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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 September 2011 (15.09.2011)

PCT

(10) International Publication Number
WO 2011/110237 A1

(51) International Patent Classification: *F28D 20/02* (2006.01)

(21) International Application Number: PCT/EP2010/058330

(22) International Filing Date: 15 June 2010 (15.06.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10156250.2 11 March 2010 (11.03.2010) EP
61/327,279 23 April 2010 (23.04.2010) US

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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, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, 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, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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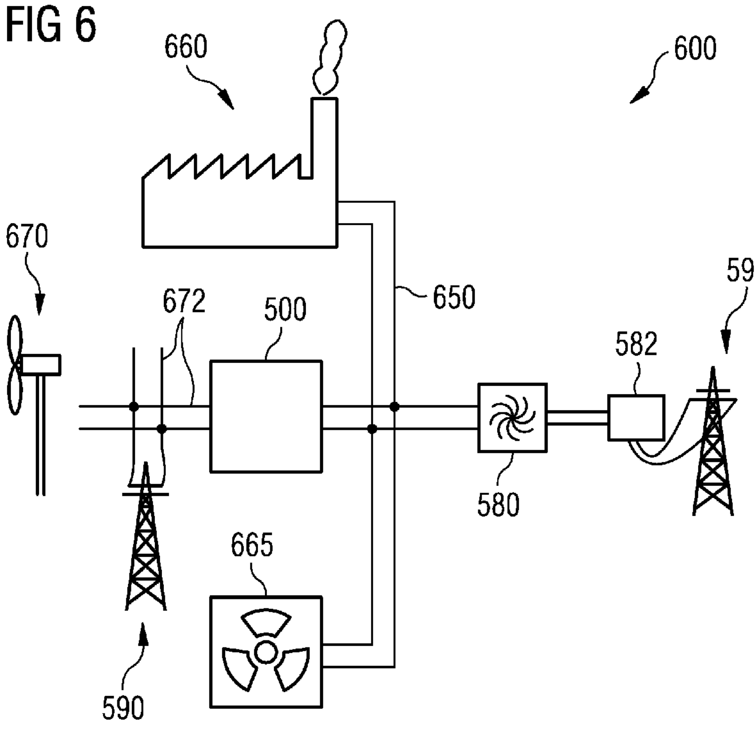
(54) Title: ENERGY HANDLING SYSTEM COMPRISING AN ENERGY STORAGE DEVICE WITH A PHASE CHANGE MATERIAL

FIG 6



(57) Abstract: It is described an energy handling system (600, 700, 800) comprising an energy storage device (100, 200, 300, 500), which comprises a Phase Change Material (115) for absorbing and temporarily storing thermal energy, which has been provided by an energy source (170, 670), and a heat extraction element (140) for extracting thermal energy from the Phase Change Material (115). The energy handling system (600, 700, 800) further comprises an energy conversion device (180, 580, 582), which is operatively connected to the heat extraction element (140) and which is capable of converting thermal energy into electric energy.

Published:

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

DESCRIPTION

Energy handling system comprising an energy storage device with a Phase Change Material

Field of invention

The present invention relates to an energy handling system, which is capable of absorbing and temporarily storing thermal energy with an energy storage device and which is further capable of extracting thermal energy from the energy storage device.

Art Background

The production of electric power from various types of alternative energy sources such as wind turbines, solar power plants and wave energy plants is not continuous. The production may be dependent on environmental parameters such as for instance wind speed (for wind turbines), insulation (for solar power plant) and wave height and direction (for wave energy plants). There is very often little or no correlation between energy production and energy demand.

One known approach to solve the problem of uncorrelated electric power production and electric power demand is to temporally store energy, which has been produced but which has not been demanded, and to release the stored energy at times at which there is a high demand. In the past there have been suggested many different methods to temporarily store energy. Suggested methods are for instance (a) mechanical energy storage methods e.g. pumped hydro storage, compressed air storage and flywheels, (b) chemical energy storage methods e.g. electrochemical batteries and organic molecular storage, (c) magnetic energy storage, and (d) thermal energy storage.

With respect to thermal energy storage it is noted that water has a high heat capacity which in principle could allow for efficient thermal storage using water as the heat storage material or heat storage medium. However, unless sophisticated pressure vessels are used the maximum temperature of heat capacity storage in water is limited to 100°C (100 degrees Celsius). Since for large capacity storage the cost of pressure vessels would be prohibitive, the use of water as a heat storage material is limited to a maximum temperature of 100°C. However, a maximum temperature of 100°C is much too low in order to provide any useful thermodynamic efficiency of a heat engine, e.g. a steam turbo generator, which is to be operated on demand for release of the stored thermal energy. Consequently, the benefits of the high heat capacity of water cannot be exploited in practice for high-volume energy storage.

Alternative heat storage media include solids and molten salts. Solids may be heated to high temperatures that could lead to good thermodynamic efficiencies of related heat engines. However, solids generally have low heat capacity, and this leads to high volume requirements and to a low energy density. Molten salts generally have higher heat capacity than solids and they have the additional benefit that, when being in the liquid phase, they can be pumped, thereby facilitating arrangements of low-loss storage tanks with high-power heat exchangers. However, molten salts have the drawback that they are generally not stable at temperatures much above 400°C, thereby limiting the thermodynamic efficiencies of related heat engines. They also have the drawback that initial melting and re-melting on unintended solidification is very difficult due to the low conductivity of crystalline salts.

One solution to the problem of low energy density of solids is to use a material that incurs a phase change at the relevant operating temperature. The amount of heat respectively heat energy Q stored in a material which does not undergo a phase change within the temperature range of a heat storage cycle, i.e. during an energy storage process comprising the increase of the storage material temperature from Ti (corresponding to the minimum starting or initial temperature) to Tf (corresponding to the maximum end or final temperature) can be calculated by the following equation (1):

$$Q = \int_{Ti}^{Tf} m \cdot Cp(T)dT \tag{1}$$

Thereby, m is the mass of the heat storage material and $Cp(T)$ is the specific heat capacity of the heat storage material, which according to the basics of thermodynamic is a function of the temperature T.

Provided that the specific heat capacity of the heat storage material does not have a pronounced dependency on temperature, this leads to a linear relation between the increase in temperature and the amount of stored heat. For a material or medium which does undergo a phase change during the heat storage cycle an additional energy is absorbed or released when the material melts or solidifies respectively. The melting and solidification process happens at a substantially constant temperature as indicated in Figure 9. Such a material is denominated a Phase Change Material (PCM).

Figure 9 illustrates how heat is absorbed or released by a PCM when the PCM undergoes a phase change from solid to liquid and back or from liquid to solid. Specifically, when starting at the solid phase at a temperature Ti, the temperature of the PCM first approximately linearly increases with the amount of heat input h. When the temperature has reached the melting temperature Tm, the temperature stays constant for a while until the fusion heat or melting heat Δhm has been absorbed and all the PCM has become liquid. After this, the temperature of the liquid PCM again linearly increases with the further amount of heat input h. It is mentioned that the gradient dT/dh is different for liquid phase as compared to the solid phase. Thereby, the gradient dT/dh corresponds to the specific heat capacity of the solid respectively the liquid PCM.

