(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 December 2024 (12.12.2024)

WIPO | PCT

(10) International Publication Number
WO 2024/251959 A1

(51) International Patent Classification:
F24H 9/20 (2022.01) *H02J 3/28* (2006.01) *H02H 1/00* (2006.01) *H02J 7/00* (2006.01) *H02H 3/087* (2006.01) *H05B 1/02* (2006.01) *H02J 1/14* (2006.01) *G06F 1/28* (2006.01) *H02J 3/14* (2006.01)

(21) International Application Number: PCT/EP2024/065758

(22) International Filing Date: 07 June 2024 (07.06.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2035048 08 June 2023 (08.06.2023) NL

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY,

(54) Title: SYSTEM AND METHOD OF CONTROLLING A HOT WATER ENERGY STORAGE SYSTEM

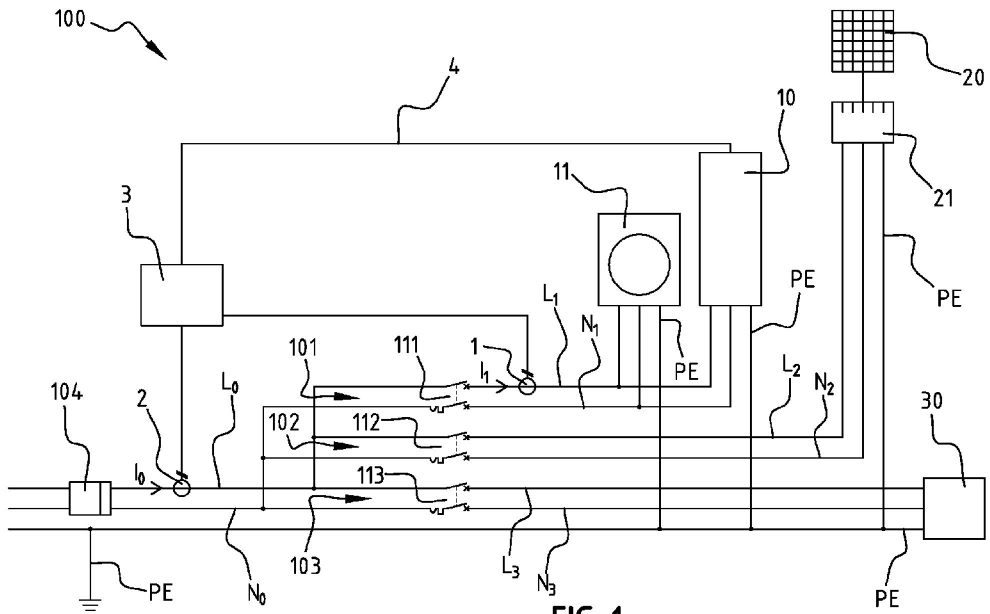

FIG. 1

(57) Abstract: Method of controlling a hot water energy storage system comprising an electrical heater for heating a volume of water, wherein the method comprises the steps of: - providing an electrical system comprising an electrical circuit and at least one load device, the electrical circuit being connected to an external electrical network such as a mains and to the at least one load device, wherein the electrical circuit comprises a main power input/output for connection to the external electrical network and a first power output for powering the at least one load device, and wherein the electrical circuit is provided with an overcurrent protection device, such as a circuit breaker, arranged between the power input/output and the first power output, wherein the overcurrent protection device is arranged to interrupt the current flowing though it when said current exceeds a predefined maximum current threshold; - providing the electrical heater in parallel to the at least one load device on the first power output; - monitoring the current at the first power

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MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

output of the electrical circuit; - determining, based on the monitored output current and the predefined maximum current threshold, an unused current amount representative for an amount of current still allowable at the first power output without exceeding the predefined maximum current threshold; and - controlling the electrical heater on the basis of the determined unused current amount. An associated control system and a method of installing a hot water energy storage system in an existing system are also described.

System and method of controlling a hot water energy storage system

The present invention relates to a method of controlling a hot water energy storage system comprising an electrical heater for heating a volume of water. The present invention further relates to a system for controlling such a hot water energy storage system.

The energy sector is turning towards renewable energy sources to support the energy transition from fossil-fuel to carbon-free energy solutions. Renewable energy sources such as solar, wind and hydro-powered sources are typically fluctuating energy sources. The irregular energy production of renewable energy sources brings with it the issue of managing the balance between the supply and the demand at the local level and at the network level.

A well-known challenge in the field is thus, in times of overproduction, the prolonged energy storage of the produced energy with a minimal energy loss. Among the storage options, electrical battery systems such as lithium-ion battery energy storage systems, and power conversion into chemicals (Power-to-X) or into heat (Power-to-Heat) are being investigated. Storage options based on conversion to heat use typically sensible heat storage, wherein heat is stored in a fluid contained in a reservoir. In sensible heat storage, heat is stored in a medium using the intrinsic heat capacity (C_p) of the medium. In contrast to latent heat storage and thermochemical storage, the medium in sensible heat storage typically does not undergo a chemical and/or phase change. Sensible heat storage has the advantage over thermochemical heat storage and latent heat storage that it allows for relatively simple systems as no multiphase physics, complex kinetics etc. are involved. One method for storing sensible heat is in the form of hot water tanks.

