(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 081 770 A1

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
19.10.2016 Bulletin 2016/42

(51) Int Cl.:
F01K 3/00 *(2006.01)*

(21) Application number: **15164057.0**

(22) Date of filing: **17.04.2015**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA

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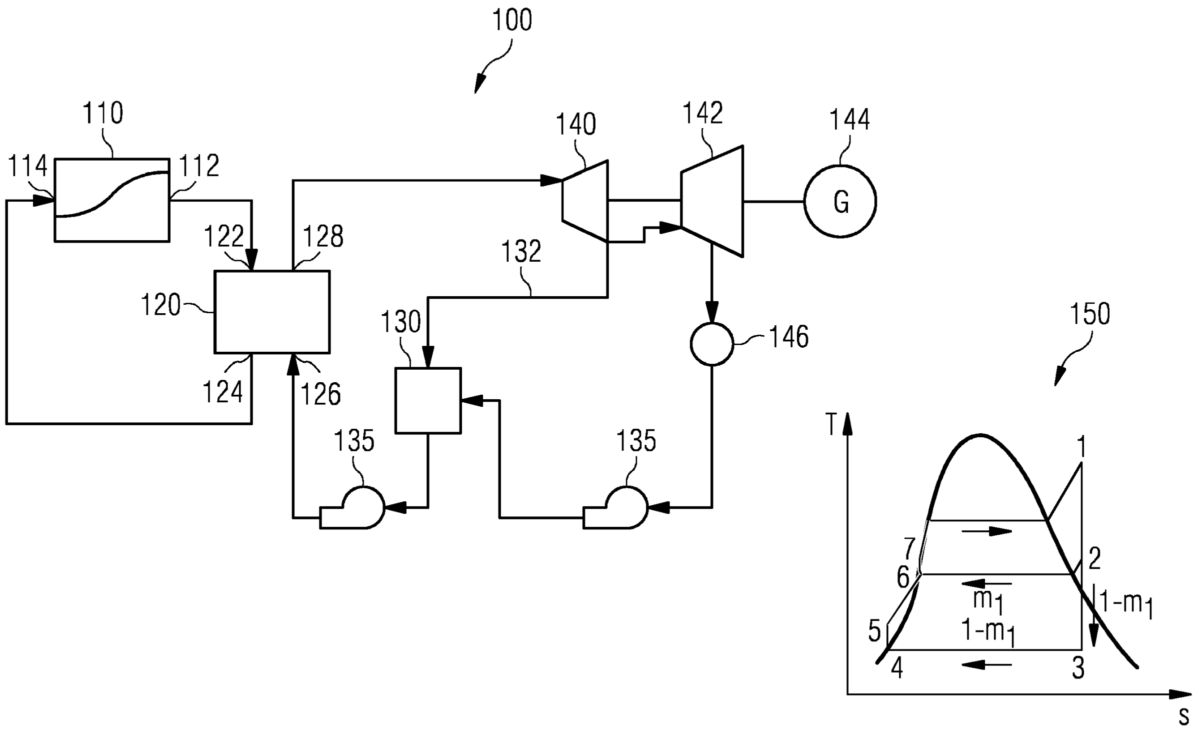
(54) **ENERGY STORAGE SYSTEM AND METHOD**

(57) There is described a system for storing energy, the system comprising (a) a thermal storage (110) for storing thermal energy, and (b) a steam generator (120) comprising a fluid input (122) and a fluid output (124), the fluid input and the fluid output being in fluid communication with the thermal storage, the steam generator further comprising a preheating device (130) for preheating a steam turbine fluid, wherein the thermal storage is adapted to receive a working fluid from a thermal energy source during a charging phase, wherein the thermal storage is adapted to output the working fluid for transportation to the fluid input of the steam generator during a discharging phase, and wherein the steam generator is adapted to heat the preheated steam turbine fluid using the working fluid received at the fluid input and to output the used working fluid through the fluid output for transportation to the thermal storage, such that thermal energy remaining in the output working fluid is injected into the thermal storage. Further, there is described a power plant and a method of storing energy.