For heat storage purposes preferably a PCM material is employed, which comprises a high melting heat. Thereby, additional energy storage capacity is provided by the phase change, i.e. when the PCM changes from solid to liquid and back. For a temperature increase of a PCM from Ti to Tf, wherein the melting temperature Tm of the PCM in between Ti and Tf, the amount of heat Q which is stored in the PCM can be calculated by the following equation (2):

$$Q = \int_{Ti}^{Tm} m \cdot Cps(T)dT + m\Delta hm + \int_{Tm}^{Tf} m \cdot Cpl(T)dT \qquad (2)$$

Thereby, m is again the mass of the PCM, $Cps(T)$ and $Cpl(T)$ are the specific heat capacity of the solid PCM respectively the liquid PCM and Δh is the latent heat respectively the melting heat of the PCM.

One problem related to the known heat storage systems is that for large scale energy storage, such as for storing energy produced from wind farms for longer time periods (hours), the capacity of known heat storage systems is not sufficient. If one would scale up a known heat storage system to a system having sufficient capacity for such purposes, the prize of such a scaled up system would be relatively high, which makes a scaled up system unattractive because of economical reasons. Even further, for a scaled-up heat storage system it is difficult and not cost-effective to recover the stored energy.

There may be a need for providing an energy handling system which allows for an improved thermal energy storage capability and for an easy an effective thermal energy extraction.

Summary of the Invention

This need may be met by the subject matter according to the independent claims. Advantageous embodiments of the present invention are described by the dependent claims.

According to a first aspect of the invention there is provided an energy handling system comprising (a) an energy storage device, which comprises (a1) a Phase Change Material for absorbing and temporarily storing thermal energy, which has been provided by an energy source, and (a2) a heat extraction element for extracting thermal energy from the Phase Change Material, and (b) an energy conversion device, which is operatively connected to the heat extraction element and which is capable of converting thermal energy into electric energy.

The described energy handling system is based on the idea that energy provided from an external source can be temporarily stored in the form of thermal energy within a Phase Change Material (PCM). If at a later time there is a demand for electric energy, at least some of the stored thermal energy can be released to the described energy conversion device for converting the released thermal energy into electric energy.

The described energy handling system may ensure that a surplus of energy, in particular electric energy, which may have been produced for instance by one or more wind turbines and/or by one or more solar plants at times with low demands for electricity, can be used to charge the PCM with thermal energy and thereby the surplus electricity can be stored as thermal energy respectively heat. Even further it is ensured by the described energy handling system that the stored energy can be released and transferred to an external heat system for use for electricity production. A suitable external heat system may be for instance a steam turbine. The step of providing thermal energy from the PCM to an external heat system may be regarded as providing thermal energy by and/or releasing thermal energy from the PCM.

The thermal energy can be stored in a single-phase energy storage process by temperature changes only. This means that the range of the temperature changes does not include the melting point temperature of the PCM. Alternatively, the thermal energy can be stored in a two-phase energy storage process, wherein in addition to one or two of the above described single-phase energy storage processes the energy is further stored in a latent energy storage process. This means that the range of a corresponding temperature change includes the melting point temperature of the PCM. Which energy storage process is preferably to be used depends on the specific application and in particular on the amount of energy put into the described energy system for storage.

It is mentioned that in principle also a three-phase energy storage process is possible. This means that the range of the temperature changes includes both the melting point temperature of the PCM and the boiling point temperature of the PCM.

It is further mentioned that it is also possible that charging the PCM with thermal energy does not result in a temperature increase of the PCM. This is the case if at the beginning of the energy absorption the PCM has a temperature, at which already a phase change occurs. In this case the charged thermal energy is used only for a phase change of at least a portion of the PCM.

It is further mentioned that in order to realize an effective heat extraction from the PCM two or even more heat extraction elements may be used.

Preferably, the at least one heat extraction element is at least partially in direct physical contact with the PCM. This may provide the advantage that a good and reliable thermal energy transfer between the PCM and the heat extraction element can be guaranteed.

In other words, a direct physical contact between the PCM and the heat extraction element may provide the advantage that substantially no losses occur in the process of transferring released thermal energy from the PCM to some means which can further distribute the released energy to the thermal energy conversion device for use and utilization.

The PCM may comprise a metal, in particular aluminum. This may provide the advantage that the PCM has a comparatively high melting point temperature. Specifically, aluminum has a melting point temperature around 660°C and a latent heat coefficient which is relatively high. Therefore, aluminum is a suitable material for the described energy storage device of the energy handling system. Further, the level of the melting point temperature makes it feasible to provide appropriate containers and isolation material as well as heat generation element(s) and/or heat extraction element(s) which can operate optimal within a temperature range around the melting point of and exploit the excessive potential for latent energy storage. Thereby, a heat generation element may be used for inserting thermal energy into the PCM and a heat extraction element may be used for withdrawing thermal energy from the PCM.

It is mentioned that there are of course also other materials, which are suitable for being used as the PCM of the described energy storage device. Specifically, PCMs which have a melting point between 200°C and 800°C are good candidates for the PCM of the described energy system.

It is further mentioned that the described energy storage unit, which is adapted for absorbing, for temporarily storing and for releasing thermal energy, may also be denominated an energy transfer system.

According to an embodiment of the invention the energy conversion device comprises (a) a heat engine, which is operatively connected to the heat extraction element and which is configured for converting thermal energy into mechanical energy, and (b) an electrical generator, which is operatively connected to the heat engine and which is configured for converting mechanical energy into electrical energy and for supplying the electrical energy to a utility grid. Hereby it is ensured that the energy handling system can supply electrical energy to the utility grid. Further, it can be ensured that the described energy handling system can provide energy directly to the utility grid without any further conversion between energy states.

According to a further embodiment of the invention the energy handling system further comprises a thermal energy transfer line, which connects the heat engine both with the heat extraction element and with at least one thermal power generation plant. This may provide the advantage that the heat engine may be used not for converting the thermal energy which has been released from the PCM but also for thermal energy which has been generated by the only by one or more thermal power generation plants.

The thermal energy transfer line may be for instance a fluid line or a fluid loop, which is capable of transferring thermal energy both form the heat extraction element and the at least one thermal power generation plant to the heat energy. Thereby, the fluid may be in particular a steam and the heat engine may be a steam turbine.

According to a further embodiment of the invention the heat engine is a heat engine of a thermal power generation plant.

This may mean that the described energy conversion device can be a heat engine of e.g. a separate thermal power generation plant such as for instance a fossil fuel plant or a nuclear power plant. Hereby it is ensured that the thermal energy storage device can be connected and operatively coupled to one or more heat engines of one or more separate thermal power generation plants. Consequently, the thermal power generation plant can exploit stored thermal energy from the described thermal energy storage device so as to effectively produce electricity while saving fossil and/or nuclear fuel.

It is further ensured that the thermal energy storage device may be regarded as a separate device which can flexibly be located in close vicinity to or remote from the power generation plant as long as the heat extraction element of the thermal energy storage unit is operatively connected to the energy conversion device.

According to a further embodiment of the invention the energy storage device is a component being assigned to a thermal power generation plant. This may provide the advantage that the energy storage device can share the energy conversion device of a thermal power generation plant.

Descriptive speaking the described energy storage device may be an add-on component of an existing thermal power generation plant and in particular an add-on component to an existing energy conversion device of a thermal power generation plant.

Hereby, the energy storage device may be positioned directly at the power generation plant thereby minimizing the extent of the common operatively connected energy conversion device.

A close physical connection respectively a small spatial separation between the power generation plant and the described energy storage device may provide the advantage that the thermal energy storage device can release respectively supply stored thermal energy very fast to the energy conversion device. Thereby, the described energy handling system can quickly react on fast demands of electric energy from the utility net.

