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(54) **SYSTEMS AND METHODS FOR INTEGRATING CONCENTRATED SOLAR THERMAL AND GEOTHERMAL POWER PLANTS USING MULTISTAGE THERMAL ENERGY STORAGE**

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(57) **ABSTRACT**

Systems and methods are described for removing thermal energy from power plant heat engines, storing, and then recovering the stored energy. The removed or stored thermal energy can raise the enthalpy of lower temperature heat sources for utilization in electric power generating plants. Included also are systems and methods for integrating and cascading multistage thermal energy storage to supply multiple heat users at different temperatures. The methods apply to power plants utilizing thermal energy from concentrated solar thermal energy collectors, fuel-fired heaters, or gas turbine-generator heat recovery units. Several embodiments use the stored energy to extend solar thermal power plant operation, particularly the bottom power cycle. Other embodiments extract thermal energy from a solar thermal power plant, storing a portion of the energy extracted, and recovering this thermal energy to continuously heat geothermal fluids utilized in a geothermal power plant, and heat geothermal power plant working fluids.

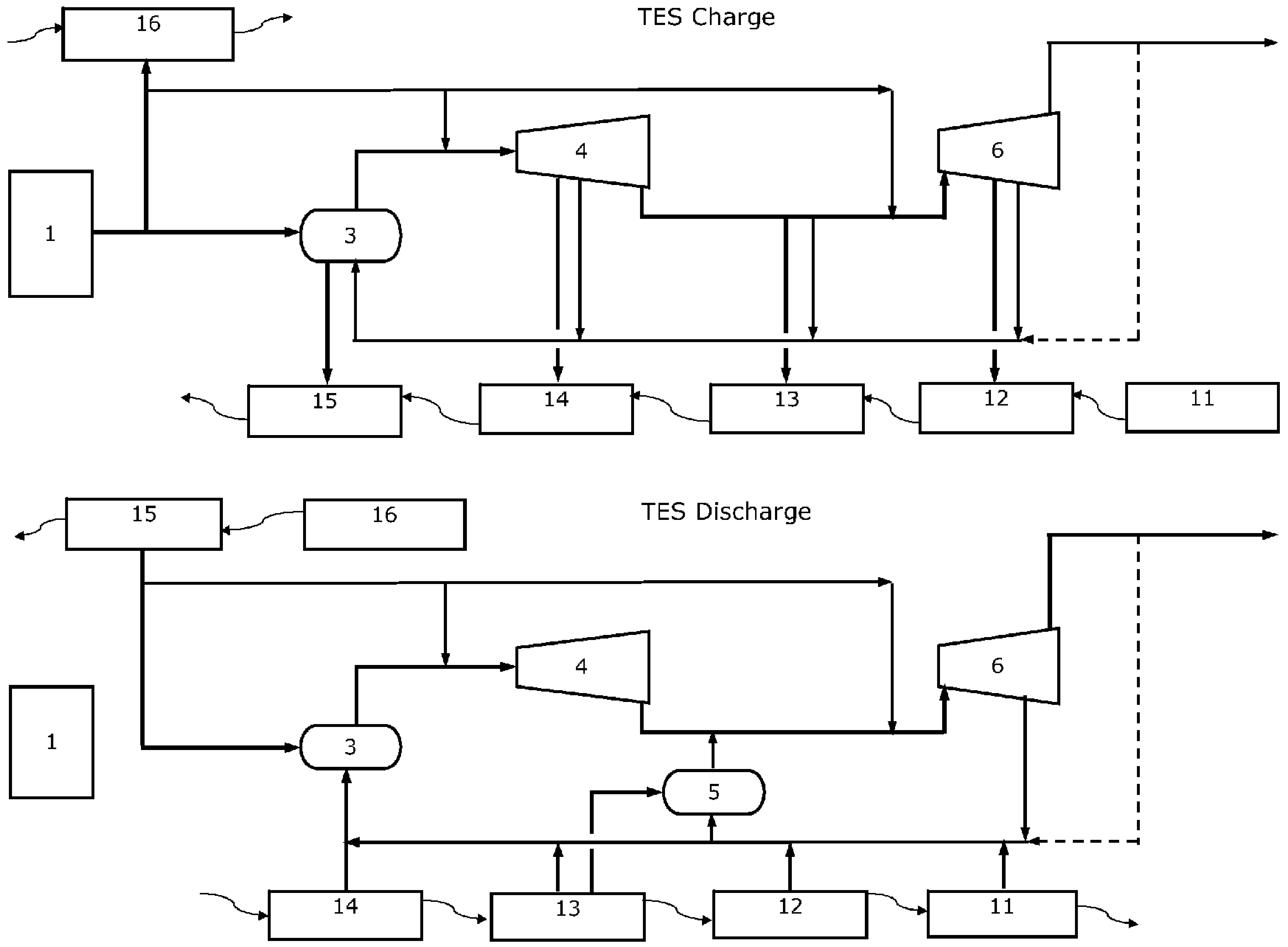
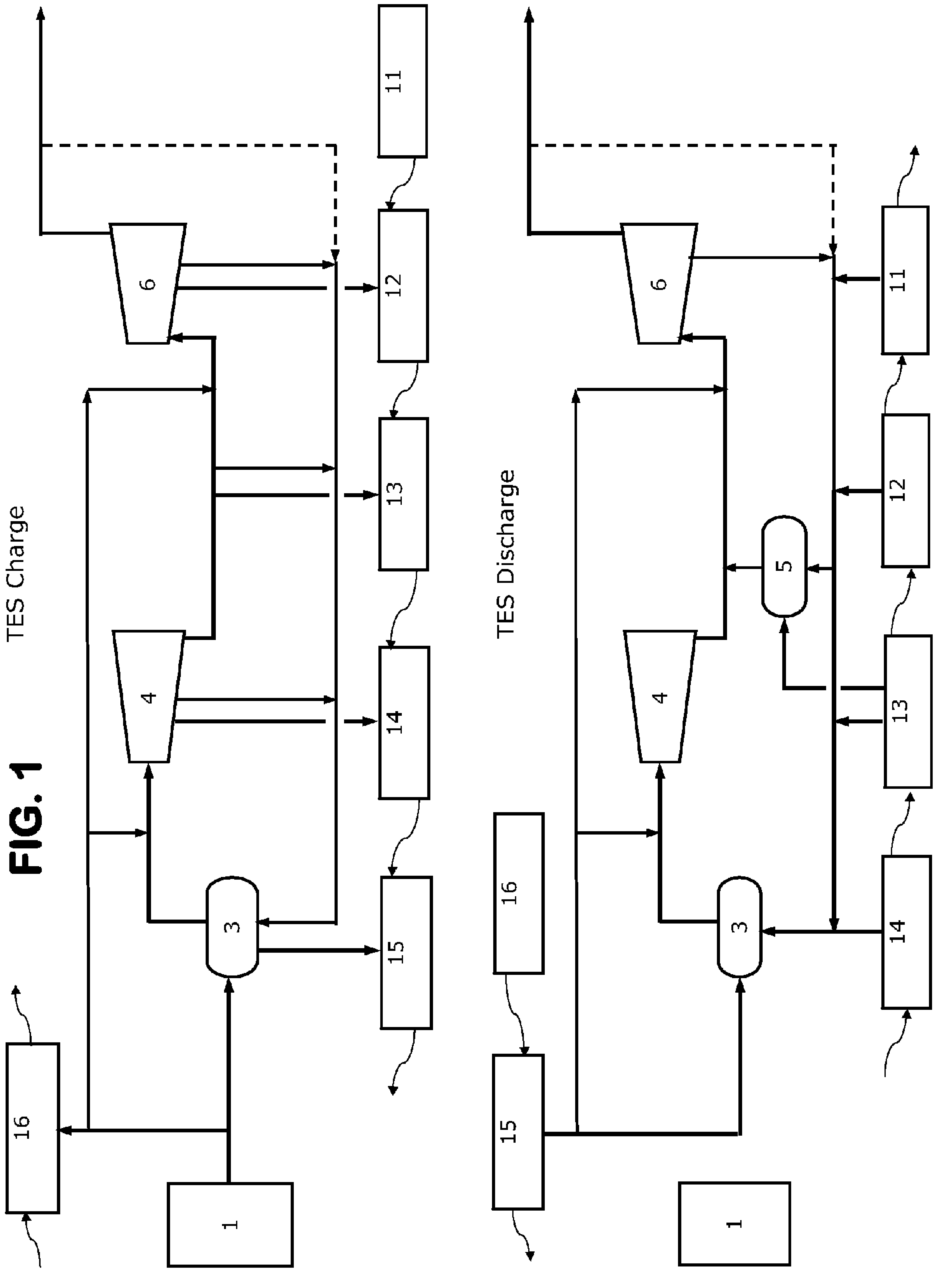


FIG. 1


TES Charge
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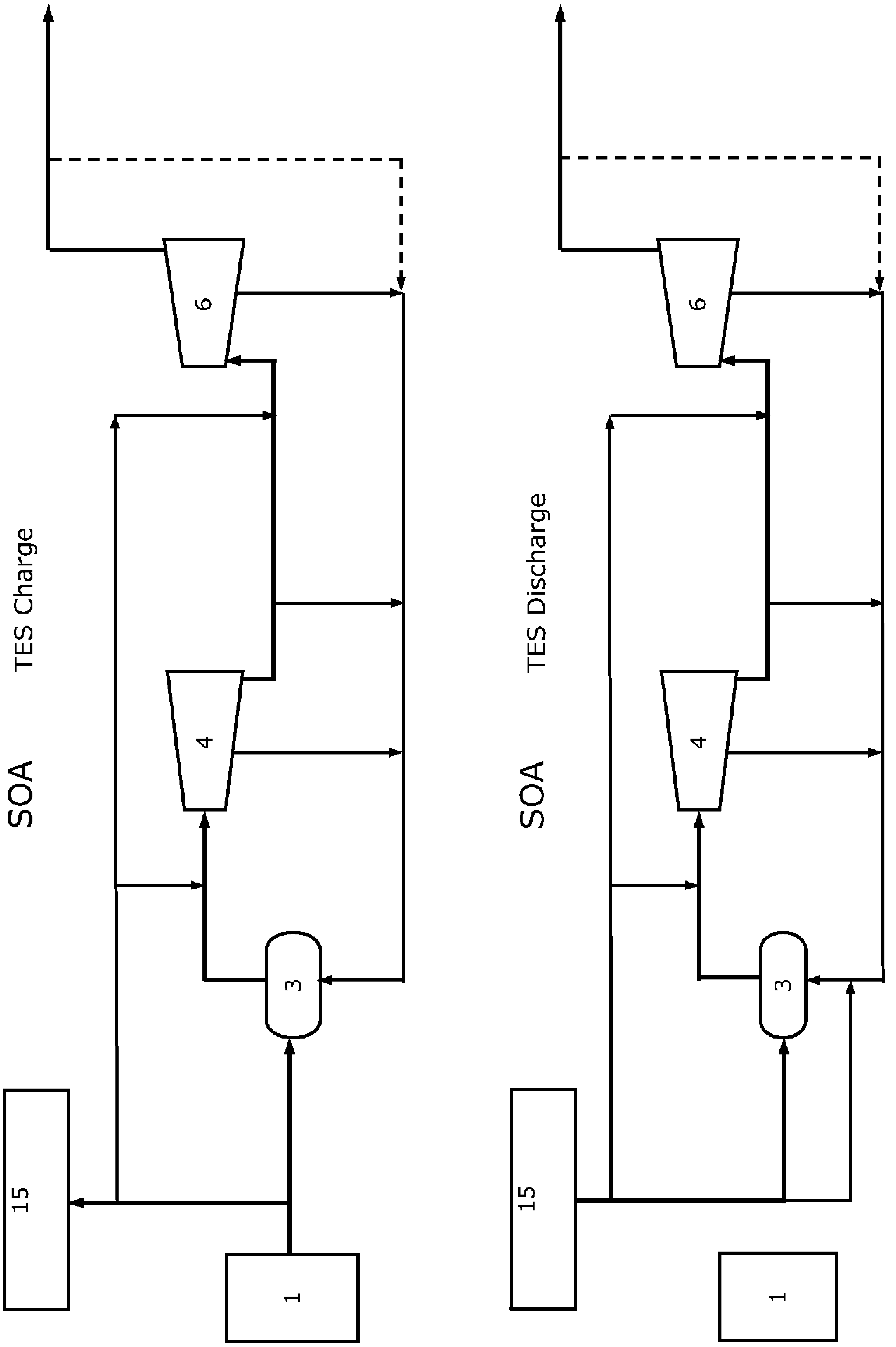
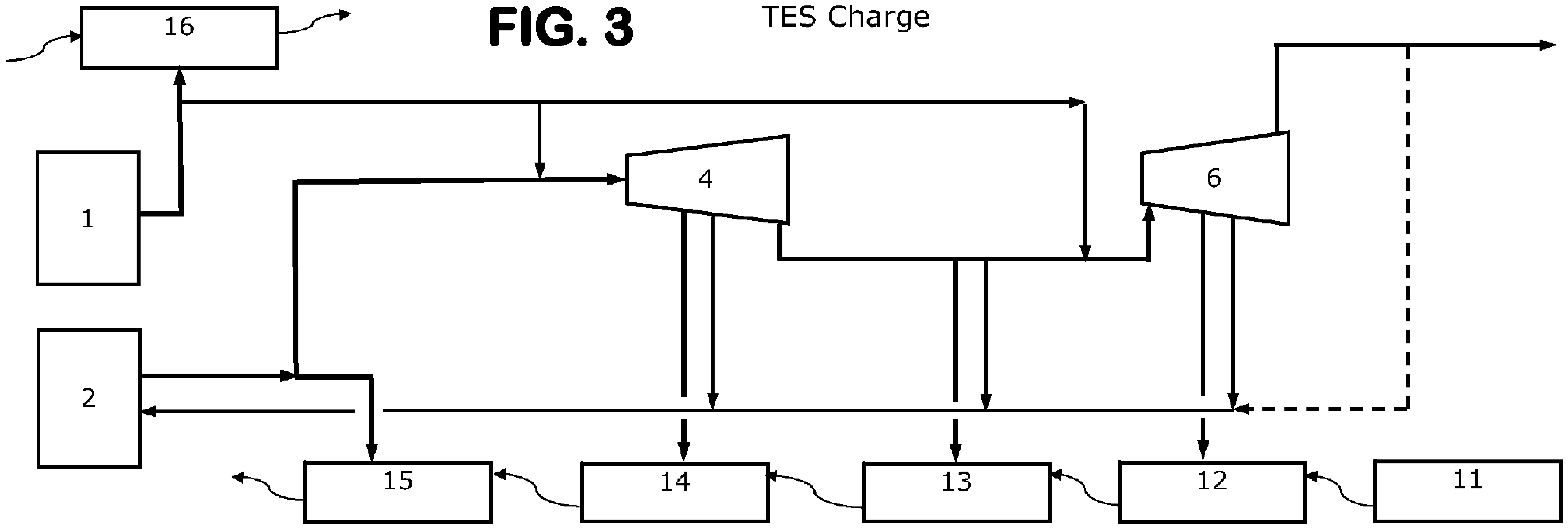