In such a hot water energy storage system, the water in the tank may be heated by an electrical heater and the energy can be stored for multiple days, typically up to five days in domestic hot water tanks. This enables the water to be heated whenever the real-time electricity prices are low due to, e.g., a renewable power generation surplus, such that the stored hot water can be cheaply consumed irrespective of the electricity prices.

The power use of such an electrical heater is considerable in comparison with domestic appliances. Therefore, when employed domestically, the electrical heater for heating the stored water is conventionally connected to a dedicated electrical circuit of a distribution board, i.e., an electrical group to which only the electrical heater is connected, wherein an electrical group is defined as the (domestic) electrical subsystem that is arranged after a circuit breaker protecting that electrical group. That is, an electrician would consider it self-evident to dedicate an electrical circuit entirely to the electrical heater to prevent that a simultaneous activation of both the electrical heater and another device would cause the respective circuit breaker to trip. Therefore, an additional electrical group is typically to be added when retrofitting such a hot water energy storage system in an existing system, but this may not always be possible in practice nor desirable in terms of costs. This raises the threshold for adopting hot water energy storage systems domestically in terms of costs and/or technical feasibility.

It is therefore an object of the present invention, amongst other objects, to at least alleviate the aforesaid drawbacks of conventional hot water energy storage systems, in particular to facilitate the installation and control of such a hot water energy storage system in existing systems.

To that end, a method of controlling a hot water energy storage system comprising an electrical heater for heating a volume of water, is provided, wherein the method comprises the steps of:

- providing an electrical system comprising an electrical circuit and at least one load device, the electrical circuit being connected to an external electrical network such as a mains and to the at least one load device, wherein the electrical circuit comprises a main power input/output for connection to the external electrical network and a first power output for powering the at least one load device, and wherein the electrical circuit is provided with an overcurrent protection device, such as a circuit breaker, arranged between the power input/output and the first power output, wherein the overcurrent protection device is arranged to interrupt the current flowing though it when said current exceeds a predefined maximum current threshold;
- providing the electrical heater in parallel to the at least one load device on the first power output;
- monitoring the current at the first power output of the electrical circuit;
- determining, based on the monitored output current and the predefined maximum current threshold, an unused current amount representative for an amount of current still allowable at the first power output without exceeding the predefined maximum current threshold; and
- controlling the electrical heater on the basis of the determined unused current amount.

By controlling the electrical heater based on an amount of current available on an existing power output without triggering the circuit breaker, the electrical heater can be connected to a non-dedicated electrical group, i.e. to an already existing electrical group powering an existing load device, such that an additional electrical group does not have to be added necessarily when installing the hot water energy storage system. An electrical group is defined as a sub circuit with a dedicated circuit breaker for protecting any load of said sub circuit located downstream of said circuit breaker. Consequently, the installation of such a hot water energy storage system can be facilitated.

As mentioned above, the hot water energy storage system may comprise a water tank, wherein the electrical heater is arranged to heat a volume of water in the water tank. The electrical heater may typically comprise an electrical heating resistance. The at least one load (device) of the electrical system may be any electrical power consuming device, such as for example a washing machine, an oven, a dishwasher, etc.

The electrical system may receive AC power from the main power input/output. The main power input/output may be connected to the grid or to another AC source. The power consumption at the main power input/output may vary over time in dependence of the power use of the devices (whether load devices or source devices) connected to the electrical circuit. As mentioned above, the electrical system may typically be divided into a plurality of electrical subsystems, also called groups. Each group may be provided with a dedicated circuit breaker and may be associated with at least one device. The electrical system comprises at least one load device powered from one power output of the electrical circuit. As discussed previously, when retrofitting the hot water energy storage system into an existing electrical system, the water boiler may be connected to an existing group powering an existing load. In such a case, the electrical heater may be connected directly in parallel with the existing load at the power output associated with said load. Similarly, when designing a new (domestic) electrical system, at least one load and the electrical heater may be connected in parallel on the power output of a single group, both load and electrical heater being associated with a single circuit breaker. A skilled person may further envisage placing further loads in parallel on that group.

The real time electrical current within the electrical group holding the hot water energy storage system may then be monitored. More specifically, according to a preferred embodiment of the method, the real time current within the electrical group comprising the electrical heater may be sensed by a sensor, preferably a current clamp, installed around a cable of the electrical circuit in the vicinity of the circuit breaker of the group. In this manner, the current measurement can advantageously take place at the electrical cabinet, i.e., close to the distribution board where the circuit breaker is installed. When talking about the current at the power output powering the parallel loads, one will realize that said current is basically the current flowing through the circuit breaker associated with these loads, so monitoring the current at the power output amounts to monitoring the operational status of the overcurrent protection device.