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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] Power generation with steam cycles has been state of the art since the end of the 19th century. When changing from steam engines in the beginning of the industrial revolution to steam turbine power plant in the 20th century, the efficiency of power stations increased significantly. The power plants were designed for requirements of the applied fuel and further development of the technology lead to very complex boiler systems with reheat of the steam, several pressure levels and multiple pressure turbines. All fossil fueled plants are thermal power plants that convert chemical energy into thermal energy and finally into electrical power and this concept is based on the theoretical Carnot-process. Heat at a high temperature level is converted into mechanical power and connected to the lower temperature level by compression and expansion processes. The efficiency of the thermal power plant is limited by the Carnot efficiency which is defined by the work divided by the heat put into 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, which is the thermodynamic process applied in steam power plants, the heat addition takes place at several temperature levels in contrast to the Carnot cycle. This further reduces the efficiency.

[0003] As mentioned above, in the Carnot and Rankine processes thermal energy (heat) at high temperature enters the system and leaves the system at low temperature. 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 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] A type of power plant in which this happens is a combined cycle power plant (CCPP), in which hot flue gas that still contains a significant amount of thermal energy leaves the system and is lost.

[0005] Another situation in which this can occur is energy storage. A thermal energy storage plant could be configured with thermal storages (also referred to as heat storages), in which thermal energy is stored, and a HRSG with a water-steam cycle for re-electrification. When the thermal energy or heat is extracted from the storage, air is guided through the 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 completely down to ambient temperature in the HRSG, so that unused thermal energy leaves the system and reduces the efficiency of the system.

[0006] 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 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 of the entire system 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 to e.g. 90°C instead of e.g. 200°C. Further reduction of this temperature is economically not feasible due to the required immense enlargement of heat exchanger surface in the relevant HRSG.

[0007] Until now the above problem mostly occurs in waste heat recovery with HRSGs, e.g. recovering the remaining thermal energy 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.

[0008] 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.

[0009] Accordingly, there may be a need for a way of storing energy more efficiently while keeping complexity and cost at a minimum.

Summary of the Invention

[0010] 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.

[0011] According to a first aspect of the invention there is provided a system for storing energy, the system comprising (a) a thermal storage for storing thermal energy, and (b) a steam generator comprising a fluid input and a fluid output, the fluid input and the fluid output being in fluid communication with the thermal storage, the steam generator further comprising a preheating device for preheating a steam turbine fluid. The thermal storage is adapted to receive a working fluid from a thermal energy source during a charging phase. Further, the thermal storage is adapted to output the working fluid for transportation to the fluid input of the steam generator during a discharging phase. The steam generator is adapted to heat the preheated steam turbine fluid using the working fluid received at the fluid input and to output the used working fluid through the fluid output for transportation to the thermal storage, such that thermal energy remaining in the output working fluid is injected into the thermal storage.

[0012] This aspect of the invention is based on the idea that remaining thermal energy in the working fluid output by the steam generator is returned to the 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 later on for other purposes. The thus minimized loss together with preheating of the steam turbine fluid makes it possible to obtain a highly efficient steam cycle at a relatively low cost.

[0013] 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. It is explicitly noted that the thermal storage referred to herein may be formed as a single integral thermal storage unit or comprise a plurality of independent and/or separate thermal storage units (i.e. two or more thermal storage units).

[0014] More specifically, the 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, which has the ability to be heated up, keep the 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, i.e. the working fluid.

[0015] The working fluid may be a medium, such as for example a gas or a liquid, which flows through the system, in particular from a thermal energy source to the thermal storage during charging and from the thermal storage and back to the thermal storage via the steam generator during discharging. Thereby, a part of the thermal energy transported away from the thermal storage by the working fluid during discharging can be used by the steam generator while remaining thermal energy is returned to the thermal storage and thus stored. 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.

[0016] 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.

[0017] 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 back to the 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.

[0018] 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).

[0019] 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 for use in the preheating device 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.

[0020] The preheating device improves the efficiency of the Rankine cycle by increasing the temperature of the steam turbine fluid at which heat is received. This internal transfer of heat from high-temperature steam to low-temperature feed water leads to an elevation of said temperature and may be referred to as regeneration as it reduces low-temperature additions of external heat to the working fluid. In this process, the latent heat and optionally also the superheat of extracted steam may be used for the preheating of the steam turbine fluid before it enters the steam generator.

