermined threshold value, the energy management module may be configured to charge the energy storage module 11 (and this charging may be performed even when the amount
30 of energy stored in the energy storage module 11 is above the associated threshold value).

When the energy management module 12 determines that the energy storage module 11 should be charged (e.g. because the amount of energy stored in the energy storage module 11 falls below the associated threshold value or because the cost of input energy falls below the associated threshold value),
5 the energy management module 12 may draw power from the polyphase power supply 21 to charge the energy storage module 11.

The energy management module 12 may, as described, be configured to balance the load on the polyphase power supply 21 when charging the energy
10 storage module 11.

The energy management module 12 may, therefore, determine the resultant neutral current for the polyphase power supply 21. If the resultant neutral current is below a threshold value, the energy management module 12 may
15 determine that the load is balanced. The threshold value may be around 1000 A, around 500 A, around 100 A, around 50 A, around 10 A, around 1 A, around 0.1 A, or around 0.01 A, for example. If the resultant neutral current is above the threshold value, the energy management module 12 may determine that the load is unbalanced. When the load is determined to be unbalanced, the energy
20 management module 12 may adjust the load used to charge the energy storage module 11 on each phase of the polyphase power supply 21 so as to minimise the resultant neutral current, as described.

The energy management module 12 may determine the load on each phase of
25 the polyphase power supply 21 (and this may be done using meter data from the polyphase energy meter 30). The energy management module 12 may compare the load on each phase to determine the phase with the lowest load. The energy management module 12 may then increase the load on the phase with the lowest load to balance the load. Similarly, the energy management
30 module 12 may decrease the load on the phase with the highest load to balance the load. This may include switching on a charger module 121 for the phase with the lowest load and/or switching off a charger module for the phase with

the highest load. This process may be repeated until the load is balanced (i.e. the resultant neutral current falls below the threshold).

As shown in Fig. 6, for a three-phase power supply 21, the energy management
5 module 12 may determine whether the load on a first phase is equal to the load
on a second phase. The loads may be considered equal if they fall within a
predetermined tolerance with respect to each other. The tolerance may be an
absolute value, such as within 100 A or within 10 A, or may be a relative
percentage value, such as if the load on the first phase is within 10% or 5% of
10 the load on the second phase.

If the loads are not equal, the energy management module 12 may determine if
the load on the first phase is greater than the load on the second phase. If the
load on the first phase is greater than the load on the second phase, the
15 amount of power drawn by the charger module 121b associated with the
second phase may be increased. This may involve switching on the charger
module 121b for the second phase. Conversely, the amount of power drawn by
the charger module 121a associated with the first phase may be decreased.
This may involve switching off the charger module 121a for the first phase.

20 If the load on the first phase is equal to the load on the second phase, the
energy management module 12 may determine if the load on the second phase
is equal to the load on the third phase. If the loads are not equal, the energy
management module may determine if the load on the second phase is greater
25 than the load on the third phase. Similarly, if the energy management module
12 determines that the load on the first phase is not equal to the load on the
second phase, and that the load on the first phase is not greater than the load
on the second phase, the energy management module 12 may determine if the
load on the second phase is greater than the load on the third phase.

30 If the load on the second phase is greater than the load on the third phase, the
amount of power drawn by the charger module 121c associated with the third

phase may be increased. This may involve switching on the charger module 121c for the third phase. Conversely, the amount of power drawn by the charger module 121b associated with the second phase may be decreased. This may involve switching off the charger module 121b for the second phase.

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If the load on the second phase is equal to the load on the third phase, the energy management module 12 may determine if the load on the third phase is equal to the load on the first phase. If the loads are not equal, the energy management module may determine if the load on the third phase is greater than the load on the first phase. Similarly, if the energy management module 12 determines that the load on the second phase is not equal to the load on the third phase, and that the load on the second phase is not greater than the load on the third phase, the energy management module 12 may determine if the load on the third phase is greater than the load on the first phase.

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If the load on the third phase is greater than the load on the first phase, the amount of power drawn by the charger module 121a associated with the first phase may be increased. This may involve switching on the charger module 121a for the first phase. Conversely, the amount of power drawn by the charger module 121c associated with the third phase may be decreased. This may involve switching off the charger module 121c for the third phase.