It is noted that, instead of a direct sensing, the current at the power output may be calculated, estimated or extrapolated, for instance based on the current in the electrical heater and the current in the at least one load. A skilled person can envisage different solutions for monitoring the current flowing through the overcurrent protection devices without inventive step, by varying the type, number and locations of the sensors within the system.

Once monitored, the actual electrical current is compared to the maximum (or nominal) current that may flow through the circuit breaker, to determine an unused current amount of the group associated with that circuit breaker. The electrical heater can then be controlled to use no more than the unused current amount for heating the water. In this way, the operation of the electrical heater may be transparent for the other loads on the same power output, since the electrical heater under normal operation would not trigger the protection device.

The predefined maximum current threshold may be defined such that a nominal current of the circuit breaker can be briefly exceeded, i.e., for a period of up to 30 seconds. That is, the overcurrent protection device may be a time-delay circuit breaker which allows a certain period and amount of overcurrent before it interrupts the current therethrough. By adapting the sampling time of the monitoring and the dynamic of the determining and controlling steps, to the time/current behavior of the overcurrent protection device, it can be made sure that under normal operation, the protection device is not triggered by the operation of the electrical heater.

For example, the circuit breaker may be a thermal magnetic circuit breaker. Specifically, the circuit breaker has tripping characteristic B. Such circuit breakers are commonly used in socket outlets and lighting circuits. For example, the circuit breaker trips about instantaneously when the current is approximately 3 to 5 times the rated current. In addition, the circuit breaker trips once the current is about 1.5 times the rated current for an uninterrupted period of between 1 and 10 minutes. Furthermore, the circuit breaker does not trip while the current is up to about 1.13 times the rated current.

Thermal energy storage can be used for balancing local energy supply and demand, in particular for peak shaving of typically intermittent renewable power generators such as photovoltaic panels. The water in the tank may then be heated whenever an on-site renewable power generation system generates a surplus of electrical power, and optionally depending on the actual energy pricing.

Specifically, according to a further preferred embodiment, the method further comprises the steps of:

- providing an on-site electrical power generation system for generating electrical power, such as a photovoltaic system comprising at least one solar panel and a power converter (inverter for converting Dc power into Ac power), wherein the electrical circuit further comprises an additional power input for connection to the on-site electrical power generation system and wherein the electrical circuit is further configured for supplying the generated electrical power from the additional power input to the main power input/output and/or to the first power output, preferably through an additional overcurrent protection device;
- monitoring the electrical power at the main power input/output;
- adapting the control of the electrical heater on the basis of the monitored electrical power at the main power input/output.

In other words, the local energy system (comprising the electrical system, the hot water energy storage system and the on-site electrical power generation system) may be connected to a public energy grid for taking electrical energy from, and supplying electrical energy to, said public energy grid. When electrical power can be supplied to the public grid due to a surplus of generated renewable power, the electrical heater is preferably controlled to use no more than the surplus amount of the electrical power for heating the water. This way, it can be ensured that the hot water energy storage system functions as a local preferred buffer for the on-site power generator by only using power when there is a surplus of power generated locally, instead of being a load for which power is to be taken from the public grid.

The hot water energy storage system can be optionally used in combination with an electrical battery storage system connected to the electrical system. As such, according to a further embodiment, the method further comprises the steps of:

- providing an electrical battery storage system for storing electrical energy, wherein the electrical battery storage system is connected to the electrical system in parallel to the electrical heater;
- controlling the electrical battery storage system on the basis of the determined unused current amount, and optionally on the basis of any one or more of the monitored electrical power at the main power input/output, the state of charge of the hot water energy storage system, the state of charge of the electrical battery storage system.

When controlling the electrical battery storage system, its charge or discharge rate is controlled, preferably also on the basis of a state of charge of the electrical battery storage system. Optionally, the state of charge of the hot water energy storage system may also be taken into account for the control of the electrical battery storage system. The state of charge of the electrical battery storage system may for example be controlled according to weighted priorities between the available current, and the states of charge of both the hot water energy storage system and the electrical battery energy storage system, The electrical battery storage system may be connected to the same electrical circuit as the hot water energy storage system or to another electrical circuit of the electrical system. The electrical battery storage system may comprise, e.g., a lithium-ion battery home energy storage system.

It is then preferred if the controller is configured to control the electrical battery storage system and the electrical heater such that the electrical battery storage system is fully charged before powering the electrical heater or, alternatively, such that the power use of the electrical heater reaches its maximum before charging the electrical battery storage system. Alternatively, the same method of control may be applied to an electrical battery storage system used on its own and connected in the same way as the hot water energy storage system into an existing system, in which case when electrical power can be supplied to the public grid due to a surplus of generated renewable power, the electrical battery storage system is preferably controlled to use no more than the surplus amount of the electrical power for storing energy. More generally, the same method of power control of an auxiliary energy storage system connected in parallel to an existing load in an existing electrical system may be used as long as the same concept of an intelligent control to store energy into the auxiliary energy storage up to an amount allowed by the circuit breaker associated to that load, is concerned. Any type of energy storage system may benefit from that control method for retrofit purposes.

