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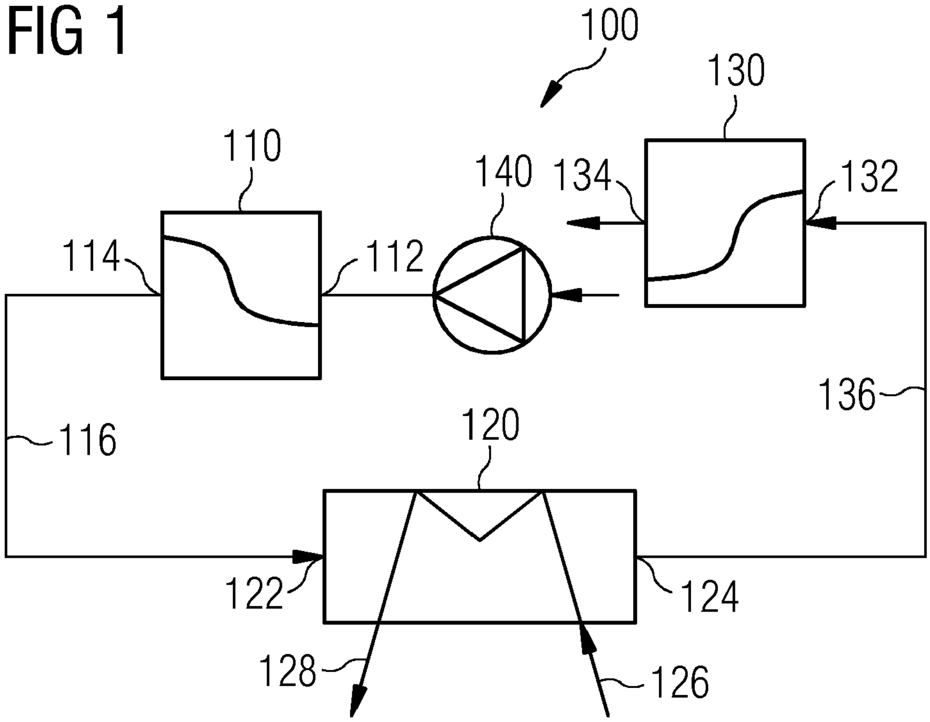
(54) **ENERGY STORAGE SYSTEM AND METHOD**

(57) There is described a system for storing energy, the system comprising (a) a first thermal storage (110, 210) for storing thermal energy, (b) a steam generator (120, 220) comprising a fluid input (222) in fluid communication with the first thermal storage (110, 210) to receive a working fluid, wherein the steam generator (120, 220) is adapted to heat a steam turbine fluid using the working fluid, the steam generator (120, 220) further comprising a fluid output (124, 224) for outputting the working fluid, and (c) a second thermal storage (130, 230) in fluid communication with the fluid output (124, 224) of the steam generator (120, 220) and adapted to store thermal energy remaining in the working fluid. Further, there is described a power plant and a method of storing energy.

FIG 1



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Description

Field of Invention

[0001] The present invention relates to the field of energy storage, in particular to a system for storing energy and a method of storing energy using thermal storage.

Art Background

[0002] In thermal steam power plants, that can be described with the Rankine process, thermal energy at high temperature (usually combustion or flue gas) enters the system and leaves the system at low temperature (in the condensing and exhaust system). The efficiency of the thermal power plant is limited by the Carnot efficiency which is defined by the work divided by the heat added to the system or a relation between the absolute temperature of the cold and hot reservoir. This is a theoretical process and its efficiency cannot be surpassed physically. In the real application, additional mechanical (e.g. flow irreversibility in the turbine, pump irreversibility), thermal, electrical and exergy losses lead to a reduced efficiency. Furthermore in the Rankine cycle the heat addition takes place at several temperature levels in contrast to the Carnot cycle. This further reduces the efficiency.

[0003] Depending on the configuration of size and complexity of the system, up to two thirds of the fuel energy leaves the system as low temperature heat in the condensing system that cannot be used economically. This is valid for every type of thermal power generation such as fossil fueled steam power plants and also internal combustion engines. It is especially true for water steam cycles, in which the steam is generated in a heat recovery steam generator (HRSG). When hot air enters the HRSG at e.g. 600°C, it cools down to a certain temperature level by transferring thermal energy to the water/steam and leaves the HRSG at temperatures of e.g. 120°C. The thermal energy that is still in this air is usually lost, as it is technically difficult and therefore not economically viable to build HRSGs with better performance parameters.

[0004] Another situation in which this can occur is energy storage. A thermal energy storage plant could be configured with a thermal storage, in which thermal energy is stored, and a HRSG with a water-steam cycle for re-electrification. When the thermal energy is extracted from the thermal storage, air is guided through the thermal storage arrangement and leaves the storage as heated air. This heated air is then used to generate steam in the HRSG. Again the problem occurs that the hot air cannot be cooled down to ambient temperature in the HRSG, so that unused heat leaves the system and reduces the efficiency of the system.

[0005] The problem may be partially solved by building more efficient and more expensive HRSGs with multiple steam pressure levels such as three pressure levels. This way the temperature of the air that leaves the HRSG is further reduced, e.g. to around 90°C in state of the art high efficiency combined cycle power plants (CCPPs). The thermodynamic efficiency of the internal steam cycles with medium and low pressure is rather low in comparison to the high pressure cycle. Nevertheless, the total efficiency adds up to a higher value when compared with a single pressure HRSG since the low temperature heat losses are reduced due to the reduction of the HRSG outlet temperature. Further reduction of this temperature is economically not feasible due to the immense amount of required heat exchanger surface in the HRSG.

