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(54) **Title:** SYSTEMS AND METHODS OF STORING ENERGY FROM GEOTHERMAL AND SOLAR RESOURCES

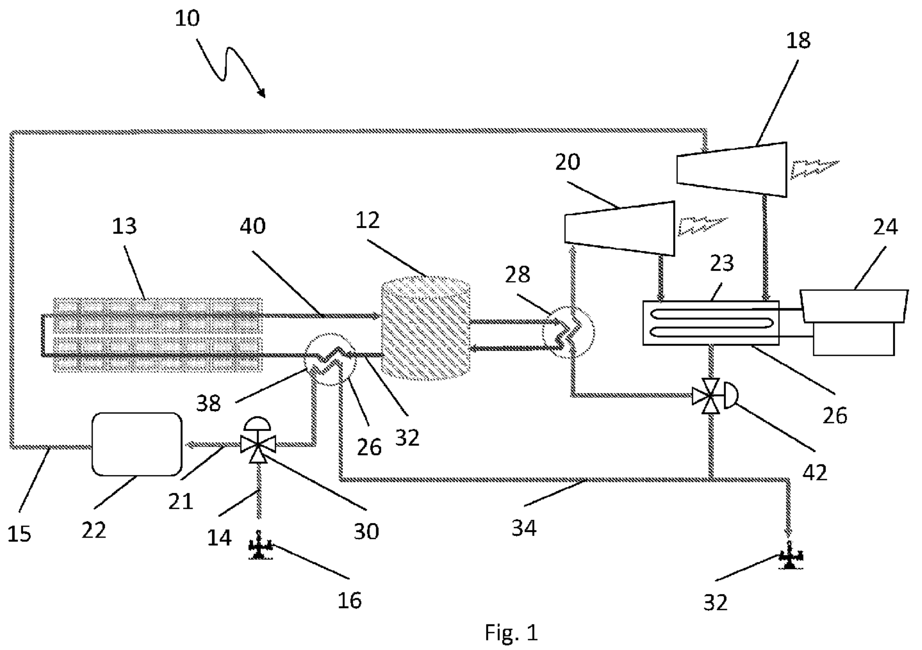

Fig. 1

(57) **Abstract:** A power plant that is a hybrid of a geothermal power plant and a concentrated solar power (CSP) plant is provided that includes a thermal energy storage medium which is configured to store heat from both the geothermal well(s) and the CSP solar field. The geothermal well(s) have dual operating modes, wherein at least one of said well or wells is configured to run geothermal fluid from a production well past a heat exchanger and transfer heat to a second medium, and where at least one of said well or wells is configured to run geothermal brine in a normal process loop for direct power production from the hot brine. The CSP solar field is configured to accept heat transfer fluid which has been preheated by heat from at least one geothermal well. The condensate from the power plant cooling unit is reheated for use in one or more turbines.

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SYSTEMS AND METHODS OF STORING ENERGY FROM GEOTHERMAL AND SOLAR RESOURCES

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and benefit of U.S. Patent Application Serial No. 62/427,738, filed November 29, 2016, which is hereby incorporated by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to thermal energy storage systems and geothermal and solar energy systems.

BACKGROUND OF THE DISCLOSURE

[0003] There has been a long-standing need to provide energy generation from renewable sources. Various renewable energy sources have been pursued, such as solar energy, wind, geothermal, and biomass for biofuels as well as others.

[0004] In recent years, the so-called "duck curve," in which excess solar photovoltaic electric energy is put onto various power grids, has caused increasing strain on legacy systems. This has led to an emerging focus on energy storage to mitigate the duck curve phenomenon. Various approaches have been taken to store energy. Batteries of various chemistries, pumped hydropower storage, flywheels and other technologies have been tried. Although pumped hydro is low cost, it is limited in terms of which sites are compatible. Batteries, flywheels and other technologies are very expensive. Thermal energy storage uses a thermal medium to store energy and is currently among the low-cost leaders.