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If the load on the third phase is not greater than the load on the first phase, or the load on the third phase is equal to the load on the first phase, then it may be determined that the load is balanced.

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The energy management module 12 may then repeat the process to monitor the load balancing status of the polyphase power supply 21.

Any computation performed by the energy management module 12 may instead be performed by the remote device 6 and the results sent to the energy management module 12 as described herein.

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The power distribution system 1 may, as described, include an input interface 14. The input interface 14 may be configured to enable the input of energy to the energy storage module 11. The input interface 14 may, therefore, include one or more input ports configured to be connected to the DC power supply 22 and/or polyphase power supply 21. Power input to the power distribution system 1 may, as described, be converted into a form compatible with the energy storage module 11 for charging the energy storage module 11 (e.g. AC power may be converted to DC). The input interface 14 may include one or more circuit breakers.

The power distribution system 1 may include an output interface 15. The output interface 15 may be configured to enable the output of energy from the energy storage module 11. The output interface 15 may, therefore, include one or more output ports configured to be connected to a DC output 16 and/or an AC output 17. The output interface 15 may include one or more circuit breakers.

The power distribution system 1 may include a power conversion module 13. The power conversion module 13 may be connected to the energy storage module 11 and may also be connected to the output interface 15. The power conversion module 13 may be configured to convert DC power from the energy storage module 11 into AC power to be output through the output interface 15. If the energy storage module 11 is configured to output AC power (e.g. generated by a turbine), the power conversion module 13 may then convert the AC power from the energy storage module 11 into DC power to be output through the output interface 15. Fig. 1 illustrates a power conversion module 13 configured to convert DC power from the energy storage module 11 (e.g. a battery) into AC power.

The power conversion module 13 may, therefore, include a rectifier or inverter as required.

The power conversion module 13 may be configured to output single phase AC power or polyphase AC power, such as three-phase power.

5 The power conversion module 13 may be configured to output power only at predetermined times, such as between certain times of day or on certain days of the week. The power conversion module 13 may be configured not to output power at certain times, such as overnight or at weekends. The power conversion module 13 may be configured to output power only when a sensor indicates that a precondition is met. The power conversion module 13 may, 10 therefore, control the status of one or more electrical devices connected to the DC or AC output 16 or 17.

The DC output 16 may include a DC circuit, socket, or similar to enable an electrical device to be powered by the energy storage module 11. The DC 15 output 16 may be electrically isolated from the input power, such as from the DC power supply 22 or polyphase power supply 21.

The AC output 17 may include an AC circuit, socket, or similar to enable an electrical device to be powered by the energy storage module 11. The AC 20 output 17 may be electrically isolated from the input power, such as from the DC power supply 22 or polyphase power supply 21.

An example of an AC output 17 is shown schematically in Fig. 4. The AC output 17 may include a single phase AC output 42, for example, which may be 25 connected in electrical communication with a plurality of circuit breakers 4. Electrical loads, such as from electrical devices 5, may be connected to the AC output via the circuit breakers 4. The AC output 17 may also include a neutral line 41 to complete the circuit.

30 The AC output 17 may, for example, include a building (e.g. residential or commercial building) electrical network or circuit. The power distribution system 1 may, therefore, be installed between a polyphase power supply 21 and a

building electrical network or circuit. The building electrical network or circuit may, therefore, be supplied with power from the energy storage module 11.

The building electrical network or circuit may, in particular, be supplied with power only through the energy storage module 11. This may improve the load
5 balancing on the polyphase power supply 21, which may then be used solely for charging the energy storage module 11.

In some versions the energy storage module 11 may include a plurality of submodules. Each submodule may, therefore, be configured to store energy.

10 The submodules may be configured to store energy by the same or different means (for example, each submodule may include a battery, or a first submodule may include a battery and a second submodule may include a flywheel or other alternative energy storage means).

15 The submodules may be located in different geographical locations with respect to each other (i.e. the submodules may not all be located at the same geographical location).

At least one energy storage submodule may be provided for each phase of the
20 polyphase power supply 21. Each energy storage submodule may be configured to receive power from only one phase of the polyphase power supply 21.