[0006] Until now the above problem mostly occurs in waste heat recovery with HRSGs, e.g. flue gas from gas turbines. Since in those cases, the flue gas usually contains NOx and needs to be guided into a chimney due to emission regulations, a certain temperature of the flue gas is required to get the necessary updraft in the chimney.

[0007] However, with the increasing significance of renewable energy sources, such as wind and solar power systems, in electrical power production, thermal storage systems are among the systems considered for temporarily storing extra power during periods of high production (e.g. strong wind, sunny days) in order to compensate for subsequent periods of low production (e.g. weak wind, cloudy days). In this context, however, the abovementioned losses are too high for providing efficient energy storage.

[0008] Accordingly, there may be a need for a way of storing energy more efficiently.

Summary of the Invention

[0009] This need may be met by the subject-matter according to the independent claims. Advantageous embodiments of the present invention are set forth in the dependent claims.

[0010] According to a first aspect of the invention there is provided a system for storing energy, the system comprising (a) a first thermal storage for storing thermal energy, (b) a steam generator comprising a fluid input in fluid communication with the first thermal storage to receive a working fluid, wherein the steam generator is adapted to heat a steam turbine fluid using the working fluid, the steam generator further comprising a fluid output for outputting the working fluid, and (c) a second thermal storage in fluid communication with the fluid output of the steam generator and adapted to store thermal energy remaining in the working fluid.

[0011] This aspect of the invention is based on the idea that remaining thermal energy in the working fluid output by the steam generator is stored in a separate (second) thermal storage instead of being led directly into the atmosphere. Thereby, the remaining thermal energy in the working fluid is not simply lost but may be used for other purposes.

[0012] In the present context, the term "thermal storage" may in particular denote a device, arrangement or structure that is capable of storing received thermal energy and of releasing (outputting) stored thermal energy.

[0013] More specifically, the (first and/or second) thermal storage may be a sensible thermal storage or a latent thermal storage. For example, the thermal storage may be filled with a thermal storage material. The thermal storage material may be a solid or bulk material, such as stones, bricks, ceramics or other solid material which has the ability to be heated up, keep its temperature and thus store thermal energy over a predetermined period of time. However, it should be understood that also water may be used as the thermal storage material. The thermal storage material may be heated up (charged) and cooled down (discharged) by a fluid, e.g. the working fluid.

[0014] An exemplary thermal storage may comprise a first opening and a second opening. A fluid, such as the working fluid, may be flowed through the thermal storage from the first opening to the second opening or from the second opening to the first opening. The fluid may be in direct physical contact with the thermal storage material when the fluid flows through the thermal storage. In an exemplary embodiment, the thermal storage material may be provided as stones and the fluid may be air. Thus, the air and the stones may come in direct physical contact with each other when the air flows through the thermal storage. Furthermore, the fluid may be in indirect contact with the thermal storage material when the fluid flows through the thermal storage.

[0015] The first opening may be an opening in the thermal storage through which fluid may be exchanged with one or more external devices, e.g. a thermal energy source, such as a heating device, and the steam generator. In an exemplary embodiment, the first opening and the device(s) may be connected by a pipe or a duct. The second opening may be a further opening in the thermal storage through which the thermal storage is able to exchange fluid with some further external device(s), such as the steam generator, the heating device, or a pump. Additionally, in a further exemplary embodiment, the second opening and the further device(s) may be connected by a pipe or a duct. Depending on the specific configuration, the first opening and the second opening may respectively be denoted the hot opening (or hot end) and the cold opening (or cold end) of the thermal storage, and vice versa. In a further exemplary embodiment the first opening and the second opening are similarly or identically formed. It should however be understood that the first opening and the second opening may also be formed to have different shapes. In a further exemplary embodiment, the first opening and the second opening may be formed in the same side surface of the thermal storage. This configuration may be advantageous when geometric restraints of the overall configuration of the system do not permit another geometrical set-up. As a matter of course, the first opening and the second opening may be formed in different side surfaces, in particular in opposing side surfaces, of the thermal storage.

[0016] The working fluid may be a medium, such as for example a gas or a liquid, which flows through the system, in particular from the first thermal storage to the second thermal storage via the steam generator. Thereby, a part of the thermal energy transported away from the thermal storage by the working fluid can be used by the steam generator while remaining thermal energy is stored in the second thermal storage. The medium may be a mixture consisting of a main component, such as water, with added supplements for influencing physical characteristics of the mixture, such as for example the evaporation point or the condensation point.

[0017] The steam generator device may be a heat exchanger. In particular, the steam generator is adapted to heat the steam turbine fluid for driving a steam turbine system. In a further exemplary embodiment, the steam generator may comprise a boiler or an evaporator. Heat exchangers are devices for transferring thermal energy from one medium to another in the direction of a temperature gradient. Heat exchangers are built for changing a temperature of a medium, for example by cooling or heating. In a further exemplary embodiment, the steam generator device may comprise an indirect heat exchanger. In indirect heat exchangers, the heat is transferred from one medium to another medium over solid walls separating the two media from each other. In a further exemplary embodiment, the steam generation device may also comprise a counter-flow heat exchanger, a parallel-flow heat exchanger, a double pipe heat exchanger, a shell and tube heat exchanger, a plate heat exchanger or a heat exchanger consisting of more than one stage of heat exchange for improving the efficiency. Boilers are closed devices in which a medium is heated up and boiled, respectively. The heated or vaporized medium leaves the boiler and may be used in the steam turbine system. Evaporators are devices which are used to turn a medium from its liquid form into its gaseous form. The evaporated medium may as well be used in the steam turbine system.