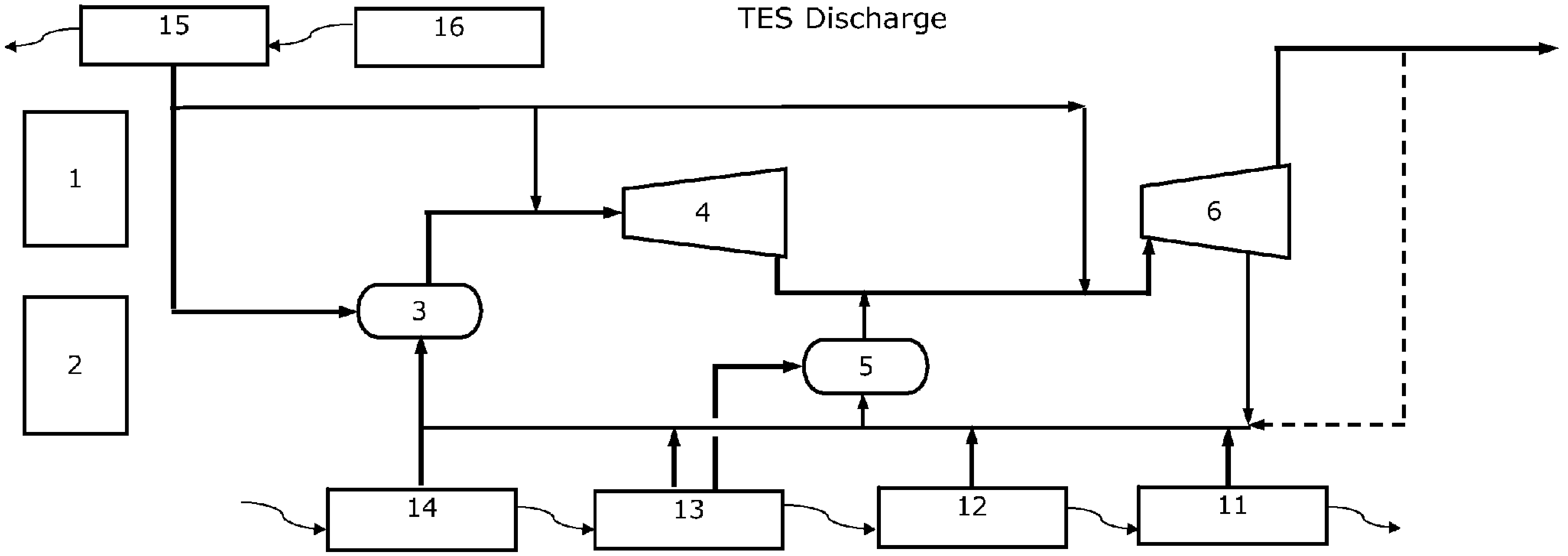
FIG. 2

FIG. 3

TES Charge



TES Discharge



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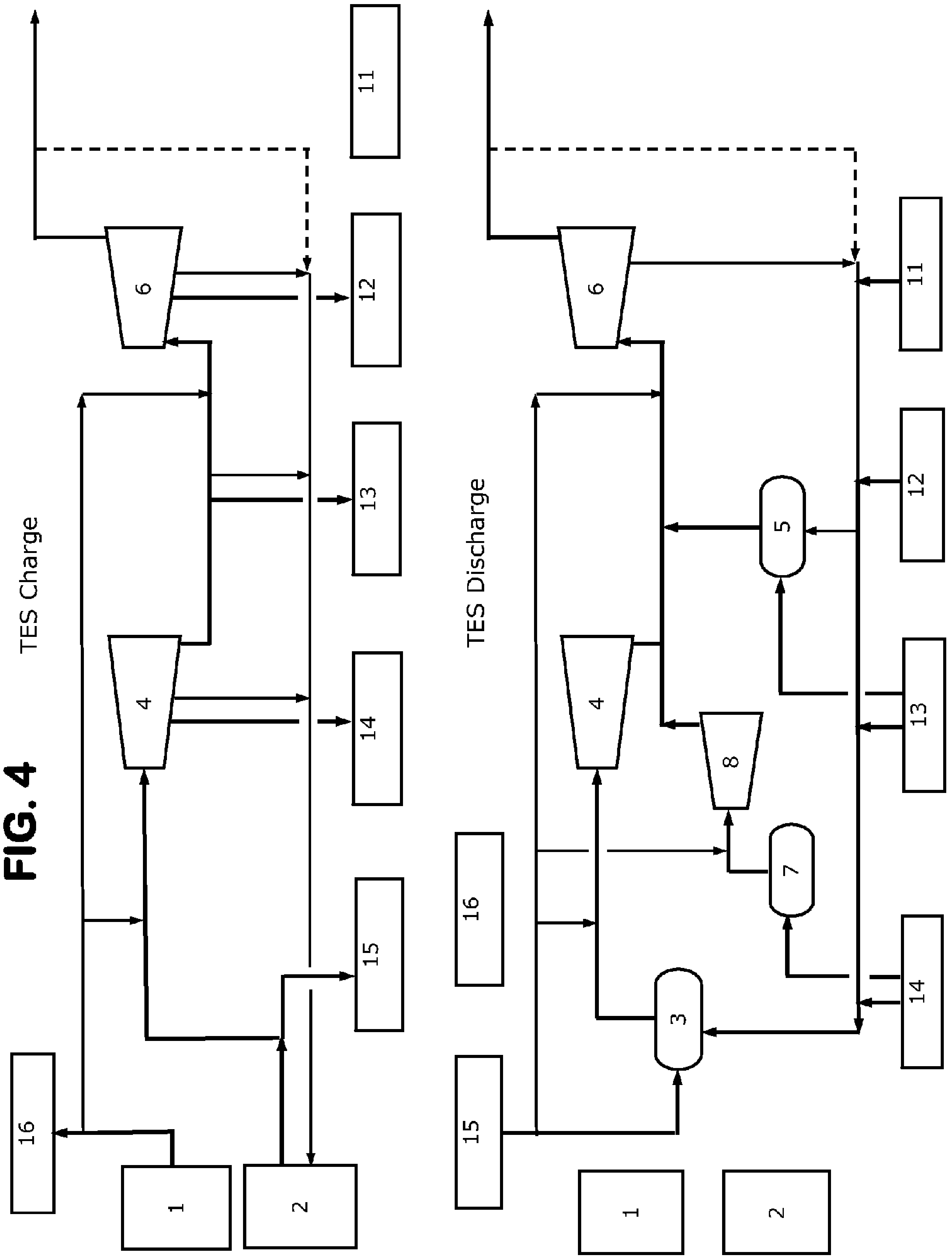
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FIG. 5

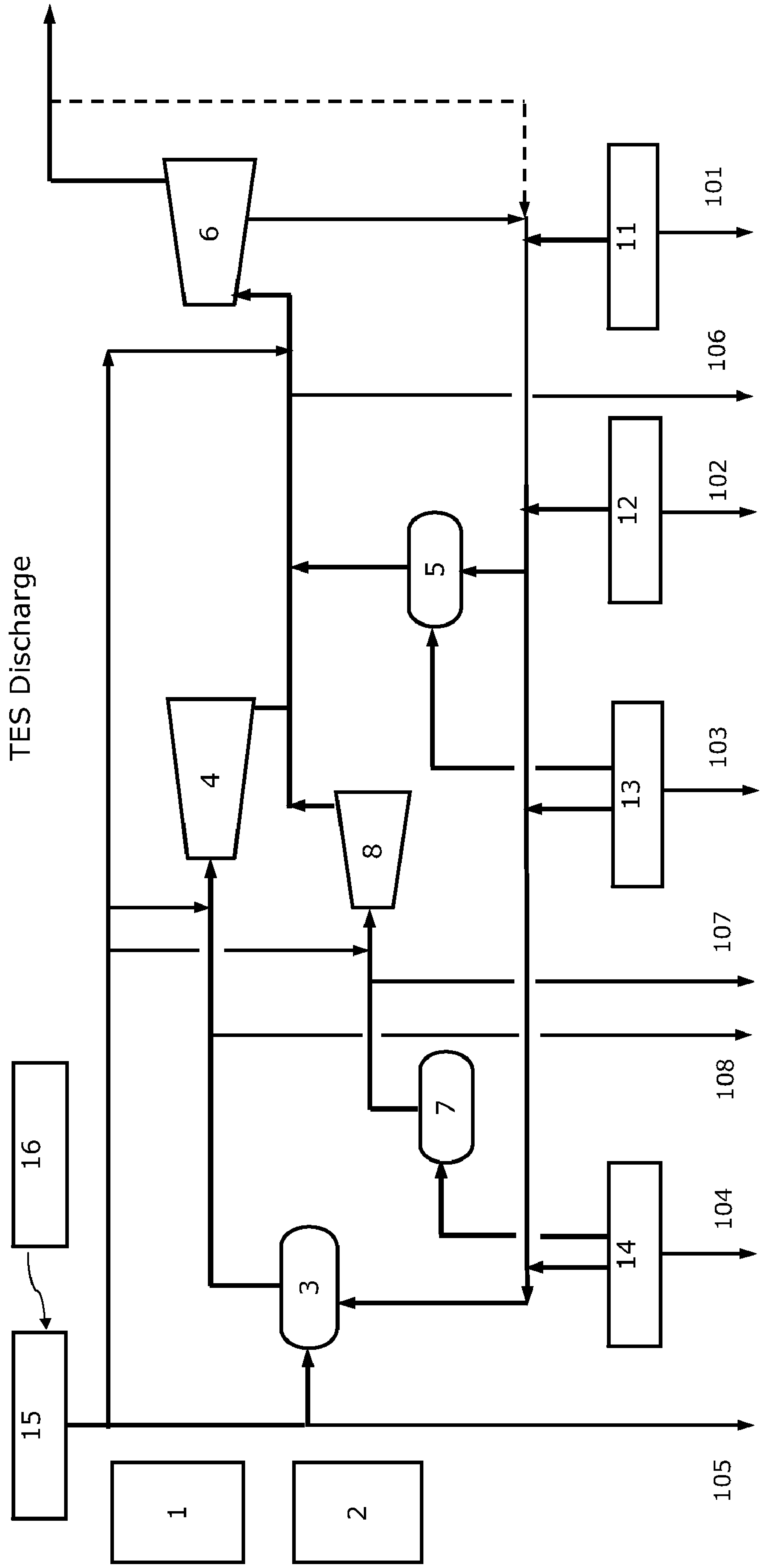
TES Discharge
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FIG. 6

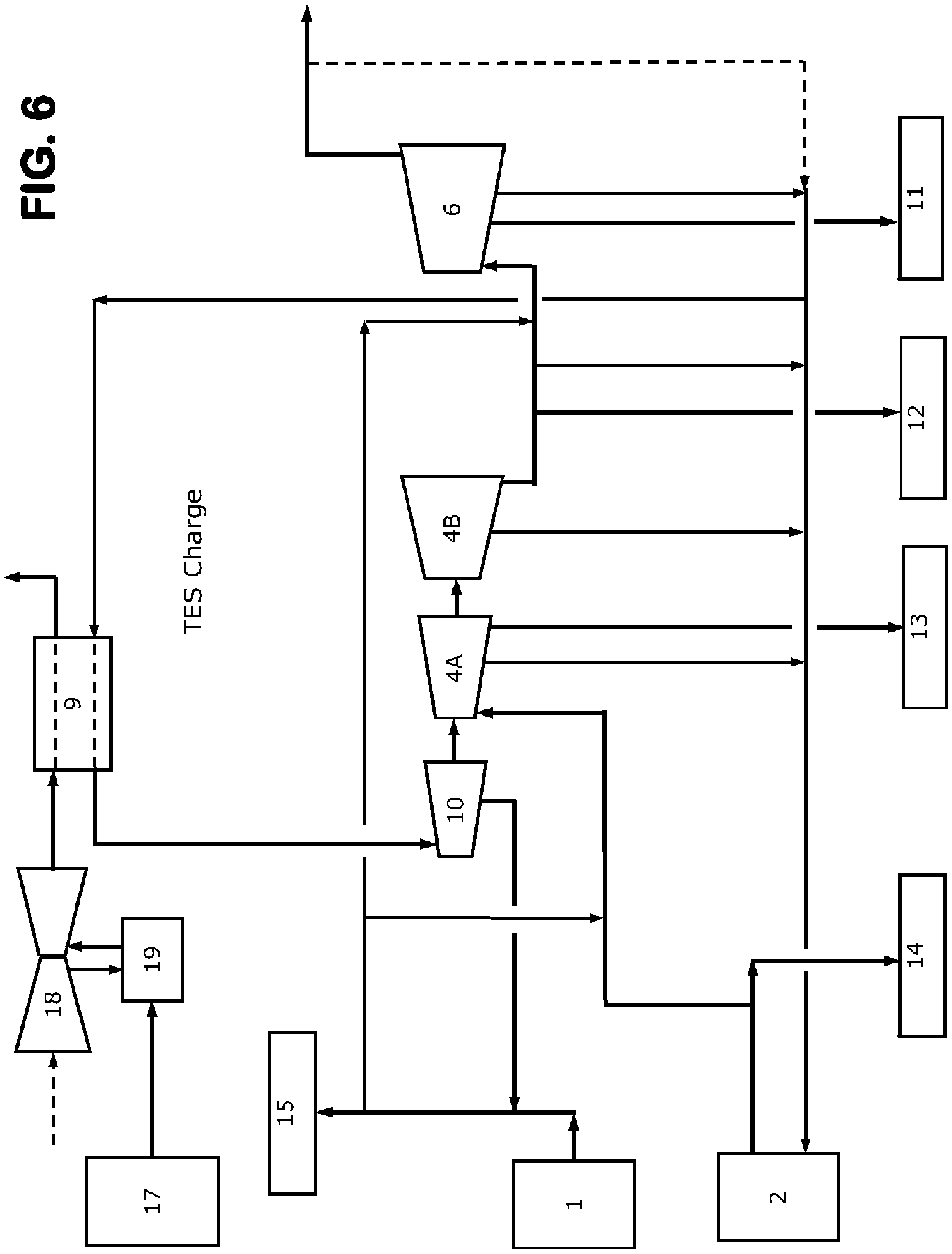
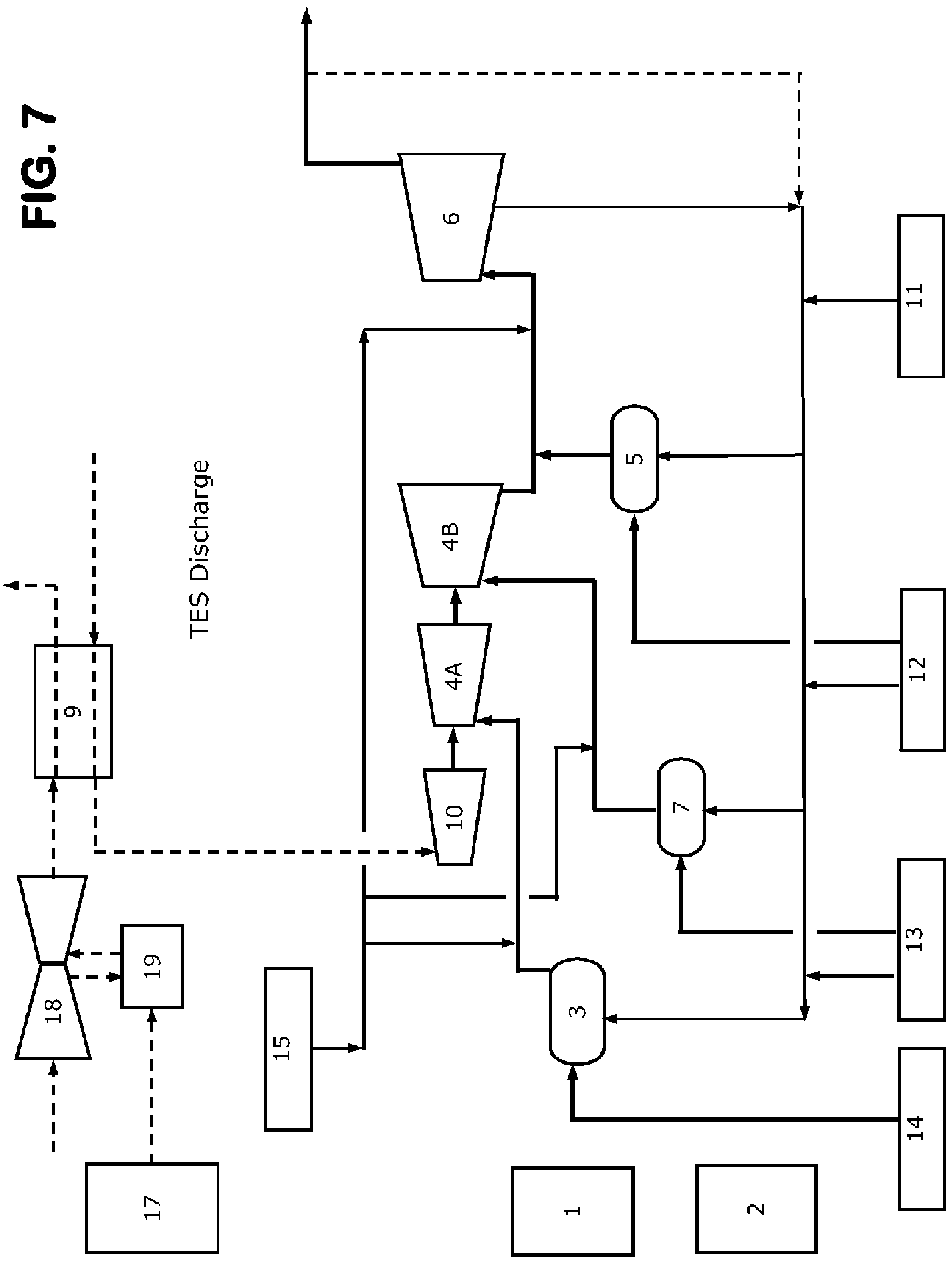


