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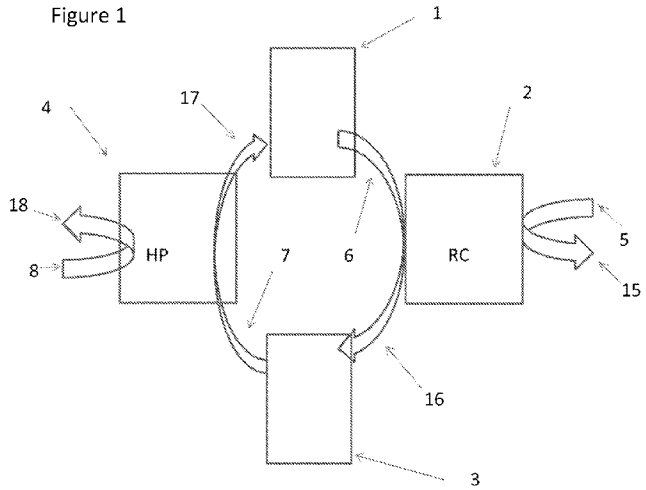
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(54) Title: METHODS TO STORE AND RECOVER ELECTRICAL ENERGY

Figure 1



(57) Abstract: Devices and methods are disclosed which allow the reversible storage of electricity. In one embodiment, a heat pump is used to convert 30 – 80 °C water or other storage medium, such as phase change materials or thermal oils, to a higher temperature, such as 60 – 120 °C. Electricity is required for the compression device of the heat pump, and preferably the heat pump is operated at times of low electricity demand and low electricity prices. The stored thermal energy which may be both a hot stream and a cold stream in separate tanks is used to operate a heat-to-power conversion device such as an organic Rankine cycle (ORC) process. This is preferably done at times of high electricity demand and high electricity prices. Further, the method may be used for quick power grid regulation, i.e. on the scale of less than one minute. The method is simple and economic as storage of hot water or hot liquid is inexpensive. Preferred heat sources are industrial plants for paper, aluminium or steel production, geothermal heat sources, district heating networks or solar heat. The method is particularly useful for the power generation process known as Carbon Carrier Cycle.

METHODS TO STORE AND RECOVER ELECTRICAL ENERGY

FIELD OF THE INVENTION

This invention relates to the field of power generation, and storage of energy and electricity.

BACKGROUND AND PRIOR ART

Energy sources, especially solar and wind, are intermittent. Electricity demand is also variable, see e.g. www.energy-charts.de/power.htm . Therefore it is desirable to store electricity, e.g. in chemical form through electrolytic hydrogen production, in batteries, flywheels, magnetic technologies, in pumped hydro storage or in the form of compressed air. This enables the production of electricity at times of high demand, also referred to as “peak shaving”. An overview of various storage technologies is found at www.sandia.gov (see keywords such as grid storage), www.store-project.eu, www.purdue.edu, (see keywords utility scale energy storage systems), www.irena.org (keywords electricity storage). Said references also discuss typical capital and operational costs of the various techniques, as well as application examples, energy densities, round-cycle efficiencies, energy and effect ranges etc.

The invention deals specifically with energy storage in the form of hot water. The following patent disclosures give an impression of the general art: US 2012/012 5019 (Sami) describes a self-sustaining energy system for a building, comprising geo- and solar heating coupled to an ORC. US 2013/030 6268 (Ducheyne and Stevens) describes a method for storing thermal energy using reversible chemical reactions of

inorganic oxoacids. WO 2013/180 685 (Armstrong) describes a scalable energy storage system connectable to an energy source, e.g. solar, geo, wind etc., and an energy conversion system such as an ORC. US 2014/036 8045 (Conry) describes a power management and energy storage method whereby energy is supplied by excess power and temporarily stored in the form of heat, for later partial recovery by an ORC at times of electricity demand. US 2012/000 0201 (Ast et.al, GE) describes a method to use the thermal mass of an ORC including the oil and working medium loop to provide transient power to an electric grid. US 2015/015 9517 (Wain and Williams, ElectraTherm) describes heat utilization in ORC systems, specifically the combination of ORC and biogas production / combustion and ORC waste heat utilization for enhanced biogas production.

The following disclosures are also of general interest: WO 2015/006 719 by Almogy et al (solar energy collection and storage for electricity generation), US 2009/ 017 9429 by Erik Ellis (low temperature thermal energy storage), US 2014/0260 246 by Fisher et al. (ORC and heat storage), WO 2015/121 036 by Lenk et al. (stratified thermal storage tanks), US 2014/005 3557 by Almogy et al. (CSP solar energy system), US 2013/0299 123 by Matula (reversible geothermal systems), US 2012/005 5462 by Berger (solar based thermal storage), US 6 996 988 by Bussard (solar thermal electric system).

The prior art does not provide economically attractive methods to generate or store heat at times of excess electricity and allowing to generate electricity from said heat at a temperature range of 70-120 °C at times of peak electricity demand.

OBJECT OF THE INVENTION

The object of the invention is to provide a method and a system for storing energy and producing electricity which has a high efficiency and profitability.

The object of the invention is to provide a method and a system for storing energy and producing electricity with a high cycle turnaround efficiency, i.e. electrical energy produced by the RC divided by the electrical energy consumed by the heat pump, >50%.

The object of the invention is to provide a method and a system for storing energy and producing electricity wherein the method and system is used for quickly, i.e. on the scale of less than one minute, regulating power demand in the grid.

The object of the invention is to provide a method and a system for storing energy and producing electricity wherein full and phase- and frequency-matched power is supplied at within less than one minute.

SUMMARY OF INVENTION

The present invention relates to a method, as well as a system, for storing energy and producing electricity by using heat.

The method and system for storing energy and producing electricity comprises:

a) at least one Rankine cycle (RC) or Organic Rankine Cycle (ORC), in the following both denoted RC, being used as a power generation device and wherein the RC is cooled by a cooling flow,

b) a cold storage receiving cold storage medium exiting from the RC,

c) a heat pump heating up the flow of cold storage medium exiting from the cold storage and thereby generating flow of hot storage medium which is received by a hot storage,

wherein the heat pump utilizes a heat source selected from the group geothermal heat, solar heat, industrial heat, waste heat, district heating network, heat from combustion engines or other devices generating heat including fuel cells and chemical processes, and wherein the heat pump is capable of providing heat at a temperature of at least 70 °C, and

d) the heat storage supplying hot storage medium to the RC when electricity production is required, wherein the flow of the hot storage medium through the RC generates electricity,

characterized in that heat is stored in the heat storage as hot storage medium having a temperature at between 70-160 °C.

The RC comprises a hot heat exchanger or evaporating section for a working fluid, cold heat exchanger for condensing said working fluid, turbine or expansion device, and at least one pump for transporting the working fluid to the high pressure section.

The hot storage medium and the cold storage medium may comprise thermal oils, phase change materials and/or water. Alternatively, the hot storage medium and the cold storage medium may comprise combinations of phase change materials with thermal oils or water. Preferably, the hot and cold storage media comprise phase change materials for increased heat storage capacity at given volume.

In preferred embodiments of the invention, the flow of hot storage medium exiting the heat storage and entering the RC has a temperature of 85-98 °C and the flow of cold storage medium exiting the RC is 5-20 °C lower in temperature than the temperature of the hot storage medium entering the RC. In further preferred embodiments of the invention, the flow of cold storage medium exits the RC at a temperature level of 80-65 °C and keeps this temperature until it passes through the cold storage and enters the heat pump where it is heated to 85-98 °C. The flow of hot storage medium which then enters the heat storage keeps the temperature of 85-98 °C in the heat storage. Consequently, in the present invention, energy is stored and converted using relatively small temperature differences in the heat and cold storages.

The cold storage and the heat storage may be at least one storage tank which is above ground or at least partly underground and has a volume of at least 10 m^3. The heat storage and/or cold storage may also be at least 100 m^3, 1000 m^3, 10 000 m^3 or at least 100 000 m^3. For storages of at least 1 000 m^3, the storage tank may be a heat storage tank/reservoir of a district heating industry.