The possibilities of sharing the thermal energy conversion device of an existing thermal power generation plant with the heat extraction element of the thermal storage device makes it feasible to add-on the thermal storage device to an existing system i.e. it may be regarded as if the described energy storage device can be "piggy-backed" on e.g. a steam turbine system of an existing thermal power generation plant.

According to a further embodiment of the invention the thermal power generation plant is a coal-fired power plant, a gas-fired power plant, a solar thermal power plant and/or a nuclear power plant.

It is pointed out that this list is not exclusive. The thermal power generation plant may also be any other plant which is capable of providing thermal energy.

According to a further embodiment of the invention the heat extraction element is a steam-liquid loop of the heat engine. Thereby, the heat extraction element may be a part of a thermal power production plant.

By realizing the heat extraction element as a steam-liquid loop it may be ensured that the described energy handling system can be a part of a power production system whereby the utilization of released thermal energy is optimized with a high utilization ratio. Furthermore it may be ensured that the released thermal energy can be utilized by known energy conversion techniques.

Preferably the energy conversion device comprises a steam turbine and the operating medium of the steam turbine is water. In this case the steam-liquid loop may be called a steam-water loop.

According to a further embodiment of the invention the heat extracting element and/or the heat engine comprises a control mechanism, which is adapted for controlling a fluid-flow within the steam-liquid loop.

The control mechanism may ensure that the amount of thermal energy can be controlled, which amount is released from the PCM and which amount is transferred via a fluid travelling within in the steam-liquid. The fluid can be used for driving a power production system and/or for cooling components of the power production system, which components are at an extreme high temperature.

The fluid may be in particular a steam and/or a liquid, in particular water, which is flowing through the liquid/water loop.

According to a further embodiment of the invention the heat engine comprises a steam turbine. By using a steam turbine a suitable heat engine component is used which is particular suitable for thermal conversion of energy.

According to a further embodiment of the invention the energy source is an electrical energy source. This may provide the advantage that the described energy handling system is capable of directly receiving electric energy from the energy source. This makes it very easy to use a surplus of electricity, which has been produced for instance by wind turbine(s) or solar plant(s) at times with low demands, to charge the PCM with thermal energy such that the surplus of electricity can be stored as thermal energy.

The energy handling system may further comprise a frequency controller, which is adapted for controlling a frequency of a voltage and/or current being associated with the electrical energy provided by the electrical energy source. By controlling the frequency of the electrical energy applied to a heat generation element being thermally coupled with the PCM it may be ensured that an optimal heating respectively thermal energy charging of the PCM can be obtained.

According to a further embodiment of the invention the electric energy source is a wind turbine, a hydroelectric power plant, a tidal power plant and/or a solar electric power plant. As has already been indicated above this may provide the advantage that regenerative energy, which often is not available when required but available when the demand for electric energy is smaller than the electric energy production capacity, can be temporarily stored in an effective manner.

According to a further embodiment of the invention the energy handling system further comprises (a) at least one heat generation element and (b) a utility grid, which electrically connects the electrical energy source with the heat generation element. Thereby, the heat generation element is capable of charging the Phase Change Material of the energy storage device with thermal energy. This may provide the advantage that the thermal energy storage device can act as a storage or accumulator for any surplus energy capacity of the utility grid. This in turn ensures that the thermal energy storage device can store energy from energy sources producing and supplying power to the utility grid on times with low energy demands, and save the energy to times with higher demands.

It is mentioned that in order to realize an effective heat insertion of thermal energy into the PCM two or even more heat generation elements may be used.

According to a further embodiment of the invention the heat generation element comprises an inductor, which is capable of providing thermal energy to the Phase Change Material by an eddy current. This may provide the advantage that it is not necessary that the heat generation element is in direct physical contact with the PCM.

Thereby, the heat generation element may be realized for instance by means of a coil or at least a part of a coil.

In detail, induction heating is a process of heating an electrically conducting material by electromagnetic induction. Thereby, eddy currents are generated within a conductive or metallic material and the ohmic resistance of the material leads to a heating of the material. Induction heating being used for putting or introducing thermal energy into the PCM may provide the advantage that this is a highly efficient process with a high degree of utility. Typically, the inductor of the heat generation element is powered by electric energy.

If the heat generation element comprises the above described inductor, i.e. the heat generation element is an induction heat generation element. Thereby, the frequency of the applied electricity may be controlled by a frequency controller, the depth and the effect of the heat can be adapted accordingly in order to realize an optimized introduction of thermal energy into the PCM.

According to a further embodiment of the invention the heat generation element is at least partially in direct physical contact with the Phase Change Material. This may provide the advantage that no extra intermediate heat distribution media has to be warmed up before the thermal energy is introduced into the PCM. Thereby, energy losses into an extra intermediate heat distribution media can be effectively avoided and all of the heat generated by the heat generation element will be transferred to the PCM.

Preferably, not only a portion but the whole heat generation element is in physical contact with the PCM. The physical contact between the heat generation element and the PCM allows that known and reliable techniques can be used for the introduction of thermal energy into the PCM. The thermal energy introduction can be realized for instance by means of a heating resistor respectively an electrical resistive heater.

According to a further embodiment of the invention the energy storage device comprises at least two thermal modules, wherein each of the thermal modules comprises a container being filled at least partially with Phase Change Material. This may provide the advantage that depending in the requested thermal energy storage capability an appropriate amount of PCM can be provided in a simple end effective manner. Thereby, the container may be formed in a standardized way, wherein a plurality of those containers may be combined in order to provide the requested amount of PCM.

Put in other words, the use of thermal modules each comprising a standardized container may allow that flexible energy storage can be provided, which comprises a sufficient number of operatively interconnected thermal modules. By operatively interconnecting two or more of the thermal modules it can be ensured that a major energy storage device can be tailored to specific tasks and requirements in terms of e.g. capacity. For instance if a specific major energy storage device with a capacity exceeding one of the above described thermal modules is required, then two or more of these modules can be concatenated in order to increase the total capacity of the concatenated major thermal energy storage device.

The described modular constructed energy storage device may allow for a grid-scale storage system to be build to the desired capacity using perfectly standardized transportable modules basically adding up to whatever capacity is desired.

Furthermore the described modularization allows for high volume serial production using known technologies.

Even further the thermal modules respectively their containers could be hooked up to e.g. an existing steam-generating fossil power station to form the described energy handling system. This in turn is flexible, eliminates the need for a power island and is further reducing cost.

In the following some further optional concepts of the described energy handing system are presented:

The energy handling system may be built of a thermal energy storage device comprising a number of identical heat storage modules plus an energy conversion device.

An energy storing element of each heat storage module may comprise a steel vessel containing a mass of e.g. aluminum. The steel vessel may be envisaged to be prismatic in shape with a rectangular footprint and sides sloping slightly outwards.

The mass of aluminum may originally be composed of ingots. Thermal energy is stored in the aluminum by melting the mass of aluminum. After the first melt the mass will form a partly melted, partly solidified mass almost filling the steel vessel.

The steel vessel may be surrounded by a heat generation element and a heat extraction element.

The heat generation element may comprise one or more electrical conductors wound around the steel vessel and capable of heating the aluminum by eddy current.

The heat extraction element may comprise a set of steam pipes placed adjacent to the outer surface of the steel vessel and kept in close thermal contact with the vessel.

The energy storing element, the heat generation element and the heat extraction element (at least partly) may all be placed in a container having an extension of about 40 feet (corresponding to approximately 12.2 meter) container. To minimize heat loss the container may be heavily insulated.