Each energy storage submodule may be associated with a corresponding
25 charger module 121 (which may, therefore, be configured to charge the associated submodule). Each charger module 121 may, therefore, be associated with a corresponding phase of the polyphase power supply 21.

In some versions, therefore, a first energy storage submodule may be
30 configured to store power from a first phase of the polyphase power supply 21. A second energy storage submodule may be configured to store power from a second phase of the polyphase power supply 21. A third energy storage

submodule may be configured to store power from a third phase of the polyphase power supply 21.

5 The energy storage submodules may be connected to a common output, for example through the output interface 15. The energy storage submodules may, therefore, be connected to the DC output 16 and/or AC output 17. In particular, all of the energy storage submodules may, in some versions, be connected to the same output. In other versions, the different energy storage submodules may be connected to different outputs (which may be provided by unique output
10 interfaces for each submodule).

Accordingly, a corresponding power conversion module 13 may be provided for each energy storage submodule in some versions.

15 The power distribution system 1 may, therefore, be used with a polyphase power supply 21 in which single phases are supplied to separate consumers, and may improve the efficiency of power distribution in such cases. This may be the case for residential properties, for example, which typically receive power from a single phase of a polyphase power supply. For example, the energy
20 management module 12 may balance the load on the polyphase power supply 21, as described, by adjusting the load used to charge the energy storage module (comprising the plurality of submodules) on each phase.

In an illustrative example, therefore, a first plurality of consumers may be
25 supplied by a first phase of a three-phase power supply 21. A second plurality of consumers may be supplied by a second phase of the three-phase power supply 21, and a third plurality of consumers may be supplied by a third phase of the three-phase power supply 21. Each phase may have an associated energy storage submodule (which may, as described, be associated with a
30 corresponding charger module 121). The energy storage submodules may together form the energy storage module 11. The energy storage submodules

may, therefore, be located in different geographical locations (e.g. on different streets).

Each plurality of consumers may, therefore, draw power from their
5 corresponding energy storage submodule. Each energy storage submodule
may, as described, be charged using power drawn from its corresponding
phase of the three-phase power supply 21. The charging of the energy storage
submodules may be controlled by the energy management module 12 as
described herein. In particular, the energy management module 12 may
10 balance the load on the three-phase power supply by adjusting the amount of
power drawn from each phase for charging the energy storage module 11 (i.e.
the submodules thereof). This may include switching associated charger
modules on and off as described herein.

15 The power distribution system 1 may, therefore, improve power distribution
efficiency for consumers connected to a single phase of a polyphase power
supply 21.

Fig. 5 illustrates an exemplary application of the power distribution system 1.
20 The energy storage module 11 may, as illustrated, be connected to a polyphase
power supply 21 (e.g. power grid). The energy management module 12 may be
configured to charge the energy storage module 11 using power from the
polyphase power supply 21. The energy management module 12 may,
therefore, convert AC power input to a DC power output.

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The energy storage module 11 may also be connected to one or more DC
power supplies 22, such as solar cells or wind turbines. These may be
configured to charge the energy storage module 11 and a controller 221 may be
provided to control this charging of the energy storage module 11.

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The energy storage module 11 may be configured to output power to a DC
output 16, which may power one or more electrical devices as illustrated. The

energy storage module 11 may also be connected to a power conversion module 13, which may convert DC power from the energy storage module 11 to AC power, for example. The power conversion module 13 may output the AC power to the AC output 17, which may provide power to one or more electrical devices or building electrical networks or circuits, as illustrated.

The power distribution system 1 may, therefore, supplement or replace a conventional power supply for a building, and may improve the load balancing and power distribution efficiency.

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When used in this specification and claims, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or components.

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The invention may also broadly consist in the parts, elements, steps, examples and/or features referred to or indicated in the specification individually or collectively in any and all combinations of two or more said parts, elements, steps, examples and/or features. In particular, one or more features in any of the embodiments described herein may be combined with one or more features from any other embodiment(s) described herein.

20

Protection may be sought for any features disclosed in any one or more published documents referenced herein in combination with the present disclosure.

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Although certain example embodiments of the invention have been described, the scope of the appended claims is not intended to be limited solely to these embodiments. The claims are to be construed literally, purposively, and/or to encompass equivalents.