FIG. 7



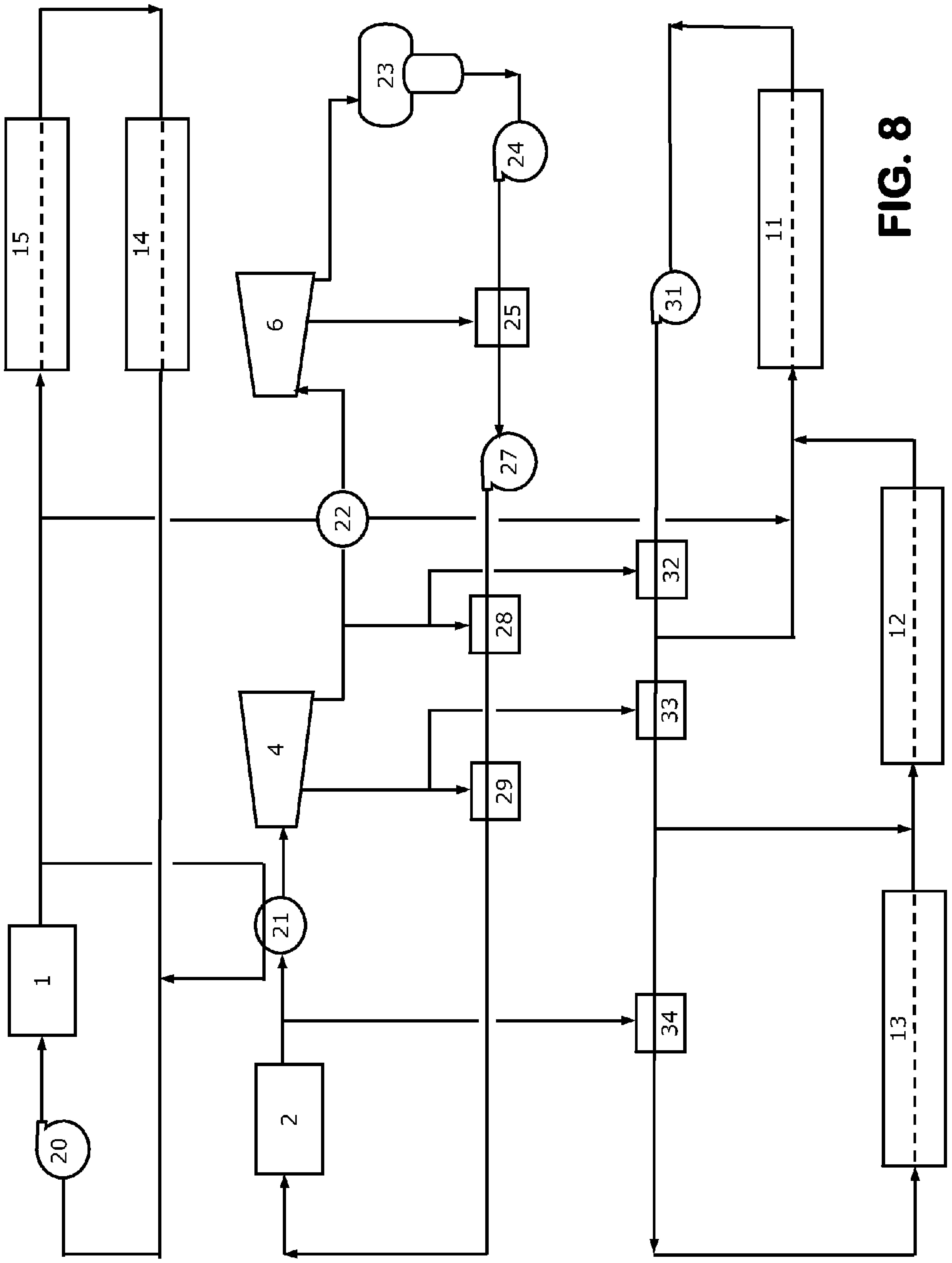
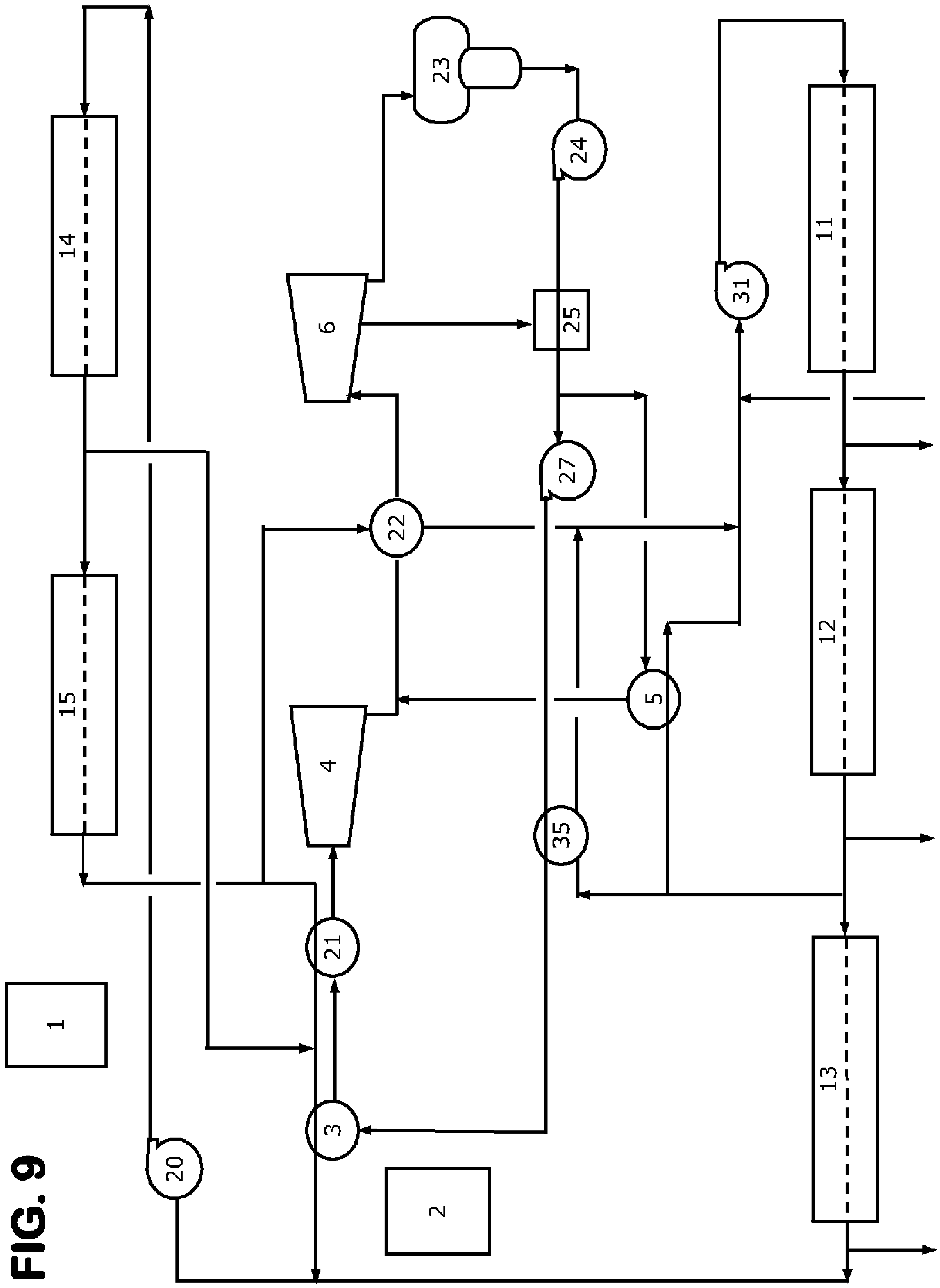


FIG. 8

FIG. 9



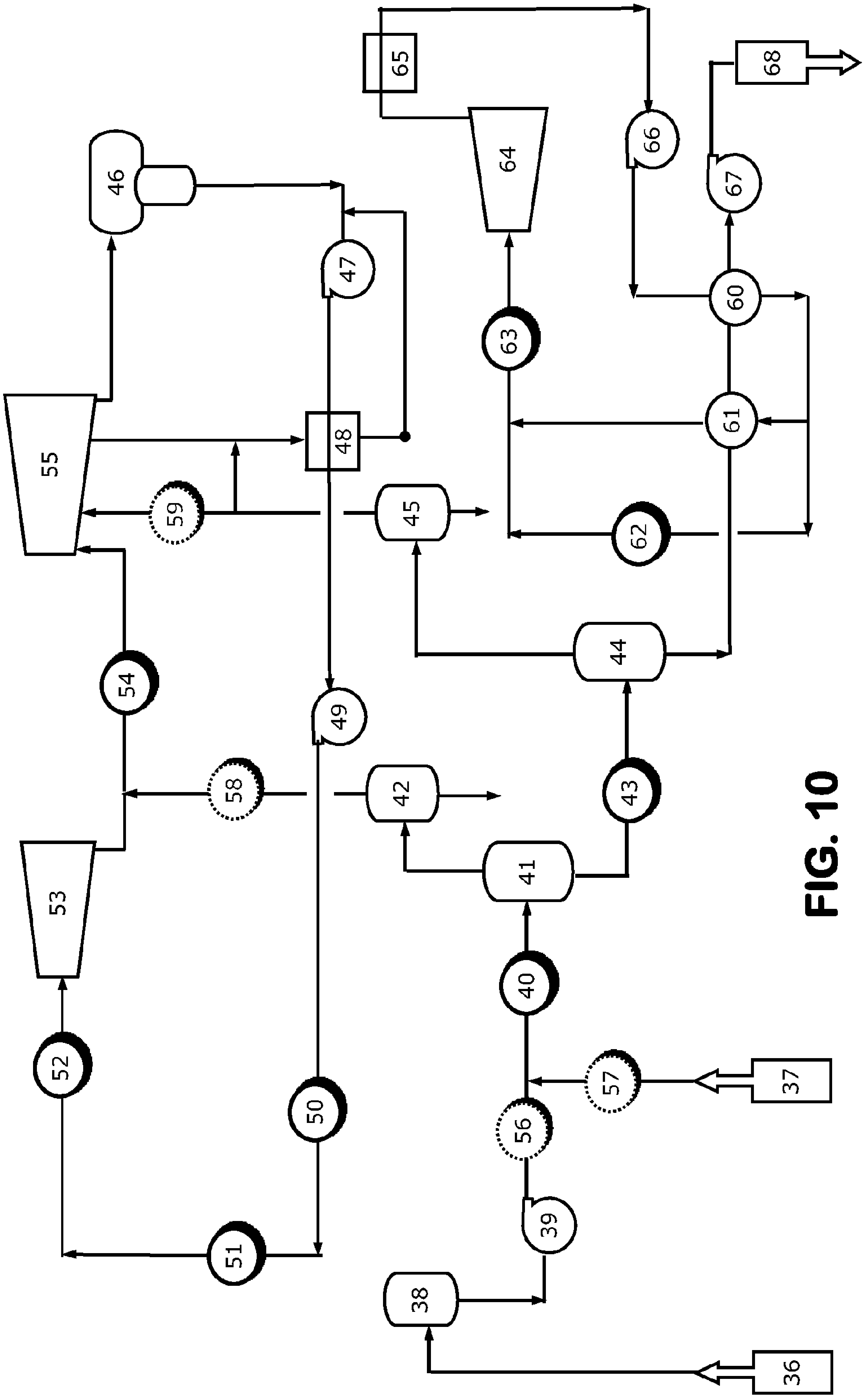

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FIG. 10

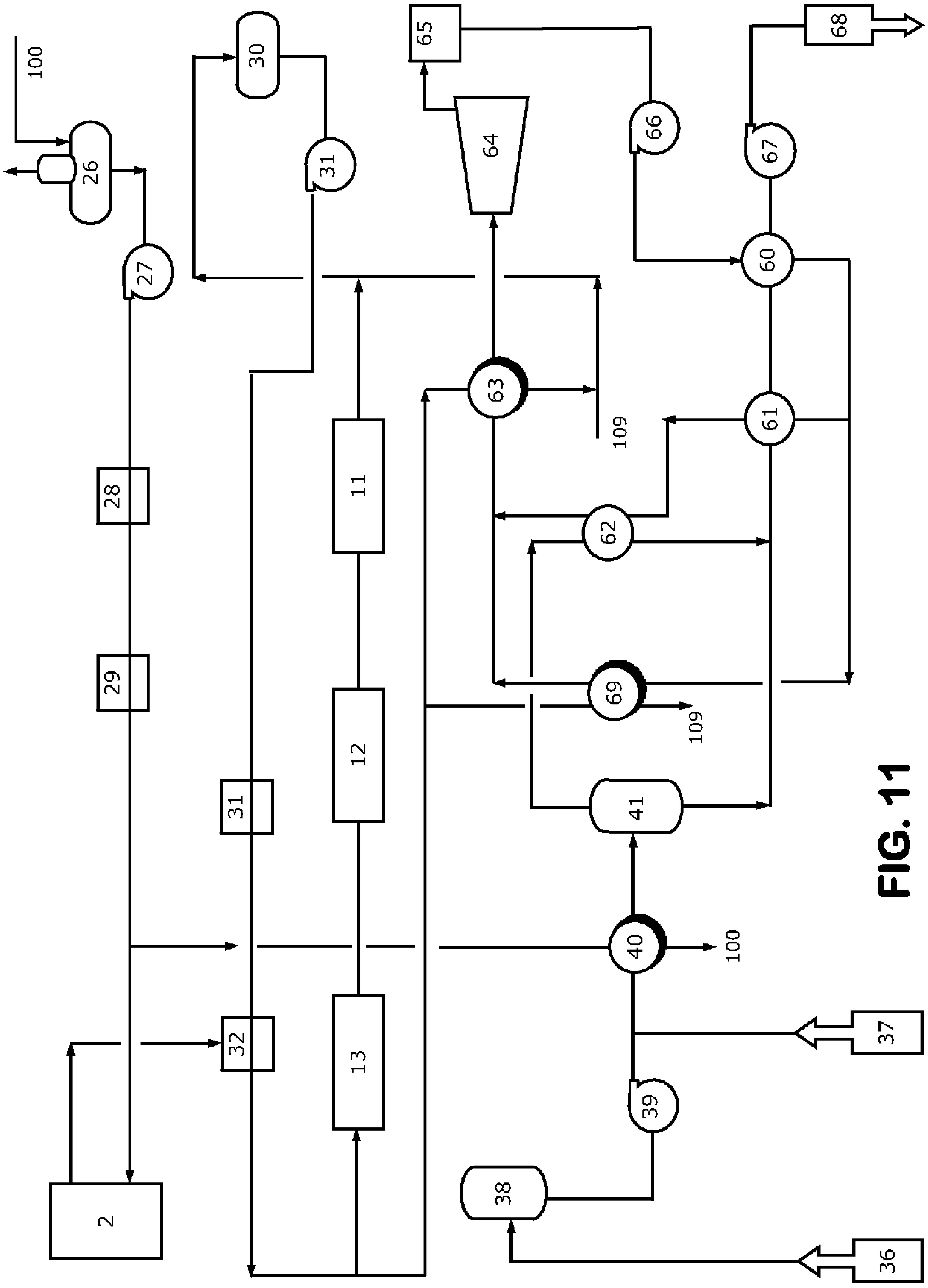
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FIG. 11

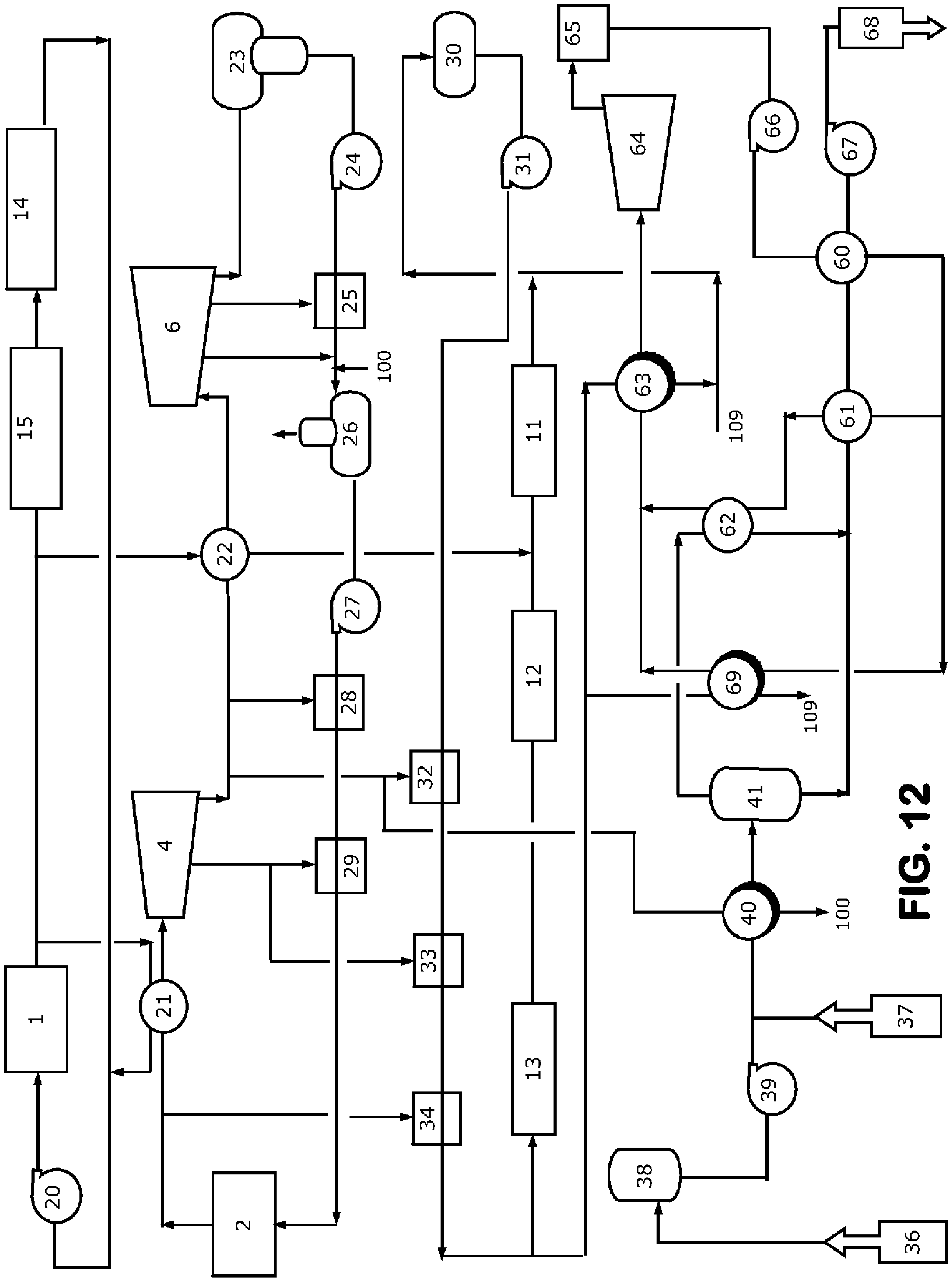
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FIG. 12

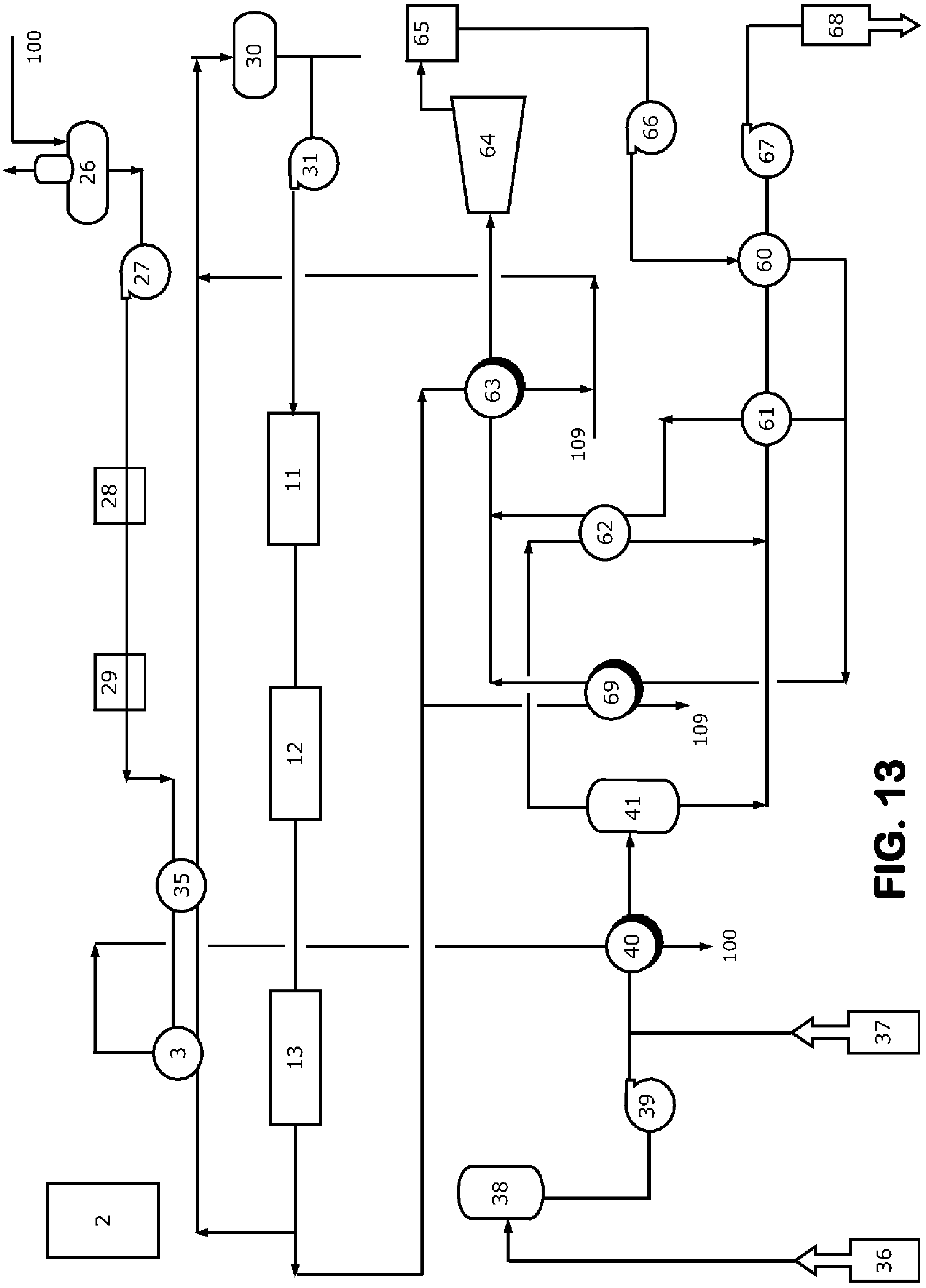
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FIG. 13