The energy conversion device may comprise a heat exchanger respectively a steam generator, a steam turbine, a generator and necessary auxiliaries such as a condenser, feed pumps, electrical switch-gear etc.

Initially heat or thermal energy is stored to heat the aluminum to partial melting. After initial heating the normal operating cycle may take place exclusively with the PCM present in both molten and solid phase.

Heat loss may be minimized by insulating the container comprising PCM. The thermal insulation material may comprise a composite ceramic material. This may provide the advantage that it can be ensured that thermal energy stored in the PCM is not released to the surroundings and it is also ensured that the insulation material has material properties suitable for the material to be used in the temperature range of suitable PCMs of the energy storage device of the described energy handling system.

The composite ceramic material may be for instance an air-bubbled ceramic material, which may be arranged between two layers of a ceramic material. Thereby, the ceramic material of the air-bubbled portion may be the same or may be different from the ceramic material of the layers.

It has to be noted that unless other notified any combination of features belonging to different embodiments and/or aspects of the present invention is considered as to be disclosed with this document.

The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

Brief Description of the Drawing

Figure 1 shows main components of an energy storage device in accordance with a first embodiment of the invention.

Figure 2 shows main components of an energy storage device in accordance with a second embodiment of the invention.

Figure 3 shows main components of an energy storage device in accordance with a third embodiment of the invention.

Figure 4 shows an induction coil integrated in the thermal isolation material of the energy storage device shown in Figure 3.

Figure 5 shows an energy handling system for extracting thermal energy from an energy storage device and for converting the extracted energy into electric energy.

Figure 6 illustrates schematically an energy handling system where a common energy conversion device is shared between an energy storage device and other power plants.

Figure 7 illustrates schematically another energy handling system where a heat extraction element of an energy storage device is a part of a steam-liquid loop of a thermal energy conversion device of a separate thermal power generation plant.

Figure 8 illustrates schematically a further energy handling system where the energy storage device is operatively connected to a thermal energy conversion device of a thermal power generation plant directly within a power generation plant.

Figure 9 illustrates how thermal energy is absorbed or released by a PCM when the PCM undergoes a phase change from solid to liquid or from liquid to solid.

Detailed Description

The illustration in the drawing is schematically. It is noted that in different figures, similar or identical elements are provided with the same reference signs or with reference signs, which differ from each other only within the first digit. For the sake of conciseness identical elements which have already been explained with reference to a previous Figure will not be explained again when being comprised in a later Figure.

Figure 1 shows main components of an energy storage device 100 in accordance with a first embodiment of the invention. A first container 110 comprising a PCM 115 is enclosed by a second container 120. The two containers 110, 120 are at least partly being thermally isolated from each other by a thermal isolation material 125.

At least one heat generation element 130 is receiving energy from an external energy source 170. The energy being received by the heat generation element 130 is used for heating the PCM 115. According to the embodiment described here the provided energy is electric energy, which is converted into thermal energy by the heat generation element 130. Further, at least one heat extraction element 140 is providing thermal energy to an external heat engine 180. The external heat engine 180 is used for converting the received thermal energy into mechanical energy. According to the embodiment described here the mechanical energy provided by the heat engine 180 is converted by means of a non depicted generator into electric energy.

From the illustrated embodiment shown in Figure 1 it can be seen that the heat generation element 130 is in direct physical connection with the PCM 115. This allows for an effective heat transfer from the heat generation element 130 to the PCM 115 for instance if the heat generation element 130 is a conductive heater e.g. in the form of resistive heating elements and if the PCM 115 comprises or is a material with suitable thermal conductive properties.

It is mentioned that for the resistive heating elements, energy may be supplied to the elements as an AC- or a DC-voltage (and of course a corresponding AC- or DC-current).

Figure 2 shows main components of an energy storage device 200 in accordance with a second embodiment of the invention. From Figure 2 it can be seen, that the heat generation element 130 is not in physical connection with the PCM 115. If the element 130 comprises at least one inductive heating element, this will allow for an effective energy respectively heat transfer to the PCM 115. In this case energy is preferably supplied to the heat generation element 130 as an AC-voltage. Thereby, the frequency of the AC may be the frequency of a utility grid. In order to adapt the applied frequency a frequency controller 235 is provided. With this frequency controller 235 the frequency of the AC voltage can be scaled to another frequency than the frequency of the utility grid. The frequency may also for various embodiments be alternated during operation.

For an even further embodiment of the invention, the heat generation element 130 may be directly connected to the utility grid. Thereby, a surplus of energy on the utility grid can be provided to the energy storage device 200.

It is mentioned that the heat generation element 130 may be separated in a plurality of sub-elements. Further, the heat generation element 130 and/or the corresponding sub-elements may be one or more induction coils made of for instance copper.

Furthermore, the heat generation element 130 may be actively cooled e.g. by ventilating air or a applying a cooled fluid such as cooled water.

Figure 3 shows main components of an energy storage device 300 in accordance with a third embodiment of the invention. As can be seen from Figure 3, at least one heat extraction element 140, which is used for extracting thermal energy from the PCM 115, can be located such that it is not in direct physically contact with the PCM 115.

Figure 4 shows an induction coil 432, which may be integrated for instance in the thermal isolation material 125 of the energy storage device 300 shown in Figure 3. The windings of the induction coil 432 are not in direct physical contact with the PCM 115 to be heated, but are separated by some refractory material 412.

Figure 5 shows an energy handling system 502 for extracting thermal energy from an energy storage device 500 and for converting the extracted energy into electric energy.

The energy handling system 502 comprises the already mentioned energy storage device 500 and an energy conversion device, which comprises a steam turbine 580 and an electric generator 582, which is mechanically connected to a rotor of the steam turbine 580. The output of the electric generator 582 is connected to a utility grid 590.

As can be seen from Figure 5, the heat extraction element 140 is realized with a steam-liquid loop, which extends between a condenser 585 and the steam turbine 580 and which runs through the energy storage device 500 in a distributed manner such a good heat transfer between the PCM 115 and the steam respectively the liquid flowing through the steam-liquid loop can be achieved.

In the language used in this document the steam turbine 580 and the electric generator 582 form an energy conversion device, which converts thermal energy extracted from the PCM 115 into electric energy fed into the utility grid 590.

According to the embodiment described here water is used as the heat transfer medium circulating through the steam-liquid loop. The water is fed into the steam-liquid loop respectively the heat extraction element 140 and is heated by the PCM 115. As the temperature of the PCM 115 may be higher than the boiling point of water, steam is generated and fed to the steam turbine 580. The steam enters the steam turbine 580 where it expands and pushes against blades to turn a generator shaft of an electric generator 582 to create electric current. After the steam has passed through the steam turbine 580, a condenser 585 converts it back to water, which in turn is returned by non depicted pumps to the heat extraction element 140 as cold water in order to repeat the described thermodynamic cycle.

As has already been mentioned above the generated electric current respectively the generated electric power is fed directly or indirectly to the utility grid 590.

Figure 6 illustrates schematically an energy handling system 600 according to a preferred embodiment of the invention. A common energy conversion device, which comprises a steam turbine 580 and an electric generator 582, is shared between an energy storage device 500 and other power plants. The output of the electric generator 582 is connected to a utility grid 590 in order to feed electric energy thereto. According to the embodiment described here the other power plants are (a) a thermal power generation plant 660 and (b) a nuclear power generation plant 665.