30

CLAIMS

1. A power distribution system including:
 - an energy storage module configured to receive and store energy from a
 - 5 polyphase power supply;
 - an energy management module comprising charger modules, each associated with each phase of the polyphase power supply, each charger module having a corresponding output to the energy storage module and configured to draw an adjustable amount of power from the polyphase power
 - 10 supply to charge the energy storage module, wherein the power is drawn from its associated phase of the polyphase power supply and wherein the energy management module is configured to determine a load to charge the energy storage module on each phase of the polyphase power supply and balance the load on each phase of the polyphase power supply when charging the energy
 - 15 storage module by adjusting the load drawn by each charger module to charge the energy storage module on each phase so as to minimise a resultant neutral current for the polyphase power supply; and
 - an output interface configured to output power from the energy storage module, wherein the output power is electrically isolated from the power supply.
 - 20
2. The power distribution system according to claim 1, wherein adjusting the load used to charge the energy storage module includes switching each charger module on or off.
- 25 3. The power distribution system according to any preceding claim, wherein the energy management module is configured to determine the resultant neutral current using meter data obtained from a polyphase energy meter connected to the polyphase power supply.
- 30 4. The power distribution system according to any preceding claim, wherein the energy management module includes at least one communications module configured to receive commands to adjust the load on at least one phase of the

polyphase power supply from a remote device, and the energy management module is further configured to adjust the load on the at least one phase of the polyphase power supply according to the received commands.

5 5. The power distribution system according to claim 4, wherein the communications module is configured to operate using a LoRaWAN protocol.

6. The power distribution system according to any preceding claim, wherein the energy management module is configured to convert AC power from the
10 polyphase power supply to DC power for charging the energy storage module.

7. The power distribution system according to any preceding claim, wherein the output interface includes a DC power output configured to output DC power from the energy storage module.

15 8. The power distribution system according to any preceding claim, further including a power conversion module configured to convert DC power from the energy storage module to AC power, and wherein the output interface includes an AC power output.

20 9. The power distribution system according to any preceding claim, wherein the energy storage module is further configured to receive and store energy from a DC power supply.

25 10. The power distribution system according to claim 9, further including a solar cell or wind turbine configured to charge the energy storage module.

11. The power distribution system according to any preceding claim, wherein the energy storage module includes a lithium iron phosphate battery.

30 12. The power distribution system according to any preceding claim, wherein the polyphase power supply is a three-phase power supply.

13. A method of distributing power, including:

charging an energy storage module from a polyphase power supply by drawing an adjustable amount of power from the polyphase power supply to

5 charge the energy storage module, wherein the power is drawn from its an associated phase of the polyphase power supply to charge the energy storage module;

determining a load to charge the energy storage module on each phase of the polyphase power supply;

10 balancing, using an energy management module, the load on each phase of the polyphase power supply, when charging the energy storage module, by adjusting the load used to charge the energy storage module on each phase so as to minimise a resultant neutral current for the polyphase power supply; and

15 outputting power from the energy storage module through an output interface, wherein the output power is electrically isolated from the power supply.

14. The method according to claim 13, wherein adjusting the load used to
20 charge the energy storage module on each phase includes switching respective charger modules associated with each phase of the polyphase power supply on or off, wherein the charger modules are configured to charge the energy storage module.

25 15. The method according to any one of claims 13 to 14, wherein the resultant neutral current is determined using meter data obtained from a polyphase energy meter connected to the polyphase power supply.

16. The method according to any one of claims 13 to 15, further including
30 receiving from a remote device, using a communications module of the energy management module, a command to adjust the load on at least one phase of

the polyphase power supply, and adjusting the load on the or each phase of the polyphase power supply according to the received command.

17. The method according to any one of claims 13 to 16, including converting,
5 using the energy management module, AC power from the polyphase power supply to DC power for charging the energy storage module.

18. The method according to any one of claims 13 to 17, wherein the output
10 interface includes a DC power output configured to output DC power from the energy storage module.

19. The method according to any one of claims 13 to 18, further including
converting, using a power conversion module, DC power from the energy
storage module to AC power, and outputting the AC power through an AC
15 power output of the output interface.

20. The method according to any one of claims 13 to 19, further including
charging the energy storage module using a DC power supply.