[0018] It is a particular advantage of the present invention that the design of the steam generator may be kept simple and thereby cheap. In particular, due to the fact that the working fluid output from the steam generator is transported to the second thermal storage such that remaining thermal energy is not simply lost, complex steam generator structures and features aiming at extracting as much thermal energy as possible from the working fluid are not necessary. In this regard, even existing steam turbine systems, for example of closed fossil fuel power plants, may advantageously be reused.

[0019] The steam turbine fluid is a fluid that may be used to drive a steam turbine system. The steam turbine fluid may be steam, water vapour or vapour with a high mass fraction of water in it, respectively. In a further exemplary embodiment, water vapour may be saturated but also unsaturated. Further, it may be possible to add supplements to the water vapour to influence physical characteristics of the water vapour, such as for example the evaporation point or the condensation point. The working fluid may further be an organic liquid which may be used in an Organic Rankine Cycle (ORC).

[0020] The steam turbine system may generally be a system which comprises a steam turbine and further devices for transforming thermal energy into mechanical energy and electricity, respectively. For example, the steam turbine system may comprise a steam turbine, a condenser, a generator, a first pump and optionally a second pump. The steam turbine may be a multi stage steam turbine or a single stage turbine. In the multi stage turbine the steam turbine fluid may be reheated between the different stages or a part of the steam turbine fluid may be extracted from the steam turbine, e.g. due to too excessive cooling of the steam turbine fluid. Fluid may also be extracted to preheat the feed water, district heating, process steam for use in the chemical industry, or breweries. The steam turbine comprises blades connected to a shaft. The energy of the steam turbine fluid flowing through the steam turbine is transmitted by the blades of the steam turbine to the shaft. The generator is connected to the shaft of the steam turbine and converts the rotational energy of the shaft of the steam turbine into electrical energy. The generated electrical energy may then be transferred to a power supply network or any other end-user. After flowing through the steam turbine, the steam turbine fluid flows through the condenser in which the steam turbine fluid is condensed into its liquid state. The first pump and the second pump drive the steam turbine fluid through the different components of the steam turbine system and through the steam generation device. The second pump may be of importance in order to reach the design pressure of the steam in the water steam cycle.

[0021] According to an embodiment of the invention, the system further comprises a heating device in fluid communication with the first thermal storage, wherein the heating device is adapted to heat a charging fluid during a charging phase.

[0022] In other words, when thermal energy is stored in the first thermal storage during a charging phase, the heating device heats a charging fluid which is then supplied to the first thermal storage. The charging fluid may be similar or identical to the working fluid discussed above. In an exemplary embodiment, the charging fluid is air.

[0023] According to a further embodiment of the invention, the heating device is adapted to transform electric or magnetic energy into heat.

[0024] More specifically, the heating may comprise a resistance heater, an electrical heater or an inductive heater. Thereby, the system may be used to store energy received in the form of electric or magnetic energy as thermal energy in the first thermal storage. The received energy may e.g. be excess energy produced by a power plant utilizing a renewable energy source, such as wind power or solar power.

[0025] According to a further embodiment of the invention, the system further comprises a first pumping device for transporting heated charging fluid from the heating device to the first thermal storage.

[0026] The first pumping device may be a blower arranged to transport air from the heating device to the first thermal storage, e.g. through a pipe or duct connecting the two.

[0027] According to a further embodiment of the invention, the heating device is in fluid communication with the second thermal storage, the system further comprising a second pumping device for transporting charging fluid from the second thermal device to the heating device.

[0028] The fluid communication between the second thermal storage and the heating device may be constituted by a pipe or a duct. The second pumping device may e.g. be a blower arranged to transport air from the second thermal storage to the heating device.

[0029] In some embodiments, the second pumping device may replace the first pumping device in the sense that the second pumping device also performs the function of the first pumping device, such that it is capable of transporting the charging fluid from the second thermal storage to the first thermal storage via the heating device. In other embodiments, the first pumping device may also undertake the function of the second pumping device, such that also in these embodiments only a single pumping device is needed in order to perform the functions of both the first pumping device and the second pumping device. Finally, in yet other embodiments, the first and second pumping devices may be implemented as two physically separate pumping devices, e.g. one (the first pumping device) between the heating device and the first thermal storage and another one (the second pumping device) between the second thermal storage and the heating device.

[0030] Independent of the specific implementation, the second pumping device serves to extract thermal energy from the second thermal storage in order to provide a pre-heated charging fluid to the heating device. Accordingly, the heating device will need less energy to heat the charging fluid to the desired temperature for storing in the first thermal storage.

[0031] Thereby, the remaining thermal energy of the working fluid that has been stored in the second thermal storage is reintroduced into the first thermal storage, such that the losses within the system are minimized independently of the efficiency of the steam generator.

[0032] According to a further embodiment of the invention, the system further comprises a third pumping device for transporting the working fluid from the first thermal storage through the steam generator and on to the second thermal storage during a discharging phase.