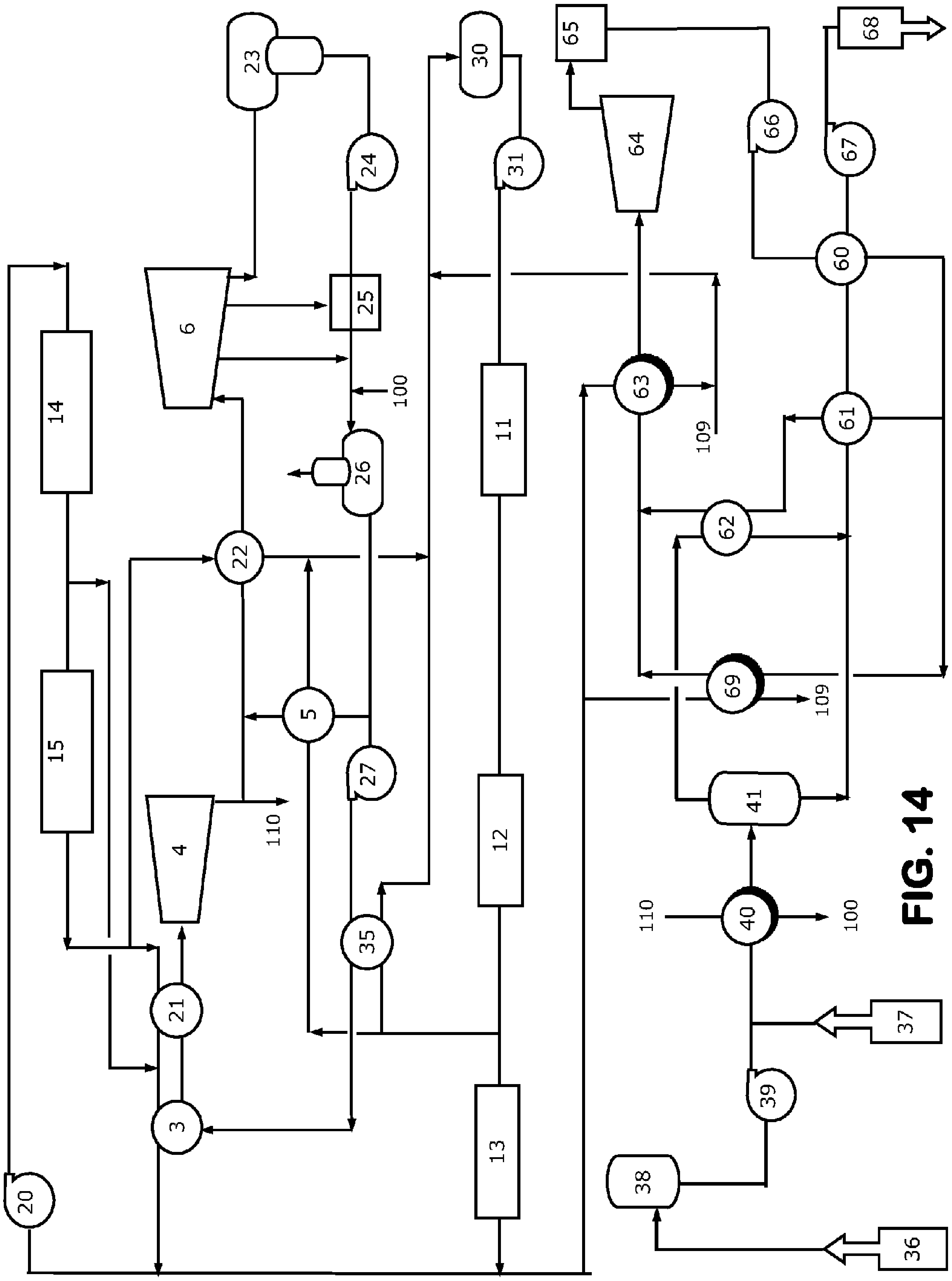
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FIG. 14

SYSTEMS AND METHODS FOR INTEGRATING CONCENTRATED SOLAR THERMAL AND GEOTHERMAL POWER PLANTS USING MULTISTAGE THERMAL ENERGY STORAGE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Patent Application No. 61/316,240 titled "Systems and Methods for Integrating Concentrated Solar Thermal and Geothermal Power Plants Using Multistage Thermal Energy Storage" and filed on Mar. 22, 2010, the entire disclosure of which is hereby incorporated by reference.

FIELD

[0002] The field of the disclosure relates generally to concentrated solar thermal electric power energy sources and geothermal energy resources. More specifically, the disclosure relates to systems and methods for using a multistage, cascade thermal energy storage system with concentrated solar thermal power plants. More particularly, the disclosure relates to the integration of concentrated solar thermal and geothermal power plants using a multistage, cascade thermal energy storage system.

BACKGROUND

[0003] This section is intended to provide a background or context to the invention recited in the claims. The description herein may include concepts that could be pursued, but are not necessarily ones that have been previously conceived or pursued. Therefore, unless otherwise indicated herein, what is described in this section is not prior art to the description and claims in this application and is not admitted to be prior art by inclusion in this section.

[0004] Various types of solar thermal electric power generation plants either already exist commercially or are in late developmental stages. These plants collect and concentrate solar energy (energy contained in sunlight) and convert the solar energy to thermal energy (heat). The thermal energy is then used to generate electric power.

[0005] For the various types of solar concentrating systems, the cost of thermal energy generally increases as the temperature of the thermal energy increases. For example, solar concentrating power towers can provide the highest temperature (well over 500 deg C.) thermal energy converted from concentrated solar energy at the highest cost per thermal unit (Megawatt-hour thermal). This thermal energy used in a thermal power plant generates electricity with a higher thermal efficiency than lower temperature thermal energy and typically in the range 40-48%. Linear concentrators, such as parabolic trough collectors (PTC) using a heat transfer fluid to collect thermal energy at about 400 deg C. (750 deg F.) at a lower cost than power towers, and this thermal energy when used in a thermal power plant results in a thermal efficiency of approximately 35-37%. PTCs typically use commercial heat transfer fluid (HTF) such as Therminol VP-1, Dowtherm A, or Syltherm 800 to collect and transport thermal energy for superheat and reheat, as well as boiler heat in the solar thermal power plant. For brevity, and clarity, the term "oil HTF" will be used to describe these kinds of commercially available heat transfer fluids. These oil HTFs have a maximum film temperature in oil HTF heaters of approximately 426 deg C., which limits the maximum temperature of oil HTF from solar collection systems to approximately 400 deg C. Some types of linear concentrators (such concentrating linear Fresnel collectors) can be used as high pressure steam boilers and generate lower cost thermal energy, which in turn is utilized in thermal power plants with thermal efficiency in the range 30-33%. Continuing advances in these solar concentrating and power plant systems may decrease costs and increase these thermal efficiencies, but in general the correlations between temperature and cost of the thermal energy, and temperature and thermal efficiency of thermal power plants, should still hold. There is a need to use these thermal energy sources at the different temperatures in the most efficient and effective methods to generate electric power.

[0006] There are solar power projects that use different solar collector systems to collect thermal energy at different temperatures and use the different sources in a thermal power plant. For example, the Andasol demonstration project in Spain has one mode of operation, where one PTC solar collector field acts as a boiler generating high pressure steam from preheated boiler feed water (BFW). Andasol uses the majority of the PTC solar collector fields to heat oil HTF to nearly 400 C. This demonstration project appears to be the first application of a hybrid system comprised of different kinds of solar thermal collection systems. The project (as understood by the Applicant) intends to demonstrate methods to use the different sources of solar thermal energy most efficiently to generate electricity. Although Andasol uses generally the same PTC design for both direct steam generation (DSG) and heating oil HTF, other organizations are believed to be working on solar collectors designed specifically for DSG. Areva (formerly Ausra) has developed a 'compact linear Fresnel reflector' collection system that generates superheated steam at higher pressures than typically can be generated by a PTC design using an oil HTF. Other Fresnel DSG systems have been developed by Novatec Biosol and Glasspoint Solar. There hasn't been a significant effort at integrating these very different systems; that collect thermal energy at different temperatures and pressures and using very different heat transfer fluids and feeding power plants designed differently for each solar collection system.

[0007] Even in geographic locations that enjoy substantial, strong sunlight and relatively clear weather year-round, the available sunlight is often not sufficient to generate enough electricity to fully utilize, and maximize the economic investment in, a solar thermal power plant. For example, solar thermal plants that lack thermal energy storage capabilities cannot generate electricity during nighttime or on overcast days. In addition, the number of hours of daylight are defined and constrained by season leading to large variability in thermal energy supply.

[0008] Some of these limitations can be overcome or lessened by storing thermal energy produced when sunlight is sufficient and recovering it to generate electricity when sunlight is unavailable or insufficient. The degree to which these limitations can be overcome or lessened, and the degree to which the overall utilization of the plant can be expanded, depend primarily on the amount of thermal storage available to the plant and the size of the solar energy collection field relative to the plant's electricity-generating capacity. Most of the thermal storage approaches that have been commercialized to date involve limited capacities that facilitate storage of thermal energy sufficient to operate the generators for four to six hours in order to extend the solar thermal power plant operation into the evening hours in order to garner peak pricing factors and improve power plant utilization by extending the hours of operation. The thermal energy storage must be used efficiently to avoid increasing the cost of electricity from the solar thermal project.

[0009] Some effort has been expended to develop molten salt storage systems that store larger quantities of thermal energy, and several solar thermal power projects have been announced using approximately twelve hours of storage.

[0010] Thermal power plants work most efficiently with high working fluid feed temperatures. In order to increase the thermal efficiency, typically superheaters are used to heat the feed working fluid in Rankine cycle power plants to superheated condition. Hot working fluids are extracted from the power cycle, typically by bleeding steam from steam turbines, and are used in regenerative heaters to increase the temperature of boiler feed working fluids being returned to the boiler. Both of these methods are known to help improve the thermal efficiency of Rankine power cycles.

[0011] Identifying and using a separate source of heat with a higher temperature than the working fluid boiler temperature for superheat increases the thermal efficiency of a power plant. Even if the higher temperature heat source costs more per unit of thermal energy delivered, the more efficient conversion of the superheat provided can result in a lower cost of the incremental power generated.

[0012] The lowest efficiency portion of a power plant is generally the low pressure power cycle, typically the low pressure steam turbine and condenser cooling system. In a solar thermal power plant, this section of the plant is typically utilized only during daylight hours, unless thermal energy storage (TES) is used. It is believed that a smaller less low pressure power cycle would significantly reduce the cost of a solar thermal power plant.

[0013] When thermal energy storage (TES) is used, the stored thermal energy is typically the only source of energy to a stand-alone solar thermal power plant during the evening and night operation, unless supplemented with a different heat source. Thermal energy recovered from TES during discharge has a lower temperature compared to the higher temperature of the thermal energy used to charge the TES. As discussed previously, a solar thermal power plant using heating oil HTF at a temperature of nearly 400 deg C. can achieve thermal efficiency of over approximately 37%, but if thermal energy is stored in solid media TES, and then recovered and utilized the thermal efficiency drops to approximately 30%. The lower temperature of the recovered energy is caused by the temperature differential required to drive the exchange of heat into the TES media and drive the exchange of heat recovered. Systems and methods for increasing the utilization efficiency of recovered thermal energy are needed.

[0014] There are several reasons to look at TES to help solve power demand variability, improve time of delivery (TOD) pricing factors, and respond to intraday, daily and seasonal variation from concentrated solar thermal energy or other renewable energy sources such as wind, photovoltaic, or hydroelectric.

[0015] For example, in the southwest of the United States, some large utilities pay for power using a TOD pricing schedule. Generally, during the superpeak period of noon until nine o'clock in the evening on weekdays, electricity sales get the highest TOD factors, which multiplied by the contract base price, determines price for electricity delivered during the various time periods. In California, the TOD factor typically exceeds 2.00 during weekday afternoon and early evening superpeak hours in the months of June through September, and 1.20 during superpeak hours in the months of October through February. In the spring months of March through May, the TOD factor falls to just above 1.00 during superpeak hours, and in the shoulder (late evening and morning) hours, and night hours year round, the TOD factor falls below 1.00. This creates a significant price incentive to shift morning electric power generation to the early evening, and this in turn has lead to the six hours storage metric commonly used to describe desirable TES capacity. There is a need for systems and methods that accomplish this economically.

[0016] Current methods of short-term thermal energy storage include steam accumulators, pressurized hot-water tanks, hot oil/rock storage vessels, solid media storage (usually concrete or ceramics), and molten salt. These methods tend to become costly when used to store more than a few hours worth of thermal energy needed for medium-size or larger electric power plants.

[0017] Solid media TES such as concrete or ceramic solid media, penetrated by a labyrinth of piping to carry and exchange heat between the HTF and the storage media appears to offer some advantages. The thermal storage capacity is determined by the temperature difference in the storage blocks from the charged state to the discharged state.

[0018] Solid media storage systems are designed in an attempt to reduce the amount of thermal energy 'mixing' that occurs within the storage media. The geometric shape of the thermal energy storage blocks is designed to be long and narrow with a relatively short depth. The heat transfer fluid enters the short end of one of these blocks, and travels to the far end, in an attempt to gradually store and recover thermal energy with relatively small approach temperatures.

[0019] Gas turbine generators are commonly used to generate electricity and feed the hot turbine exhaust gases to a heat recovery unit to generate superheated high-pressure steam that in turn is feed to a steam turbine. These plants are commonly called combined cycle power plants because they use a top Brayton cycle (gas turbine) followed by a Rankine cycle (steam turbine) as a bottom cycle. If a second heat source is used, then these plants are called integrated combined cycle plants (IGCC). There have been IGCC plants built that use gas turbines followed by heat recovery steam generation (HRSG) units, which utilize additional steam generated from solar thermal energy. Thermal Energy Storage (TES) systems could be used for storing energy from integrated solar thermal/IGCC projects, allowing a much higher solar component. However, superheated steam commonly generated from the exhaust of HRSG units typically has a temperature of over 500 deg C., which exceeds the temperature limit of about 400 deg C. on TES systems charged using oil HTF.

[0020] Most TES methods at high temperatures over 500 deg C. generally use molten salt as the heat transfer fluid to collect solar thermal energy from the solar fields or solar power tower and then store the thermal energy in either a stratified one tank system, or in a two tank system.

[0021] Systems and methods for using very high temperature solar concentrated thermal energy in an Ericsson or Brayton cycle using a gas mixture as the working fluid, then storing the heat from the exhaust gases has been proposed (Mills, 2009). This method is understood to use TES between a very high temperature Brayton or Ericsson thermodynamic power cycle and a lower temperature Rankine or Kalina thermodynamic power cycle.

[0022] Geothermal power plants usually have fairly low thermal efficiencies relative to solar thermal plants and most other power plants, because of the lower-temperature fluids (brine, steam, and non-condensable gases) produced from most geothermal reservoirs. Often geothermal produced fluids will flash less than 10% steam in production flash separators with temperatures less than approximately 350° F. (232° C.). An optimized steam Rankine-cycle power plant utilizing steam flashed from produced geothermal brine will typically operate with a thermal efficiency of approximately 15% or less, and such efficiency only applies to heat available in the flashed steam, typically only a small portion of the total mass of the produced geothermal fluids. For this reason, many geothermal resources that might otherwise be considered potential sites for geothermal electric power production do not have sufficiently high thermal efficiency to result in an economically attractive project. Thus, many geothermal and hydrothermal reservoirs are not developed for electric power generation. The thermal energy otherwise available in such resources remains inaccessible from an economic standpoint and thus remains untapped.

[0023] Typically, geothermal power plants are fairly small, with the majority less than about 100 MW in generating capacity, as a result of reservoir and other limitations. Despite current limitations in generating capacity, which result from a combination of the limitations of current methods, commercial considerations, and reservoir characteristics, many geothermal reservoirs contain a very large amount of thermal energy that could be extracted if the combination of technological and commercial considerations allowed, especially over a long period of time. Unfortunately, many geothermal sources do not have the requisite temperatures and hydrothermal flows needed to economically sustain a geothermal power plant over a period of time sufficient to make such a project economically attractive. Thus, methods to efficiently access a greater portion of the immense thermal energy within a broad range of geothermal reservoirs would substantially increase society's ability to harness geothermal resources for electric power generation.

[0024] Many existing geothermal fields have wells that have limited productivity in terms of relatively low temperature and low production rates for the produced fluids. Some zones in existing geothermal reservoirs remain undeveloped and un-drilled because of concerns that production wells drilled into these zones would not have the necessary productivity to be utilized.

[0025] Anderson (1978) (as understood by the Applicant) attempted to increase the overall efficiency of a geothermal power plant by segregating higher-temperature wells that produce more steam into a high-temperature gathering system and collecting lower-temperature geothermal fluids in a separate gathering system. In the geothermal electric power plant used in this method, the higher-temperature thermal energy is transferred by heat exchange into a dual power-fluid cycle, which improves the capability of the plant to efficiently generate electric power. Unfortunately, sizable geothermal reservoirs that are suitable for the segregation process of Anderson are rare, resulting in limited opportunities for the application of this process.