[0005] Although thermal energy storage is low cost, getting the renewable energy in the form of heat has been a high-cost process. Concentrated solar power plants have been used, but suffer from high capital cost. Geothermal power stations are typically lower cost, but have lower temperature heat than CSP, which precludes cost effective storage. To date, no geothermal power plant has yet implemented thermal energy storage.

[0006] It should be appreciated that there remains a need for a system and method of storing energy that captures both the cost advantages of geothermal power generation and thermal energy storage systems, but with the high-quality heat of concentrated solar power (CSP). The present disclosure fulfills this need and others.

SUMMARY OF THE DISCLOSURE

[0007] In general terms, the present disclosure provides a hybrid geothermal and concentrated solar power thermal energy storage (TES) system that makes use of both CSP and geothermal heat sources. Embodiments of the TES system can use thermal oil, molten salt, concrete, rocks, or other materials as thermal energy storage media. A heat transfer fluid, such as thermal oil, or water can be used to move heat into and out of the TES system.

[0008] In exemplary embodiments, a hybrid geothermal and concentrated solar power plant comprises a thermal energy storage medium configured to store heat from at least one geothermal well and a concentrated solar power field. The at least one geothermal well may have dual operating modes and may be configured to run geothermal fluid from a production well past a heat exchanger and transfer heat to a medium. The medium may comprise one or more of thermal oil, water, molten salt, or supercritical CO2. In exemplary embodiments, the at least one geothermal well is configured to run geothermal brine in a normal process loop for direct power production from the hot brine.

[0009] The concentrated solar power field may be configured to accept heat transfer fluid which has been preheated by heat from at least one geothermal well. In exemplary embodiments, the heat transfer fluid is one or more of thermal oil, water, molten salt or supercritical CO2. The power plant may further comprise a cooling unit, and condensate from the cooling unit is reheated for use in one or more turbines by either geothermal heat from one or more of the at least one geothermal well and heat from the concentrated solar power field.

[0010] It is important to note that the condensate from a typical thermal power plant, geothermal or conventionally fueled, is liquid water at or below 100° Centigrade (C). This liquid water will typically be below the temperature of a typical “flash” geothermal plant, which will typically have production well temperatures above 100° C. This presents the opportunity to reheat this condensate using at least a portion of energy from one or more production wells.

[0011] It is further important to note that typically, heat exchangers involve the step-down in temperature of heat as energy flows from the hot side to the cold side. Typically, storing geothermal heat energy in this way would mean that the temperature of the stored heat would decrease to the point that it is no longer usable by a geothermal steam turbine. However, the present invention includes a step to further add heat to a storage medium from a Concentrated Solar Power (CSP) solar field which will typically be much hotter than a geothermal production well. In this way, the temperature of stored energy remains high enough to later be used by a typical geothermal steam turbine.

BRIEF DESCRIPTION OF THE DRAWINGS

[0001] The above-mentioned features and objects of the present disclosure will become more apparent with reference to the following description taken in conjunction with the accompanying drawings wherein like reference numerals denote like elements and in which:

[0002] FIG. 1 is a schematic of an exemplary embodiment of a hybrid geothermal and concentrated solar power plant in accordance with the present disclosure;

[0003] FIG. 2 is a schematic of an exemplary embodiment of a hybrid geothermal and concentrated solar power plant in accordance with the present disclosure;

[0004] FIG. 3 is a schematic of an exemplary embodiment of a hybrid geothermal and concentrated solar power plant in accordance with the present disclosure;

[0005] FIG. 4 is a graph depicting the “duck curve”;

[0006] FIG. 5 is a graph depicting the “duck curve”; and

[0007] FIG. 6 is a graph depicting the “duck curve.”

DETAILED DESCRIPTION

[0012] In the following detailed description of exemplary embodiments of the disclosure, reference is made to the accompanying drawings in which like references indicate similar elements, and in which is shown by way of illustration specific embodiments in which disclosed systems and devices may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the embodiments, and it is to be understood that other embodiments may be utilized and that logical, mechanical, functional, and other changes may be made without departing from the scope of the present disclosure. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present disclosure is defined by the appended claims. As used in the present disclosure, the term “or” shall be understood to be defined as a logical disjunction and shall not indicate an exclusive disjunction.