According to an embodiment, monitoring the electrical power at the main power input/output comprises:

- sensing in real time the current I_0 flowing at the main power input/output with a current sensor, preferably with a clamp, and
- determining a surplus amount of electrical current I_s according to the following equations: when $I_0(t) \geq 0$, $I_s(t) = 0$ and when $I_0(t) < 0$, $I_s(t) = -I_0(t)$, wherein $I_0(t)$ denotes the current at the main power input/output and $I_s(t)$ denotes the surplus amount of electrical current at an instant t.

That is, I_0 is positive when the current at the main power input/output flows from the external electrical network to the electrical system, i.e. when the external electrical network operates as a source delivering power to the electrical system. In comparison, Io is negative when the current at the main power input/output flows towards the external electrical network, i.e. when the electrical system operates as a source delivering power to the external electrical network.

In this way, the flow of power at the main power input/output can be easily monitored. Yet the flow of power could also be deduced, calculated, extrapolated from other sensed variables within the system, like for instance the current in each group of the electrical circuit.

According to another embodiments, adapting the control of the electrical heater on the basis of the monitored electrical power at the main power input/output comprises determining a target current for the electrical heater I_t according to the following equations:

when $I_s(t) = 0$ or $I_s(t) > I_u(t)$, $I_t(t+1) = I_t(t) + \quad I_u(t)$

when $0 < I_s(t) < I_u(t)$, $I_t(t+1) = I_t(t) + I_s(t)$

wherein I_t (t) denotes the target current for the electrical heater at a control instant t in time, I_t (t+1) denotes the target current through the electrical heater at the next control instant (t+1) in time, I_s (t) denotes the surplus amount of current at a control instant t and I_u (t) denotes the unused current amount at an instant t.

In this way, the target current for the electrical heater can be easily set to fulfill the protection requirement of the group holding it and make the best use of the energy regenerated by the on-site electrical power generation system. In this way, the adoption of both domestic renewable energy sources and hot water energy storage can be facilitated while optimizing the benefits of both. It is further noted that extra and/or alternative control rules may influence the selection of a target current for the electrical heater. It may for instance be preferred when I_0 is positive ($I_s(t) = 0$) to reduce the target current $I_t(t+1)$ such as to reduce I_0 down to zero, in order to minimize costs. Further the target current may for instance be controlled to ensure that the current flowing through any wire of a portion of the electrical circuit associated with the circuit breaker (i.e. the group holding the hot water energy storage system and/or the electrical battery energy storage system) does not exceed the predefined maximum current threshold.

According to another aspect, the present invention also relates to a system configured for executing the method described above. Hereto, a control system for controlling a hot water energy storage system comprising an electrical heater for heating a volume of water, is provided for use in an electrical system comprising an electrical circuit and at least one load device, the electrical circuit being connected to an external electrical network such as a mains and to the at least one load device, wherein the electrical circuit comprises a main power input/output for connection to the external electrical network and a first power output for powering the at least one load device, and wherein the electrical circuit is provided with an overcurrent protection device, such as a circuit breaker, arranged between the power-input/output and the first power output, wherein the overcurrent protection device is arranged to interrupt the current flowing though it when said current exceeds a predefined maximum current threshold, wherein the electrical heater is connected in parallel to the at least one load device on the first power output; wherein the control system comprises:

- a first monitoring device for monitoring the current at the first power output of the electrical circuit;
- a processor configured for receiving the monitored output current and the predefined maximum current threshold, and for determining based thereon an unused current amount representative for an amount of current still allowable at the first power output without exceeding the predefined maximum current threshold;
- a controller in communication with the processor and configured for controlling the electrical heater on the basis of the determined unused current amount.

This allows to integrate the hot water energy storage system into an existing local electricity distribution system having a plurality of occupied electrical groups, wherein each group is defined by its own circuit breaker, without the need to add an additional group, and thus an additional circuit breaker, as the system ensures that the current passing through the respective circuit breaker, to which the hot water storage system is connected, does not exceed the maximum allowable current.

According to a preferred embodiment of the system, the first monitoring device is a current sensor, preferably a clamp, for sensing the current at the first power output flowing through the overcurrent protection device. In this way, the current may be easily monitored. Alternatively, the current may be obtained indirectly from other measured, estimated, extrapolated data from the system.

According to a preferred embodiment, the processor comprises a comparator for comparing the current sensed at the first power output with the predefined maximum current threshold. Via a comparator, the unused current amount may easily be determined.

According to a preferred embodiment, the controller is configured for regulating the current to the electrical heater to remain under the determined unused current amount, preferably the controller is configured for setting a target current of the electrical heater based on the determined unused current amount. In this way, the addition of the electrical heater may remain transparent to the rest of the system.

According to a preferred embodiment, the electrical system further comprises an on-site electrical power generation system for generating electrical power, such as a photovoltaic system comprising solar panels,

- wherein the electrical circuit further comprises an additional power input for connection to the on-site electrical power generation system and wherein the electrical circuit is further configured for supplying the generated electrical power from the additional power input to the main power input/output and/or to the first power output;
- wherein the control system further comprises a second monitoring device for monitoring the electrical power supplied at the main power input/output;
- wherein the processor is further configured for adapting the control of the electrical heater on the basis of the monitored electrical power at the main power input/output.