Moreover, the heat storage tank and cold storage tank are either two separate storage tanks or a combined storage tank. The combined storage tank may be a stratified tank which may have a separating layer such as a floating separating layer. In a combined storage tank, the colder storage medium is collected at the bottom and the hot storage medium is collected at the top of the combined storage due to difference in densities of the cold and warm media.

RCs are usually cooled by a cooling medium which may be from a cooling tower, radiator, and large water body (from a nearby river, lake or sea) or underground well. In preferred embodiments of the present invention, the RC is cooled by a cooling flow of the cooling medium entering the RC from a second tank. The flow of heated cooling medium exiting the RC is collected in the second tank, i.e. the second tank is a combined tank comprising both cooling medium and heated cooling medium. Moreover, the second tank may be a stratified tank optionally comprising a separating layer which may be a floating separating layer. The temperature of the cooling flow entering the RC is preferably 5-20 °C and the temperature of the flow of heated cooling medium exiting the RC is preferably 20-40 °C. The cooling medium may circulate in a closed loop from the second tank to the RC and from the RC to the second tank.

In preferred embodiments of the invention, the heated cooling medium exits the RC and serves as heat source for the heat pump and thereafter exits the heat pump as lower temperature medium and returns to the second tank. The temperature of the cooling flow entering the heat pump is preferably 20-40 °C and the temperature of the flow of lower temperature medium exiting the heat pump is preferably 5-20 °C. The cooling medium may circulate in a closed loop from the second tank to the heat pump and from the heat pump to the second tank.

In preferred embodiment of the invention, the heat exchanger of the RC is kept at an operational temperature by circulating hot water through said heat exchanger and by idling the RC, and where after the RC may be started up within less than one minute to provide full and phase- and frequency-matched power supply. Moreover, the cycle turnaround efficiency, i.e.

electrical energy produced by the RC divided by the electrical energy consumed by the heat pump, is at least 50%.

The heat pump and the RC may share components such as heat exchangers and pumps. Furthermore, if the heat pump is operated as an RC then the same working medium can be used.

In further embodiments, two Rankine Cycles (RCs) can be coupled in series and each RC is cooled by cooling flow. In further embodiments comprising two RCs, one cooling flow is used first to cool one RC, preferably the second RC operating at a lower temperature than the first RC, where the flow is heated by ca 10 °C to 30 °C, and this flow enters the remaining RC, preferably the first, in order to operate both RC at roughly the same temperature difference.

The RC in the above mentioned embodiments may be an organic Rankine Cycle.

The above disclosed embodiments may be used as a rechargeable electrical battery, i.e. as a system in which electrical energy can be stored temporarily until such time when electrical power is required.

DESCRIPTION OF FIGURES

Figure 1 is a block diagram of a combination of power generation device or ORC (2), heat pump (4) and storage tanks (1 and 3) according to the invention. (5) represents the flow of cooling through the ORC (2), (6) represents hot water driving the ORC (2), (7) represents the flow of colder water being heated by heat pump (4), and (8) represents the flow of a hot source driving the heat pump (4). It should be

understood that tanks (1) and (3) can be combined, and that also the heat pump (4) and the ORC (2) can share major components, or provided they use the same working medium, they can share most or all components.

Figure 2 shows a heat pump (4), an ORC (2), a stratified tank (11) with a separating layer indicated by arrow (9). Cooling of the ORC is represented by flow (5), thermal input to the heat pump (4) is indicated by flow (8).

Figure 3 shows a heat pump (4), an ORC (2), a stratified tank (11) and a second tank (10) which stores cooling medium for the ORC (2). The heated cooling fluid/medium (15) for the ORC (2) in tank (10) serves as heat source (8) for the heat pump (4). This arrangement obviates the need for a separate cooling tower for the ORC (4). Cooling medium can be circulated in a closed loop, saving e.g. water. Such an arrangement is useful to supply e.g. 1-100 or 20-1000 households with electricity at peak times, like a stand-alone electrical battery. At the same time, this system can be coupled to a district heating network.

Figure 4 shows a heat pump (4), an RC (2), a stratified tank (11) and a second tank (10) which stores cooling medium for the RC (2). The flow of heated cooling medium (15) in tank (10) is derived from the operation of the RC (2) and serves as exclusive heat source (8) for the heat pump (4). The flow of heated cooling medium (18) which produced by the cooling down operation of the heat pump (4) returns to the second tank (10) and may thereafter be used as cooling flow (5) for cooling the RC. Advantageously, the cooling medium can be circulated in a closed loop and thereby saving medium. Moreover, the RC may be an ORC. The arrangement in Figure 4 obviates the need for a

separate cooling tower for the OR (2). Moreover, whereas in Figure 3 the heat pump (4) and the RC (2) can be supplied with external heat sources, the system in Figure 4 is truly stand-alone. Such an arrangement is useful to supply e.g. 1-100 or 20-1000 households with electricity at peak times, like a stand-alone electrical battery. Like the system in Figure 3, this system can be coupled to a district heating network.

Figure 5 represents embodiments described in Figures 1-4, as well as Examples 1-4,in which the single RC has been replaced by two Rankine Cycles (RCs) which are coupled in series and wherein each RC is cooled by cooling flow (5). The flow of hot storage medium (6) enters the first RC and then exits as flow hot storage medium having lower temperature (26) and thereafter enters the second RC. The temperature of the storage medium decreases and said storage medium flows (36) into the first RC where the storage medium is cooled further and then flows (16) into the combined tank (11). Although Figure 5 illustrates the use of a combined tank, also systems having separate cold and heat storage tanks (1, 3) may be used. Hence, the flow of hot storage medium (6) to the first RC is from the heat storage tank (1) and the flow of cold storage medium is from the first RC to the cold storage tank (3).

Figure 6 differs from the Figure 5 in that one cooling flow (5) is used first to cool one RC, preferably the second, where the flow is heated by ca 10 °C to 30 °C, and this flow (25) enters the remaining RC, preferably the first, in order to operate both RC at roughly the same temperature difference. The heated cooling flow (35) exist the first RC.

DETAILED DESCRIPTION

The Rankine cycle is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work. An Organic Rankine cycle (ORC) is a Rankine cycle using other working fluids than water/steam, in particular organic fluids. Moreover, in the present invention, the term "ORC" is meant as any power generation process capable of converting 50-150 °C heat streams to electricity. The applicant uses the process termed C3 as described in WO 2012/128 715 and SE 2013 / 051 059, PCT SE 1300 576-4, SE 1400 027-7 and SE 1400 160-6, and WO 2015/112 075 and PCT SE 2015/050 368, and SE 1400 514-4, and related documents in the patent families, all hereby incorporated by reference. Essentially, C3 is a particularly efficient power generation cycle operating at low pressures and capable of utilizing heat of low temperatures, e.g. 70-120 °C, for power generation. Other ORC processes may be used as well in the embodiments of the present invention.

The Rankine cycle works by pressurizing and heat water to produce steam. Electricity is produced by expanding the steam from this point with pressure at typically 100 Bar and temperature at 500 degrees centigrade down to below 100 degrees centigrade where it is condensed back to water during cooling creating a low pressure close to vacuum. The low temperature cycle named Organic Rankine Cycle, ORC, uses the same principle but, instead of water, employs a different working medium with a lower boiling point than water. Typically, this cycle uses a pressure range between 28 Bar to 7 Bar between 300-150 degrees centigrade, sometimes down to 90 degrees centigrade heat source and 100-25 degrees centigrade cold source. The Carbon carrier cycle, C3, works in a different way. Heat is used to chemically desorb CO_2 from a carrier medium or working fluid. After the CO_2 has created

electricity through expansion it is chemically absorbed into the carrier medium during cooling. The chemical absorption is very efficient at creating low pressure, and the CO_2 can be expanded to temperatures as low as -78 degrees centigrade resulting in high power output, despite of low heat source temperatures. The term C3 is thus used by applicant to also describe optimised Organic Rankine Cycles using at least one solvent or working fluid.