[0013] With reference to FIGS. 1-3, a hybrid geothermal and concentrated solar power (CSP) plant 10 is provided that includes a thermal energy storage medium 12 configured to store heat from both the geothermal well(s) 16 and the CSP solar field 13. The geothermal well(s) have dual operating modes - storage mode and power production mode - wherein at least one of the well or wells is configured to run geothermal fluid 14 from a geothermal production well 16 past a heat exchanger 26 and transfer heat to a second medium 32. The second medium 32 can be thermal oil, water, molten salt, or other fluid. At least one of the well or wells is configured to run geothermal brine in a normal process loop for direct power production from the hot brine.

[0014] In exemplary embodiments, at least one valve or other process control apparatus 30 is used to switch between operating modes. In power production mode, the at least one valve or other process control apparatus is set to divert some or all hot geothermal brine 21 from a geothermal production well 16 through process control equipment 22, including a flash tank and then on to at least one turbine 18. In storage mode, hybrid power plant 10 is configured to run at least one or more turbine(s) 20, from stored geothermal heat from thermal energy storage system 12.

[0015] The CSP solar field 13 is configured to accept heat transfer fluid 32, either thermal oil, water, molten salt, or some other heat transfer fluid which has been preheated in heat exchanger 26 by heat from at least one geothermal well 16. The condensate from the power plant cooling unit 23 for any or all turbines 18, 20 of the plant 10 is reheated in heat exchanger 28, fed from thermal energy storage 12 for use in one or more turbines by either the geothermal heat from at least one geothermal production well 16, or the heat from the CSP solar field 13, or both geothermal heat and solar thermal heat.

[0016] In general, a geothermal power plant includes many process steps to handle hot solids laden with geothermal brine before the energy contained in the brine is used to produce steam for power production in a steam turbine. An exemplary embodiment includes a method to direct geothermal brine from a production well to either a flash tank 22 or to a heat exchanger. In the flash tank 22, it can be flashed to steam and then sent through one or more turbines. If some or all of the brine is diverted to a heat exchanger, then it can pre-heat thermal oil (or another heat transfer fluid) that is lower temperature than the brine. The thermal oil (or other heat transfer fluid) is then run through a CSP collector field 13 where it gains additional heat. Importantly, this improves the exergetic efficiency of the TES system, a significant quantum leap in performance that you cannot get without CSP. Once the thermal oil leaves the collector field 13, it moves to a hot oil storage location (or packed bed system, or other thermal energy storage system) 12, or transfers its heat to another medium for storage.

[0017] When the plant is operated in storage mode, at least some of the geothermal brine is routed to the injection well 32 after being passed through heat exchanger 26. FIG. 2 shows the plant operating with all brine from production well 16 being reinjected after being passed through heat exchanger 26. In power production mode, the condenser 23 is cooled by a cooling tower 24 to remove heat from the system. In all operating modes, injection well 32 receives cold brine from the plant 10 and reinjects it into the geothermal reservoir. FIG. 3. shows the hybrid power plant operating in full power production mode.

[0018] In this way, the turbine or turbines can be partially or completely shut off during the day when solar PV energy is widely available and power plants help the grid by shutting down. Then when the sun goes down and grid power plants are desired to be turned back on, the heat transfer fluid (oil or other HTF) can be used to transfer thermal energy from the storage medium to a heat exchanger, where brine from the production well can be heated further, or condenser water from the output of a turbine can be reheated. In any case, the heat would be captured by steam which would then run through one or more turbines. Both the geothermal and CSP energy is stored for later use.

[0019] While the apparatus, systems, and methods have been described in terms of what are presently considered to be the most practical and preferred embodiments, it is to be understood that the disclosure need not be limited to the disclosed embodiments. It is intended to cover various modifications and similar arrangements included within the spirit and scope of the claims, the scope of which should be accorded the broadest interpretation to encompass all such modifications and similar structures. The present disclosure includes any and all embodiments of the following claims.