This allows to optimize the energy management within the local energy system. The electrical heater may be indeed preferably controlled to use no more than the surplus amount of the electrical power for heating the water. This way, it can be ensured that the hot water energy storage system functions as a local preferred buffer for the on-site power generator by only using power when there is a surplus of power generated locally, instead of being a load for which power is to be taken from the public grid. The power consumption from the external network and thus the associated costs can thus be mitigated.

According to another aspect of the invention, a method of installing a hot water energy storage system comprising an electrical heater (10) for heating a volume of water in an existing electrical system is provided. The existing electrical system comprises an existing electrical circuit and at least one existing load device, the existing electrical circuit being connected to an external electrical network such as a mains and to the at least one existing load device, wherein the existing electrical circuit comprises a main power input/output for connection to the external electrical network and a first power output for powering the at least one existing load device, and wherein the existing electrical circuit is provided with an existing overcurrent protection device, such as a circuit breaker, arranged between the power-input/output and the first power output, wherein the existing overcurrent protection device is arranged to interrupt the current flowing though it when said current exceeds a predefined maximum current threshold. The method of installing comprises the steps of:

- connecting the electrical heater in parallel to the at least one existing load device on the first power output of the existing electrical circuit;
- installing a control system according to any of the above control system claims.

In this way, no modification of the existing system is required and the hot water energy storage can be electrically retrofitted at low costs.

According to an embodiment, the electrical heater may be physically installed in the vicinity of the at least one load device, while the control system may be physically installed in the vicinity of the overcurrent protection device. The electrical heater is associated with a tank of water and requires typically a rather consequent amount of installation space, like an attic, a garage, a utility room, and may typically be physical arranged close to a washing machine having similar space requirements. In the installation space, the power output cables may not be easily accessible (cabling in the walls) but an easy connection to the power output may well be available (plug in the wall). The overcurrent protection device is typically located in an electrical cabinet at the entrance of the premises with cables leaving said electrical cabinet which are typically easily accessible and identifiable for each group. By installing the electrical heater in the vicinity of the load device and the control system in the electrical cabinet, a simple, practical and unintrusive installation method is offered. Wireless communication in between the electrical heater and the control system may further avoid any large cable laying on the premises.

The present invention is herein further elucidated with reference to the attached drawing. Figure 1 schematically represents an electrical system 100 comprising a first electrical circuit 101, a second electrical circuit 102 and a third electrical circuit 103. Each electrical circuit 101, 102, 103 is provided with a double pole circuit breaker 111, 112, 113 and comprises a current carrying conductor L_1, L_2, L_3 that carries current from the respective circuit breaker 111, 112, 113 to electric loads connected to that circuit, and a current returning conductor N_1, N_2, N_3 that returns current to the circuit breaker 111, 112, 113. The circuit breakers 111, 112, 113 are connected to an AC source, for instance the public grid, via main conductors L_0 and N_0 (defining a main input/output) and a kilowatt-hour meter 104, for instance a smart meter. Each circuit breaker 111, 112, 113 interrupts the current therethrough when the current exceeds a respective predefined maximum current threshold.

A hot water energy storage system 10 that includes a water tank and an electrical (variable-power) heater for heating a volume of water in the tank is connected to the first electrical circuit 101. In addition, washing machine 11 is connected to the first electrical circuit 101. The conductors L_1 and N_1 define the power output of the first electrical circuit 101, to which the hot water energy storage system 10 and the washing machine 11 are connected in parallel.

A photovoltaic system, comprising a photovoltaic module 20 and an inverter 21, is connected to the second electrical circuit 102 via the inverter 21 for supplying generated electrical power to the grid by means of the main conductors L_2 and N_2. One or more other loads, schematically represented as a single load 30, are similarly connected to the third electrical circuit 103. The various loads 10, 11, 30 and the photovoltaic system 20, 21 are provided with a protective earthing PE.

A first current sensor, typically a clamp, 1 is installed around the current carrying conductor L_1 of the first electrical circuit 101 and is configured to measure the current I_1 through the first current carrying conductor L_1. A second current sensor 2, typically a clamp, is installed around the main current carrying conductor L_0 and is configured to measure the current I_0 through the main current carrying conductor L_0, i.e., from the grid to the electrical circuits 101, 102, 103. The sensors 1, 2 are connected to a processing and control module 3 in communication with the hot water storage system 10 via a (optionally wireless) connection 4.

In case the meter 104 is a smart meter, the smart meter 104 may be connected to the processing and control module 3 and configured to measure the current I_0 through the main current carrying conductor L_0 such that the second clamp 2 can be omitted. The smart meter 104 then functions as the second current sensor.

Furthermore, instead of wireless communication, the connection 4 may use power-line communication (PLC). In this way, data may be communicated via the conductors of the electrical system 100, ie the communication may be performed over the existing electrical wires within the building in which the electrical system 100 is arranged.