[0033] In other words, during discharge of the thermal energy stored in the first thermal storage, the third pumping device serves to transport the working fluid from the first thermal storage to the second thermal storage via the steam generator. Thereby, the working fluid leaves the first thermal storage with a relatively high content of thermal energy and is transported through the steam generator where a certain amount of the thermal energy is used to heat the steam turbine fluid. The working fluid then leaves the steam generator with a lower content of thermal energy. This remaining thermal energy is, except for unavoidable losses, stored in the second thermal storage for later use.

[0034] In some embodiments, the third pumping device comprises a single pumping unit arranged either between the first thermal storage and the steam generator or between the steam generator and the second thermal storage. In other embodiments, the third pumping device comprises two or more pumping units, of which at least one is arranged between the first thermal storage and the steam generator while another one is arranged between the steam generator and the second thermal storage.

[0035] According to a further embodiment of the invention, the working fluid and/or the charging fluid is air.

[0036] According to a further embodiment of the invention, the steam generator is a heat recovery steam generator (HRSG).

[0037] A HRSG may be an energy recovery heat exchanger which recovers energy from a fluid stream. The HRSG may e.g. comprise the following four principal components: an economizer, an evaporator, a superheater and a re-heater. The four principal components are put together to meet several requirements such as for example operating requirements or a given efficiency of the HRSG. Different HRSGs may be distinguished by the direction of an exhaust gas flow or the number of pressure levels integrated into the HRSG. In an exemplary embodiment, the HRSG may be a vertical type HRSG, a horizontal type HRSG, a single pressure HRSG or a multi pressure HRSG.

[0038] According to a further embodiment of the invention, the steam generator is adapted to receive the working fluid at the fluid input at a temperature between 550°C and 1000°C, such as around 600°C, and to output the working fluid through the fluid output at a temperature between 100°C and 400°C, in particular between 150°C and 350°C, in particular between 200°C and 300°C, in particular around 250°C.

[0039] Highly advanced - and thus expensive - steam generators are capable of providing a working fluid output having a temperature of 90°C. By collecting the remaining thermal energy of the output working fluid in the second thermal storage, the present invention can provide a highly efficient system for storing thermal energy, even if the steam generator as such is not particularly effective. Thereby, significant savings can be obtained by using simple and/or existing (old) steam generators.

[0040] According to a further embodiment of the invention, the steam generator has a pinch point of at least 10K, in particular at least 20K.

[0041] Highly advanced - and thus expensive - steam generators may have a pinch point significantly below 10K, such as around 5K. By collecting the remaining thermal energy of the output working fluid in the second thermal storage, the advanced and expensive technology for obtaining such a low pinch point can be dispensed with.

[0042] Thus, in sum the system according to various embodiments of the present invention as set forth above is capable of providing a highly efficient system for storing energy as thermal energy at a relatively low price.

[0043] According to a second aspect of the invention there is provided a power plant comprising (a) a power generator for producing electrical energy based on a renewable energy source, and (b) a system according to the first aspect or any of the above embodiments thereof, wherein the system is adapted to store excess energy from the power generator during overproduction by charging the first thermal storage, and wherein the system is adapted to release stored energy during insufficient production by discharging the first thermal storage.

[0044] This second aspect of the invention is based on essentially the same idea as the first aspect described above. More specifically, the second aspect uses a system according to the first aspect as part of a power plant that relies upon a renewable energy source, such as wind power or solar power, which by nature is prone to fluctuations.

[0045] Accordingly, the power plant according to the second aspect is capable of providing a more stable level of output by buffering excess energy during overproduction for later use to compensate for insufficient production.

[0046] According to a third aspect of the invention there is provided a method of storing energy, the method comprising (a) feeding a heated charging fluid to a first thermal storage to store thermal energy in the first thermal storage during a charging phase, (b) feeding a working fluid from the first thermal storage to a fluid input of a steam generator during a discharging phase, wherein the steam generator is adapted to heat a steam turbine fluid using the working fluid, and (c) conducting the working fluid from a fluid output of the steam generator to a second thermal storage to store thermal energy remaining in the working fluid.

[0047] This third aspect of the invention is based on essentially the same idea as the first and second aspects described above. More specifically, the third aspect relates to a method of using or operating the system according to the first aspect or a power plant according to the second aspect. That is, thermal energy is stored in a first thermal storage during a charging phase and then, during a discharging phase, the thermal energy is extracted from the first thermal storage by a working fluid and used to heat a steam turbine fluid. Remaining thermal energy in the working fluid output by the steam generator is stored in a second thermal storage.

[0048] It is noted that embodiments of the invention have been described with reference to different subject-matters. In particular, some embodiments have been described with reference to method type claims whereas other embodiments have been described with reference to apparatus type claims. However, a person skilled in the art will gather from the above and the following description that, unless otherwise indicated, in addition to any combination of features belonging to one type of subject-matter also any combination of features relating to different types of subject-matter, in particular to combinations of features of the method type claims and features of the apparatus type claims, is part of the disclosure of this document.

[0049] The aspects defined above and further aspects of the present invention are apparent from the examples of embodiments to be described hereinafter and are explained with reference to the examples of embodiments. The invention will be described in more detail hereinafter with reference to examples of embodiments. However, it is explicitly noted that the invention is not limited to the described exemplary embodiments.

Brief Description of the Drawing

[0050]

Figure 1 shows a schematic diagram of a system according to an embodiment of the present invention.