[0021] In the Rankine process with regeneration as described above, the HRSG (steam generator) outlet temperature is consequently influenced, since the temperature gap between flue gas in the economizer and the heated feed water is reduced and shifted to higher temperatures. More specifically, the HRSG outlet temperature increases and in conventional steam cycles, such as CCPP, the thermal energy in the flue gas is lost.

[0022] However, in the system according to this aspect of the invention, the thermal energy in the gas leaving the HRSG is directed back to the thermal storage and is therefore not lost. This allows the outlet temperature to be increased in order to elevate the steam cycle efficiency.

[0023] This means that the steam cycle can be designed for high efficiency by the consequent use of preheating and disregarding restrictions in the steam generator (HRSG) outlet temperature.

[0024] According to an embodiment of the present invention, the system further comprises a steam turbine, wherein the preheating device is in fluid communication with the steam turbine and adapted to receive steam extracted from the steam turbine.

[0025] Accordingly, the preheating device uses steam extracted from the steam turbine to preheat the steam turbine fluid, e.g. feed water.

[0026] According to a further embodiment of the present invention, the steam turbine comprises a first steam turbine stage and a second steam turbine stage, wherein the first steam turbine stage is adapted to operate at a higher pressure than the second steam turbine stage, and wherein the preheating device is in fluid communication with the first steam turbine stage and adapted to receive steam extracted from at least the first steam turbine stage.

[0027] The steam turbine may comprise further steam turbine stages, such as a third, fourth, fifth etc. steam turbine stage, each additional steam turbine stage operating at individual pressures. In some embodiments, the steam turbine may comprise seven steam turbine stages or even more, each operating at individual pressure levels and thus providing a corresponding number of extraction points. Furthermore, the preheating device may be in fluid communication with more steam turbine stages in order to increase the temperature of the preheated steam turbine fluid to a level below the saturation temperature of the applied steam pressure level.

[0028] In the present context, the various stages (i.e. first stage, second stage etc.) with individual pressure levels may be realized as corresponding stages within one steam turbine (i.e. within a single steam turbine unit). Alternatively, the stages may be realized within several e.g. two or three) individual steam turbine units connected in series. In the latter case, more than one stage may be realized within each individual steam turbine unit, such that the total number of stages is larger than the number of steam turbine units.

[0029] It should be noted that the preheating device may comprise several preheating stages, each connected to a corresponding steam turbine stage.

[0030] 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.

[0031] Highly advanced - and thus expensive - steam generators are capable of providing a working fluid output having a temperature of 90°C. Instead, by re-collecting the remaining thermal energy of the output working fluid in the thermal storage and preheating the steam turbine fluid, the present invention can provide a cheaper but highly efficient system for storing thermal energy.

[0032] According to a further embodiment of the invention, the steam generator has a pinch point of at least 10K, in particular at least 20K.

[0033] 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.

[0034] According to a further embodiment of the invention, the thermal storage comprises a first opening and a second opening, the first opening is in fluid communication with the fluid input of the steam generator, and the second opening is in fluid communication with the fluid output of the steam generator.

[0035] A fluid, such as a 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.

[0036] 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.

[0037] According to a further embodiment of the invention, the system further comprises a heating device arranged in a fluid path between the second opening of the thermal storage and the first opening of the thermal storage.

[0038] The heating device is used during the charging phase to heat the working fluid extracted from the second opening of the thermal storage and feed the heated working fluid to the first opening of the thermal storage. Thereby, the heating device may not have to heat the working fluid from the temperature of the surroundings but only from a significantly higher starting temperature.

[0039] The heating device may preferably be adapted to transform electric or magnetic energy into heat. More specifically, the heating device 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 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.

[0040] According to a further embodiment of the invention, the system further comprises a controller adapted to end the charging phase when the temperature at the second opening of the thermal storage reaches a predetermined temperature value.

[0041] During charging of the thermal storage, the heated working fluid flows through the thermal storage from the first opening to the second opening, such that a high temperature front moves from the first opening towards the second opening. When the high temperature reaches the vicinity of the second opening, the temperature of the working fluid that leaves the thermal storage through the second opening starts to rise. In other words, by detecting when this occurs, i.e. when the temperature at the second opening has risen to a certain predetermined temperature value, it can be determined that no further thermal energy can be stored in the thermal storage, such that the charging phase should be ended.