The processing and control module 3 is configured to calculate, based on the predefined maximum current of the first circuit breaker 111 and the measured current through the first current carrying conductor L_1, an unused current amount representing an amount of current that still can be potentially consumed (consumable) at the first power output without exceeding the predefined maximum current threshold of the first circuit breaker 111. The unused current amount may be calculated using the following equation wherein I_u (t) denotes the unused current amount at an instant t, I_{max} denotes the predefined maximum current, and I_1 (t) denotes the current through the first current carrying conductor L_1 at an instant t :

$$I_u(t) = I_{max} - I_1(t)$$

The processing and control module 3 is further configured to calculate, based on the measured current I_0 through the main current carrying conductor L_0 a surplus amount of electrical current. That is, when the photovoltaic system 20, 21 generates and supplies more current to the electrical system 100 than used by the loads 10, 11, 30, the current through the main current carrying conductor L_0 would be negative. In other words, a surplus amount of electrical current may be monitored by detecting when the current I_0 through the main conductor flows from the electrical circuit 100 towards the external network connected to the main input/output Lo and No, i.e. in the example of a domestic installation connected to a grid, towards the grid upstream of the kilowatt-hour meter 104. When monitoring the current $I_0(t)$ through the current sensor 2, the direction of the power flow between the external network and the local network may be established and be described according to the following equations:

- when $I_0(t) \geq 0$, $I_s(t) = 0$ and
- when $I_0(t) < 0$, $I_s(t) = - I_0(t)$

The current through the electrical heater may be controlled (open loop or closed loop regulation) to follow a target. The processing and control module 3 is configured to then control the target current I_t of the water heater of the hot water storage energy system 10 on the basis of the surplus amount of electrical current I_s and the unused current amount I_u using for example the following equations, wherein I_t (t) denotes the target current for the electrical heater at a control instant t in time, I_t (t+1) denotes the target current through the electrical heater at the next control instant (t+1) in time, I_s (t) denotes the surplus amount of current at a control instant t and I_u (t) denotes the unused current amount at an instant t :

- when I_s (t)= 0 or when $I_s(t) > I_u(t)$, $I_t(t+1) = I_t(t) + I_u(t)$
- when $0 < I_s(t) < I_u(t)$, $I_t(t+1) = I_t(t) + I_s(t)$

The surplus amount of current I_s and the unused current amount I_u may thus be used as thresholds for determining the maximum heating power (current) of the boiler. It is noted that the processor and the controller may be incorporated in a single element or in separate elements, which need not be collocated. The processor and/or controller may each be housed either in the vicinity of the electrical heater or in the vicinity of the protection device, depending on circumstances.

According to the previous equations, all the surplus current may be transferred to the water heater rather than the external network. Yet, based on the electricity pricing, a different strategy may be selected to rather prioritize redistribution to the external network if financially more interesting. As a further alternative, a weighted system between redistribution to the external network, and local use by the water heater may be envisaged taking into account real time electricity pricing information.

Although schematically shown separated in Figure 1, the sensors 1, 2, the processing and control module 3, the meter 104 and the circuit breakers 111, 112, 113 may be conveniently arranged in a single electrical cabinet.

Instead or in addition of a hot water energy storage system 10, an electrical battery storage system may be connected to the first electrical circuit 101 in the same way as the hot water energy storage system 10 in which case the electrical battery storage system may be as well controlled on the basis of the determined unused current amount. For instance, when electrical power can be supplied to the public grid due to a surplus of generated renewable power, the electrical battery storage system 10 may be controlled on the basis of the determined unused current amount to charge the electrical battery storage up to an amount of current still allowable at the first power output without exceeding the predefined maximum current threshold.

More generally, when more than one storage system would be available, the amount of current consumed or generated by each storage system should further be taken into account when deciding how to control each storage systems. For instance when an electrical battery system may be delivering power (to the hot water storage system), the amount of current delivered by the electrical battery system may be taken into account in the control equations of the hot water storage system, since this added current would be transparent to the first circuit breaker 111. For that purpose an additional sensor sensing the current flowing to/from the electrical battery storage system may be used. An electrical battery storage system may indeed (contrary to a hot water storage system) operate electrically in the electrical circuit 101 both as a source or as a load. Depending on the status of the battery storage system (load or source), the control of the current through the electrical heater may thus be adapted according to other equations/control schemes as long as the concept of keeping the current flowing through the first circuit breaker 111 under its predefined maximum current I_{max} is kept.

The electrical battery storage system and/or the hot water energy storage system 10 can be similarly installed as described above in a three-phase electrical system.

The present invention is not limited to the shown embodiment but extends also to other embodiments falling within the scope of the appended claims.