Figure 2 shows a schematic diagram of a system according to a further embodiment of the present invention.

Figure 3 shows a plot of heat transfer in a steam generator in accordance with embodiments of the present invention.

Detailed Description

[0051] The illustration in the drawing is schematic. It is noted that in different figures, similar or identical elements are provided with the same reference numerals or with reference numerals which differ only within the first digit.

[0052] Figure 1 shows a schematic diagram of a system 100 according to an embodiment of the present invention. More specifically, the system 100 comprises a first thermal storage 110, a steam generator 120, a second thermal storage and a pump 140.

[0053] The first thermal storage 110 is schematically illustrated as having a first opening 112 and a second opening 114 that allow a fluid, such as a gaseous or liquid working fluid or charging fluid, to enter and exit the thermal storage 110, whereby the fluid gets into direct or indirect contact with a thermal storage material disposed within the first thermal storage 110. The thermal storage material may e.g. comprise stone, bricks, ceramics or another solid material which is capable of storing thermal energy over a predetermined period of time, such as 12 hours or more.

[0054] Like the first thermal storage 110, the second thermal storage 130 is schematically illustrated as having a first opening 132 and a second opening 134 that allow a fluid, such as a gaseous or liquid working fluid output by the steam generator 120, to enter and exit the thermal storage 130, whereby the fluid gets into direct or indirect contact with a thermal storage material disposed within the second thermal storage 130. Again, the thermal storage material may e.g. comprise stone, bricks, ceramics or another solid material which is capable of storing thermal energy over a predetermined period of time, such as 12 hours or more.

[0055] The steam generator 120 comprises a fluid input 122 in fluid communication with the second opening 114 of the first thermal storage 110 via fluid connection 116. The steam generator 120 further comprises a fluid output 124 in fluid connection with the first opening 132 of the second thermal storage 130 via fluid connection 136. The steam generator 120 receives water via water supply 126 and outputs generated steam via steam output 128. The steam output 128 may be connected to a steam turbine (not shown) for producing electricity.

[0056] The pump 140 may preferably be a blower arranged to blow a working fluid into the first thermal storage 110 through the first opening 112 in order to extract or discharge thermal energy stored in the first thermal storage 110. The thus heated working fluid is transported through fluid connection 116 to the fluid input 122 of steam generator 120.

[0057] It is noted that figure 1 only relates to the discharging of the system 100. Charging of the system 100 will be described in more detail in conjunction with the embodiment shown in figure 2.

[0058] In operation, the steam generator 120 uses a hot working fluid received from the first thermal storage 110 at the fluid input 122 to heat water received via water supply 126 and thereby generate steam. The hot working fluid preferably has a temperature around 600°C. During the heat exchange with water, the working fluid loses thermal energy and thus leaves the steam generator through fluid output 124 at a lower temperature, such as between 100°C and 400°C, preferably around 200°C, depending on the efficiency of the steam generator 120. The output working fluid is transported to the first opening 132 of the second thermal storage 130 via fluid connection 136. Thereby, the remaining thermal energy of the working fluid is stored in the second thermal storage such that it can be used for other purposes when needed.

[0059] The thermal energy stored in the second thermal storage 130 may be used for a number of purposes. For example, it may be used to generate electric or mechanical energy that may be needed at a power plant relying on renewable energy during periods of low energy availability, e.g. little or no wind or sunlight. As will be discussed in more detail with regard to the embodiment shown in figure 2, the stored thermal energy may also advantageously be used when charging the first thermal storage 110.

[0060] In any case, the remaining thermal energy in the working fluid output by the steam generator 120 is not lost but can (at least to a large extent) be used for any suitable purpose. Therefore, the efficiency requirements for the steam generator do not have to be particularly strict such that significant cost and effort may be saved by using a simple and/or already existing steam generator 120.

[0061] Figure 2 shows a schematic diagram of a system 200 according to a further embodiment of the present invention. More specifically, the system 200 comprises a first thermal storage 210, a steam generator 220, such as an HRSG, and a second thermal storage 230. These elements correspond to and are interconnected in the same way as the first thermal storage 110, the steam generator 120, and the second thermal storage 130 described above in conjunction with the embodiment shown in figure 1. It is noted that a pump 244, such as a blower, is shown in the fluid connection 236 in order to transport the output working fluid from the HRSG 220 to the first opening 232 of the second thermal storage 230.

[0062] The system 200 further comprises a heating element 250 and a pump 242, such as a blower, arranged in a fluid path between the first opening 232 of the second thermal storage 230 and the second opening 214 of the first thermal storage 210. As shown, the fluid path comprises a fluid connection 218 arranged between the first thermal storage 210 and the heating device 250, and a fluid connection 238 between the second thermal storage 230 and the blower 242.

[0063] Discharging or recovery of energy stored in system 200, i.e. thermal energy stored in the first thermal storage 210 is done in a similar way as described above in conjunction with the embodiment shown in figure 1. Therefore, the corresponding description is not repeated here.

[0064] Charging the system 200 with energy is done by guiding a pre-heated charging fluid (e.g. having a temperature around 200°C) from the second thermal storage 230 towards the heating device 250 by means of blower 242. The heating device 250 adds thermal energy to the charging fluid and the fully heated charging fluid (e.g. having a temperature of around 600°C) is injected into the first thermal storage 210 to store the corresponding thermal energy therein. By using thermal energy stored in the second thermal storage 230 (during a preceding discharge/recovery operation of system 200) to provide the pre-heated charging fluid to the heating device 250, less energy is needed to heat the charging fluid and energy loss caused by steam generator 220 is minimized.