As can be seen from Figure 6, an output of the thermal power generation plant 660, an output of the nuclear power generation plant 665 and an output (i.e. a non depicted heat extraction element) of the energy storage device 500 are connected by means of a thermal energy transfer line 650. An input (i.e. a non depicted heat generation element) of the energy storage device 500 is electrically connected with another portion of the utility grid 590 by means of an electric energy transfer line 672. The other portion of the utility grid 590 is fed with electric energy inter alia from an external energy source 670. According to the embodiment described here the external energy source is a wind turbine 670.

Figure 7 illustrates schematically another energy handling system 700 where a heat extraction element of an energy storage device 500 is a part of a steam-liquid loop 750 of a thermal energy conversion device 580, 582 of a separate thermal power generation plant 660.

This embodiment illustrates that the thermal energy storage device 500 can act as energy storage and that the energy can be released using a shared thermal energy conversion device which is physically located at or within the power plant 660. Again, the thermal energy conversion device comprises a steam turbine 580 and an electric generator 582.

As can be seen from Figure 7, the steam-liquid loop 750 connects the three components (a) energy storage device 500, (b) steam turbine 580 and (c) a heat source 761 of the thermal power generation plant 660 with each other. Further, a utility grid 590 connects (a) the output of the electric generator 582, (b) the input of the energy storage device 500, (c) an output of a wind turbine 670 and (d) an output of a nuclear power generation plant 665 with each other. This means that the electric energy can be transferred from the utility grid 590 to the energy storage device 500, wherein it can be stored as thermal energy. This means further that electric energy can be fed from the electric generator 582, from the wind turbine 670 and/or from the nuclear power generation plant 665 into the utility grid 590.

Figure 8 illustrates schematically a further energy handling system 800 where the energy storage device 500 is operatively connected to a thermal energy conversion device 580, 582 of a thermal power generation plant 660 directly at the location of or within a power generation plant 660. This may mean that the energy storage device 500 is an integrated part of the power generation plant 660 itself.

In order to recapitulate the above described embodiments of the present invention one can state: The system and the methods disclosed within this document relate to the storage of energy from an external source in a Phase Change Material (PCM) and to the release of at least a fraction of the stored energy to an external heat engine representing a part of an energy conversion device for generation of electricity. The energy can be stored in a sensible energy storage process by temperature changes only i.e. where the ranges of the temperature changes in the PCM do not comprise the melting point temperature of the PCM. Alternatively and/or additionally, the energy can be stored in a latent energy storage process i.e. where the range of the temperature changes of the PCM comprises the melting point temperature of the PCM. Which particular energy storage process is used depends on the amount of energy which is supposed to be put into the system for storage. Once having supplied energy to the PCM for storage, a thermal isolation material, which at least partly encloses the PCM, ensures that only a limited energy is released to the surroundings during storage. A PCM is a substance with a high heat of fusion and is therefore capable of storing and releasing amounts of energy by exploiting that heat which is absorbed or released when a PCM experiences a phase change. In general, the energy storage can be achieved through either of solid-solid, solid-liquid, solid-gas, and liquid-gas phase changes. However, in practice changes from solid to liquid and back are currently preferred. Through an energy storage process, the PCM initially behaves as a sensible heat storage material i.e. the temperature of the PCM rises as it absorbs heat. When the temperature reaches the melting temperature of the PCM, the material absorbs large amounts of heat at a substantially constant temperature until the material entirely has become liquid. The release of energy is achieved by a reverse process where the material solidifies. Which material is preferred to be used for the PCM is dependent on the specific task and the properties of the material e.g. (a) melting temperature in the desired operating range, (b) high latent heat of fusion, (c) high conductivity, (d) rate of volume change on phase transformation, (e) chemical stability and/or (f) price. The PCMs can be organic or inorganic. For various embodiments of the invention, the PCM is Silicon (Si) or preferably Aluminum (Al).

It should be noted that in this document the term "comprising" does not exclude other elements or steps and the use of the articles "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

List of reference signs:

100	energy storage device
110	first container
115	Phase Change Material (PCM)
120	second container
125	thermal isolation material
130	heat generation element
140	heat extraction element
170	external energy source
180	external heat engine
200	energy storage device
235	frequency controller
300	energy storage device
412	refractory material
432	induction coil
500	energy storage device
502	energy handling system
580	steam turbine
582	electric generator
585	condenser
590	utility grid
600	energy handling system
650	thermal energy transfer line
660	thermal power generation plant
665	nuclear power generation plant
670	external energy source / wind turbine
672	electric energy transfer line
700	energy handling system
750	steam liquid loop
761	heat source
800	energy handling system

CLAIMS:

1. An energy handling system comprising

an energy storage device (100, 200, 300, 500), which comprises

a Phase Change Material (115) for absorbing and temporarily storing thermal energy, which has been provided by an energy source (170, 670), and

a heat extraction element (140) for extracting thermal energy from the Phase Change Material (115), and

an energy conversion device (180, 580, 582),

which is operatively connected to the heat extraction element (140) and

which is capable of converting thermal energy into electric energy.

2. The energy handling system as set forth in the preceding claim, wherein

the energy conversion device comprises

a heat engine (180, 580),

which is operatively connected to the heat extraction element (140) and

which is configured for converting thermal energy into mechanical energy, and

an electrical generator (582),

which is operatively connected to the heat engine (180, 580) and

which is configured for converting mechanical energy into electrical energy and for supplying the electrical energy to a utility grid (590).

3. The energy handling system as set forth in the preceding claim 2, further comprising

a thermal energy transfer line (650), which connects the heat engine (180, 580) both

with the heat extraction element (140) and

with at least one thermal power generation plant (660, 665).

4. The energy handling system as set forth in the preceding claims 2 and 3, wherein
the heat engine is a heat engine (580) of a thermal power generation plant (660).

5. The energy handling system (502) as set forth in the preceding claim 2 and 4, wherein
the energy storage device (500) is a component being assigned to a thermal power generation plant (660).

6. The energy handling system as set forth in the preceding claims 4 to 5, wherein
the thermal power generation plant is a
coal-fired power plant (660), a gas-fired power plant (660), a solar thermal power plant and/or a nuclear power plant (665).

7. The energy handling system as set forth in any one of the preceding claims 2 to 6, wherein
the heat extraction element (140) is a steam-liquid loop (750) of the heat engine (180, 580).

8. The energy handling system as set forth in the preceding claim, wherein
the heat extracting element (140) and/or the heat engine (180, 580) comprises a control mechanism, which is adapted for controlling a fluid-flow within the steam-liquid loop (750).

9. The energy handling system as set forth in any one of the preceding claims 2 to 8, wherein
the heat engine (180) comprises a steam turbine (580).

10. The energy handling system as set forth in any one of the preceding claims, wherein
the energy source is an electrical energy source (170).

11. The energy handling system as set forth in the preceding claim, wherein
the electric energy source is a wind turbine (170), a hydroelectric power plant, a tidal power plant and/or a solar electric power plant.

12. The energy handling system as set forth in any one of the preceding claims 10 to 11, further comprising
at least one heat generation element (130) and
a utility grid (590), which electrically connects the electrical energy source (170, 570) with the heat generation element (130), wherein
the heat generation element (130) is capable of charging the Phase Change Material (115) of the energy storage device (100, 200, 300, 500) with thermal energy.

13. The energy handling system as set forth in the preceding claim, wherein
the heat generation element (130) comprises an inductor, which is capable of providing thermal energy to the Phase Change Material (115) by an eddy current.