CLAIMS

1. Method of controlling a hot water energy storage system comprising an electrical heater for heating a volume of water, wherein the method comprises the steps of:
- providing an electrical system comprising an electrical circuit and at least one load device, the electrical circuit being connected to an external electrical network such as a mains and to the at least one load device, wherein the electrical circuit comprises a main power input/output for connection to the external electrical network and a first power output for powering the at least one load device, and wherein the electrical circuit is provided with an overcurrent protection device, such as a circuit breaker, arranged between the power input/output and the first power output, wherein the overcurrent protection device is arranged to interrupt a current flowing though it when said current exceeds a predefined maximum current threshold;
- providing the electrical heater in parallel to the at least one load device on the first power output;
- monitoring a current at the first power output of the electrical circuit;
- determining, based on the monitored output current and the predefined maximum current threshold, an unused current amount representative for an amount of current still allowable at the first power output without exceeding the predefined maximum current threshold; and
- controlling the electrical heater on the basis of the determined unused current amount.

2. Method according to claim 1, wherein monitoring the current at the first power output of the electrical circuit comprises sensing in real time the current flowing through the overcurrent protection device with a current sensor, preferably with a clamp.

3. Method according to the previous claim, wherein determining the unused current amount comprises comparing the current sensed at the first power output with the predefined maximum current threshold.

4. The method of any of the above claims, wherein controlling the electrical heater on the basis of the unused current amount comprises regulating the current to the electrical heater to remain under the determined unused current amount, preferably by setting a target current of the electrical heater based on the determined unused current amount.

5. Method according to any of the above claims, further comprising the steps of:
- providing an on-site electrical power generation system for generating electrical power, such as a photovoltaic system comprising at least one solar panel and a power converter,
- wherein the electrical circuit further comprises an additional power input for connection to the on-site electrical power generation system and wherein the electrical circuit is further configured for supplying the generated electrical power from the additional power input to the main power input/output and/or to the first power output, preferably through an additional overcurrent protection device (102);
- monitoring an electrical current at the main power input/output;
- adapting the control of the electrical heater on the basis of the monitored electrical current at the main power input/output.

6. Method according to the previous claim, further comprising the steps of:
- providing an electrical battery storage system for storing electrical energy, wherein the electrical battery storage system is connected to the electrical system in parallel to the electrical heater;
- controlling the electrical battery storage system on the basis of the determined unused current amount, and optionally on the basis of any one or more of : the monitored electrical current at the main power input/output, a state of charge of the hot water energy storage system, a state of charge of the electrical battery storage system, an electrical current flowing from/to the electrical battery storage system.

7. Control system for controlling a hot water energy storage system comprising an electrical heater for heating a volume of water, for use in an electrical system comprising an electrical circuit and at least one load device, the electrical circuit being connected to an external electrical network such as a mains and to the at least one load device, wherein the electrical circuit comprises a main power input/output for connection to the external electrical network and a first power output for powering the at least one load device, and wherein the electrical circuit is provided with an overcurrent protection device, such as a circuit breaker, arranged between the power-input/output and the first power output, wherein the overcurrent protection device is arranged to interrupt the current flowing though it when said current exceeds a predefined maximum current threshold, wherein the electrical heater is connected in parallel to the at least one load device on the first power output; wherein the control system comprises:
- a first monitoring device for monitoring the current at the first power output of the electrical circuit;

- a processor configured for receiving the monitored output current and the predefined maximum current threshold, and for determining based thereon an unused current amount representative for an amount of current still allowable at the first power output without exceeding the predefined maximum current threshold; and
- a controller in communication with the processor and configured for controlling the electrical heater on the basis of the determined unused current amount.

8. Control system according to the previous claim, wherein the first monitoring device is a current sensor, preferably a clamp, for sensing the current at the first power output flowing through the overcurrent protection device.

9. Control system according to the previous claim, wherein the processor comprises a comparator for comparing the current sensed at the first power output with the predefined maximum current threshold.

10. Control system of any of the above control system claims, wherein the controller is configured for regulating the current to the electrical heater to remain under the determined unused current amount, preferably the controller is configured for setting a target current of the electrical heater based on the determined unused current amount.