[0065] It is noted that the arrangement of the pumps 242 and 244 in figure 2 is schematic and that additional pumps may be arranged within the respective fluid paths depending on the circumstances.

[0066] Figure 3 shows a plot 301 of heat transfer in a steam generator in accordance with embodiments of the present invention. More specifically, the plot 301 shows heat transfer in an HRSG system with an inlet temperature of 600°C and a pressure of 120 bar.

[0067] The solid curves 360 and 362 shows the characteristic curves of a state of the art CCPP system. That is, the solid curve 360 shows water temperature and the solid curve 362 shows the temperature of the working fluid (e.g. hot air) in the system. The exit temperature 364 of the working fluid (i.e. the output fluid temperature) is below 200°C in this conventional CCPP system.

[0068] The dashed curves 370 and 372 shows the characteristic curves of a HRSG system suitable for use with embodiments of the present invention. Here, the dashed curve 370 shows water temperature and the dashed curve 372 shows the temperature of the working fluid (e.g. hot air) in the system. The exit temperature 374 of the working fluid (i.e. the output fluid temperature) is around 250°C, i.e. significantly higher than in the conventional CCPP system characterized by the solid curves 360, 362.

[0069] The pinch point is the minimum temperature difference in the steam generator between gas and water flow. In HRSGs the pinch point is the difference between the gas temperature leaving the evaporator and the saturation temperature. The pinch point for the conventional CCPP system is indicated by arrows 366 in figure 3.

[0070] The recovery of the thermal energy in the air downstream of the HRSG and the increase of its temperature has a positive impact on the HRSG design and costs. In systems according to the present invention, the pinch point of the HRSG can furthermore be larger compared to conventional CCPPs with only minor effect on the cycle efficiency. This is due to the fact that in CCPP thermal energy remaining in the flue gas is discharged to the environment. Hence the pinch point is chosen as small as techno-economically feasible. The heat exchanger surface area in the HRSG strongly increases when reducing the pinch point. In systems according to the present invention, the energy in the air downstream of the HRSG is recovered (in the second thermal storage 130, 230) and reduces the temperature difference between the air upstream and downstream of the charging equipment. The thermal energy that is not transferred to the steam in the HRSG remains in the system and is not lost. Therefore the HRSG can be designed with a larger pinch point and with significant less heat exchanger surface and consequently costs compared to a conventional CCPP.

[0071] When increasing the steam pressure (and consequently the saturation temperature), the HRSG exit temperature increases which is not desired in CCPPs because the thermal losses then increase. The systems according to the present invention can achieve higher steam cycle efficiency because the steam pressure and the HRSG exit temperature can be increased due to the recovery of the thermal energy in the storage system.

[0072] With the systems illustrated in figures 1 and 2, the steam pressure can be increased regardless of the HRSG outlet temperature. In CCPP systems, the steam pressure in one pressure HRSGs is usually relatively low (compared to fired steam generators) to reduce the saturation temperature of the water and consequently the HRSG exit temperature, cf. figure 3. Here, the continuous lines 360, 362 illustrate the water/steam and air temperature in a HRSG of a conventional system and the dashed line the temperatures of thermal storage systems according to the present invention.

[0073] In systems according to the present invention, the steam generator layout is especially designed for thermal storages. This allows for higher steam pressure and higher outlet temperature at the HRSG 120, 220 than in conventional CCPPs and hence these systems achieve higher steam cycle efficiency. The recovery of the thermal energy in the steam generator 120, 220 outlet air reduces the required charge power for the storage and improves the total system efficiency. The thermal energy remaining in the exhaust gas is not discharged in the environment but stored in the system. The pinch point can be designed larger with minor effects on the cycle efficiency and the costs of the steam generator reduce significantly compared to conventional CCPPs. Furthermore the exhaust system of the HRSG is obsolete because the thermal energy in the exhaust air of the HRSG is stored in a thermal storage. The environmental impact of the low temperature thermal energy in the waste heat is avoided.

[0074] It is noted that 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 is further noted that reference signs in the claims are not to be construed as limiting the scope of the claims.

Claims

1. A system for storing energy, the system comprising a first thermal storage (110, 210) for storing thermal energy,
a steam generator (120, 220) comprising a fluid input (222) in fluid communication with the first thermal storage (110, 210) to receive a working fluid, wherein the steam generator (120, 220) is adapted to heat a steam turbine fluid using the working fluid, the steam generator (120, 220) further comprising a fluid output (124, 224) for outputting the working fluid, and
a second thermal storage (130, 230) in fluid communication with the fluid output (124, 224) of the steam generator (120, 220) and adapted to store thermal energy remaining in the working fluid.

2. The system according to the preceding claim, further comprising a heating device (250) in fluid communication with the first thermal storage (110, 210), wherein the heating device (250) is adapted to heat a charging fluid during a charging phase.

3. The system according to the preceding claim, wherein the heating device (250) is adapted to transform electric or magnetic energy into heat.

4. The system according to claim 2 or 3, further comprising a first pumping device for transporting heated charging fluid from the heating device (250) to the first thermal storage (110, 210).