In addition – already referring to figure 1 - use of a heat pump (4) is an essential element of the invention, and whilst the applicant uses heat pumps according to PCT/SE2014/050991 and SE 1400 541-7, any heat pump may be used as long as it can produce heat at a temperature above 70 °C, ideally at 80-120 °C and for practical purposes up to 98 °C. A high COP (coefficient of performance) is desirable. Further, at least one tank (1) for storing a hot medium, preferably water, is required. Also, hot water has to be stored after it has passed the ORC (2), but this may be done in the same tank as colder water will collect at the bottom of the tank (1, 3). Technically, a range of tanks (underground, above ground) are common, e.g. in the district heating industry, and available with excellent thermal insulation at reasonable costs, as long as the tank is operated at atmospheric pressure, e.g. with water at below 100 °C.

The heat pump (4) is used to heat up the storage liquid (preferably water) to a temperature which is ideal for electricity generation in the ORC (2), typically at times of excess and cheap electricity. The heat source (8) for the heat pump may be waste heat generated in industry, solar or geothermal heat or other. Technically, also a gas-fired heat pump may be used. Once electricity is required (e.g. high

demand and price), the ORC (2) uses hot water flow (6) to produce electricity. The ORC (2) requires cooling through flow (5). The resulting heat, typically 35 °C water, may be used to heat agricultural areas or larger underground volumes, e.g. as heat source for heat pumps operated in winter-time.

The method according to the invention can be compared with competing technologies, such as pumped hydro storage and other techniques. It is found that all technologies have their advantages and drawbacks. The method described here is advantageous when access to heat sources is abundant, volume for heat storage is cheap and available, electricity production is intermittent, electricity demand is fluctuating. Hot water as such has a rather low energy density: the "extractable electricity content" (EEC) is calculated as product of efficiency of converting hot water into electricity, e.g. 10%, mass in kg, temperature difference in K and heat capacity of the medium used, e.g. 4.2 kJ/kg*K (water at 90 °C). A tank of 1000 m^3 "contains" ca. 4200 MJ or 1.2 MWh electricity if the water temperature is decreased in the hot section of the ORC from 90 to 80 °C (valid for any 10 °C temperature difference).

Water is a convenient and cheap medium for storing thermal energy, however, thermal energy may also be stored by or in combination with "phase change materials", commonly abbreviated as PCM's. Such PCM comprise e.g. materials which melt at a certain temperature and thereby take up large amounts of energy without immediate temperature increase. Upon cooling, the molten materials solidify and release the melting enthalpy. For the purposes of this invention, PCM comprising materials melting at e.g. 80, 85, 90 or 95 °C are used in combination with a water tank, and the heat storage capacity

of a tank containing water and PCM at the mentioned temperatures can be increased significantly. PCM's often have phase change enthalpies around 50-200 J/K*g, much higher than the heat storage capacity of pure water: 4.18 J/K*g. PCM's can be used as such, but preferably encapsulated.

PCM's are also available with melting points such as 5, 10, 15, 20 or 25 °C, or 75, 80, 85, 90 or 95 °C. These can be useful to increase the storage capacity of a water tank which shall be maintained at said temperatures. Using PCM's, it is thus realistic that a tank containing 1000 m^3 water contains e.g. ten times more cooling energy (for low temperatures) orextractable electricity (for high temperatures) than the same tank without PCM. There are various commercial suppliers of PCM's, macro- or microencapsulated PCM's or structural components.

For the purposes of this invention, PCM encapsulated in polyolefin such as polypropylene, e.g. in the shapes of tubes, rods or mats is a useful embodiment. In one embodiment, ice or snow is used as natural PCM to provide cooling capacity.

Provided the heat pump operates with a COP of 5, i.e. for 1 kWh electrical input 5 kWh heat is generated, then the combination of ORC, heat pump and storage works with a cycle efficiency of 50%, not considering potential use of the warm cooling water exiting the ORC. In many cases, a higher COP can be expected such that cycle efficiencies >50% are possible. Comparing with alternative ways of "storing electricity", the method according to the invention is economically attractive due to low investment and operational costs.

Potential heat sources for the heat pump are solar, geothermal, industrial or other (waste) heat, or flows in a district heating network, in the latter case both the incoming high temperature flow or the colder return flow. For the operation of a CHP plant (combined heat and power), it may be advantageous to reduce the temperature of the return flow as this represents further cooling, increasing the efficiency of power generation at the CHP plant.

Fig. 1 shows a flow diagram. Preferred temperature ranges are 95-85 °C → 80-65 °C for flow (6), and the reverse for flow (7). The cooling flow (5) is typically 5-20 °C → 20-40 °C.

Fig. 2 shows an embodiment using only one tank. Hot water accumulates at the top of the tank. A floating separating layer may be used to avoid mixing of hot and colder water.

The method described is useful for temporary storage of energy which can be converted to electricity upon demand. The method may be used at large scale, e.g. with water tanks exceeding 100 000 m^3, or it may be used at small scale, e.g. using tanks of 1000 m^3.

At small scale, a 1000 m^3 tank may supply a few detached houses with peak electricity, and the heat pump may be supplied or supplemented with district heating heat or solar heat. Further, the ORC generates an effluent for cooling, typically at 30-40 °C if cooling is provided at e.g. 20 °C. The warm effluent may be stored in the tank and may constitute the heat source for the heat pump which lifts hot water to 80-98 °C. This has the advantage that no cooling tower for the ORC is needed, and that cooling at even lower temperatures than 20 °C can be provided (by extracting more heat from said flow). Figure 3 shows the intended arrangement.

At large scale, the heat effluent from a paper or steel or aluminium factory may be used to upgrade water from 50-75 °C to high temperatures (including low or high pressure water steam), and electricity generation may be operated at peak demand times in proximity to said factories.

The operational times of heat pump and ORC may differ. As an example, the ORC may be designed to generate electricity at e.g. 20% of the time (at peak demand times), and the heat pump may operate the reminder of the time. Therefore, the respective sizes of the heat pump and ORC are chosen accordingly.

In one embodiment, excess steam or excess heat from heat sources such as district heating networks or industrial plants is used to heat up the hot water storage, as hot liquid water is cheaper to store than steam.

In one embodiment, the method is used for quickly, i.e. on the scale of less than one minute, regulating power demand in the grid. For this, the heat exchanger of the ORC is preferably kept at operational temperature, e.g. 70-100 °C, by circulating some hot water through said heat exchanger, and by idling the ORC. This allows a very fast start-up of the ORC and full and phase- and frequency-matched power supply at within less than one minute.

EXAMPLES

Example 1

The system illustrated in Figure 1 may also be used to describe the embodiments of Example 1.

The heat pump (4) heats up the flow of cold medium (7) exiting from the cold storage tank (3) and the resulting flow of hot medium (17) exits the heat pump (4) and enters the heat storage tank (1). The temperature of the cold medium in the cold storage tank (3) is 80-65 °C while the temperature of the hot medium in the heat storage tank (1) is 85-98 °C.

The heat pump (4) may utilize a heat source (8) such as geothermal heat, solar heat, industrial heat, waste heat, district heating network, heat from combustion engines or other devices generating heat including fuel cells and chemical processes.

The energy stored as heat in the heat storage tank (1) is converted into electricity when the flow of hot medium (6) exiting the hot storage tank (1) flows through the RC (2). The resulting flow of cold medium (16) flows to the cold storage tank (3). The RC (2) is cooled by a flow of cooling flow (5) which has a temperature of 5-20 °C, however, when said flow exits the RC the temperature of the heated cooling medium (15) is 20-40 °C.

The above described process is repeated until the circulation of the medium is stopped in the system. Hence, electricity is being produced when the medium is circulated in the system, while energy is stored as heat in the heat storage tank (1) when the circulation of the medium is paused.

In various embodiments of Example 1, the medium which is circulated in the system may comprise thermal oils, phase change materials and/or water, or alternatively, the medium may comprise combinations of phase change materials with thermal oils or water.

In alternative embodiments of Example 1, at least two RCs can be coupled in series and each RC is cooled by cooling flow (5). In further embodiments comprising at least two RCs, one cooling flow is used first to cool one RC, preferably the second RC operating at a lower temperature than the first RC, where the flow is heated by ca 10 °C to 30 °C, and this flow enters the remaining RC, preferably the first, in order to operate both RC at roughly the same temperature difference.