[0042] A similar mechanism may be used to detect when to end the discharging phase. In this case, it may be detected when the temperature of the working fluid that leaves the thermal storage through the first opening (and is guided towards the fluid input of the steam generator) has decreased to a given temperature value.

[0043] The predetermined temperature value is preferably equal to or larger than the temperature of the used working fluid output by the steam generator through the fluid output.

[0044] Thereby, the temperature at the second opening (cold end) of the thermal storage is equal to or larger than the temperature of the working fluid that will be output by the steam generator during a subsequent discharging phase. In other words, it is assured that the lowest temperature within the system is that of the output fluid from the steam generator, such that losses are minimized.

[0045] In particular, when the temperature at the second opening of the thermal storage is larger than the output temperature of the steam generator, the corresponding temperature difference may be at least 10%, in particular at least 20%, and further in particular at least 30% of the total temperature difference within the system, i.e. the difference between the highest and the lowest temperature inside the thermal storage. In one exemplary embodiment, the above mentioned 10% may correspond to around 50°K, the above mentioned 20% may correspond to around 100°K, and the above mentioned 30% may correspond to around 150°K.

[0046] According to a further embodiment of the invention, the thermal storage comprises a first thermal storage unit and a second thermal storage unit, wherein the first thermal storage unit is in fluid communication with the thermal energy source and the fluid input of the steam generator, and wherein the second thermal storage unit is in fluid communication with the fluid output of the steam generator.

[0047] In this embodiment of the invention, the thermal storage comprises two separate thermal storage units. The first thermal storage unit serves to store thermal energy from the thermal energy source during charging and to feed the stored thermal energy to the fluid input of the steam generator during discharging. The second thermal storage serves to collect and store remaining thermal energy in the working fluid output from the steam generator during discharging.

[0048] With this structure, the thermal energy that is collected in the second thermal storage unit may be used for a number of purposes, including preheating of the working fluid during subsequent charging phases as well as various industrial uses.

[0049] According to a further embodiment of the invention, the thermal storage comprises a bulk thermal storage material.

[0050] The thermal storage material may be a solid or bulk material, such as sand or gravel, rubble, split, clinker, pebble, slag, stones, bricks, ceramics or other bulk materials, such as basalt or iron silicate slag, which have the ability to be heated up, keep the temperature and thus store thermal energy over a predetermined period of time.

[0051] According to a further embodiment of the invention, the working fluid is air and/or the steam turbine fluid is water.

[0052] According to a further embodiment of the invention, the steam generator is a heat recovery steam generator (HRSG).

[0053] 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.

[0054] Throughout the embodiments described above, pumps or blowers may be provided to transport the working fluid and the steam turbine fluid in the described manner.

[0055] More specifically, the system may comprise a first pumping device for transporting heated working fluid from the heating device to the (first opening of the) thermal storage.

[0056] The first pumping device may be a blower arranged to transport air from the heating device to the thermal storage, e.g. through a pipe or duct connecting the two.

[0057] The system may further comprise a second pumping device for transporting the working fluid from the second opening of the thermal storage (or from the second thermal storage unit) to the heating device.

[0058] Again, the fluid communication 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 opening of the thermal storage to the heating device.

[0059] 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 opening of the thermal storage to the first opening of the 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 opening of the thermal storage and another one (the second pumping device) between the second opening of the thermal storage and the heating device.

[0060] Independent of the specific implementation, the second pumping device serves to extract thermal energy from the thermal storage in order to provide a pre-heated working fluid to the heating device. Accordingly, the heating device will need less energy to heat the working fluid to the desired temperature for storing in the (hot part of the) thermal storage.

[0061] Thereby, the remaining thermal energy of the working fluid that has been stored or buffered in the (cold part of the) thermal storage is re-introduced into the thermal storage, such that the losses within the system are minimized independently of the efficiency of the steam generator.

[0062] According to a further embodiment of the invention, the system further comprises a third pumping device for transporting the working fluid from the first opening of the thermal storage (or from the first thermal storage unit) through the steam generator and on to the second opening of the thermal storage (or to the second thermal storage unit) during the discharging phase.

[0063] In other words, during discharge of the thermal energy stored in the thermal storage, the third pumping device serves to transport the working fluid from the first opening of the thermal storage to the second opening of the thermal storage via the steam generator. Thereby, the working fluid leaves the 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, restored in the thermal storage for later use.