[0020] Thus, it is seen that hybrid geothermal and concentrated solar power plants are provided. It should be understood that any of the foregoing configurations and specialized components or chemical compounds may be interchangeably used with any of the systems of the preceding embodiments. Although illustrative embodiments are described hereinabove, it will be evident to one skilled in the art that various changes and modifications may be made therein without departing from the disclosure. It is intended in the appended claims to cover all such changes and modifications that fall within the true spirit and scope of the disclosure.

CLAIMS

What is claimed is:

1. A hybrid geothermal and concentrated solar power plant comprising a thermal energy storage medium configured to store heat from at least one geothermal well and a concentrated solar power field.

2. The power plant of claim 1 wherein the at least one geothermal well has dual operating modes, wherein the at least one geothermal well is configured to run geothermal fluid from a production well past a heat exchanger and transfer heat to a medium.

3. The power plant of claim 2 wherein said medium comprises one or more of thermal oil, water, molten salt, or supercritical CO_2.

4. The power plant of claim 1 wherein the at least one geothermal well is configured to run geothermal brine in a normal process loop for direct power production from the hot brine.

5. The power plant of claim 1 wherein the concentrated solar power field is configured to accept heat transfer fluid which has been preheated by heat from at least one geothermal well.

6. The power plant of claim 4 wherein the heat transfer fluid is one or more of thermal oil, water, molten salt or supercritical CO_2.

7. The power plant of claim 1 further comprising a cooling unit, wherein condensate from the cooling unit is reheated for use in one or more turbines by either geothermal heat from one or more of the at least one geothermal well and heat from the concentrated solar power field.