14. The energy handling system as set forth in any one of the preceding claims 12 to 13, wherein
the heat generation element (130) is at least partially in direct physical contact with the Phase Change Material (115).

15. The energy handling system as set forth in any one of the preceding claims, wherein
the energy storage device (100, 200, 300, 500) comprises at least two thermal modules, wherein each of the thermal modules comprises a container (110) being filled at least partially with Phase Change Material (115).

FIG 1

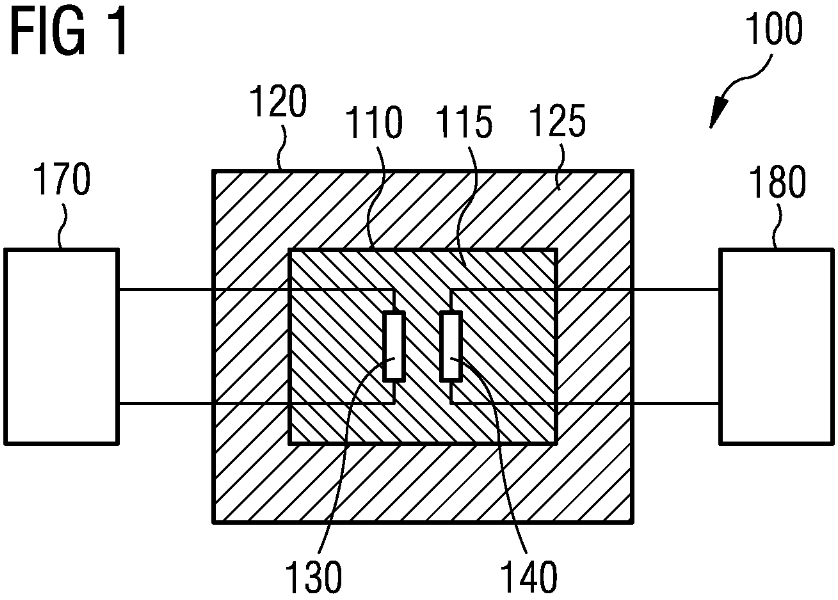
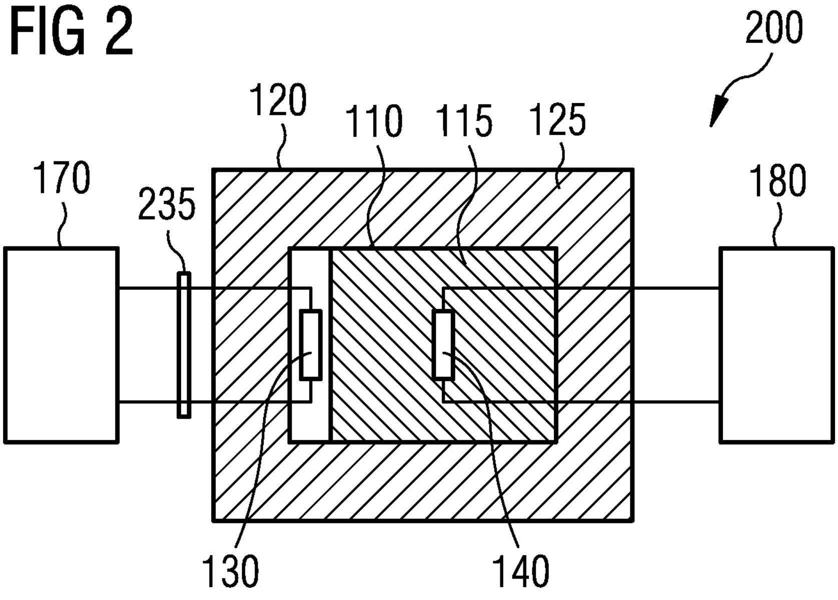

100
120
110
115
125
170
180
130
140

FIG 2


200
120
110
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170
235
180
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140