[0064] In some embodiments, the third pumping device comprises a single pumping unit arranged either between the first opening of the thermal storage and the steam generator or between the steam generator and the second opening of the 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 opening of the thermal storage and the steam generator while another one is arranged between the steam generator and the second opening of the thermal storage.

[0065] 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.

[0066] 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 thermal storage, and wherein the system is adapted to release stored energy during insufficient production by discharging the thermal storage.

[0067] 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.

[0068] 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.

[0069] According to a third aspect of the invention there is provided a method of storing energy, the method comprising (a) feeding a heated working fluid to a thermal storage to store thermal energy in the thermal storage during a charging phase, (b) preheating a steam turbine fluid during a discharging phase to provide a preheated steam turbine fluid having a temperature closer to a corresponding boiling point, (c) feeding the working fluid from the thermal storage to a fluid input of a steam generator during the discharging phase, wherein the steam generator is adapted to heat the preheated steam turbine fluid using the working fluid, and (d) conducting the used working fluid from a fluid output of the steam generator to the thermal storage to store thermal energy remaining in the working fluid.

[0070] 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 thermal storage during a charging phase and then, during a discharging phase, a steam turbine fluid is preheated and the thermal energy is extracted from the thermal storage by a working fluid and used to heat the preheated steam turbine fluid. Remaining thermal energy in the working fluid output by the steam generator is returned to the thermal storage and thus stored.

[0071] More specifically, by preheating the steam turbine fluid, the fluid temperature is raised to a temperature closer to the corresponding boiling point, i.e. the boiling point at a corresponding temperature and pressure of the fluid. Thereby, the amount of heat which the steam generator has to provide is correspondingly reduced.

[0072] According to an embodiment of the invention, the preheating is performed using a preheating device, the preheating device being in fluid communication with a steam turbine and adapted to receive steam extracted from the steam turbine.

[0073] In this embodiment, the preheating device may use steam extracted from the steam turbine to preheat the steam turbine fluid. That is, the preheating device raises the temperature of the steam turbine fluid such that it is close to the boiling point at the corresponding temperature and pressure of the fluid at the extraction point or stage of the steam turbine. The extracted steam is condensed and added to the fluid.

[0074] 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.

[0075] 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

[0076] Figure 1 shows a schematic diagram of a system according to an embodiment of the present invention together with a corresponding T-s diagram.

Detailed Description

[0077] 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.

[0078] Figure 1 shows a schematic diagram of a system 100 according to an embodiment of the present invention. Figure 1 1 also shows a corresponding T-s (temperature-entropy) diagram 150. More specifically, the system 100 comprises a thermal storage 110, a steam generator 120, a preheating device 130, a first steam turbine stage 140, a second steam turbine stage 142, a generator 144, a condenser 146, and pumps 135.

[0079] The thermal storage 110 comprises a first opening 112 and a second opening 114 that allow a fluid, such as a gaseous or liquid working 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 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.

[0080] The steam generator 120 comprises a fluid input 122 in fluid communication with the first opening 112 of the thermal storage 110. The steam generator 120 further comprises a fluid output 124 in fluid connection with the second opening 114 of the thermal storage 110. One or more pumps or blowers (not shown) are arranged in the fluid paths to transport a working fluid, e.g. air, from the first opening 112 (temperature e.g. around 600°C) of the thermal storage 110 to the fluid input 122 of the steam generator 120 and from the fluid output 124 (temperature e.g. around 200°C) of the steam generator 120 to the second opening 114 of the thermal storage 110. The steam generator 120 receives preheated water (temperature e.g. around 160°C) from the preheating device 130 (via pump 135) at water supply 126 and outputs generated steam via steam output 128 (temperature e.g. around 540°C). The steam output 128 is connected to the first steam turbine stage 140 (high pressure steam turbine stage) which is followed by the second steam turbine stage 142 (low pressure steam turbine stage). The steam turbine stages 140 and 142 drive the generator 144 to produce electricity. The condenser 146 receives the steam downstream of the turbine stages 140, 142 and provides water (temperature e.g. around 46°C) to the preheating device 130. Extracted steam (temperature e.g. around 300°C) from the first steam turbine stage 140 and/or second steam turbine stage 142 is conducted via fluid connection 132 to the preheating device 130 where it is used to preheat the water received from condenser 146. It is explicitly noted that the shown embodiment is exemplary and related to a relatively small system, e.g. less than 5MW. In other embodiments relating to larger systems, there may a significant number of pressure and corresponding temperature levels, which will improve the system efficiency significantly. For example, a system above 600MW may have between 7 and 11 extraction points.