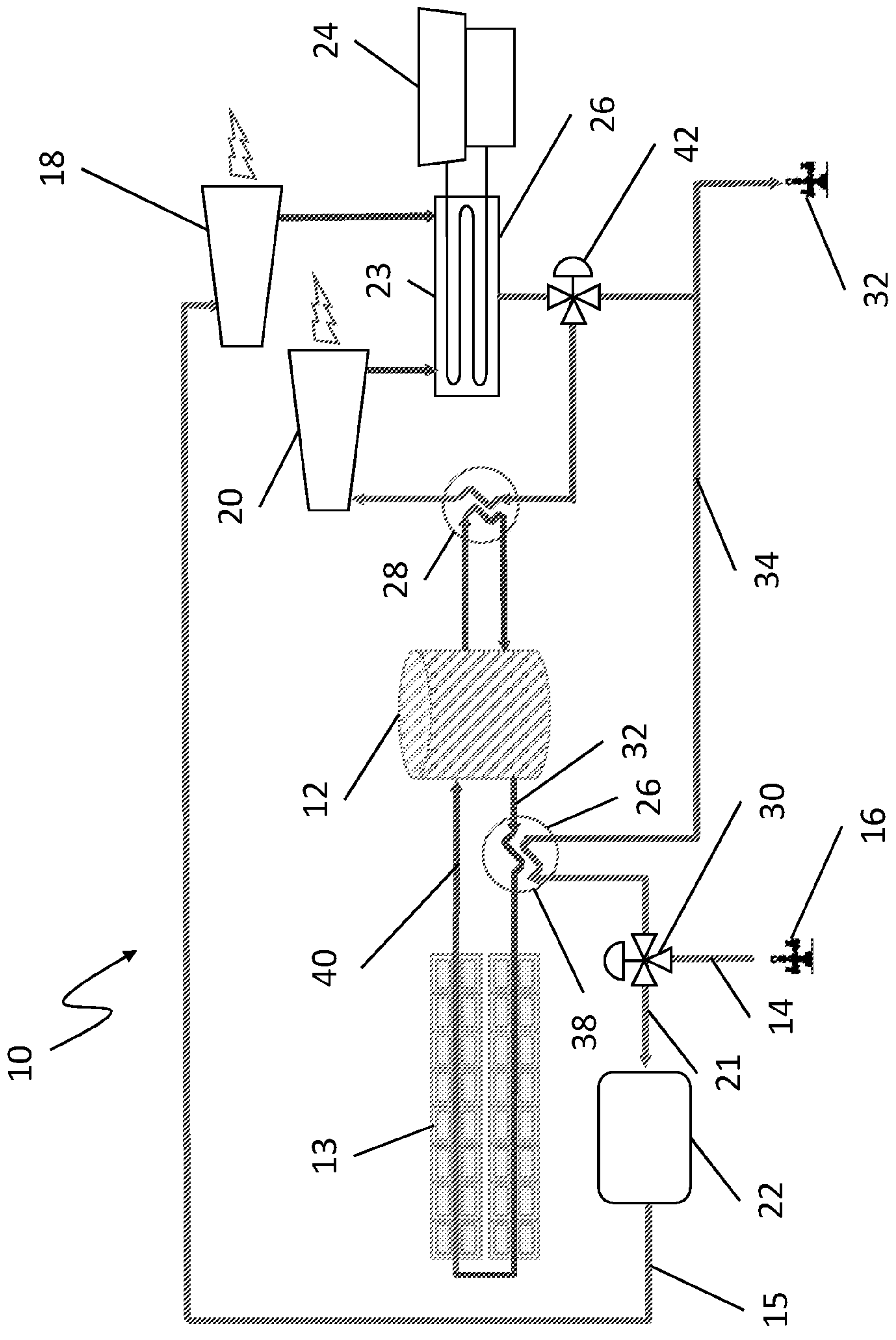

Fig. 1

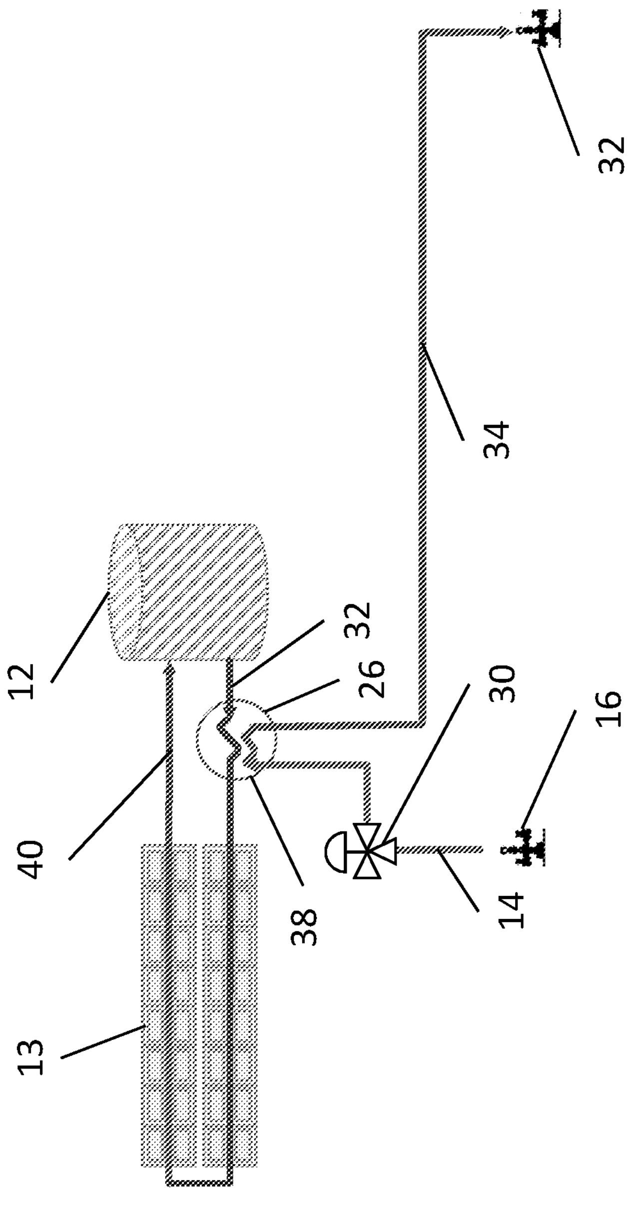

Fig. 2

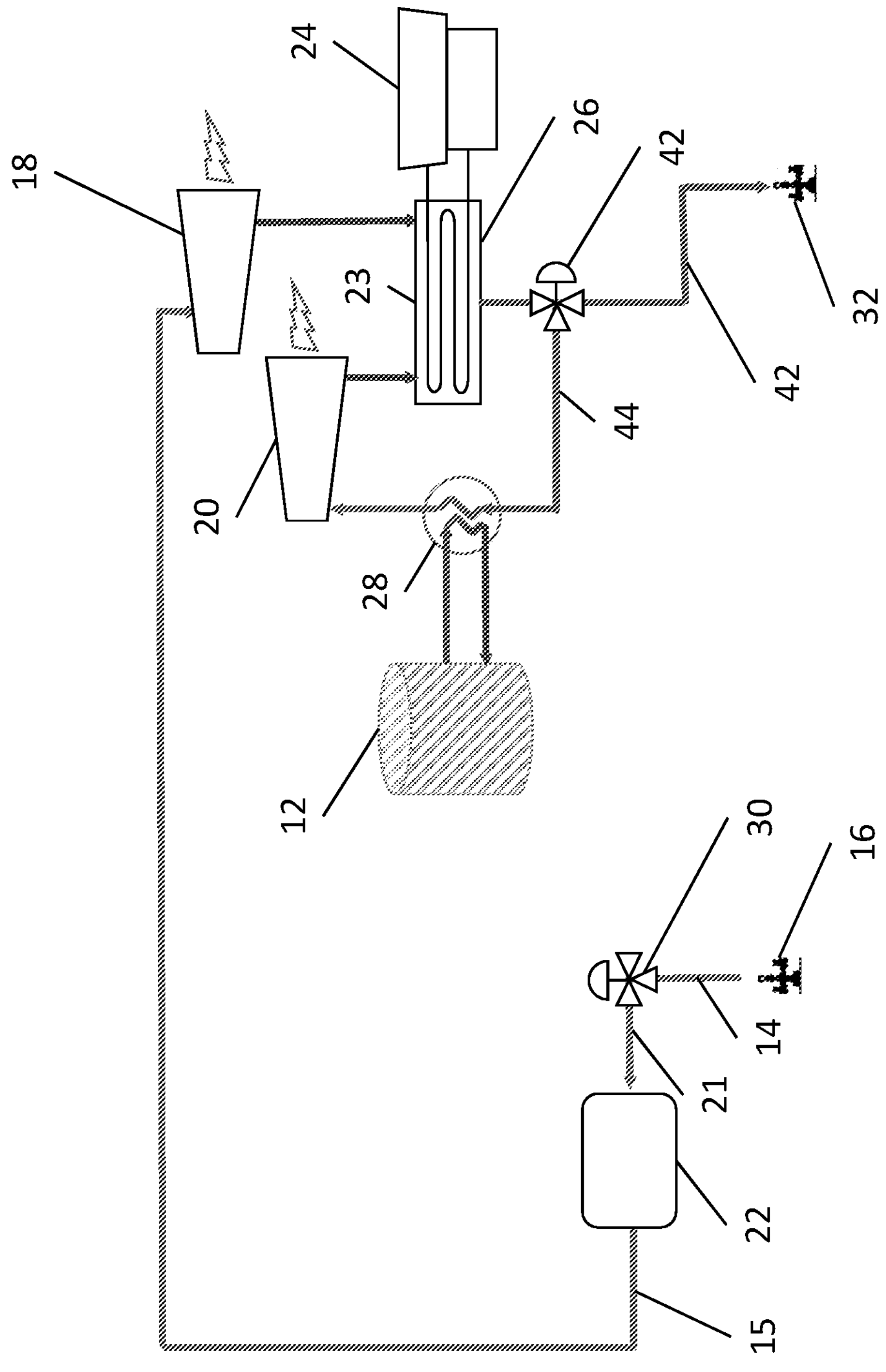

Fig. 3

The Duck Curve

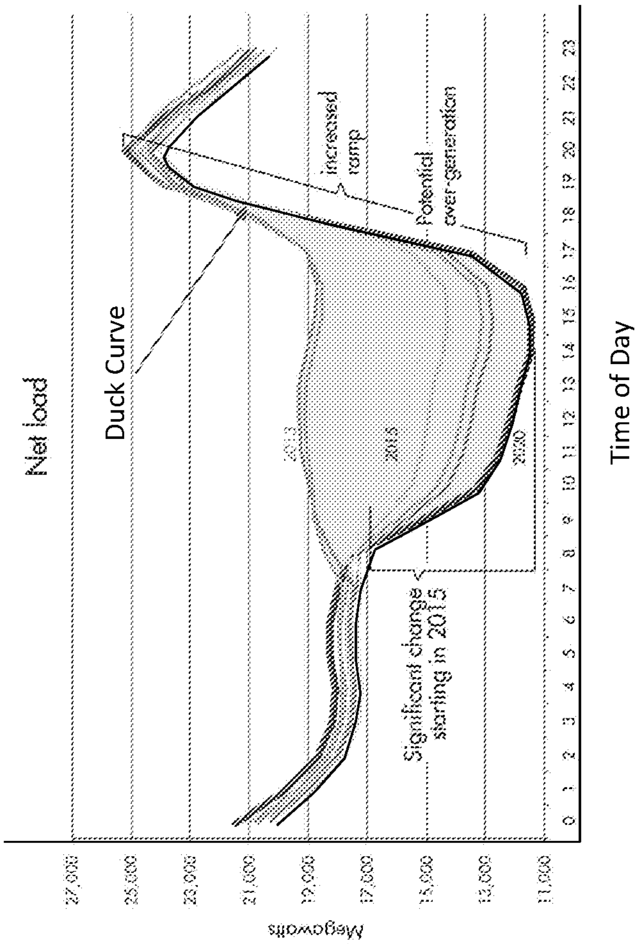

Fig. 4

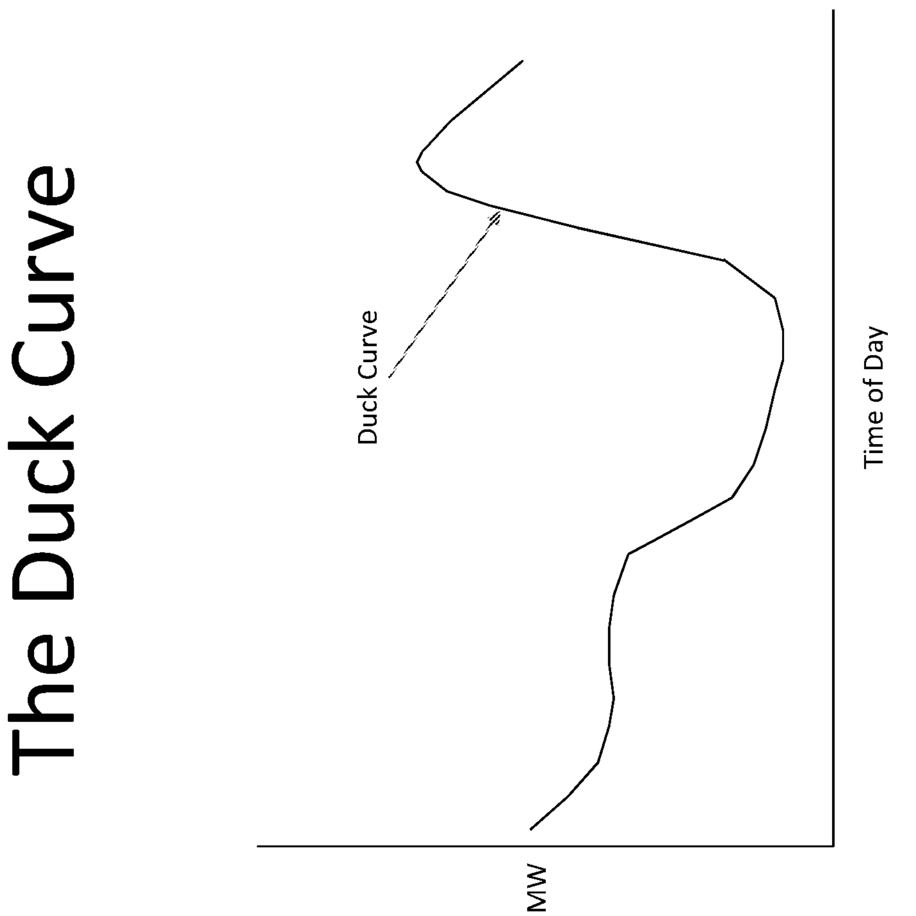

Fig. 5

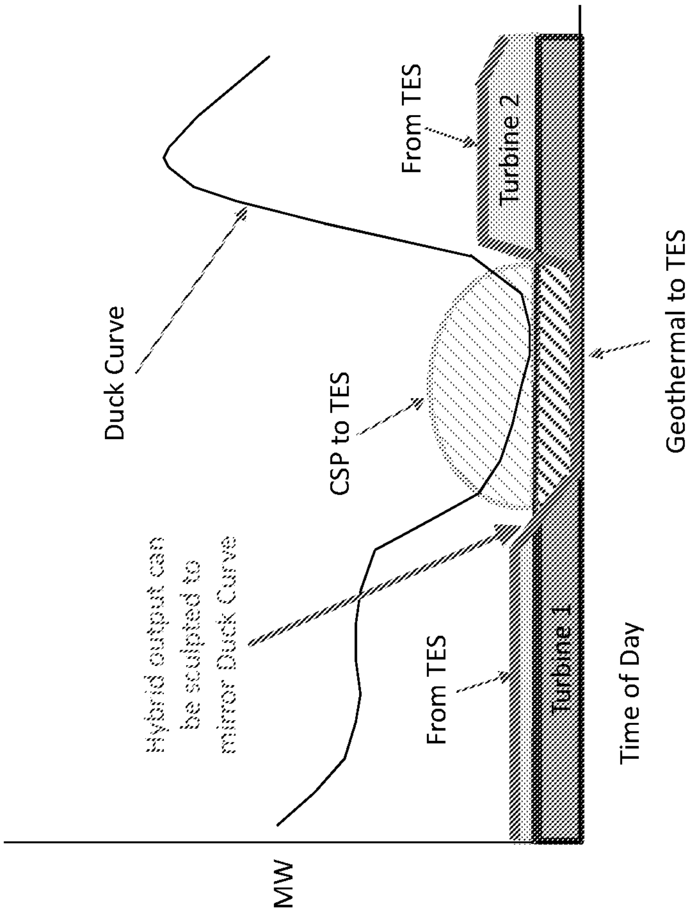
MW
Duck Curve
Hybrid output can be sculpted to mirror Duck Curve
CSP to TES
From TES
From TES
Turbine 1
Turbine 2
Time of Day
Geothermal to TES

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 17/63342

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F24J 2/00 (2018.01)
CPC - F24J 2/0023

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History Document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/0071366 A1 (KLEMENCIC) 25 March 2010 (25.03.2010) entire document	1-4, 7
X	CN 103423108 A (DENGRONG ZHOU et al) 04 December 2013 (04.12.2013) entire document	1, 5, 6
A	US 2014/0298806 A1 (JETER) 09 October 2014 (09.10.2014) entire document	1-7
A	WO 2016/098192 A1 (MITSUBISHI HITACHI POWER SYSTEMS) 23 June 2016 (23.06.2016) entire document	1-7
A	CN 102287344 A (YANG SHANRANG) 21 December 2011 (21.12.2011) entire document	1-7

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 January 2018	01 FEB 2018

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774