The RC in Example 1 may be an organic Rankine Cycle.

Example 2

The system illustrated in Figure 2 may also be used to describe the embodiments of Example 2.

The embodiments of Example 2 differ from the embodiments of Example 1 in that the heat storage tank (1) and the cold storage tank (3) of the system described in Example 1 have been exchanged with a single tank (11), i.e. a combined tank, in which the hot storage medium accumulates at the top while the cold storage medium accumulates at the bottom due to the differences in densities. Hence, the temperature of the medium at the top of the tank is 85-98 °C while the temperature of the medium at the bottom of the tank is 80-65 °C. The combined

tank (11) may be a stratified tank which optionally may have a floating separating layer (9).

Consequently, in the embodiments of Example 2, the heat pump (4) heats up the flow of cold medium (7) exiting from the combined storage tank (11) and the resulting flow of hot medium (17) exits the heat pump (4) and enters the combined storage tank (11). Subsequently, the flow of hot medium (6) exits the combined storage tank (11) and flows through the RC. The resulting flow of cold medium (16) which exits from the RC flows to the combined storage tank (11). The medium which is circulated in the system may be thermal oils, phase change materials and water, or alternatively, the medium may comprise combinations of phase change materials with thermal oils or water.

The heat source of the heat pump (4) is the same as in Example 1 and the cooling of the RC (2) is carried out by the cooling flow (5).

In an alternative embodiments of Example 2, at least two RCs can be coupled in series and each RC is cooled by cooling flow (5). This arrangement of RCs and cooling flow is illustrated in Figure 5. In further embodiments comprising at least two RCs, one cooling flow (5) is used first to cool one RC, preferably the second RC operating at a lower temperature than the first RC, where the flow is heated by ca 10 °C to 30 °C, and this flow (25) enters the remaining RC, preferably the first, in order to operate both RC at roughly the same temperature difference. This arrangement of RCs and cooling flow are illustrated in Figure 6.

The RC in Example 2 may be an organic Rankine Cycle.

Example 3

The system illustrated in Figure 3 may also be used to describe the embodiments of Example 3.

The embodiments of Example 3 are specific embodiments of Example 2 in which the cooling flow (5) is derived from a second tank (10). The second tank (10) has the functional features of (i) storing cooling medium which is to be used as the cooling flow (5) for cooling the RC, and (ii) storing the heated cooling medium exiting as flow (15) from the RC.

Consequently, in the embodiments of Example 3, the flow of cooling medium (5) exits the second tank (10) and then flows through the RC (2). The flow of heated cooling medium (15) subsequently flows out from the RC (2) and is collected in the second tank (10). The cooling flow (5) has a temperature of 5-20 °C, and when the medium exits the RC the temperature of the heated cooling medium flow (15) temperature is 20-40 °C.

The process in Example 3 has the advantage that no cooling tower for the RC is necessary, and that cooling at even lower temperatures than 20 °C can be provided by extracting more heat from the cooling flow (5) entering the RC (2).

The medium which is circulated between the RC (2) and the second tank (10) may comprise thermal oils, phase change materials and/or water, or alternatively, the medium may comprise combinations of phase change materials with thermal oils or water. Moreover, the cooling medium (5, 15) flowing to and from the RC may be circulated in a closed loop in order to save medium.

In an alternative embodiments of Example 3, at least two RCs can be coupled in series and each RC is cooled by cooling flow (5). This arrangement of RCs and cooling flow is illustrated in Figure 5. In further embodiments comprising at least two RCs, one cooling flow is used first to cool one RC, preferably the second RC operating at a lower temperature than the first RC, where the flow is heated by ca 10 °C to 30 °C, and this flow enters the remaining RC, preferably the first, in order to operate both RC at roughly the same temperature difference. This arrangement of RCs and cooling flow are illustrated in Figure 6.

The RC in Example 3 may be an organic Rankine Cycle.

Example 4

The system illustrated in Figure 4 may also be used to describe the embodiments of Example 4.

The embodiments of Example 4 are specific embodiments of Example 3 in which the flow of the heated cooling medium (15) of temperature 20-40 °C exiting from the RC (2), i.e. the heated effluent, constitutes a heat source (8) for the heat pump (4) for lifting the temperature of the flow of cold medium (7) flowing through the heat pump (4) to 80-98 °C, or more preferably for lifting the temperature to 85-98 °C. The flow of heated cooling medium (18) which is cooled down to 5-20 °C by the operation of the heat pump (4) returns to the second tank (10) and may thereafter be used for cooling the RC.

The process in Example 4 has the advantage that no cooling tower for the RC is necessary, and that cooling at even lower temperatures than 20 °C can be provided by extracting more heat from the cooling flow (5) and/or heat pump (4).

The medium (5,15) which is circulated between the second tank (10) and the heat pump (4) may be thermal oils, phase change materials and water, or alternatively, the medium may comprise combinations of phase change materials with thermal oils or water. Moreover, the medium (5, 15) may be circulated in a closed loop in order to save medium.

In an alternative embodiments of Example 4, at least two RCs can be coupled in series and each RC is cooled by cooling flow (5). This arrangement of RCs and cooling flow is illustrated in Figure 5. In further embodiments comprising at least two RCs, one cooling flow is used first to cool one RC, preferably the second RC operating at a lower temperature than the first RC, where the flow is heated by ca 10 °C to 30 °C, and this flow enters the remaining RC, preferably the first, in order to operate both RC at roughly the same temperature difference. This arrangement of RCs and cooling flow are illustrated in Figure 6.

The RC in Example 4 may be an organic Rankine Cycle.

Example 5

In the present invention, energy is stored and converted using relatively small temperature differences in the hot and cold storages. This technical effect appears to be coupled to technically feasible heat transfer rates. The following results are obtained as function of hot/cold storage medium (before/after entering RC):

Table 1: RC performance as function of hot storage medium flow at set temperature 98 °C.

Hot and cold storage medium flow l/s	Storage medium - Temp in °C	Storage medium - Temp out °C	Electric Effect kW	Cooling flow Temp in °C	Cooling flow Temp out °C
10	98	74	78	20	41
15	98	80	80	20	36
20	98	83	120	20	33
30	98	87	145	20	30
40	98	89	160	20	28

As illustrated in Table 1, if the flow of hot storage medium is increased, power production increases, and the temperature difference before/after entry into the RC is decreasing. The table shows that there is an optimum flow in this preferred RC of about 15-35 liter/second (l/s) giving a temperature reduction of 5-20 °C.

Table 2 shows the same trends as Table 1, including decreasing temperature difference in the hot storage medium flow with increasing flow (in l/s), increasing electrical effect with increasing hot medium flow. In these experimental data, a 9.8% electrical efficiency was achieved with a turbine of a high efficiency (about 85%) for an 85 °C heat source and a 20 °C cooling source. For higher temperature differences, the electrical or Carnot efficiency increases.

Table 2: RC performance as function of hot storage medium flow at set temperature 85 °C.

Hot and cold storage medium flow l/s	Storage medium - Temp in °C	Storage medium - Temp out °C	Electric effect kW	Cooling Flow temp in °C	Cooling temp out °C
10	85	67	56	20	37
15	85	71	71	20	33
20	85	74	83	20	30
30	85	77	98	20	27
40	85	78	107	20	26

Tables 1 and 2 illustrate that two RCs can be coupled in series. As an example, a hot storage medium flow of about 25 l/s can enter a first RC at 98 °C and leave this first RC at about 85 °C, producing about 130 kW, and the flow can then enter a second RC at 85 °C and leave this second RC at 75 °C, producing about 90 kW, provided both RC's are cooled by about two times 25 l/s of 20 °C (see Figure 5).

In a variation of this embodiment, one cooling flow of 25 l/s is used first to cool one RC, preferably the second, where the flow is heated by ca 10 °C to 30 °C, and this flows enters the remaining RC, preferably the first, in order to operate both RC at roughly the same temperature difference (see Figure 6).