[0081] The fluid path shown between the first opening 112 and second opening 114 of the thermal storage 110, including the steam generator 120 and pumps (not shown), is used to discharge the thermal storage 110.

[0082] The system comprises a further fluid path between the openings 112 and 114 of the thermal storage 110 for charging the thermal storage 110. This fluid path (not shown) may include a heating device which is used to charge the thermal storage 110. More specifically, a corresponding pump, such as a blower, transports air from the second opening 114 (cold end) of the thermal storage 110 to the aforementioned heating device and on to the first opening 112 (hot end) of the thermal storage 110.

[0083] During a discharging operation, the steam generator 120 uses a hot working fluid received from the thermal storage 110 at the fluid input 122 to heat water received via water supply 126 and thereby generate steam. During the heat exchange with water, the working fluid loses thermal energy and thus leaves the steam generator 120 through fluid output 124 at a lower temperature. The output working fluid is transported to the second opening 114 of the thermal storage 110. Thereby, the remaining thermal energy of the working fluid is returned to and stored in the thermal storage 110 such that it can be used when needed at a later stage.

[0084] Thereby, the remaining thermal energy in the working fluid output by the steam generator 120 is not lost but instead maintained within the system. 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.

[0085] Charging the system 100 with energy is done by guiding a pre-heated working fluid (e.g. having a temperature around 200°C) from the second opening 114 of the thermal storage 110 towards a heating device (not shown), e.g. by means of a blower (not shown). The heating device adds thermal energy to the working fluid and the fully heated working fluid (e.g. having a temperature of around 600°C) is injected into the thermal storage 110 through the first opening 112 to store the corresponding thermal energy therein. By using thermal energy already stored in the thermal storage 110 (during a preceding discharge/recovery operation of system 100) to provide the pre-heated working fluid to the heating device, less energy is needed to heat the working fluid and energy loss caused by steam generator 120 is minimized.

[0086] It is noted that the arrangement of the pumps 135 in the figure is schematic and that additional pumps may be arranged within the respective fluid paths depending on the circumstances.

[0087] The charging and discharging operations are controlled by a system controller (not shown). In particular, the system controller ends a charging operation when it detects that the temperature at the second opening 114 of the thermal storage 110 has risen to a predetermined temperature value (equal to or larger than the output temperature of the steam generator 120). Thereby, the cold part of the thermal storage 110 is maintained at the same temperature level as the output working fluid from steam generator 120. Similarly, the system controller ends a discharging operation when it detects that the temperature at the first opening 112 of the thermal storage has decreased to a predetermined value (equal to or below the input temperature of the steam generator 120). Thereby, the hot part of the thermal storage 110 is maintained at the specified input temperature level of the steam generator 120.

[0088] With the system 100, the waste of thermal energy that leaves the HRSG at medium temperature of e.g. 120°C is avoided by storing the thermal energy in the same thermal storage 110, from which the high temperature heat was extracted.

[0089] Furthermore, by extracting steam from the steam turbine stages 140, 142 and using it to preheat the water supplied from condenser 146, the efficiency of the steam cycle is improved.

[0090] The thermal storage 110 can be a single storage as shown in figure 1. Such a single thermal storage 110 may however comprise an arrangement of two or more thermal energy storages which can be flown through in parallel.

[0091] Alternatively, the thermal storage can be formed as two separate thermal storage units. In this case, one thermal storage unit will serve to store thermal energy from a source, such as a heating device, and output it to the fluid input 122 of the steam generator 120 during discharging. The other thermal storage then serves to collect the remaining thermal energy from the fluid output 124 of the steam generator 120.

[0092] Returning to the embodiment shown in figure 1, the storage of medium temperature thermal energy that remains in the exhaust flow of the HRSG (e.g. 200°C) is realized by storing high and medium temperature thermal energy in the same thermal storage. Therefore, the lower temperature level of the system 100 is not the ambient temperature, but rather the temperature of the working fluid (e.g. air) leaving the HRSG. This temperature is higher than ambient air temperature.