[0026] In many cases, the geothermal power plants associated with existing geothermal fields are underutilized and have excess generating capacity available. Additional electricity could be generated if additional thermal energy was available in the design temperature range for the feed to these plants. Some geothermal plants use single or double flash designs, with the flashed steam from the production separators generating electricity in a steam Rankine power cycle. Heat added to the production fluids should increase the flash steam flows thereby increasing the flash power plant output. Many geothermal plants are binary fluid plants, named because they use a binary working fluid typically isobutane/normal hexane mixtures in a Rankine cycle, typically called an Organic Rankine Cycle (ORC). Binary fluid plants can extract additional heat from geothermal produced fluids, typically cooling the liquid produced brine down to temperatures of approximately 160-190 deg F. (70-88 deg C.). Combined cycle binary plants use a combination of a steam turbine coupled with a binary fluid power cycle. These various geothermal power plants would generate more electricity if additional thermal energy was added to the feed.

[0027] There have been attempts to recover heat energy from geothermal heated rock formations that do not contain significant quantities of water. Typically these formations are called hot dry rock (HDR) formations to distinguish these sources of geothermal heat from traditional geothermal heat sources such as hydrothermal fields or dry steam fields. The methods for recovery of geothermal heat from HDR formations typically involves drilling a well into the rock formation, fracturing the formation and mapping the fractured structure, then drilling and completing a second well into the fractured zone of the rock formation. A fluid, typically water or brine, is injected into the first well and migrates through the rock fractures to the second well. The fluid will absorb heat from the HDR and the heated fluid will be produced in the second well and utilized in a geothermal power plant. There are many methods for drilling, fracturing, treating, and completing the set of wells for injecting and recovering the fluid and collectively these methods are typically called 'engineered geothermal systems' (EGS).

[0028] The temperatures of HDR formations will generally increase with depth, and although geothermal heated rock formations could be reached by deep drilling, in certain geographical regions there are locations where the temperature gradient of the drilled wells is higher and where higher temperature geothermal heated rock formations are more accessible. Most initial EGS projects have been tested on anomalous HDR formations where the geothermal heat has conducted up through a geological structure of rock formations to a depth that can be reached with drilled wells without incurring extraordinary drilling costs. For the United States mainland for example, the western portions typically have temperatures suitable for EGS projects to recover HDR geothermal heat at depths that can be reached with wells drilled to a depth of 20,000 feet. If EGS produced fluids were further heated to supplement the geothermal heat extracted, then this would increase the feasibility to extract heat from shallower or lower temperature HDR formations for utilization in a geothermal power plant.

[0029] There have been attempts to vary the production rates of EGS produced fluids in order to increase EGS geothermal power plant output during peak demand periods, and turn down the power plant during non-peak demand periods. In particular, Brown (1997) (as understood by the Applicant) proposes a method of injecting at a steady rate into the injection wells in a HDR fractured zone, but producing at a variable rate from the coupled production wells, to help meet peak demand.

[0030] There have also been attempts to use solar energy to "augment" geothermal energy by heating geothermal fluids after they are produced from a reservoir. Rappoport (1978) (as understood by the Applicant) used heat-transfer fluids to collect geothermal heat from remote wells, then uses solar collectors to replenish heat lost from these streams in transit and to add heat to the heat-transfer fluid before utilizing the heat in a centralized geothermal power plant. There have been attempts to evaluate and develop hybrid solar geothermal energy electric power generation systems. In these processes, the radiant energy from solar concentrators is absorbed directly into the fluids that contain the geothermal sourced heat and these fluids are utilized for power generation.

[0031] Accordingly, it would be desirable to provide improved systems and methods for integration of concentrated solar thermal and geothermal power plants using a multistage, cascade thermal energy storage system that overcomes the drawbacks and limitations of the known systems.

SUMMARY

[0032] One embodiment of the invention uses thermal energy contained in hot working fluids extracted from a heat engine in either a Rankine cycle or a Kalina cycle thermal power plant to heat thermal energy storage media and more specifically, to heat and charge multiple stages of thermal energy storage. Some embodiments would use an intermediate heat transfer fluid to heat thermal energy storage, and subsequently recover thermal energy from storage for utilization in a power plant. The heat transfer fluid is heated using the extracted working fluids in a series of heat exchangers, each using a separate working fluid flow in a sequentially higher temperature range. A portion of the heat transfer fluid at each stage is used to heat a thermal energy storage module across that temperature range.

[0033] The thermal energy storage consists of a set of thermal energy storage modules, connected with piping and valves that can switch the position of each module in a series sequence of connected modules. The thermal energy storage modules are charged in a cascade process, where a discharged module is heated and charged at a lower temperature range, then switched to a higher step in the cascade and then heated and charged at a higher temperature range. At the highest cascade steps, the storage modules are heated by thermal energy from the heat sources for the thermal power plant. At each step in the cascade, the storage module is heated to raise the average temperature in the storage module within a range of at least approximately 40 deg C. and up to 100 deg C. In the last steps of the cascade, the storage module is charged using thermal energy from the heat sources for the thermal power plant, which could include concentrated solar thermal energy collection systems; heat recovery units on Brayton cycle or Ericsson cycle heat engine exhaust; or fired heaters including heat recovery units on fired heater flue gas.

[0034] A mixture of different thermal energy storage modules with different heat exchange designs, different storage media including solid media sensible heat storage, phase change materials, or molten salt storage can be used. A majority of the storage modules will likely use design modifications such as closer heat exchange element spacing, additional heat exchange area, embedded metal fins or rods, or higher thermal conductivity storage media to achieve higher heat transfer rates so that up to six cascade charge steps can be completed on a storage module in twelve hours. Some of the modules could use higher heat transfer rate segments at the front and back of the module to improve the temperature profile across the module.

[0035] Thermal energy recovered from the charged modules, possibly augmented by hot working fluids extracted from the thermal power plant, would be used to provide a continual supply of thermal energy at the varied temperature ranges to the first power plant, or to a second power plant. One embodiment would use thermal energy from multiple cascade discharge steps to heat multiple boilers to supply vaporized working fluid to multiple heat engine stages. As the highest temperature thermal energy storage is depleted, intermediate temperature thermal energy from storage is used to supply medium pressure boilers, and even lower temperature storage modules provide thermal energy to heat lower pressure boilers. Various configurations using storage modules at different temperature stages to supply boilers, preheaters, and superheaters, and different heat engines operating using the vaporized working fluid can provide a continual source of mechanical energy to an electric power generator. These power plant configurations are useful to efficiently utilize thermal energy from concentrated solar thermal energy collection systems, particularly if several types of solar thermal collection systems are used.

[0036] Thermal energy recovered from storage could also be utilized in a second power plant, particularly to heat produced fluids for utilization in a geothermal power plant, or to heat geothermal power plant working fluids. In a combined cycle geothermal power plant, thermal energy storage modules at various temperature ranges can heat produced fluids to increase flash steam, provide heat to preheaters, boilers, and superheaters in a top steam Rankine cycle, and provide heat to binary fluid preheaters, boilers, and superheaters in a bottom organic Rankine cycle. In some embodiments, a solar thermal power plant will supply hot working fluid (steam) to the geothermal power plant. In some embodiments the geothermal flash steam generated by heating the produced fluids will end up providing a source of water for wet cooling in a solar thermal power plant. The geothermal flash steam can also be used in the solar thermal power plant by combining with lower pressure steam in the power plant, or by heating boiler feed water either by direct contact heat exchange or by condensation in a heat exchanger. Systems and methods according to the various exemplary embodiments described herein that use thermal energy removed from solar thermal power plants, with much of the thermal energy stored and later recovered, to boost geothermal power plant output are referred to herein and "Basic Geosolar Methods."

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] All the drawings illustrate different configurations or embodiments of a power plant integrated with cascade multistage thermal energy storage (TES).

[0038] FIG. **1** is a block flow schematic diagram illustrating the major thermal energy flows in an exemplary embodiment of the invention utilizing one heat source and two heat engines, showing multiple TES modules charged and discharged in a cascade process.

[0039] FIG. **2** is a block flow schematic diagram illustrating the major thermal energy flows in a SOA process according to the embodiment of FIG. **1**.

[0040] FIG. **3** is a block flow schematic diagram illustrating the major thermal energy flows in an exemplary embodiment of the invention utilizing two different heat sources with different temperatures and different heat transfer fluids and two heat engines for comparison with FIG. **1**.

[0041] FIG. **4** is a block flow schematic diagram illustrating the major thermal energy flows in an exemplary embodiment of the invention utilizing two different heat sources with different temperatures and different heat transfer fluids and three heat engines for comparison with FIG. **3**.

[0042] FIG. **5** is a block flow schematic diagram illustrating the major thermal energy flows during TES discharge in an exemplary embodiment of the invention shown in FIG. **4**, further showing thermal energy supply points for adding thermal energy to other sources of thermal energy.

[0043] FIG. **6** and FIG. **7** are block flow schematic diagrams illustrating respectively, the TES charge (FIG. **6**) and TES discharge (FIG. **7**) thermal energy flows for an exemplary embodiment of the invention using a third heat source; a heat recovery steam generator located on the exhaust of an Ericsson cycle turbine.

[0044] FIG. **8** and FIG. **9** are block flow schematic diagrams illustrating respectively, the TES charge (FIG. **8**) and TES discharge (FIG. **9**) flows of various fluids in an exemplary embodiment of the invention using two heat sources with different temperatures and heat transfer fluids, showing the exchangers for exchanging thermal energy in the process.

[0045] FIG. **10** is a block flow schematic diagram illustrating a combined cycle geothermal power plant used in one embodiment of the invention, showing possible heat exchanger locations where thermal energy can be added from either thermal energy storage or where steam extracted from a thermal power plant can be used to heat either produced geothermal fluids or geothermal plant working fluids.

[0046] FIG. **11**, FIG. **12**, FIG. **13** and FIG. **14** are block flow schematic diagrams showing examples of facilities installed in the first two phases in a phased implementation of a basic geosolar project in one embodiment of the invention. FIG. **11** and FIG. **13** depict first phase daytime and night operation; while FIG. **12** and FIG. **14** depict second phase daytime and night operation.

DETAILED DESCRIPTION

[0047] The systems and methods disclosed herein relate to collecting, transporting and storing thermal energy from various heat sources in conjunction with using a thermal power plant designed to generate electricity from the thermal energy, while at the same time facilitating the storage, recovery, and utilization of a portion of the thermal energy in order to generate electric power at a subsequent time. The systems and methods use multiple thermal energy storage capacities (storage stages) in different temperature ranges, which permit the efficient extraction of thermal energy from a power plant using vaporized working fluids in the heat engines, such as Rankine and Kalina thermodynamic cycles. Systems and methods are provided according to exemplary embodiments described herein to eventually efficiently recover the thermal energy from the storage stages at approximately the same temperature range as the stored thermal energy. The systems and methods result in more efficient utilization of stored and recovered thermal energy feeds at each temperature range in the power plant, when compared to existing thermal energy storage systems and methods.

[0048] Certain embodiments would use the ability of these systems and methods to store and recover thermal energy efficiently, to take advantage of variable and intermittent heat sources at high temperatures to generate electricity and store excess thermal energy to provide a steady and consistent source of thermal energy during periods the thermal energy supply from the heat source is interrupted or unavailable. This consistent supply of thermal energy can be used to provide a constant electric power generating capability.

[0049] The systems and methods of the present embodiments can reduce the complexity and cost of power blocks (heat engine coupled to an electric generator) for lower temperature lower pressure generating units. The systems and methods reduce the peak cooling requirements needed to provide a large heat sink during periods when an intermittently operated power plant operates at high capacity. The systems and methods achieve this by utilizing high temperature thermal energy during high capacity power plant operating periods, while storing a significant portion of the moderate and lower temperature thermal energy for later utilization.

[0050] Alternatively, if sufficient power plant generating capacity exists, the stored thermal energy can be recovered and utilized to generate electricity during peak demand periods, or generate electricity "on demand" versus "as available" as these terms are used in electricity power purchase agreements (PPAs). This capacity can also fill in if the primary heat source feeding the power plant is interrupted or unavailable during peak demand periods.

[0051] One of the intended applications of this invention, CSP projects, can cost effectively deploy larger solar collection systems, such as solar fields or power towers, to collect high temperature thermal energy needed to generate high pressure superheated steam or heated oil HTF according to an exemplary embodiment. The CSP plant using the systems and methods herein, can handle higher peak flows of thermal energy from the solar collectors and thus avoid the cost of 'dumping' excess solar energy by turning the concentrating reflectors away from the sun. Since the current methods extract and store thermal energy from the higher-pressure turbines, increased high-pressure high-temperature steam turbine capacity relative to the lower-pressure turbine capacity can be deployed to handle the higher peak solar thermal energy flows. This would typically necessitate larger lower-pressure steam turbines (and larger cooling systems) to handle the high-pressure turbine exhaust using current CSP plant designs and methods, and these large lower-pressure systems would only operate at capacity during high insolation periods. The systems and methods according to the embodiments described herein recover thermal energy from storage to feed moderate-pressure turbines and the lower-pressure systems over a prolonged time period, long after the higher-pressure turbine in the CSP plant had shut down.

[0052] Systems and methods are also included to recover and utilize the thermal energy to augment lower temperature energy sources. In particular thermal energy removed from the CSP plant can heat and raise the enthalpy of geothermal fluids prior to utilization in a geothermal power plant. Additionally, the removed thermal energy can be added to the working fluids in the geothermal power plant, and in some cases, hot working fluids extracted from the CSP plant can be utilized directly in the geothermal power plant. In many process configurations, thermal energy is added to the geothermal plant at higher temperatures than the highest temperature thermal energy recovered from the produced geothermal fluids. The conversion of the added thermal energy can be higher than would have been obtained if the thermal energy had not been removed from the CSP plant.

[0053] Optimizing an integrated electric power generation system with various feed sources of thermal energy at different temperatures, and with different enthalpies, involves matching temperatures of thermal energy flows from various heat sources to power plant heat user demands. Another optimization strategy uses high enthalpy sources, such as vapor (steam), in an appropriate heat engine (turbine); or in a train of heat exchangers using condensing steam in each to heat a liquid or a solid where the thermal energy is absorbed as sensible heat. When removing sensible heat from a solid, or liquid, using a series of exchangers or a set of boilers (which in turn supply multiple turbine feed points) improve the efficiency of transferring thermal energy without losing excessive energy. In an integrated project including at least one CSP plant and one geothermal power plant, better matching of heat supplies to uses, and reduced temperature drops during heat transfers, should result in better conversion of thermal energy to electricity (higher thermal efficiencies) in the power plants. In general, adding expensive high temperature thermal energy to lower cost moderate and low temperature thermal energy sources generates economically attractive integrated power projects, and result in more flexibility in operating the power plants. This operating flexibility could lead to significant cost optimizations and increased revenues due to better pricing factors.

[0054] In order to improve the efficiency of a Rankine cycle, one of the issues is to counter-currently extract, condense, regenerate (reheat) the condensed working fluid and return the fluid to collect additional thermal energy from the primary heat source at a higher temperature closer to the heat source temperature. As appreciated by those skilled in the art, working fluid extracted from the power cycle and condensed in boiler feed regeneration heaters reduces the amount of the circulated working fluid that ends up in the condenser. This reduces the heat rejected to the heat sink compared to the power generated, thus raising the thermal efficiency of the power cycle. In steam Rankine cycle power plants, these design objectives are met by using regenerative heaters that use steam extracted from the steam turbines to preheat the boiler feed water (BFW). The amount of steam that can be removed, condensed, and returned to collect more heat from the heat source depends on the BFW circulation rate. The BFW circulation rate in turn is determined by the heat and material balance of the entire power cycle and is primarily set by the amount of heat available from the heat source. In typical power plant steam Rankine cycles, over 15% of the steam working fluid is removed from the high-pressure steam turbine and turbine exhaust and used in the BFW regeneration heaters.

[0055] In a steam Rankine power plant utilizing solar derived thermal energy, when steam is extracted from the high-pressure steam turbine and used to replenish TES, the resulting steam condensate is mixed into the BFW prior to the primary BFW charge pump. Whereas, typically 10-20% of the steam is extracted or removed from the HP turbine exhaust for use in BFW regeneration heaters, the steam extracted and removed and utilized as described in the current method would likely exceed approximately 50% and may even exceed approximately 70%. If the HP turbine exhaust is additionally used to heat a lower temperature heat source or provide process heat, the entire steam flow from the turbine exhaust is condensed, with the net effect of completely eliminating the LP turbine in the solar power plant, so in this case 100% of the steam is extracted. This is similar to the cogeneration use of topping steam turbines where exhaust steam is used for process heating. The current methods go beyond this existing application, by extracting steam interstage from the HP turbine, and using steam extracted from the power cycle for TES replenishment.

[0056] The current methods extract hot working fluid from the power cycle, and uses thermal energy removed from the working fluid to charge thermal energy storage (TES). Various types of TES could be used in the methods, including storage modules that use media that stores sensible heat; or storage modules designed and constructed with storage media consisting of primarily phase change material (PCM). There are a number of commercially proven systems that used sensible heat for storage, including solid media systems such as concrete or ceramic, or molten salts circulated in a stratified or two-tank system, or low pressure storage vessels filled with hot oil HTF and rocks. In some variant of these systems, each could be used in the current methods. Although PCM TES systems are still in the development phase, TES modules using PCM would be useful in the methods. For the purposes herein, the term 'storage module' will mean a system consisting of the storage media containing either internally or externally a type of heat exchanger to exchange heat into the storage media, unless the heat transfer fluid (HTF) is also acting as the storage media. Molten salts and oil HTF could act as storage media in some of the systems just listed. Although generally not economical for the large TES systems targeted as the primary application of these methods, steam accumulators can store smaller amounts of thermal energy, and could be incorporated into the current methods as 'storage modules'.