The advantage of the arrangement with serially or sequentially coupled RC's is that more energy is extracted from the hot storage medium flow.

Tables 1 and 2 show further that the electricity production can be adapted easily to market needs by adjusting primarily the flow of hot and cold storage media in a wide range.

It should be understood that above embodiments described in the present invention are merely examples of useful sequences to achieve the objective of the invention, namely to generate and store heat for electricity generation, in combination with a heat pump and an RC.

Similar arrangements should be seen as falling under the spirit of this invention.

In summary, a simple solution is disclosed for storing electricity in the form of hot medium. The solution is cheap in construction and operation.

CLAIMS

1. A method for storing energy and producing electricity using heat, comprising the steps of:

a) At least one Rankine cycle (RC) or Organic Rankine Cycle (ORC), in the following both denoted RC, being used as a power generation device, wherein the RC is cooled by a cooling flow (5), and wherein said RC preferably comprises a hot heat exchanger or evaporating section for a working fluid, cold heat exchanger for condensing said working fluid, turbine or expansion device, and at least one pump for transporting the working fluid to the high pressure section,

b) a cold storage receiving cold storage medium (16) exiting from the RC (2),

c) a heat pump (4) heating up the flow of cold storage medium (7) exiting from the cold storage and thereby generating flow of hot storage medium (17) which is received by heat storage,
wherein the heat pump (4) utilizes a heat source (8) selected from the group geothermal heat, solar heat, industrial heat, waste heat, district heating network, heat from combustion engines or other devices generating heat including fuel cells and chemical processes, and wherein the heat pump is capable of providing heat at a temperature of at least 70 °C,

d) the heat storage supplying flow of hot storage medium (6) to the RC when electricity production is required, wherein the flow of the hot storage medium (6) through the RC (2) generates electricity,

characterized in that heat is stored in the heat storage as hot storage medium having a temperature of 85-98 °C, wherein the flow of cold storage medium (16) exiting the RC is 5-20 °C

lower in temperature than the temperature of the flow of hot storage medium (6) at 85-98 °C entering the RC, wherein the hot storage medium and the cold storage medium comprise thermal oils, phase change materials (PCM) and/or water, or alternatively, the hot storage medium and the cold storage medium comprise combinations of phase change materials with thermal oils or water.

2. Method according to claim 1, wherein the hot and cold storage media comprise a phase change material for increased heat storage capacity at given volume.

3. Method according to claim 1 or 2, wherein the flow of hot storage medium (6) exits the heat storage at a temperature level of 85-98 °C, and wherein the flow of cold storage medium (16) exits the RC (2) at a temperature level of 89-65 °C, preferably the flow of cold storage medium (16) exits the RC (2) at a temperature level of 80-65 °C.

4. Method according to any one of the previous claims, wherein the flow of storage medium (6, 16, 7, 17) is 10-40 l/s, preferably 15-35 l/s.

5. Method according to any one of the previous claims, wherein at least one storage tank, above ground or at least partly underground, of a volume of at least 10 m^3, is used as heat storage and cold storage, and wherein the heat storage tank and cold storage tank are either separate storage tanks (1, 3) or a combined storage tank (11).

6. Method according to any one of the previous claims, wherein the heat storage and the cold storage are part of a combined

storage (11) comprising said heat storage and said cold storage.

7. Method according to the previous claim 5 or 6, wherein the combined storage (11) is a stratified tank, preferably the colder storage medium is collected at the bottom of the combined storage and the hot storage medium is collected at the top of the combined storage.

8. Method according to any one of the previous claims 5-7, wherein the combined storage (11) is a stratified tank, optionally comprising a separating layer (9).

9. Method according to any one of the previous claim, wherein the RC is cooled by the cooling flow of the cooling medium (5) entering the RC from a second tank (10), and wherein the resulting flow of heated cooling medium exiting (15) the RC is collected in the second tank (10), wherein the second tank (10) is preferably a combined tank comprising both cooling medium and heated cooling medium.

10. Method according to the previous claim, wherein the second tank (10) is a stratified tank and wherein the flow of heated cooling medium exiting (15) the RC is collected in said second tank (10), and wherein said second tank (10) optionally comprises a separating layer.

11. Method according to any one of the previous claims, wherein the temperature of the cooling flow of the cooling medium (5) entering the RC is 5-20 °C.

12. Method according to any one of the previous claims, wherein the temperature of the flow of heated cooling medium (15) exiting the RC is 20-40 °C.

13. Method according to any one of the previous claims, wherein the RC is cooled by the cooling flow of the cooling medium (5) having a temperature of 5-20 °C entering from a second tank (10), and wherein the resulting flow of heated cooling medium (15) having a temperature of 20-40 °C and exiting the RC is collected in the second tank (10).

14. Method according to the previous claim, wherein the flow of heated cooling medium (15) exiting the RC serves as heat source (8) for the heat pump (4).

15. Method according to the previous claim, wherein the flow of heated cooling medium (15) exits the RC and serves as heat source (8) for the heat pump (4) and thereafter exits the heat pump as lower temperature medium (18) and returns to the second tank (10).

16. Method according to the previous claim, wherein the flow of heated cooling medium (15) exits the RC with a temperature of 20-40 °C and serves as heat source (8) for the heat pump (4) and thereafter exits the heat pump (4) as lower temperature medium (18) with a temperature of 5-20 °C and returns to the second tank (10).

17. Method according to any one of claims 9-16, wherein the flow of cooling medium (5, 15) to and from the RC circulates in a closed loop.

18. Method according to any one of the preceding claims characterized in that the heat exchanger of the RC is kept at an operational temperature by circulating hot water through said heat exchanger and by idling the RC, and where after the RC may be started up within less than one minute to provide full and phase- and frequency-matched power supply.

19. Method according to any one of the previous claims, wherein the cycle turnaround efficiency, i.e. electrical energy produced by the RC divided by the electrical energy consumed by the heat pump, is at least 50%.

20. Method according to any one of the previous claims, wherein the heat storage and/or cold storage is at least 1000 m^3, more preferably the storage tank is at least 10 000 m^3, and wherein the storage tank of at least 10 000 m^3 is preferably a heat storage tank of a district heating industry.

21 The method according to one of the preceding claims, where the combination of RC, heat pump, heat storage and cooling storage comprises a closed loop which either operates in heat generation mode, i.e. where the heat pump is operational, or in electricity generation mode, i.e. where the RC is operational.

22. The method according to one of the preceding claims, where the heat pump and the RC share components such as heat exchangers, pumps, or where the heat pump can be operated as RC, using the same working medium.

23. The method according to one of the preceding claims, wherein the heat exchanger of the RC is kept at an operational temperature by circulating hot water through said heat

exchanger and by idling the RC, and thereby the RC may be started up within less than one minute to provide full and phase- and frequency-matched power supply within less than one minute.

24. Method according to any one of the previous claims, wherein two Rankine Cycles (RCs) are coupled in series, and wherein each RC is either cooled by a cooling flow (5) or wherein the RCs are cooled by a cooling flow (5) which is used first to cool one RC, preferably the second RC operating at a lower temperature than the first RC, where the flow is heated by ca 10 °C to 30 °C, and this flow (25) enters the remaining RC, preferably the first.