[0093] The working fluid flows through the system 100 in different directions, depending on whether it is in charging or discharging mode.

[0094] The storage system 100 has two certain states. The charge cycle of the storage system 100 is completed when the outlet temperature of the thermal storage 110 starts to rise. The discharging cycle is finished when the outlet temperature of the thermal storage 110 decreases.

[0095] The recovery of the thermal energy in the air downstream of the HRSG 120 and the increase of its temperature have 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 120 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 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 120 remains in the system 100 and is not lost. Therefore the HRSG 120 can be designed with a larger pinch point and with significant less heat exchanger surface and consequently costs compared to a conventional CCPP.

[0096] 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.

[0097] With the system illustrated in figure 1, 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.

[0098] In systems according to the present invention, the steam generator layout may be especially designed for thermal storages. This allows for higher steam pressure and higher outlet temperature at the HRSG 120 than in conventional CCPPs and hence these systems achieve higher steam cycle efficiency. The recovery of the thermal energy in the steam generator 120 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.

[0099] 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 thermal storage (110) for storing thermal energy, and
a steam generator (120) comprising a fluid input (122) and a fluid output (124), the fluid input and the fluid output being in fluid communication with the thermal storage, the steam generator further comprising a preheating device (130) for preheating a steam turbine fluid,
wherein the thermal storage is adapted to receive a working fluid from a thermal energy source during a charging phase,
wherein the thermal storage is adapted to output the working fluid for transportation to the fluid input of the steam generator during a discharging phase, and wherein the steam generator is adapted to heat the pre-heated steam turbine fluid using the working fluid received at the fluid input and to output the used working fluid through the fluid output for transportation to the thermal storage, such that thermal energy remaining in the output working fluid is injected into the thermal storage.

2. The system according to the preceding claim, further comprising a steam turbine, wherein the preheating device is in fluid communication with the steam turbine and adapted to receive steam extracted from the steam turbine.

3. The system according to the preceding claim, wherein the steam turbine comprises a first steam turbine stage (140) and a second steam turbine stage (142), wherein the first steam turbine stage is adapted to operate at a higher pressure than the second steam turbine stage, and wherein the preheating device is in fluid communication (132) with the first steam turbine stage and adapted to receive steam extracted from at least the first steam turbine stage.

4. The system according to any of the preceding claims, wherein the steam generator is adapted to receive the working fluid at the fluid input at a temperature between 550°C and 1000°C and to output the working fluid through the fluid output at a temperature between 100°C and 400°C.

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

6. The system according to any of the preceding claims, wherein the thermal storage comprises a first opening (112) and a second opening (114), wherein the first opening is in fluid communication with the fluid input of the steam generator, and wherein the second opening is in fluid communication with the fluid output of the steam generator.

7. The system according to the preceding claim, further comprising a heating device arranged in a fluid path between the second opening of the thermal storage and the first opening of the thermal storage.

8. The system according to claim 6 or 7, further comprising a controller adapted to end the charging phase when the temperature at the second opening of the thermal storage reaches a predetermined temperature value.

9. The system according to any of claims 1 to 5, wherein the thermal storage comprises a first thermal storage unit and a second thermal storage unit, wherein the first thermal storage unit is in fluid communication with the thermal energy source and the fluid input of the steam generator, and wherein the second thermal storage unit is in fluid communication with the fluid output of the steam generator.

10. The system according to any of the preceding claims, wherein the thermal storage comprises a bulk thermal storage material.