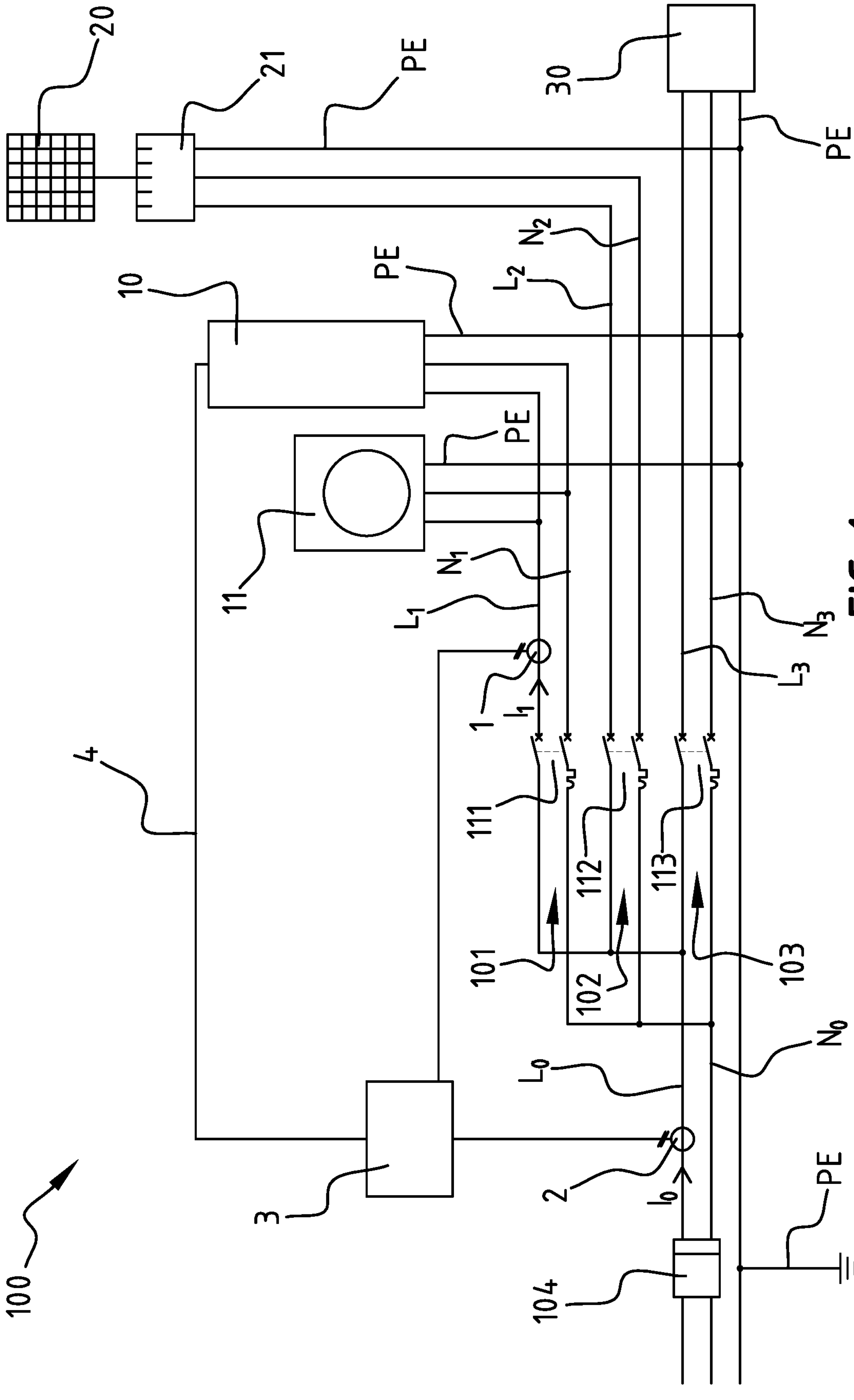
11. Control system according to any of the above control system claims,
- wherein the electrical system further comprises an on-site electrical power generation system for generating electrical power, such as a photovoltaic system comprising solar panels,
- wherein the electrical circuit further comprises an additional power input for connection to the on-site electrical power generation system and wherein the electrical circuit is further configured for supplying the generated electrical power from the additional power input to the main power input/output and/or to the first power output;
- wherein the control system further comprises a second monitoring device for monitoring the electrical power supplied at the main power input/output;
- wherein the processor is further configured for adapting the control of the electrical heater on the basis of the monitored electrical power at the main power input/output.

12. Method of installing a hot water energy storage system comprising an electrical heater (10) for heating a volume of water in an existing electrical system, said existing electrical system comprising an existing electrical circuit and at least one existing load device, the

existing electrical circuit being connected to an external electrical network such as a mains and to the at least one existing load device, wherein the existing electrical circuit comprises a main power input/output for connection to the external electrical network and a first power output for powering the at least one existing load device, and wherein the existing electrical circuit is provided with an existing overcurrent protection device, such as a circuit breaker, arranged between the power-input/output and the first power output, wherein the existing overcurrent protection device is arranged to interrupt the current flowing though it when said current exceeds a predefined maximum current threshold, the method comprising the steps of:

- connecting the electrical heater in parallel to the at least one existing load device on the first power output of the existing electrical circuit; and
- installing a control system according to any of the above control system claims.

13. The method of the previous claim, wherein the electrical heater may be physically installed in the vicinity of the at least one load device, while the control system may be physically installed in the vicinity of the overcurrent protection device.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21
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FIG. 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/065758

A. CLASSIFICATION OF SUBJECT MATTER
INV. F24H9/20 H02H1/00 H02H3/087 H02J1/14 H02J3/14
H02J3/28 H02J7/00 H05B1/02 G06F1/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F24H H02H H05B G06F H02J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	WO 2015/172183 A1 (GNG ELECTRICAL PTY LTD [AU]) 19 November 2015 (2015-11-19) paragraphs [0019] - [0023], [0068] - paragraph [0081]; figures 11, 15 -----	1-13
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A	DE 10 2013 109608 A1 (SMA SOLAR TECHNOLOGY AG [DE]) 5 March 2015 (2015-03-05) the whole document -----	1-13
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☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 July 2024	05/08/2024

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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