25. Method according to any one of the previous claims, wherein the RC is an ORC.

26. A system for storing energy and producing electricity using heat, comprising:

a) at least one RC (2) or Organic Rankine Cycle (ORC), in the following both denoted RC, used as a power generation device, wherein the RC is cooled by a cooling flow (5), and wherein said RC preferably comprises a hot heat exchanger or evaporating section for a working fluid, cold heat exchanger for condensing said working fluid, turbine or expansion device, and at least one pump for transporting the working fluid to the high pressure section,

b) a cold storage for receiving flow of cold storage medium (16) exiting from the RC (2), and wherein said RC preferably comprises a hot heat exchanger or evaporating section for a working fluid, cold heat exchanger for condensing said working fluid, turbine or expansion

device, and at least one pump for transporting the working fluid to the high pressure section,

c) a heat pump (4) for heating up the flow of cold storage medium (7) exiting from the cold storage, wherein the generated flow of hot storage medium (17) is received by a heat storage, and

wherein the heat pump (4) utilizes a heat source (8) selected from the group geothermal heat, solar heat, industrial heat, waste heat, district heating network, heat from combustion engines or other devices generating heat including fuel cells and chemical processes, and

wherein the heat pump is capable of providing heat at a temperature of at least 70 °C,

wherein the heat storage supplies flow of hot storage medium (6) to the RC when electricity production is required, and

wherein the flow of the hot storage medium (6) through the RC generates electricity,

characterized in that heat is stored in the heat storage as hot storage medium having a temperature at 85-98 °C, wherein the flow of cold storage medium (16) exiting the RC is 5-20 °C lower in temperature than the temperature of the flow of hot storage medium (6) at 85-98 °C entering the RC,

wherein the hot storage medium and the cold storage medium comprise thermal oils, phase change materials and/or water, or alternatively, the hot storage medium and the cold storage medium comprise combinations of phase change materials with thermal oils or water.

27. System according to claim 26, wherein the hot and cold storage media comprise a phase change material for increased heat storage capacity at given volume.

28. System according to claim 26 or 27, wherein the flow of hot storage medium (6) exits the heat storage at a temperature level of 85-98 °C, and wherein the flow of cold storage medium (16) exits the RC (2) at a temperature level of 89-65 °C, preferably the flow of cold storage medium (16) exits the RC (2) at a temperature level of 80-65 °C.

29. System according to any one of the previous claims 26-28, wherein the flow of storage medium (6, 16, 7, 17) is 10-40 l/s, preferably 15-35 l/s.

30. System according to any one of previous claims 26-29, wherein at least one storage tank, above ground or at least partly underground, of a volume of at least 10 m^3 is used as heat storage and cold storage, and wherein the heat storage tank and cold storage tank are either separate storage tanks (1, 3) or a combined storage tank (11).

31. System according to any one of previous claims 26-30, wherein the heat storage and the cold storage are part of a combined storage (11) comprising said heat storage and said cold storage.

32. System according to the previous claims 30 or 31, wherein the combined storage (11) is a stratified tank, preferably the colder storage medium is collected at the bottom of the combined storage and the hot storage medium is collected at the top of the combined storage.

33. System according to any one of the previous claims 30-32, wherein the combined storage (11) is a stratified tank, optionally comprising a separating layer (9).

34. System according to any one of the previous claims 26-33, wherein the RC is cooled by the cooling flow of the cooling medium (5) entering the RC from a second tank (10), and wherein the resulting flow of heated cooling medium exiting (15) the RC is collected in the second tank (10), wherein the second tank (10) is preferably a combined tank comprising both cooling medium and heated cooling medium.

35. System according to the previous claim 26-34, wherein the second tank (10) is a stratified tank and wherein the flow of heated cooling medium (15) exiting the RC is collected in said second tank (10), and wherein said second tank (10) optionally comprises a separating layer.

36. System according to claim 34 or 35, wherein the temperature of the flow of the cooling medium (5) entering the RC is 5-20 °C.

37. System according to any one of the previous claims 34-36, wherein the temperature of the flow of heated cooling medium (15) exiting the RC is 20-40 °C.

38. System according to any one of the previous claims 34-37, wherein the RC (2) is cooled by the cooling flow of the cooling medium (5) having a temperature of 5-20 °C entering from a second tank (10), and wherein the resulting flow of heated cooling medium (15) having a temperature of 20-40 °C exiting the RC is collected in the second tank (10).

39. System according to any one of the previous claims 34-38, wherein the flow of heated cooling medium (15) exiting the RC (2) serves as heat source (8) for the heat pump (4).

40. System according to any one of the previous claim 34-39, wherein the flow of heated cooling medium (15) exits the RC (2) and serves as heat source (8) for the heat pump (4) and thereafter exits the heat pump as flow of lower temperature medium (18) and returns to the second tank (10).

41. System according to any one of the previous claim 34-40, wherein the heated cooling medium (15) exits the RC with a temperature of 20-40 °C and serves as heat source (8) for the heat pump (4) and thereafter exits the heat pump as lower temperature medium with a temperature of 5-20 °C and returns to the second tank (10).

42. System according to any one of claims 34-41, wherein the flow of cooling medium (5, 15) to and from the RC circulates in a closed loop.

43. System according to one of the preceding claims 26-42, characterized in that the heat exchanger of the RC is kept at an operational temperature by circulating hot water through said heat exchanger and by idling the RC, and where after the RC may be started up within less than one minute to provide full and phase- and frequency-matched power supply.

44. System according to any one of the previous claims 26-43, wherein the cycle turnaround efficiency, i.e. electrical energy produced by the RC divided by the electrical energy consumed by the heat pump, is at least 50%.

45. System according to any one of the previous claims 26-44, wherein the heat storage and/or cold storage is at least 1000 m^3 or at least 10 000 m^3, and wherein the storage tank of at

least 10 000 m^3 is preferably a heat storage tank of a district heating industry.

46. System according to one of the preceding claims 26-45, wherein the combination of RC, heat pump, heat storage and cooling storage comprises a closed loop which either operates in heat generation mode, i.e. where the heat pump is operational, or in electricity generation mode, i.e. where the RC is operational.

47. System according to any one of the preceding claims 26-46, where the heat pump and the RC share components such as heat exchangers, pumps, or where the heat pump can be operated as RC, using the same working medium.

48. System according to one of the preceding claims 26-47, wherein the heat exchanger of the RC is kept at an operational temperature by circulating hot water through said heat exchanger and by idling the RC, and thereby the RC may be started up within less than on minute to provide full and phase- and frequency-matched power supply within less than one minute.

49. System according to any one of the previous claims 26-48, wherein two Rankine Cycles (RCs) are coupled in series, and wherein each RC is either cooled by a cooling flow (5) or wherein the RCs are cooled by a cooling flow which is used first to cool one RC, preferably the second RC operating at a lower temperature than the first RC, where the flow is heated by ca 10 °C to 30 °C, and this flow (25) enters the remaining RC, preferably the first.

50. System according to any one of the previous claims 26-49, wherein the RC is an ORC.

51. System for storing energy and producing electricity using heat, wherein said system is obtained by the methods according to claims 1-25.

52. The use of the method or system according to one of the preceding claims for generation of electricity when electricity demand and prices are high, and for generation and storage of heat when electricity demand and prices are low.

53. The use of the method or system according to one of the preceding claims for quickly, i.e. on a time scale of less than one minute, regulating power demand of the grid.

54. The use of the method or system according to one of the preceding for regulating power demand of the grid on a time scale of less than one minute characterized in that the heat exchanger of the RC is kept at an operational temperature by circulating hot water through said heat exchanger and by idling the RC, and thereby the RC may be started up within less than on minute to provide full and phase- and frequency-matched power supply within less than on minute, and wherein said RC is preferably an ORC.

55. The use of the method or system according to one of the preceding claims in combination with the C3 thermodynamic cycle.

56. The use of the method or system according to one of the preceding claims as a rechargeable electrical battery, i.e. as

a system in which electrical energy can be stored temporarily until such time when electrical power is required.