5. The system according to any of claims 2 to 4, wherein the heating device (250) is in fluid communication with the second thermal storage (130, 230), the system further comprising a second pumping device (242) for transporting charging fluid from the second thermal storage (130, 230) to the heating device (250).

6. The system according to any of the preceding claims, further comprising a third pumping device for transporting the working fluid from the first thermal storage (110, 210) through the steam generator (120, 220) and on to the second thermal storage (130, 230) during a discharging phase.

7. The system according to any of the preceding claims, wherein the working fluid and/or the charging fluid is air.

8. The system according to any of the preceding claims, wherein the steam generator (120, 220) is a heat recovery steam generator.

9. The system according to any of the preceding claims, wherein the steam generator (120, 220) is adapted to receive the working fluid at the fluid input (122, 222) at a temperature between 550°C and 1000°C and to output the working fluid through the fluid output (124, 224) at a temperature between 100°C and 400°C.

10. The system according to any of the preceding claims, wherein the steam generator (120, 220) has a pinch point of at least 10K, in particular at least 20K.

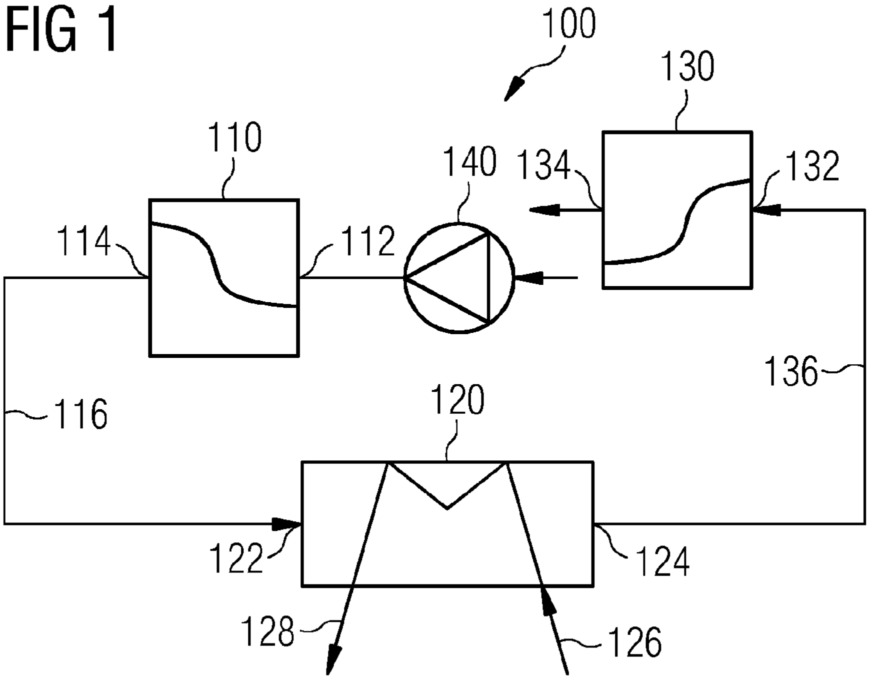
11. A power plant comprising
a power generator for producing electrical energy based on a renewable energy source, and
a system (100, 200) according to any of the preceding claims, wherein the system is adapted to store excess energy from the power generator during overproduction by charging the first thermal storage (110, 210), and wherein the system (100, 200) is adapted to release stored energy during insufficient production by discharging the first thermal storage (110, 210).

12. A method of storing energy, the method comprising
feeding a heated charging fluid to a first thermal storage to store thermal energy in the first thermal storage during a charging phase,
feeding a working fluid from the first thermal storage to a fluid input of a steam generator during a dis-

charging phase, wherein the steam generator is adapted to heat a steam turbine fluid using the working fluid, and

conducting the working fluid from a fluid output of the steam generator to a second thermal storage to store thermal energy remaining in the working fluid.

FIG 1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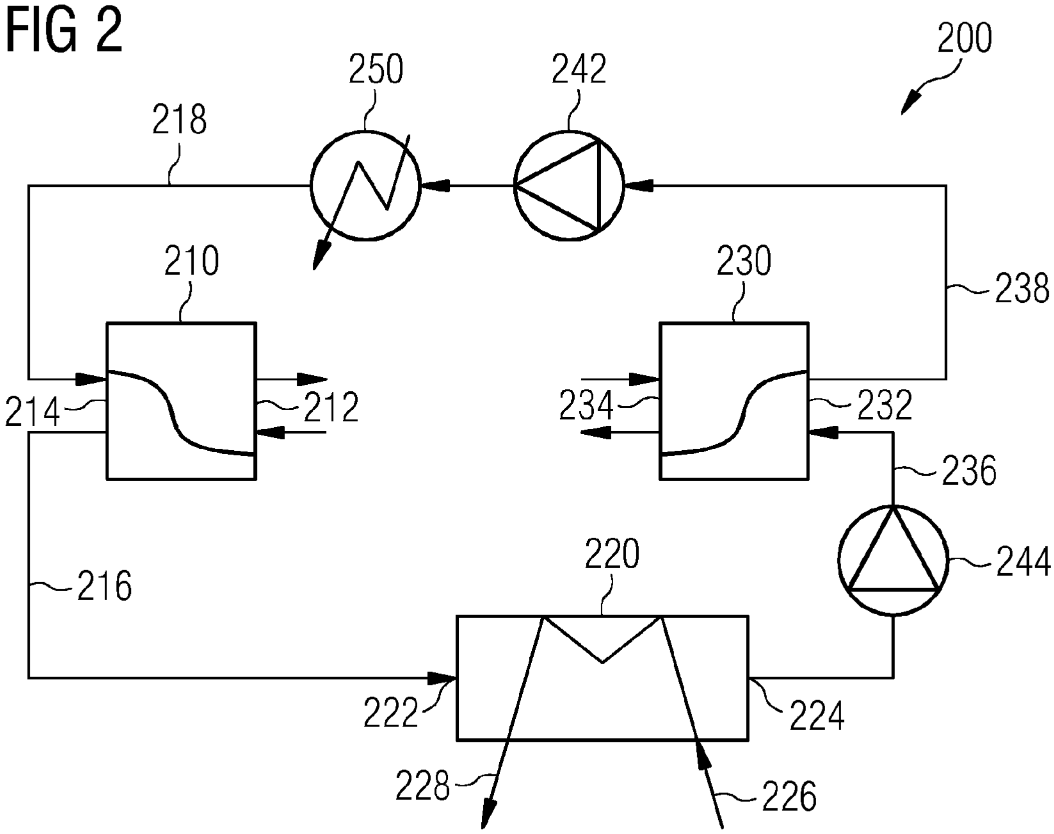
126