FIG 3

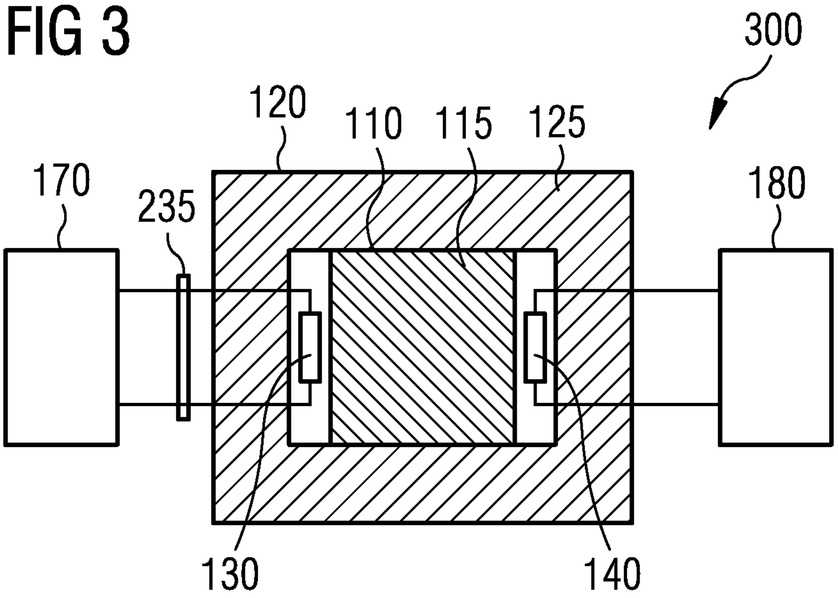


FIG 4

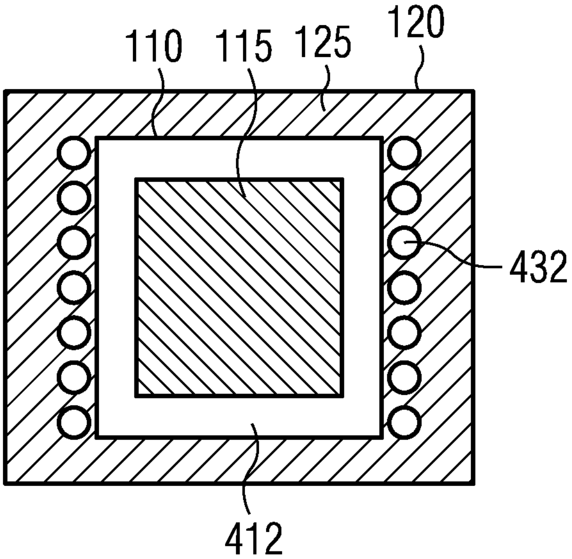


FIG 5

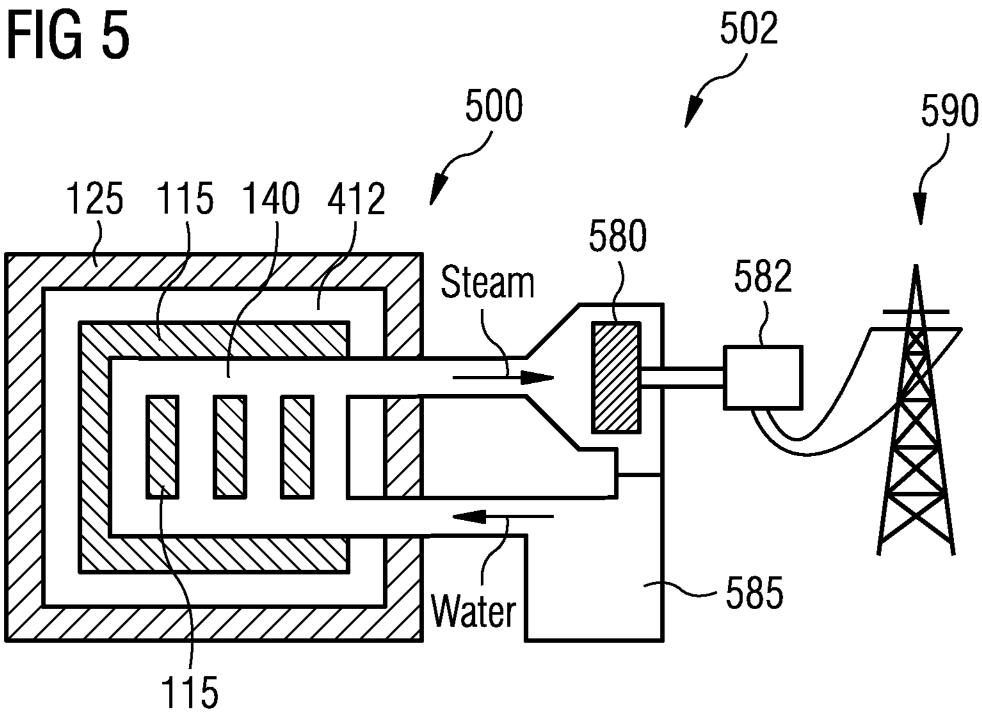

502
500
590
125
115
140
412
580
Steam
582
Water
585
115

FIG 6

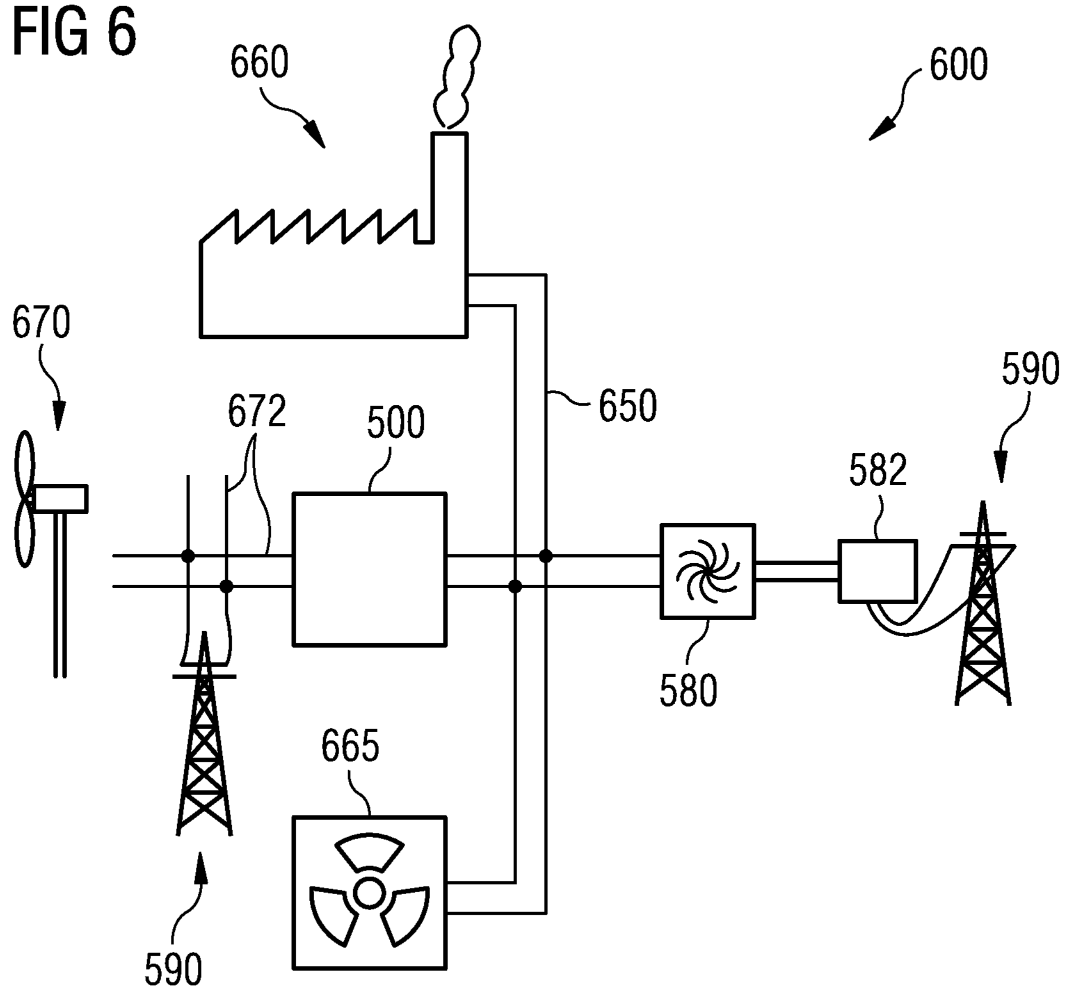

660
600
670
672
500
650
590
582
580
665
590

FIG 7

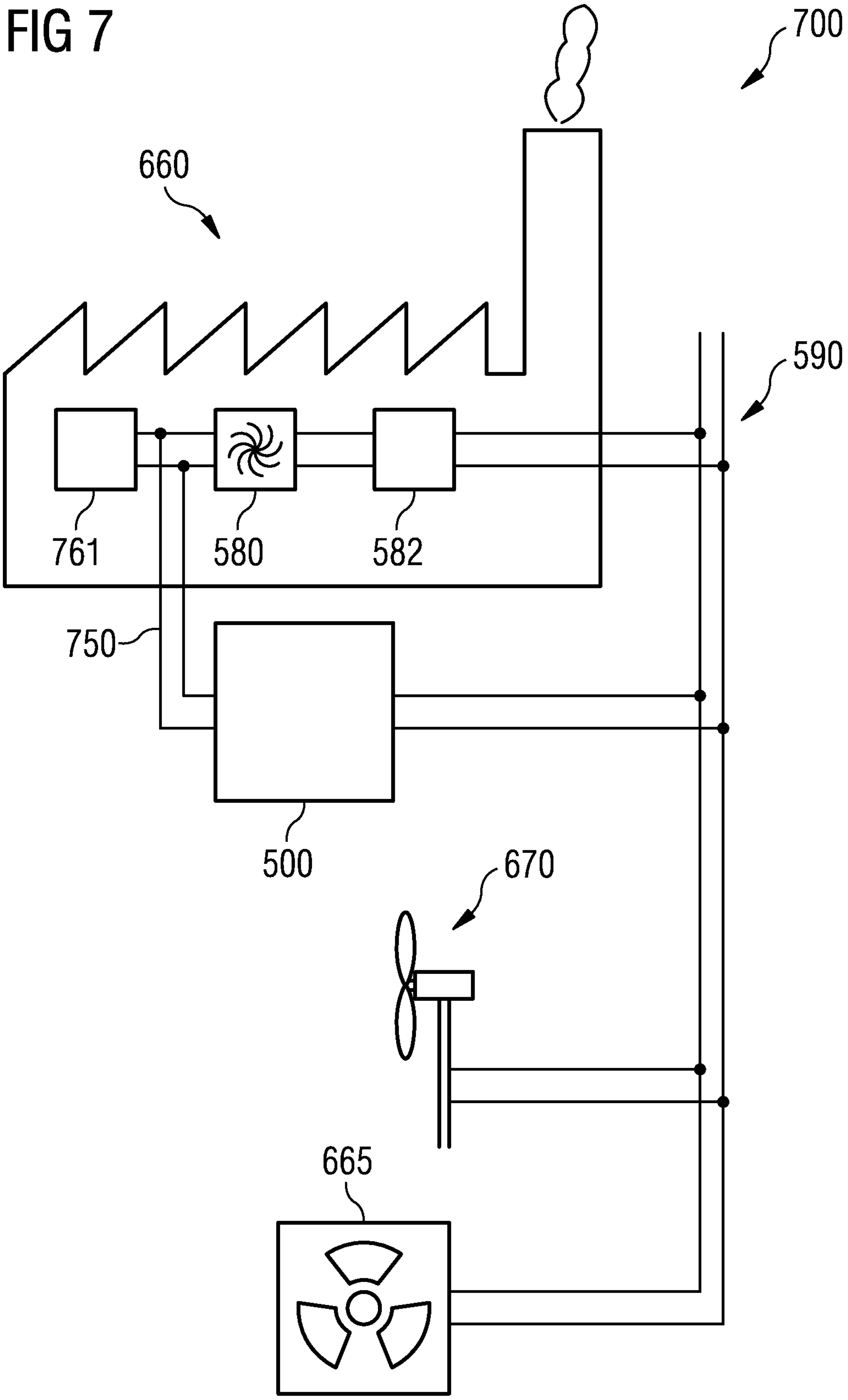


FIG 8

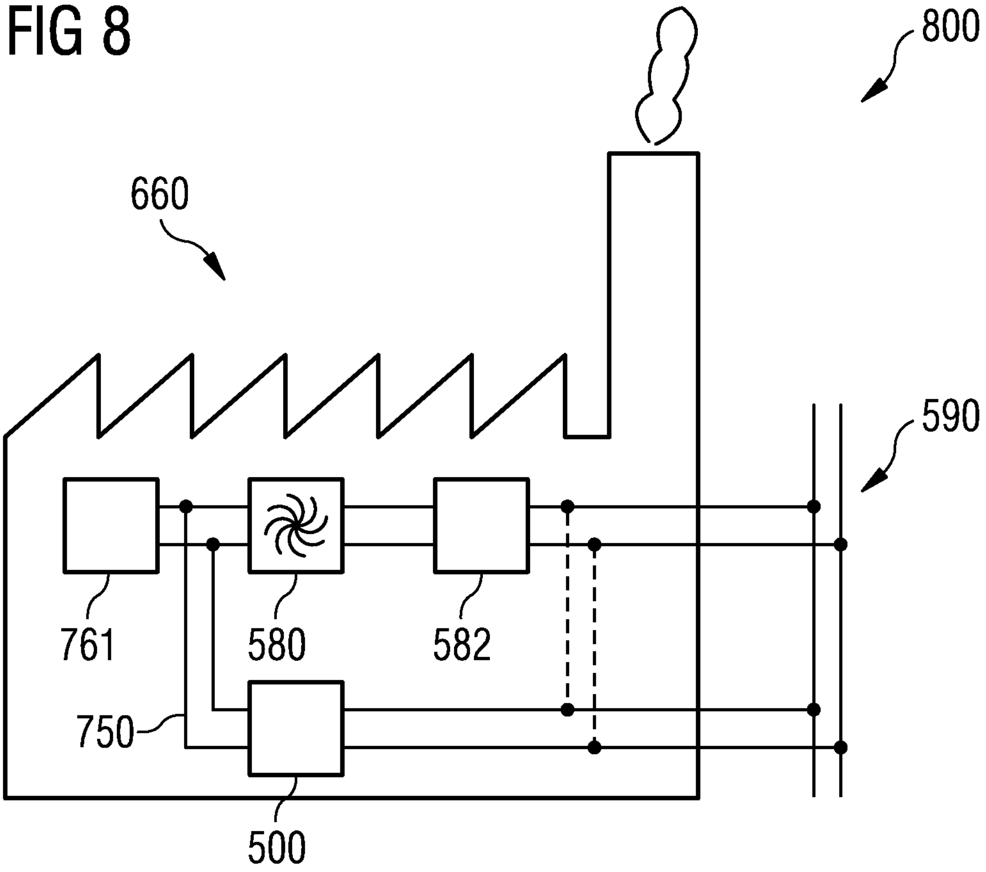
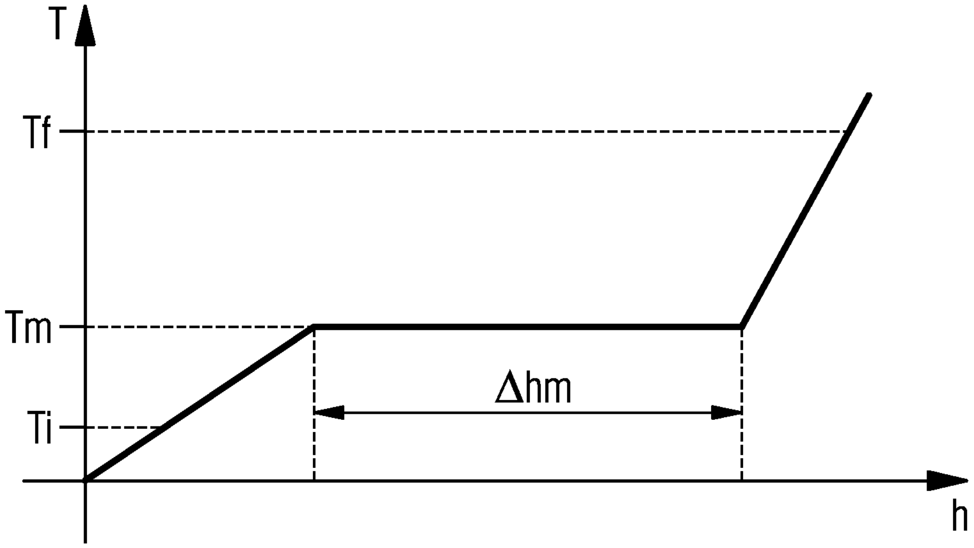


FIG 9

PRIOR ART



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/058330

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28D20/02
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)
F28D

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/276616 A1 (FLYNN BRIAN J [US] ET AL) 13 November 2008 (2008-11-13) figures 10,12	1-15
X	US 2008/289793 A1 (GEIKEN GERALD [US] ET AL) 27 November 2008 (2008-11-27) figure 13	1-15
X	EP 2 096 305 A1 (SOPHIA ANTIPOLIS EN DEV [FR]) 2 September 2009 (2009-09-02) figure 1	1-12,14, 15
X	DE 103 26 027 A1 (DEUTSCH ZENTR LUFT & RAUMFAHRT [DE]) 30 December 2004 (2004-12-30) figure 1	1-12,14

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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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"O" document referring to an oral disclosure, use, exhibition or other means

"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 25 October 2010	Date of mailing of the international search report 05/11/2010
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Vassoille, Bruno

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/058330

C(Continuation). **DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 28 47 989 A1 (SOELCH ROLAND) 14 May 1980 (1980-05-14) the whole document -----	1-12,14
X	US 4 037 579 A (CHUBB TALBOT A) 26 July 1977 (1977-07-26) the whole document -----	1-12,14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2010/058330

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EP 2096305	A1	02-09-2009	FR 2927959	A1	28-08-2009
			US 2009211249	A1	27-08-2009
DE 10326027	A1	30-12-2004	NONE		
DE 2847989	A1	14-05-1980	NONE		
US 4037579	A	26-07-1977	NONE		