[0057] FIG. **1** is a schematic diagram illustrating the major thermal energy flows in an exemplary embodiment of the invention, where thermal energy contained in extracted hot working fluids from a Rankine cycle power plant is used to heat TES modules. For purposes of explanation, this discussion will use terminology applicable to solid media TES modules, and thermal energy in this embodiment will be oil HTF at the highest temperatures these systems have demonstrated. This embodiment shows only one heat source **1**, which typically would be a concentrating solar thermal field heating an oil HTF to a temperature of 390 deg C. Some portion of the thermal energy from the oil HTF is stored in the TES storage module **16**, eventually raising the storage module hot end to a temperature very close to the fresh hot oil HTF from the solar field.

[0058] For the purposes herein, the 'temperature range' of a TES module will be the effective range of temperatures for the thermal energy absorbed by a TES module during the charge process, wherein the module is heated and thermal energy is stored. The temperature range during the charge process would initially be from the temperature of the charge fluid entering at the hot end ranging down to the temperature of the cold end of the storage module. For example, the temperature range for the storage module **16** in this explanation would initially range from approximately 360 deg C. at the hot end down to approximately 290 deg C. at the cold end. So at the beginning of the charge process for module **16**, the entering oil HTF at approximately 390 deg C. would heat the storage module until it leaves the cold end at a temperature approaching 290 deg C. As the temperature of the storage module increases during the charge step, the hot end will typically heat up to approach the entering hot oil temperature of approximately 390 deg C.; and the cold end would heat up to a maximum temperature of approximately 310 deg C., at point the module would be fully charged. Although this temperature is well short of the entering oil HTF, the temperature of the oil HTF leaving the TES module to return to the solar field is approaching a temperature where the solar field will heat the feed oil HTF to over approximately 400 deg C. bulk, and exceed the film temperature maximum of approximately 426 deg C., resulting in oil HTF degradation, and fouling of the collector tubes. When the charge step is stopped, the hot end temperature has increased about 30 deg C., the cold end has increased about 20 deg C., but the bulk of the media in the middle will increase approximately 50 deg C. This results in an overall TES module heating of approximately 40 deg C., which is similar to the current performance by concrete TES systems. But even though the TES temperature rose an average of only 40 deg C., the temperature range of thermal energy removed from the oil HTF began from approximately 390 deg C. down to approximately 290 deg C., and finished removing thermal energy from approximately 390 deg C. down to approximately 310 deg C. This is the temperature range of the thermal energy removed and stored (charged). Similarly when the TES module is discharged, the temperature range of the recovery stage will be defined similarly, such that the oil HTF temperature will increase over the temperature range of the TES module during recovery (discharge).

[0059] The storage module at the end of the discharge phase still contains a large quantity of thermal energy over the boiler temperature of approximately 290 deg C., since the average temperature across the module is still approximately 30 to 35 deg C. higher. If all the thermal energy over the 290 deg C. could be recovered in a second discharge step, it would increase the thermal energy storage capacity of this storage module over approximately 75%, but the increase in storage capacity expressed as Mwh will be significantly less, since the thermal energy recovered will have a lower temperature, and therefore lower thermal efficiency when converted into electricity. Nevertheless, there still remains a large quantity of quite valuable stored thermal energy in the storage module, if it can be recovered without a significant loss in temperature. The systems and methods according to the exemplary embodiments described herein accomplish this recovery.

[0060] Continuing with the description of the thermal energy flows in FIG. **1**; the majority of the thermal energy from the solar field is used in the high-pressure boiler **3**. A typical temperature in the boiler would be within a range of approximately 270 to 300 deg C., although in other embodiments the temperature could be higher or lower. The temperature of the oil HTF from the solar field is higher than the temperature in the boiler, such that sensible heat flows from the HTF to the preheated working fluid, typically boiler feed water (BFW). The vaporized working fluid, typically high-pressure steam, expands in the high-pressure turbine **4** to drive an electricity generator (not shown).

[0061] The oil HTF used in the boiler still has a temperature slightly higher than the boiler temperature, so this flow of oil HTF could be used in this embodiment to charge TES storage module **15**. Eventually this would raise the hot end of storage module **15** to over approximately 270 deg C., but at a cost of reducing the temperature of the hot oil returned to the solar field; so this flow would normally be a minor portion of the oil HTF. A minor portion of the oil HTF flow from the solar field **1** is used to superheat the steam feed to the high-pressure turbine **4** and reheat the steam feed to the low-pressure turbine **6**. Typically these two uses together would consume less than approximately 20% of the thermal energy from the solar field that is feeding the CSP plant directly, and in this invention, the two uses should consume an even smaller portion, since the method extracts steam from the power plant prior to reheating steam feed to the low pressure turbine **6**.

[0062] Hot working fluid bleeds, typically steam bleeds are extracted from the high-pressure turbine **4**, as well as the exhaust, and possibly from the low-pressure turbine **6**, and used to charge TES modules **14**, **13**, and **12**. The locations and quantity of the bleed streams depends on the interstage pressure selected, the amount of superheat in the turbine feed, and the desired temperature ranges desired for each storage stage. Typically the temperature of the thermal energy absorbed by the modules will from a high steam bleed temperature of around 220 to 250 deg C. to charge storage module **14** down to the lowest steam bleed temperature of approximately 150 to 170 deg C. charging storage module **12**. Module **11** is shown waiting to be charged in FIG. **1**. Steam bleeds from the LPT **6** and the HPT **4** are also used to heat the BFW prior to feeding the boiler **3**.

[0063] The discharge of the TES modules is shown in the bottom section of FIG. **1**. In this embodiment, modules **11**, **12**, **13** and **14** feed thermal energy to heat BFW, and all but the low-pressure turbine bleeds of working fluid to heat BFW have been discontinued. Thermal energy from module **13** heats the lower-pressure boiler **5**, thermal energy from module **14** and module **15** heat the higher-pressure boiler **3**, while module **15** provides superheat to both turbine feeds. Module **16** is fully charged, on standby until Module **15** depletes to the point where the temperature drops too low to be considered sufficient for superheat. The heat source **1** (e.g. solar field) isn't producing heat during the discharge process shown. Often the solar field will still be contributing solar energy when the TES begins discharging, but in the case of CSP plants the TES will be discharging most of the time during periods when there isn't any solar radiant energy to collect.

[0064] For comparison, FIG. **2** shows the flow of thermal energy in a CSP project similar to the flows expected if TES systems were added to an existing CSP plant (e.g. Nevada Solar 1, and similar to the thermal energy flows from the basic process configuration used at the Andasol solar thermal project in Spain—other process configurations were tested at Andasol). The basic process configuration shows the TES module **15** only receiving thermal energy flows from the solar field, so there is only one storage stage over one temperature range during the charge step. During discharge, module **15** provides high temperature thermal energy for superheat, reheat, and boiler heat, along with a significant amount of thermal energy to preheat BFW prior to the high-pressure boiler **3**. In this embodiment, the steam bleeds are still used to heat BFW during the discharge stage.

[0065] The contrast between the systems and methods described herein according to this embodiment, as compared to generally known projects, show that the system and methods of the present embodiments employ multiple stages of TES, covering multiple temperature ranges. This is accomplished by extracting hot working fluids (e.g. mostly steam, with some moisture, etc.) from the boiler, turbines, and interstage, and by using these fluids to heat TES raises the module temperature through several temperature ranges. In order to store this quantity of thermal energy, the TES module was discharged and depleted down to the lower temperature ranges.

[0066] Thermal energy can be recovered from TES and utilized for different purposes. For example, TES is used in a CSP projects to store heat from the high temperature HTF returning from the solar field, followed by recovery and utilization of the thermal energy to heat the power plant working fluid when solar energy isn't available. Once the stored high temperature thermal energy is recovered from the TES, some types of TES media still holds a significant amount of thermal energy available to provide lower temperature heat, if a use for the stored energy exists. Lower temperature thermal energy from TES can be recovered and used by multiple heat consuming processes, including use as thermal energy feed to the bottom power cycle, top Rankine power cycle boiler feed preheat, and heating lower temperature heat sources. The lower temperature thermal energy could also be used as process heat for a variety of manufacturing processes. Once the TES is depleted, the same TES media can be partially replenished using thermal energy from extracted working fluid from the top power cycle. For some applications, thermal energy can be recovered from TES down to temperatures low enough to consider replenishment using working fluid from the bottom power cycle.

[0067] The embodiment shown in FIG. **1** already provides a new user for the recovered thermal energy; a lower-pressure boiler **5** that would use thermal energy left in place after the higher-pressure boiler recovery stage. The interstage temperatures of Rankine steam systems typically is in the range of 170 deg C. to 180 deg C., and the lower-pressure boiler would operate just slightly above the interstage temperature and pressure. The average temperature of a module when it is finished providing boiler heat, is still approximately 325 deg C. Even when a module provides preheat to the BFW to the higher-pressure boiler, the average temperature is still likely over 270 deg C., so there is a lot of thermal energy left in the module to heat the lower-pressure boiler. In fact, there appears to be too much thermal energy left at too high a temperature. But clearly, adding the lower-pressure boiler provides thermal energy from TES while at the same time, likely extending the power plant operation.

[0068] One of the factors to improve CSP efficiency is to collect and utilize thermal energy at the highest temperatures possible when absorbing radiant energy from sunlight. One design objective is raising the temperature of heat transfer fluids sent to the solar fields such that the bulk of the solar radiation absorbed and converted into thermal energy in the concentrators is added to the HTF at higher average temperatures. Increasing the average temperature of thermal energy input to a Rankine cycle is understood to increase the cycle efficiency. In a solar field generating steam, the BFW should be returned at a temperature close to the boiling point of the high-pressure steam. In a solar field heating hot oil, the temperature of hot oil sent to the solar field should be in the range of approximately 290 to 310 deg C., and is heated in the solar field to a temperature of approximately 390 to 400 deg C. The solar concentrating collectors are designed to operate efficiently at these design bases for steam and hot oil systems.

[0069] FIG. **3** illustrates the thermal energy flows in an exemplary embodiment that uses a hybrid CSP project, with a PTC/hot oil collection system **1** and a DSG field **2**. The higher temperature thermal energy from the PTC field charges the superheat storage stage module **16** and supplies thermal energy to superheat and reheat the turbines **4** and **6**. The DSG field supplies the major steam flow to the HPT during charge periods and also charges the boiler stage thermal energy storage module **15**, although bringing module **15** up to the needed storage temperature for the boiler, will require some higher temperature heat from the PTC oil HTF system. The DSG is intended to help meet the large heat duty required by the HP boiler, and fills in a hole in one of the TES stages. The DSG system also permits the CSP plant to sink a lot of thermal energy into the large BFW circulation, raising the average temperature of solar thermal heat absorbed in the solar field and increases the thermal efficiency.

[0070] The result of extracting a large portion of the steam from the top power cycle is to substantially increase the circulation rate and likely raise the temperature of the preheated BFW sent to the solar field. This in turn results in a higher average temperature of the thermal energy collected from the solar field, which in turn increases the thermal efficiency of the power plant. The higher BFW circulation rate also increases the amount of the high-pressure steam turbine-generator (HPT) power relative to the power from the low-pressure steam turbine-generator (LPT). The design of a coupled HPT/LPT steam turbine-generator set would change with a higher ratio of the top cycle power output to the bottom cycle output.

[0071] As discussed, TES can be operated with more than one stage of heat storage and recovery. A single stage of TES would include storage of thermal energy by exchanging heat into the TES media causing either a phase change and storing latent heat, or raising the media temperature thus storing sensible heat, followed by recovery of the thermal energy by exchanging HTF with the TES media either reversing the phase change or lowering the media temperature. A single stage of TES would supply thermal energy over a temperature range that is useful for one thermal energy use. A second stage of TES can be accomplished by extending the circulating loop of oil HTF through another storage module. The second storage module is exposed to cooler oil HTF lowering the temperature of the storage media further recovering thermal energy at a lower temperature than the first TES stage. The second TES stage would be utilized to supply demands for lower temperature heating.

[0072] The systems and methods of the current embodiments provide an improved approach to getting multistage TES to work well. Using extracted hot working fluids to charge TES at certain stages helps provide thermal energy at the temperature ranges needed to charge the storage modules across that temperature range. Using a hybrid solar field with a low cost DSG field helps fill a big hole in the thermal energy needed in the boiler stage. With both methods together, the reliance on the high temperature solar thermal source, typically PTC with oil HTF, is reduced. However if dedicated storage modules for each stage is necessary, then the cost of a multistage system is relatively high, and much higher when expressed in the metric of cost per unit of electricity, cents per kilowatt hour.

[0073] In order to make multistage TES practical and useful, an exemplary embodiment uses one storage module for several stages of storage each solar cycle. This involves relatively fast charge and discharge times.

[0074] Using cascaded multistage TES improves the efficiency of the TES because the medium temperature sources and medium temperature heat users are more easily matched, and similarly for the high temperature thermal energy sources and users. Cascaded multistage TES also operates over a wider temperature with an increase in thermal energy storage capacity.

[0075] In order to operate the TES efficiently over a multiple stages of temperature ranges, requires that the TES be operated in a cascade recovery (discharge) and storage (charge) process described in the current methods. In a cascade process, a storage module collects stored thermal energy when charged over one stage (range of temperatures). When filled at that step, the position of the module is switched up to a higher step in the cascade, and a different storage module fills the hole.

[0076] During the recovery of thermal energy from the module, the process is reversed, with the module emptied (discharged) at one stage over the temperature range for that stage by a user of thermal energy in that temperature range. When emptied of thermal energy at that stage the module switches down to a lower step in the cascade. A storage module with sufficient thermal energy in the temperature range of the stage vacated fills the hole.

[0077] For multistage sensible heat TES, the Applicants believe that the most effective method for recovering thermal energy and storing TES is to utilize cascade methods. TES modules using sensible heat storage media are cycled through a series of temperature ranges with enough overlap that the modules never sees an excessive temperature difference between the storage media and the charge fluid. For example, the charge step begins after all the useful thermal energy has been recovered from TES and used in the power cycles, typically either in a BFW regenerative heater or a low pressure boiler to provide hot working fluid to the bottom cycle. Alternatively the thermal energy recovered from the TES is used to heat a low temperature heat source, such as geothermal production fluids. After the recovery step, the TES will be depleted of thermal energy down to the interstage temperature, typically approximately 180 deg C., and if a need for lower temperature existed, then even lower.

[0078] When the charge process begins, the flow through the TES is reversed so that the hot charge fluid enters the hot end. The hot oil is initially provided to each storage block at a temperature consistent with collecting thermal energy from hot working fluid vapor extracted from the power cycle at an intermediate temperature. When the warm temperature front breaks through to the outlet of the module, the module is switched up to the next cascade step, and the feed temperature of the charge oil HTF is raised to the next higher temperature range, again using hot oil that was heated using hot working fluid from the top power cycle. The hot oil HTF exiting the storage module returns to exchange against the next higher range of hot working fluids extracted from the power cycle. Eventually the storage module will be raised to the boiler temperature level. The effective "cost" of thermal energy extracted from the power plant at the lower temperature ranges is lower than the "cost" of thermal energy from the solar fields, since some useful work has already been extracted in the top power cycle, typically a high pressure steam turbine.

[0079] Using cascaded multistage TES improves the efficiency of the TES because the medium temperature sources and medium temperature heat users are more easily matched, and similarly for the high temperature thermal energy sources and users. Cascaded multistage TES also operates over a wider temperature with an increase in thermal energy storage capacity. FIG. **1** and FIG. **3** show arrows depicting the movement of the storage modules in the cascade. The top section of each drawing shows the movement of the modules up the cascade as they charge and fill up with stored energy at each stage. The bottom section of each drawing shows the movement of the modules down the cascade as energy is recovered at each stage.

[0080] The cascade process is somewhat more complicated, since existing storage modules need to be charged and discharged using oil HTF. TES systems that can be charged by condensing steam, or discharged by heating water, or even more difficult, discharged by acting as a boiler, are currently considered unavailable and unproven. When oil HTF is used to charge TES, the process will likely charge several modules in several cascade steps in series are charged at the same time.

[0081] Several different techniques are shown in FIG. **8**, which illustrates a Rankine cycle power plant utilizing two different heat sources with different temperatures. Vaporized working fluid generated from one heat source boiler **2** is superheated in a superheater **3** using a HTF from a higher temperature heat source **2** and feeds the HP turbine **4**. The exhaust from the HP turbine is reheated in a reheater **22** and is used to feed the LP turbine **6**. The LPT and HPT turbines are coupled to a generator thus generating electricity. The exhaust from the LPT is condensed in condenser **23**, and the condensed BFW is pumped to an intermediate pressure in pump **24**. The BFW is partially heated in regeneration heater **25**, fed to the main BFW feed pump **26**. The high-pressure liquid working fluid is heated in additional regeneration heaters **27** and **28** before returning to the boiler **1**.

[0082] A high temperature oil HTF circulation loop through pump **20** drives oil HTF out to a solar field that heats the oil up to the maximum temperature permitted, which then in turn heats module **15** up to the superheat stage range of temperatures, and then flows in series through module **14** heating that module up to the boiler heat temperature range.

[0083] The hot working fluids extracted from the power cycle are used to heat a medium temperature circulation loop of oil HTF in exchangers **30**, **31**, and **32**. Heated oil HTF is routed to storage module **11** after exchanger **30** and oil HTF returning from the interstage reheater **22** is combined in at approximately the same temperature. The remaining oil HTF is heated in exchanger **31** to the next higher temperature stage and again a portion of the flow is routed to storage module **12** to charge that module; then the process is repeated yet again with oil HTF heated in **32** and charges module **13**.

[0084] FIG. **9** shows the flows in both oil HTF circulation loops reversed as the modules discharge providing heat to the superheater **21** and reheater **22** from the superheat stage module **15**, and the HP boiler **3** from module **14** as well as the oil HTF leaving the superheater. In the medium temperature oil HTF circulation loop, module **11** provides preheat to the LP boiler and module **12** provides LP boiler **5** heat and the preheater **33**. Module **13** provides heating up to the HP boiler temperature, then sends the heated oil HTF to makeup to the high temperature circulation loop. In effect, each module is being heated across a single stage of temperatures at a time in a cascade charge process, even though the oil HTF is heating several modules in series, each over a cascade step, in a circulation loop.