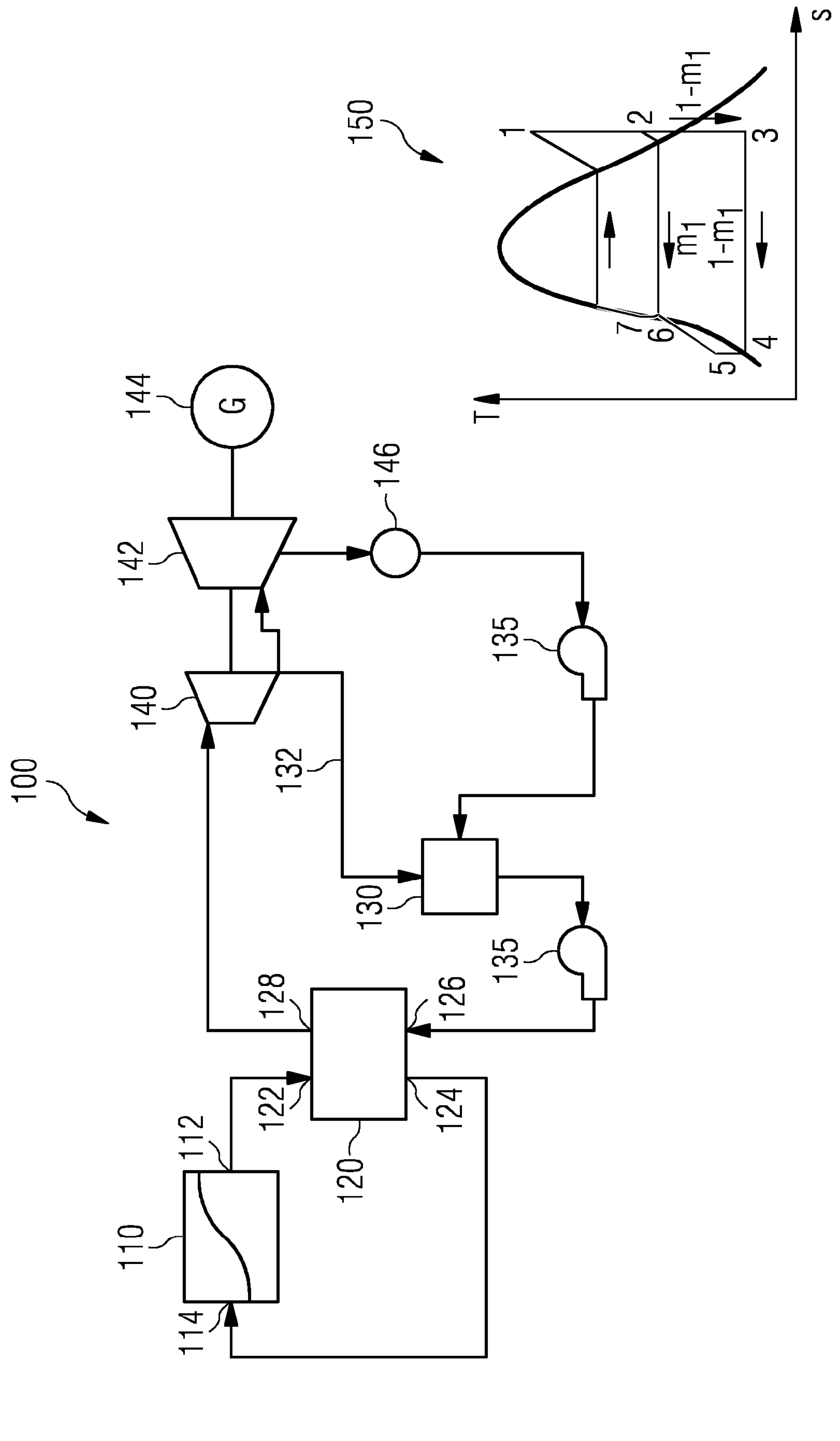
11. The system according to any of the preceding claims, wherein the working fluid is air and/or wherein the steam turbine fluid comprises water.

12. A power plant comprising
a power generator for producing electrical energy based on a renewable energy source, and
a system (100) 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 thermal storage, and wherein the system is adapted to release stored energy during insufficient production by discharging the thermal storage.

13. A method of storing energy, the method comprising
feeding a heated working fluid to a thermal storage to store thermal energy in the thermal storage during a charging phase,
preheating a steam turbine fluid during a discharging

phase to provide a preheated steam turbine fluid having a temperature closer to a corresponding boiling point,
feeding the working fluid from the thermal storage to a fluid input of a steam generator during the discharging phase, wherein the steam generator is adapted to heat the preheated steam turbine fluid using the working fluid, and
conducting the used working fluid from a fluid output of the steam generator to the thermal storage to store thermal energy remaining in the working fluid.

14. The method according to the preceding claim, wherein the preheating is performed using a preheating device, the preheating device being in fluid communication with a steam turbine and adapted to receive steam extracted from the steam turbine.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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
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