FIG 2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236
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222
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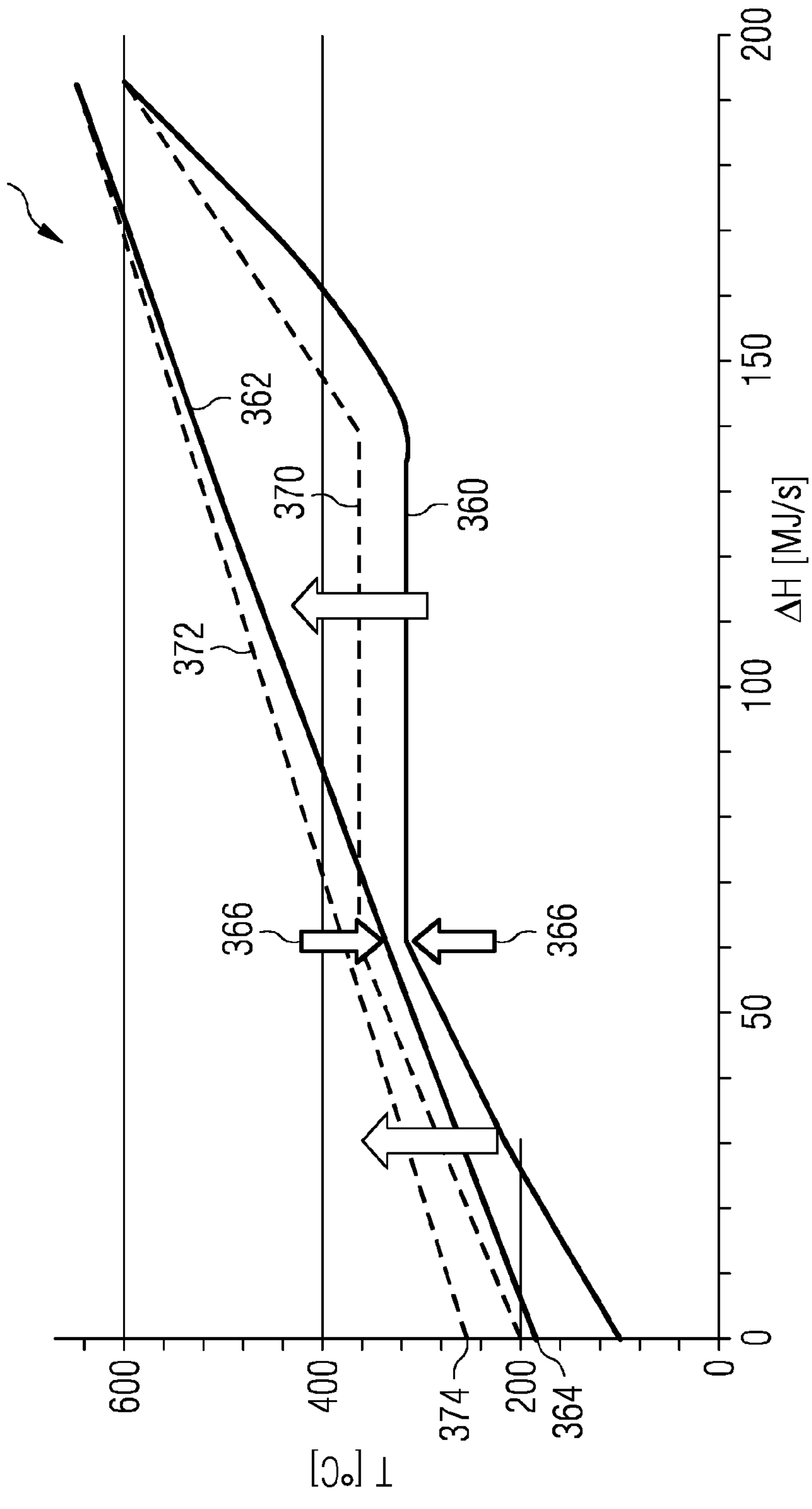
228
226

FIG 3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EUROPEAN SEARCH REPORT

Application Number
EP 15 16 1946

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	4 September 2015	Coquau, Stéphane

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