[0085] In order for cascaded TES to work most effectively, the Applicant believes that each stage of the thermal energy storage should be completed within an average charge period of approximately two to four hours, so that over the course of high insolation period of the day, the excess thermal energy from a CSP power plant and the solar fields can be stored. For example, if three stages of TES storage are used, and the storage period with available thermal energy is eight hours, the sum of the charge period for each stage must be completed within the eight hour period. The maximum time insolation is available during the months were the TES system would be pushed is ten hours. If three to four stages are used, then typically each stage charge period must be completed with an average charge period of less than three hours. In the cascade system and method of the illustrated embodiment, a storage module is first charged during a low temperature thermal energy storage stage, then switched into a moderate temperature storage stage, then cascaded up to a high temperature storage stage, and finally filled with very high temperature thermal energy in a very high temperature stage.

[0086] The cascade method of the illustrated embodiment thus requires a quicker dynamic response of the TES modules during the unsteady heat transfer period, than current development efforts in TES where development work is understood to be concentrated on single stage utilization of solid media storage. The Applicant believes that design techniques are available to increase the thermal energy transfer rate during the charging and discharging of solid media TES, and thus high thermal conductivity (high k modules) with the higher transfer rates can be utilized.

[0087] In order to increase the thermal energy stored in a solid media module, the sharper heat front that occurs because of higher thermal transfer results in a higher average storage temperature in the module. Using a section of the module with higher heat transfer at the end of the TES module (segmented module) results in a sharper heat front during the finish of each charge step. Likewise, when the flow of the HTF is reversed during the discharge cycle, the front section of the module becomes the last portion of module where significant thermal energy is recovered, and a sharper heat front in this section during discharge will allow a fuller recovery resulting in a lower average temperature in the depleted TES module. Therefore both the first and last sections of a TES module in this method should use higher heat transfer design modifications to increase heat transfer rates. This increases the amount of thermal energy stored for a given amount of solid media, as well as decrease charge times.

[0088] In addition to design modifications discussed above, the thermal conductivity of the solid media itself can be improved, for example, by using castable ceramics and high temperature concrete. In addition, metal needles can be added to further increase the thermal transfer rate into and from the solid media. The combination of fins and high conductivity materials with higher heat capacity increases the amount of thermal energy that can be stored and recovered. Although the cost of using these high thermal conductivity modules may be higher, the faster thermal heat transfer allows a module to be cycled up over several temperature ranges during the day, then cycled down during the evening and nighttime hours.

[0089] According to other embodiments, it is possible that some portions or modules of TES could utilize phase change materials (PCM), particularly if the phase change temperature is slightly higher than the temperature of the working fluid boiler, or a different PCM at a temperature desired in the superheater and reheater. In this case, the cascade system is particularly useful, since heat source temperatures are matched with the different PCMs. Such TES modules that utilize phase change materials are intended to be within the scope of this disclosure.

[0090] According to one embodiment, the intermediate temperature thermal energy stored and recovered from TES in a CSP project could be used to operate a LP steam turbine-generator as a base load power generator, with the HP steam turbine-generator only operational when sufficient high temperature solar thermal energy is available. The impact of these design changes is to substantially decrease the size and cost of the LP steam turbine generator and the associated condenser and cooling system compared to a standalone CSP plant. Alternatively, a larger LP steam turbine generator system can be used and operated to provide additional superpeak power in the afternoon and evening using thermal energy stored during the morning. The system and method of using thermal energy extracted from the power cycle hot working fluids to replenish TES is effective in improving the design issues for CSP plants.

[0091] The method of extracting thermal energy from heat engines such as turbines, is believed to be more effective with Rankine or Kalina cycles than other power cycles such as Brayton or Ericsson cycles. The working fluid in both the Rankine cycle or Kalina cycle is a vapor, and when the vapor is removed and condensed, the latent heat released can be used to transfer more heat nearly isothermally to a heat consumer or to heat storage. The hot working fluid vapor could be exchanged with another power cycle working fluid or a HTF, or the heated working fluid removed could be used to replenish TES directly, or exchanged against fluids from a lower temperature heat source, or used in process heat exchangers. Brayton and Ericsson cycles use a mixture of gases as the working fluid, so if these gases are removed, only the sensible heat from lowering the temperature of the gases is available for heating. In addition the hot gas exhaust from many Brayton or Ericsson cycle heat engines often is at quite a high temperature, so generally a heat recovery unit (HRU) is used to recover heat from the exhaust. Typically a HRU will recover the heat and generate steam that can be used in a steam Rankine cycle power plant. Such a heat recovery unit may be provided in the form of a Heat Recovery Steam Generator (HRSG).

[0092] FIG. **6** is a block flow schematic diagram illustrating an embodiment of the current systems and methods and showing thermal energy flows using a HRSG **9** to generate steam from the exhaust of an Ericsson cycle heat engine **18** to feed a Rankine cycle power plant steam turbine **10**. Typically the superheated high pressure steam temperatures from a HRSG will exceed approximately 500 deg C. The high pressure turbine **10** exhausts steam to the next stage turbine **4**. A portion of the steam could be extracted using an interstage bleed at a temperature in the range of approximately 400 to 425 deg C., which in some cases could be at the exhaust of steam turbine **10**, and used to heat an oil HTF which in turn charges the TES module **15**. The thermal energy added to the power plant by the higher temperature superheated steam from the HRSG should be converted to electricity with a fairly higher thermal efficiency.

[0093] FIG. **7** shows another block flow schematic diagram for the same process configuration as FIG. **6**, but illustrating the operation during TES discharge. The high temperature HRSG heat source doesn't provide thermal energy during operation in the evening or at night, so the steam turbine **10** is bypassed. However, thermal energy recovered from TES modules **12**, **13**, and **14** feed the high pressure boiler **3**, the medium pressure boiler **7** and the low pressure boiler **5** keeping the power plant generator loaded. TES module **15** provides superheat and reheat. The relative capacities of the thermal energy storage and solar collection systems can be designed to provide for a significantly extended run time compared to operating the power plant solely on the high temperature TES modules. This embodiment demonstrates the effectiveness of using hybrid solar collection systems in a CSP project, especially when a cascade multistage TES system is used.

[0094] This embodiment also demonstrates another advantage of using hybrid solar collections systems. Solar energy may be concentrated by using reflectors to concentrate solar radiant energy. The amount of solar radiant energy that can be concentrated depends on the aperture of the concentrating device, where the aperture is the cross-section area of the device normal to the incoming solar radiation, and thus intercepting the direct beam sunlight. For parabolic trough collectors, the aperture is set by the width of the trough across the open mouth. The troughs are usually oriented north/south and track the sun across the sky, so PTC apertures remain reasonably constant until the sun is close enough to the horizon that the PTCs shade each other. The amount of solar radiant energy still declines when the sun is close to the horizons since the sunlight must travel at an angle across the atmosphere through more than one air mass unit resulting in increased solar scattering and dispersion.

[0095] By contrast high collection ratio point systems such as power towers will experience a more significant change in effective aperture over the course of the day, especially if relatively flat reflectors are used. The tilt of the reflectors isn't normal to the incoming sunlight, and the tilt will be at shallower angles during the early morning and late afternoon. Accordingly, the Applicant believes that power tower collection systems should have greater variability in thermal energy flow over the course of the day than PTCs. Using similar logic, the Applicant also believes that linear Fresnel collection devices should also have a greater variability in thermal energy flow than PTCs. Since the power towers collect solar thermal energy at very high temperatures with resulting high thermal efficiencies when the thermal energy is used in the CSP plant, there is an incentive to include power towers in a hybrid solar collection project. Similarly, but at the opposite end of the thermal energy cost curve, linear Fresnel collection systems should provide some of the lowest cost DSG systems generating lower temperature thermal energy, and have a distinct cost advantage in providing saturated steam to the CSP plant. If both types of collection systems are used, the variability in the thermal energy feed could be quite high, and this places a strong incentive for the CSP plant to have a large and effective TES system in order to counter the inherent variability of these collection systems. The current systems and methods provide a more robust solar thermal power plant with integrated TES system than other existing processes.

[0096] As appreciated by those skilled in the art, the vaporized working fluid extracted from Rankine and Kalina cycles also exchanges heat more effectively given the higher heat transfer coefficient of condensing vapor. Hot gases from either a Brayton or Ericsson cycle generally have much lower heat transfer coefficients than condensing vapor at the same approximate temperature. Most commercial applications of Brayton or Ericsson cycles intend to use air as the working fluid gas mixture, and clearly air or hot combustion gases from these cycles will have poor heat transfer characteristics, and suffer pressure drops if used to replenish TES. Nevertheless, hot gases from these cycles still may be used for TES replenishment, particularly at temperatures exceeding 400 C where other options may not be available. In addition to using a variety of solid media or hot oil/solid storage systems for storing thermal energy from sources such as HRUs, the systems and methods of the current embodiments could use steam or hot HTF from a HRU as one of the thermal energy sources for TES replenishment.

[0097] As appreciated by those skilled in the art, there are many different process configurations for Rankine cycle power plants, and FIGS. **8** and **9** only depict a simple Rankine cycle. For example, Rankine cycle power plants could use other types of heat engines, sometimes three or more heat engine stages or turbines are used instead of only two stages, the reheater also removes condensed liquid droplets interstage, there are typically multiple regeneration heaters used for each stage, a direct contact exchanger is used as one or more regeneration heater, and a BFW surge and deaerator vessel is included in the BFW circulation loop. The systems and methods described according to the exemplary embodiments described herein can be used to extract additional hot working fluid from the power cycle in any of these configurations, and are intended to be within the scope of this disclosure.

[0098] If an intermittent high temperature heat source used to feed a thermal power plant is co-located near a continuous low temperature heat source, then either thermal energy extracted from the power plant or recovered from TES can be utilized to supply medium temperature thermal energy to upgrade the low temperature heat source for utilization in a second thermal power plant. In particular, if concentrated solar thermal collection systems are located near a geothermal power plant, thermal energy removed from a CSP plant can be stored, and then recovered from medium temperature TES and used to raise the enthalpy of the geothermal produced fluids in the current methods. This is a particularly advantageous application of the embodiments of the invention.

[0099] A geosolar electric power generation process as well as additional methods used to inject, circulate, and recover heated fluids from a geothermal reservoir (referred to herein as "Geosolar Injection Methods") is described in U.S. patent application Ser. No. 12/562,080 titled "Methods and Systems for Electric Power Generation Using Geothermal Field Enhancements" and filed on Sep. 17, 2009, the subject matter of which is incorporated by reference herein in its entirety; wherein thermal energy extracted from a solar thermal power plant was used to heat produced geothermal fluids, followed by injecting the heated fluids into the geothermal reservoir to create a hot zone. Subsequently, the heated fluids were produced from the hot zone and utilized in a geothermal power plant, typically a combined cycle power plant with a geothermal flash steam expansion turbine coupled with a binary fluid organic Rankine cycle (ORC). In addition, short term TES was used to store thermal energy that could be used to heat either the injected fluids or working fluids in the geothermal power plant.

[0100] The systems and methods of the embodiments described herein extend and further define the geosolar process, particularly regarding the use of cascade multistage TES used to store thermal energy extracted from a solar thermal power plant, and using recovered thermal energy from TES to extend the operation of the solar thermal power plant. These systems and methods also uses both thermal energy removed from the solar thermal power plant and thermal energy recovered from cascade multistage TES to boost the enthalpy of geothermal fluids utilized in a geothermal power plant or heat geothermal power plant working fluids, but without involving the injection of heated geothermal fluids into the geothermal reservoir, as addressed by the Geosolar Injection Methods. The current systems and methods complement and facilitate the Geosolar Injection Methods, but involve a combination of thermal power plant methods combined with cascade multistage TES to provide a heat boost to a geothermal plant. In this description the systems and methods according to the embodiments described herein will be referred to as "Basic Geosolar Methods."

[0101] FIG. **5** shows one example of possible supply thermal energy flows that could be removed from the power plant that can be used to either boost lower temperature heat sources for utilization in power plants or heat working fluids in a second power plant. FIG. **5** shows a high pressure boiler **3** feeding a high pressure turbine **4**, a medium pressure boiler **7** feeding a medium pressure turbine, and a low pressure boiler **5** feeding a low pressure turbine **6**. If the hot working fluid is steam, then steam flows **106**, **107**, and **108** taken from each boiler are available to provide thermal energy to boost lower temperature heat sources. Thermal energy can be recovered from TES storage modules in various temperature ranges for use in different stages, shown in FIG. **5** as thermal energy flows **101**, **102**, **103**, **104**, and **105**. Although FIG. **5** shows the TES discharge operation of the thermal power plant integrated with multistage TES, all of these thermal flows should be available during the TES charge operation of the thermal power plant as well.

[0102] In one embodiment using the Basic Geosolar Methods of the embodiments described herein, the thermal power plant in FIG. **5** will be a CSP plant, generally using a superheated high pressure steam turbine driving an electric generator. The second power plant in the basic geosolar process using the thermal energy removed and stored from the CSP plant, would likely be a combined cycle geothermal power plant utilizing thermal energy from geothermal produced fluids. The top power cycle in the geothermal plant will likely be a steam Rankine turbine, possibly with the turbine exhaust condensed against the bottom cycle working fluid. The bottom cycle will typically be an ORC using a binary fluid working fluid.

[0103] Since additional thermal energy feed is available from the CSP plant and associated TES, the steam Rankine cycle in the geothermal power plant could be modified from typical geothermal power plants using this process. FIG. **10** is a schematic block flow diagram showing an embodiment using a combined cycle power plant that has a higher pressure turbine added to the basic design to take advantage of the somewhat higher temperature thermal energy available from the CSP plant and TES. Possible heat exchanger locations (**40**, **43**, **50**, **51**, **52**, **54**, **62**, and **63**) are shaded where thermal energy removed from the thermal power plant (CSP plant) or recovered from TES could be added to the geothermal power plant. The dotted shaded heat exchanger locations (**56**, **57**, **58**, **59**) show some alternate locations for some of the heat exchangers. As appreciated by those skilled in the art, there are many different process configurations for power plants using different heat engine (turbine) configurations including alternative heat exchanger locations, and FIG. **10** illustrates one possible configuration for explanatory purposes. Many other power plant configurations exist that would use the systems and methods according to the embodiments described herein, all of which are intended to be within the scope of this disclosure.

[0104] One alternative to add thermal energy to a geothermal power plant involves heating the produced geothermal fluids, typically a mixture of brine and steam with a small fraction of non-condensable gases. The geothermal fluids from the geothermal wells **37** are typically produced to a production flash separator **41** to separate flash steam from produced brine. The produced fluids could be heated in a production (brine) heater **40** prior to the flash separator in order to increase the amount of flash steam. In many geothermal fields there typically are marginal production wells that don't quite produce at the rates, temperatures, or flash enough steam and may not have a sufficiently high wellhead pressure to combine with more productive geothermal well fluids. Produced fluids from these lower productivity wells **36** would be segregated and the produced fluids likely pumped using a booster pump **39** and possibly heated using a brine heater **56**, or combined with other produced fluids and heated in the brine heater **40** prior to the production flash separator **41**.

[0105] A second brine heater **43** could be used to flash additional steam from the brine prior to a lower pressure flash separator **44**. This double flash configuration with separate brine heaters shown in FIG. **10** is useful to increase flash steam rates and condense additional water that could be used for water makeup or wet cooling in either the CSP plant or the geothermal power plant. Other configurations and embodiments could also use brine heaters and flash separators to add thermal energy to the geothermal produced fluids, all of which are intended to be within the cope of this disclosure.

[0106] Steam will typically flash from the produced fluids as they are heated. There will be a limit on the fraction of the produced fluids that can be flashed into steam, before fouling and salt and mineral concentrations become a problem. In most cases, approximately 15% of the produced fluids can be flashed to steam, and if the produced brine has low salinity, the percentage that can be flashed could be higher, perhaps approaching 25% or even higher. Adding geothermal fluids with lower salinity or mineral content would generally help reduce fouling. As appreciated by those skilled in the art, there are heat exchanger designs, operating procedures, and maintenance procedures to help control salt deposition and fouling in the brine heaters.

[0107] In order to control fouling in the production heaters, and to increase production rates from the low productivity geothermal wells, these wells could be produced using downhole submersible pumps, or the low wellhead pressure would be boosted in a booster pump before entering the production heaters as shown in FIG. **10**. As a result of the combination of this pressure boost and production heaters, the pressure in the flash separator **41** could be raised, thus resulting in higher pressure steam feed to the steam turbine **55** in the steam Rankine power cycle.

[0108] Another possible method to reduce fouling, uses a degasser separator **38** ahead of a booster pump **39** to raise the brine pressure high enough to reduce the amount of steam flashed in the brine heater **56**, then the brine pressure would be dropped through an expansion valve and flash steam in the production separator **41**. This 'pump, heat, expand and flash' process is somewhat inefficient, but this method would help reduce brine heater **56** fouling significantly while generating flash steam.

[0109] The flash steam from the production separator **41** could be routed through a knockout separator **42** to remove brine droplets. Generally a spray of preheated water is used in geothermal steam knockouts to wash down salt deposits, particularly if demisters or baffles are used in the knockout. Flash steam from the knockout feeds the steam turbine **55** and condenses in condenser **46** using a source of cooling (not shown). Flash steam from the lower pressure flash separator **44** also flows through a knockout **45** prior to feeding the steam turbine **55** interstage. In some cases, it may be desirable to use a separate steam turbine for this lower pressure flash steam. The expansion turbines in FIG. **10** all drive electric generators. In some embodiments, the turbines would provide mechanical energy to a common electric generator.

[0110] Although it is desirable to heat the geothermal fluids to increase flash steam to provide working fluid makeup and cooling water, the amount of thermal energy that can be added to a geothermal power plant by heating the produced geothermal fluids is limited. Another method for adding thermal energy to a geothermal plant is to heat the working fluids in the geothermal plant.

[0111] In FIG. **10**, thermal energy can be recovered from the heated brine from the flash separators by using a binary fluid organic Rankine cycle. The binary fluid flows through a preheater **60** and boiler **61** collecting thermal energy exchanged from the hot brine and cooling the brine prior to injecting the spent brine in a spent brine injection well **68**. As appreciated by those skilled in the art, there typically is a lower outlet temperature limit on the brine outlet from the binary fluid preheat exchanger **60**. The brine temperature can only drop to this temperature limit before severe silica fouling in this exchanger. This outlet temperature depends on the temperature the geothermal fluids reached in the geothermal reservoir, where the silica was absorbed. Higher temperatures in the geothermal reservoir, will lead to higher silica fouling temperatures in the brine-binary fluid exchangers.

[0112] Thermal energy can be added to the binary fluid using an additional binary fluid boiler **62**, and by adding a binary fluid superheater **63** in the ORC. The binary fluid vapor is used in the expansion turbine **64** to drive an electric generator (not shown) and then is condensed in condenser **65**. A portion of the thermal energy that was used to heat the brine prior to the flash separators can be recovered from the brine in the binary fluid preheater **60**. The preheated binary fluid can be boiled in **62** using thermal energy flows with a temperature approximately the same as the interstage temperature in the CSP plant (such as flows **102** and **106** in FIG. **5**). The binary fluid can be heated in superheater **63** using thermal energy flows with a temperatures ranging up to the high pressure boiler in the CSP plant (such as flows **103** and **107** in FIG. **5** and possibly flows **104** and **108**). Thermal energy in these temperature ranges are considered only moderately useful in the CSP plant, but represent a valuable heat boost in the ORC geothermal power plant.

[0113] Thermal energy can also be used to superheat geothermal flash steam before the steam turbine **55** in superheaters **58** and **59**. Alternatively, the condensate water can be circulated using pumps **47** and **49** and preheated using low pressure steam extracted from the steam turbine or a portion of the geothermal flash steam in a regenerative heater **48**. This moderately preheated BFW can be further heated using thermal energy from the CSP/TES in exchanger **50** and in boiler **51**, and in superheater **52**, before being used in a higher pressure steam turbine **53** added to the geothermal power plant. The exhaust from steam turbine **53** can be combined with geothermal flash steam from the flash separator **41** and reheated (superheated) in the reheater **54**. Significant quantities of thermal energy flows in a temperature range suitable for the CSP low pressure boiler would be used in the preheater **50** (flows **103** and **107** in FIG. **5**), and thermal energy flows in a temperature range suitable for the CSP medium pressure boiler would be used in the boiler **51** (flows **104** and **108** in FIG. **5**). The superheaters **52**, **54**, **58**, and reheater **59** would use smaller flows of thermal energy at a temperature range higher than the C SP high pressure boiler (flow **105** in FIG. **5**).

[0114] In summary, thermal energy can be added to the combined cycle geothermal power plant shown in FIG. **10** by heating geothermal fluids using various brine heaters and flash separators; by using thermal energy in binary fluid heaters, boilers, and superheaters; and by using thermal energy in steam Rankine BFW preheaters, boilers, superheaters, and reheaters. In addition, the geothermal flash steam could be superheated prior to the steam turbines. The sum of all these thermal energy users represents a significant heat sink for thermal energy removed from a CSP plant, and temporarily stored in TES. Most of the thermal energy supplied by CSP/TES has a higher temperature than thermal energy provided by the geothermal produced fluids, and can be efficiently utilized in a geothermal power plant designed for its use.

[0115] A binary fluid geothermal power plant is effective for recovering heat added in the geothermal production heaters. In some embodiments, such as illustrated in FIG. **10**, a combined cycle geothermal power plant is used with a steam Rankine cycle integrated with a binary fluid Rankine cycle. A steam Rankine cycle would be useful in generating electricity from flashed geothermal steam, followed by condensing the geothermal steam flows, possibly using the binary fluid as a heat sink and recovering the steam condensate for use in CSP plant wet cooling systems. Typically the binary fluid cycle can be dry cooled, so the steam condensate from a combined cycle geothermal plant could be accumulated around the clock and used in a CSP plant wet cooling system. In this manner the geothermal plant provides the water for wet cooling the CSP plant during the day, which can increase the overall power output from a CSP plant by approximately 10%.

[0116] One intended application of the systems and methods according to the embodiments described herein is retrofitting existing geothermal power plants. Many geothermal plants in Nevada and California and elsewhere in the world are in locations where there is a high solar insolation. These geothermal plants would be candidates for retrofit to geosolar projects. In a retrofit, the new systems can be added in a phased manner, with some of the solar fields and the production heaters added first, followed by the CSP plant. The TES systems can be added in the first phase, and expanded in the second phase. Eventually the geosolar project could be expanded to a full geosolar injection project using Geosolar Injection Methods by adding additional brine heaters, brine injection pumps, and drilling hot injection and production wells into a hot zone in the geothermal reservoir.

[0117] The basic geosolar embodiment encompassing solar fields, CSP plant, TES, geothermal production heaters, and a geothermal power plant in an geothermal field, sets the stage for expanding a basic geosolar electric power generation project into a full geosolar injection project. The systems required to implement these methods can be constructed and begin operations on a phased schedule. At least one solar field along with the HTF system (either steam or hot oil), the geothermal production heaters, and a smaller sized TES system are likely for the first phase; followed by a second solar field, the CSP plant, more extensive cascade multistage TES, and possibly a new binary fluid geothermal plant could be installed in the second phase; followed by a hot fluids injection system with injection pumps along with additional brine heaters, hot injection and production wells, and a hot fluid (brine) distribution and gathering system could be installed in the third phase.

[0118] The embodiments of the present invention are particularly useful to boost existing geothermal plant output where the existing plant is currently operated at power generating rates lower than the power plant capacity, due to a shortage of geothermal energy availability. In this case, the first phase modifications are a steam generating solar field along with BFW system, production heat exchangers, low pressure steam distribution system, and any modifications to the geothermal wells and gathering system. The geothermal production separator and the geothermal power plant are already installed and operational.

[0119] In order to extend the availability of low pressure steam for the geothermal production heaters, a set of TES modules would be provided, to store daily solar thermal energy for used during the evening and night. The MT stage of TES with a hot oil system would be likely be needed in this case, and so this system is also shown for the first phase.

[0120] FIG. **11**, FIG. **12**, FIG. **13** and FIG. **14** are block flow schematic diagrams showing examples of facilities likely installed in the first two phases in a phased implementation of a basic geosolar project. In all these diagrams, a relatively simple binary fluid geothermal power plant is depicted, with preheater **60** and boiler **61** heated by geothermal brine, and a superheater **62** heated by flash steam. An additional boiler **69** and superheater **63** are heated by oil HTF. The expansion turbine **64** drives an electric generator and the binary fluid is condensed **65** and pumped **66** back to the preheater.

[0121] The first phase daytime operation is shown in the embodiment of FIG. **11**, and would involve the installation of a DSG solar collector field **2** that uses solar concentrated energy to heat BFW and boil low pressure steam. Typically the steam pressure would not be greater than approximately 18 bars, although the solar collector system would be designed and built to generate high pressure steam over approximately 70 bars for use in later phases of the project. The steam generated is used in at least one production heater **40** in order to increase the enthalpy of the produced fluids prior to a geothermal production flash separator **41**. Both the flash steam and heated brine are used to heat the binary fluid in the geothermal plant, and the spent brine is re-injected **68**. The steam from the DSG field also is used to heat oil HTF in exchanger **32**, and trapped to exchangers **31**, **28**, and **27**, prior to return to a deaerator and surge **26**. The BFW pump **27** feeds the BFW back to the solar field. Heated oil HTF is used to charge TES modules **13**, **12**, and **11**, with a portion used in the binary fluid boiler **69** and superheater **63**. This is intended to be a relatively straightforward system, with only three points where thermal energy is removed from TES and the DSG and added to the geothermal power plant.

[0122] FIG. **13** shows the night time operation for the first phase with the operation almost the same but with the steam generated in boiler **3** and preheated in **35** by oil HTF that recovered thermal energy from TES modules **11**, **12**, and **13**.

[0123] In the second phase, the high temperature solar field along with HT TES is added, along with the solar thermal HP turbine-generator power cycle. These systems should allow extended operation of the solar plant and extract low pressure steam from the turbine exhaust to use in the production heaters. The DSG solar field steam generators are now operated to generate HP steam, and the high temperature hot oil is used for superheat. Because the solar plant will likely require higher steam flows, the DSG solar field will likely require expansion, and the BFW system exchangers and pump will need to be modified.

[0124] Since much of the equipment needed for the second phase could require long delivery schedules, and the size of the solar fields may be significantly larger than the first phase, the second phase is anticipated to take longer to install and require higher capital investments, but is expected to generate significantly more electricity than the first phase. However the increase in capacity is still limited due to the limits of heating the produced geothermal fluids and the capacity of the geothermal power plant.

[0125] FIG. **12** shows the embodiment previously described in FIG. **11**, but now expanded in the second phase, and showing facilities operating during the day. In this embodiment, a two stage CSP plant has been installed, using a HP turbine **4** and a LP turbine **6** to drive the electric generator, and a condenser **23** with associated cooling system (not shown), and a completed regenerative heater train. In addition, an PTC solar field **1** has been added to heat oil HTF for superheat **21** and reheat **22**, and to charge higher temperature TES modules **15** and **14**. Thermal energy used in the geothermal remains the same in this embodiment, although other embodiments could use an expanded geothermal plant such as the one depicted in FIG. **10**.

[0126] FIG. **14** shows second phase facilities operating during the night. Thermal energy recovered from TES modules **14** and **15** is used in the superheater **21**, reheater **22**, and the HP boiler **3**. Thermal energy recovered from TES modules **11**, **12**, and **13** is used in the preheater **35** and the LP boiler **5**.

[0127] The third phase involves expanding the solar thermal energy derived power generating capacity. This involves adding a low pressure turbine-generator to the solar thermal power plant (if not previously included in the second phase). At the same time the solar field and TES capacities are increased. If wet cooling is used for the bottom power cycle in the solar thermal power plant, it may be possible to use the condensed steam from a combined cycle geothermal power plant as the source of water for the wet cooling system. If the existing power plant uses only an ORC, then adding a geothermal steam turbine-generator set that uses flash steam from the production separator could be added. This top cycle in the geothermal power plant would condense the steam turbine exhaust against the binary fluid, thus collecting the steam condensate for use as a cooling water source.

[0128] If the existing geothermal power plant uses only flash steam, a replacement combined cycle steam Rankine/ORC binary plant can be added, and the existing plant could be converted for use as the solar thermal power plant bottoming cycle.

[0129] Using steam condensate from the produced geothermal fluids for wet cooling may cause loss of brine levels in the geothermal reservoir over time. The current methods allow addition of lower temperature brines from nearby non-geothermal reservoirs for injection for pressure maintenance. In this embodiment, non-geothermal brines or non-potable water would be used to substitute for the loss of water from the geothermal reservoir.

[0130] In the fourth phase of a geosolar injection project, the systems needed to pump and heat hot brine for injection are added. Hot brine injection wells are drilled or selected from existing geothermal field wells, and wells that can communicate with the hot brine injection wells are drilled and completed, or selected from existing wells, for use as hot production wells. The portion of the geothermal field between the hot injection wells and the hot producers becomes the hot zone in a geosolar project as discussed in the Geosolar Injection Methods. The phased implementation of a geosolar project decreases the financial risks and permits multiyear purchase contracts for the solar field concentrators, which should make geosolar projects more economically attractive. The systems and methods using heat extracted from the solar power plant, along with the methods using cascaded multistage TES, in conjunction with the use of the extracted and stored thermal energy to heat geothermal fluids, make this phased implementation feasible. The systems and methods of the embodiments of the present invention provide for an effectively phased implementation of a geosolar project by taking advantage of the high temperature solar thermal energy by utilizing it in a CSP plant, coupled with TES designed to supplement heat extracted from the solar thermal power plant, and the ability to use the lower temperature thermal energy in the geothermal production heaters and to heat geothermal plant working fluids.

[0131] It is also important to note that the construction and arrangement of the elements of the system and methods for integration of concentrated solar thermal and geothermal power plants using a multistage, cascade thermal energy storage system as shown schematically in the embodiments is illustrative only. Although only a few embodiments have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible without materially departing from the novel teachings and advantages of the subject matter recited.

[0132] Accordingly, all such modifications are intended to be included within the scope of the present invention. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and arrangement of the preferred and other exemplary embodiments without departing from the spirit of the present invention.

[0133] Unless otherwise indicated, all numbers used in the specification and claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification and attached claims are approximations that may vary depending at least upon the specific analytical technique, the applicable embodiment, or other variation according to the particular details of an application.

[0134] The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. In the claims, any means-plus-function clause is intended to cover the structures described herein as performing the recited function and not only structural equivalents but also equivalent structures. Other substitutions, modifications, changes and omissions may be made in the design, operating configuration and arrangement of the preferred and other exemplary embodiments without departing from the spirit of the present invention as expressed in the appended claims.

1-108. (canceled)

109. A method for storing thermal energy comprising heating a thermal storage media using thermal energy contained within hot partially expanded working fluids extracted from a heat engine expansion step in either a Rankine cycle or a Kalina cycle thermal power plant.

110. The method of claim **109**, wherein the hot working fluids exchange thermal energy into the storage media.

111. The method of claim **109**, wherein the Rankine cycle working fluids comprise water and steam, and the hot working fluids extracted are predominantly steam flows at multiple pressures and temperatures.

112. The method of claim **111**, wherein the heat engine is a steam expansion turbine that drives an electricity generator in the power plant.

113. The method of claim **110**, further comprising the step of using thermal energy to charge multiple stages of thermal energy storage; charging storage modules at each stage using either the extracted working fluids or the heat transfer fluid in a temperature range chosen for that stage; such that at the end of the charge period, the storage media in the storage modules in each stage has been heated to a different temperature range.

114. The method of claim **113**, wherein at least one flow of extracted working fluid exchanges thermal energy into the storage media in the temperature range chosen for that stage.

115. The method of claim **113**, wherein the heat engine is an expansion turbine and further comprising the step of extracting flows of hot working fluids from the selected stages of the turbine; then using the flows to heat the heat transfer fluid sequentially in series of heat exchangers; selecting each extracted fluid flow to provide the heat duty required by each heat exchanger to achieve the desired temperature change.

116. The method of claim **115**, further comprising the step of heating the heat transfer fluid using working fluids with temperatures in the range of the lowest temperature stage; then using a portion of the heat transfer fluid flow to heat the lowest temperature storage stage; followed by heating the remainder of the heat transfer fluid flow using working fluids with temperatures in the next higher temperature range; then using a portion of the heat transfer fluid flow to heat the next higher temperature storage stage; and so forth with additional sequential heat exchange using higher temperature working fluids to increase the temperature of the heat transfer fluid coupled with using a portion of the heat transfer fluid flow to charge sequentially higher temperature stages of the thermal energy storage; until the remaining heat transfer fluid flow is heated to highest temperature range that can be reached using thermal energy from the highest temperature working fluids in thermal power plant; then using at least a portion of the remaining heat transfer fluid to heat a storage stage to that temperature range.

117. The method of claim **113**, further comprising the step of using thermal energy contained in hot vaporized working fluid from the boiler in the thermal power plant to charge at least one of the thermal energy storage modules in a storage stage such that the storage stage temperature range approaches the boiler temperature.

118. Method of claim **113**, further comprising the step of using thermal energy from heat source at a higher temperature than the boiler temperature to charge at least one of the thermal energy storage modules in a storage stage such that the storage stage temperature range approaches the heat source temperature.

119. Method of claim **118**, wherein the thermal energy charges the storage stage using the heat transfer fluid, and further comprising the step of using a separate high temperature circulation loop wherein: heat transfer fluid from a surge vessel is pumped to a heat exchanger train; and the heat transfer fluid is heated in a heat exchanger train having of at least one heat exchanger using hot working fluids extracted from the thermal power plant; and the heat transfer fluid is heated further by a higher temperature heat source exchanging thermal energy into the heat transfer fluid; and the fully heated heat transfer fluid is circulated through at least two thermal energy storage modules in series, exchanging heat into the storage modules and recharging each module through the temperature range of at least one storage stage.

120. The method of claim **118**, wherein the thermal energy is transferred to storage using molten salt and the thermal energy storage consists of molten salt storage.

121. The method of claim **113**, further comprising the step of charging the different stages of thermal energy storage in a cascade charge method with at least two cascade steps; with a discharged or partially discharged storage module heated and charged at a lower temperature stage in one step; then switched into a different position in the cascade, then heated and charged at a higher temperature stage in a second step.

122. The method of claim **121**, wherein the fluid transferring thermal energy into the storage media flows through at least two storage modules; and further comprising the step of charging the first module in a higher temperature cascade step; then charging the following module in a sequentially lower temperature cascade charge step.

123. The method of claim **122**, further comprising the step of adding more cascade steps at higher temperature ranges; wherein the thermal energy storage is charged in at least one of the additional cascade steps using heat transfer fluid heated by one of the heat sources for the thermal power plant.

124. The method of claim **123**, wherein at least one of the heat sources is one of the following:

concentrated solar thermal energy collectors that concentrate solar energy and converts the solar energy to thermal energy, which then heats a heat transfer fluid that feeds thermal energy to the thermal power plant;

a fired heater;

a heat recovery unit that recovers heat from flue gas of a fired heater;

a heat recovery unit recovering thermal energy from the exhaust working fluid from a Brayton cycle or Ericsson cycle heat engine.

125. The method of claim **123**, wherein the thermal energy storage has a mixture of storage modules using different energy storage media, including at least one of the following:

the storage module uses sensible heat storage material as the storage media;

the storage module uses a phase change material as the storage media;

the module uses phase change material and stores thermal energy at a high enough temperature to heat the boiler in the thermal power plant.

126. The method of claim **109**, further comprising the step of recovering thermal energy from the storage media using power plant working fluids or a heat transfer fluid.

127. The method of claim **126**, further comprising the step of using the heated fluids and using additional extracted hot working fluids to provide a continuous supply of thermal energy to users; wherein the thermal energy is supplied by utilizing either the heated working fluids directly; or using either the heated working fluids or the heated heat transfer fluid in a heat exchanger to provide thermal energy.

128. The method of claim **127**, further comprising the step of recovering thermal energy from storage media in stages, with each stage recovering thermal energy in a different temperature range.

129. The method of claim **128**, further comprising the step of using a cascade discharge method that recovers the thermal energy with at least two cascade steps; such that a charged storage module discharges thermal energy at a higher temperature stage in one step; then the storage module is switched into a different position in the cascade and discharges thermal energy at a lower temperature stage in a second step.

130. The method of claim **129**, wherein fluid recovering thermal energy from the storage media flows through at least two storage modules; and further comprising the step of recovering thermal energy from the first module in a lower temperature cascade discharge step; then recovering thermal energy from the following modules in sequentially higher temperature cascade discharge steps.

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