Figure 1

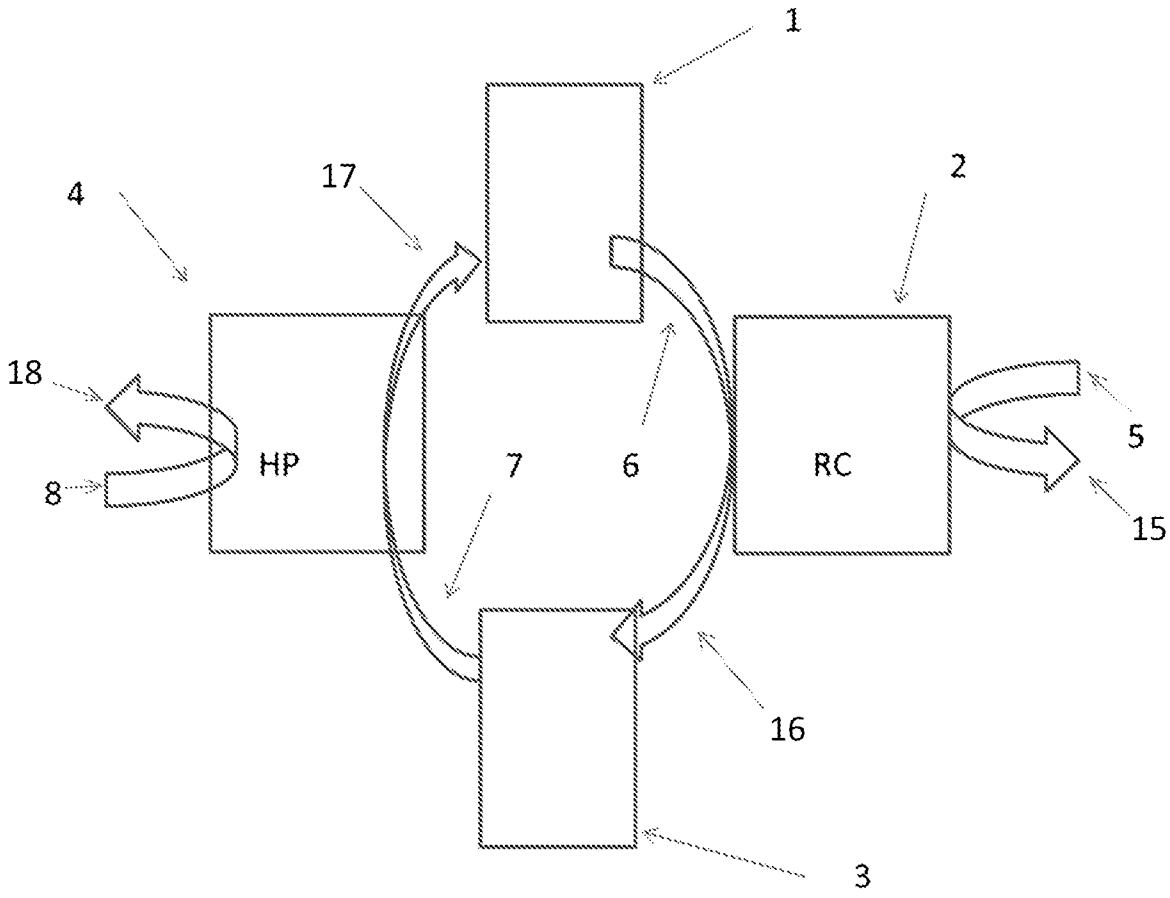


Figure 2

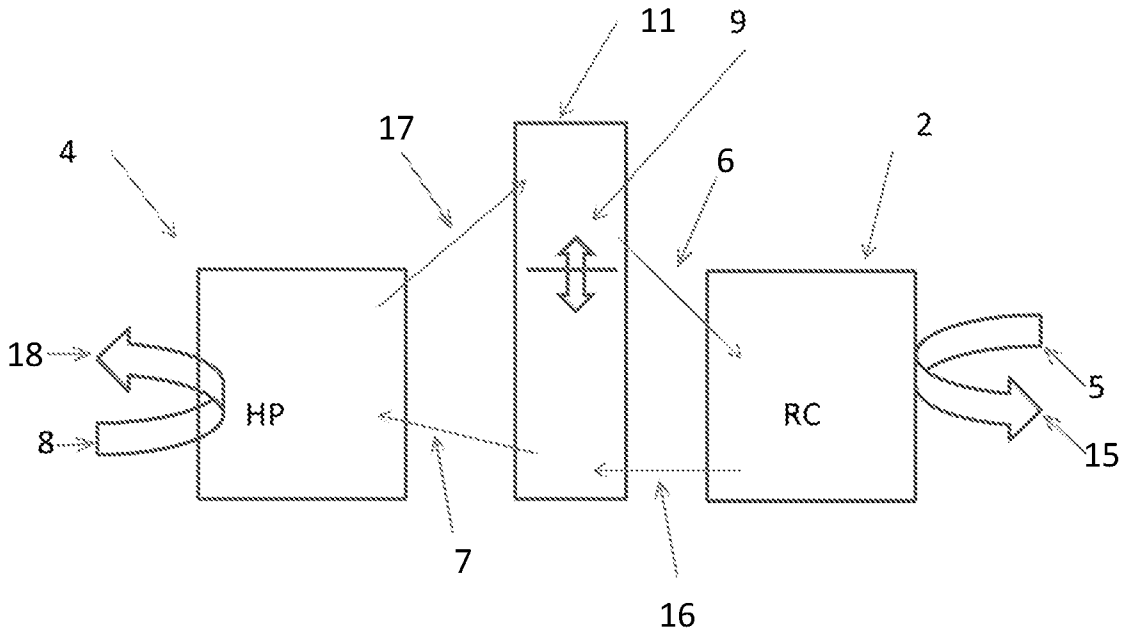


Figure 3

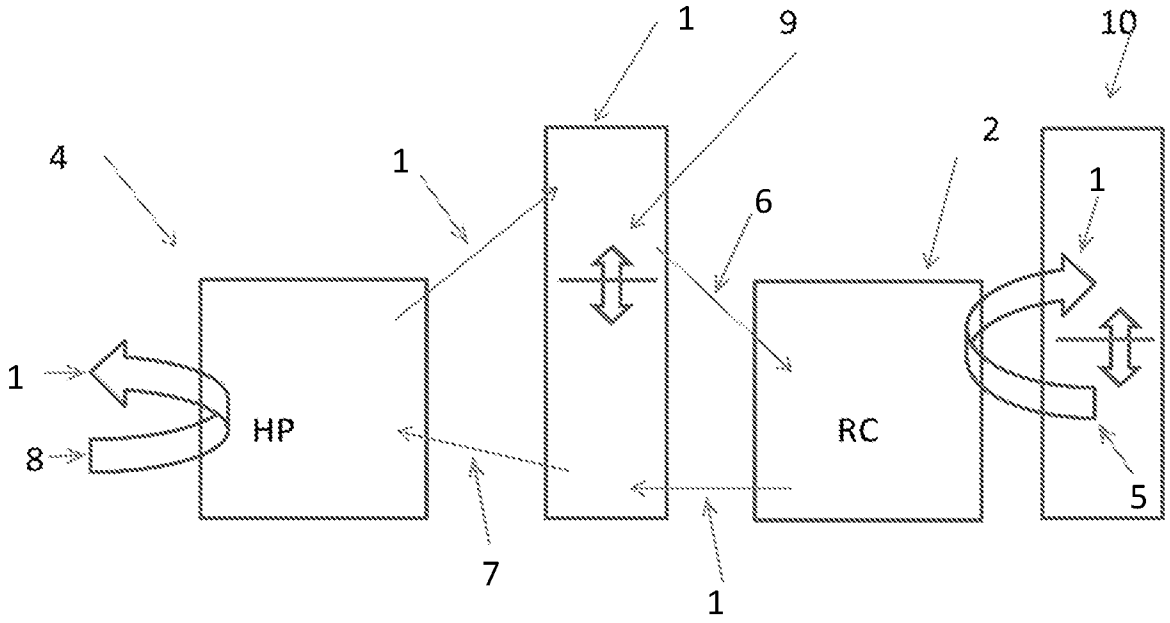


Figure 4

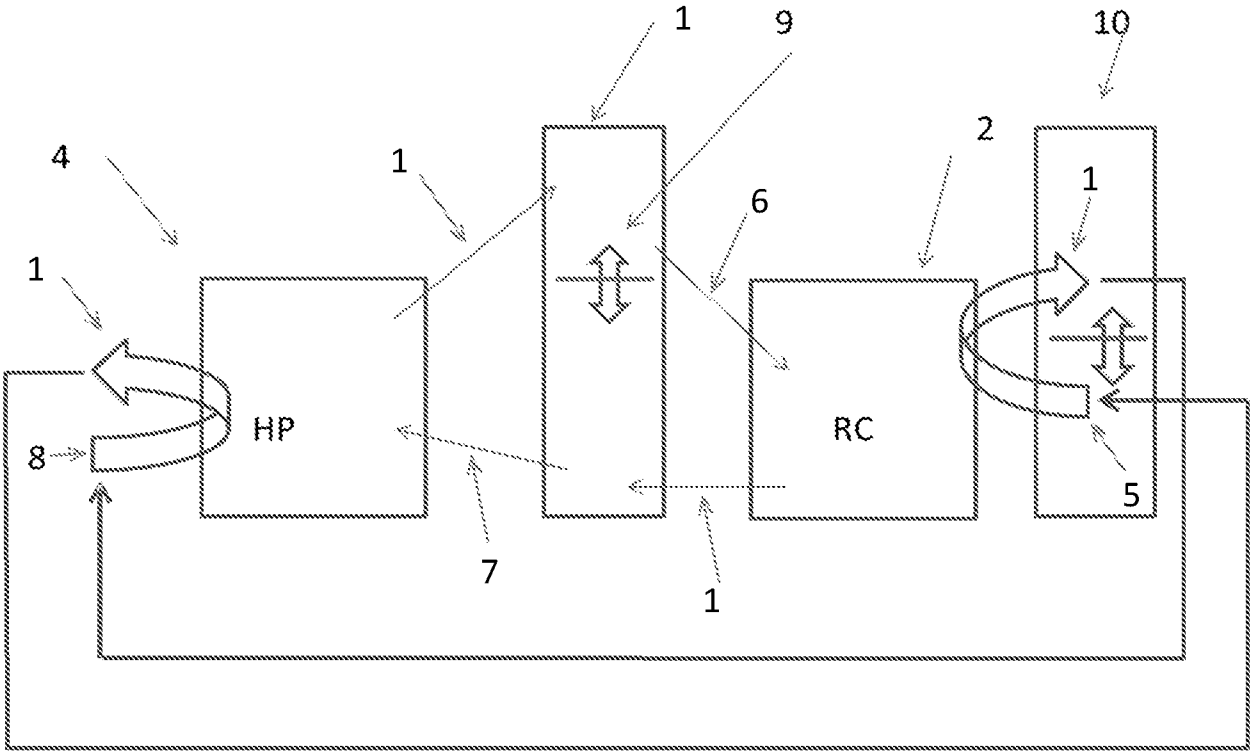


Figure 5

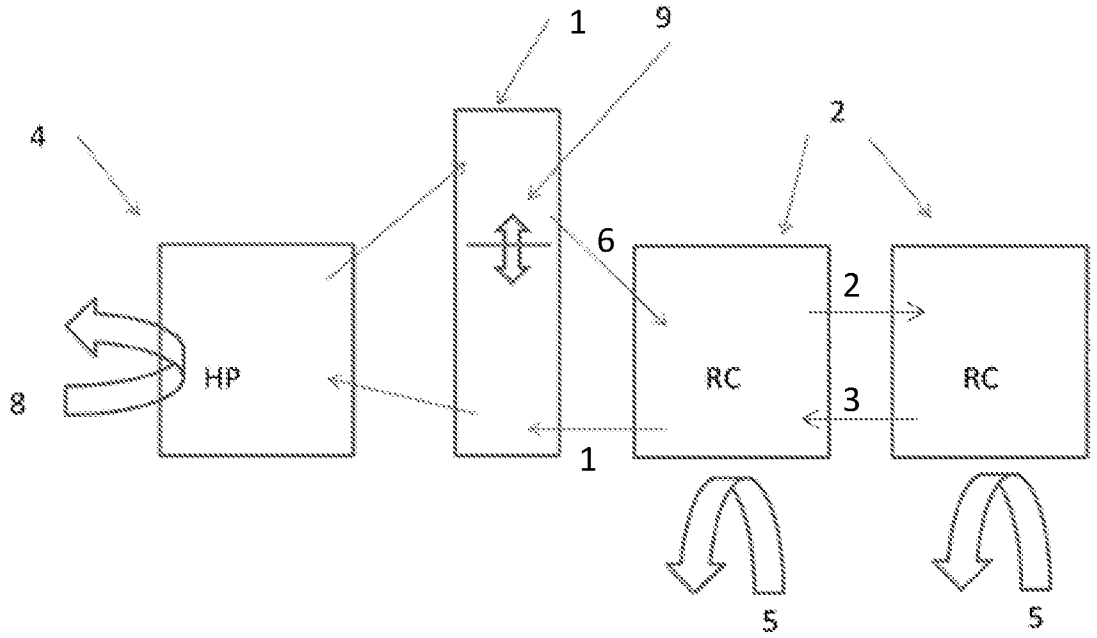
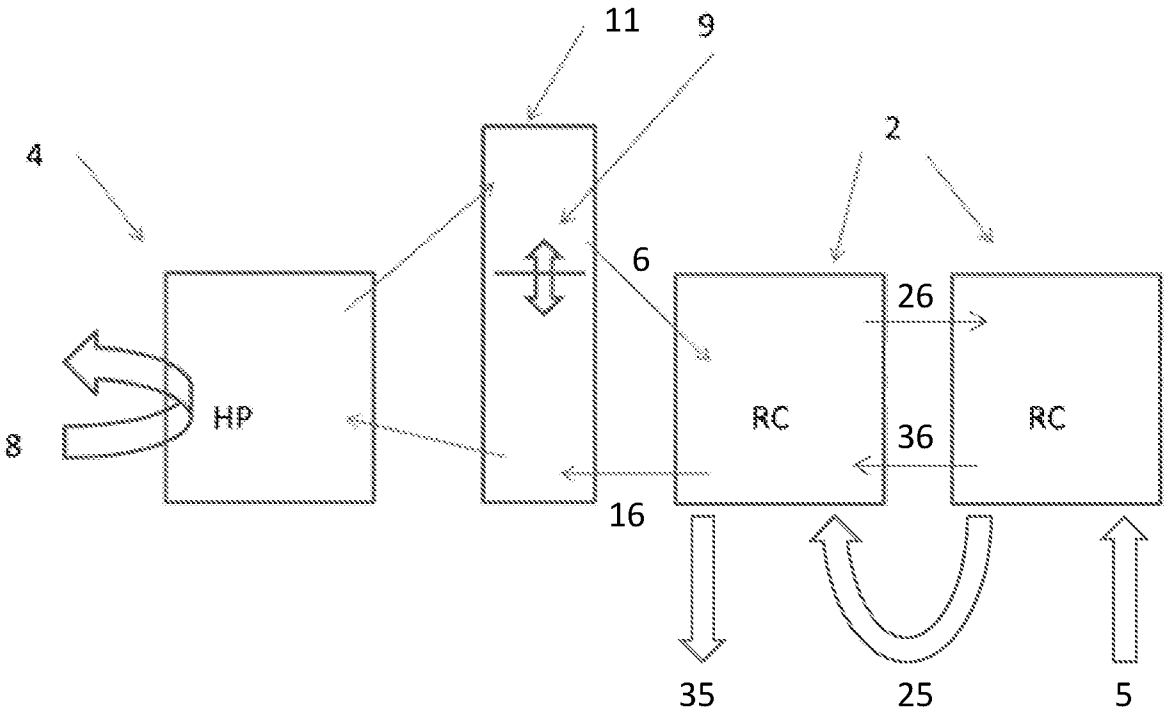


Figure 6



INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2016/050996

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01K17/00 F01K3/12
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01K

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/179429 A1 (ELLIS ERIK [US] ET AL) 16 July 2009 (2009-07-16) cited in the application abstract; figures 1, 2 paragraphs [0008], [0016], [0017] - [0019], [0034] - [0082] -----	1-56
A	EP 2 157 317 A2 (ABB RESEARCH LTD [CH]) 24 February 2010 (2010-02-24) abstract; figures 2, 3 paragraphs [0008] - [0040] -----	1-56

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 February 2017	01/03/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Varelas, Dimitrios

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/SE2016/050996

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009179429 A1	16-07-2009	US 2009179429 A1	16-07-2009
		WO 2009064378 A2	22-05-2009
EP 2157317 A2	24-02-2010	CN 102132012 A	20-07-2011
		CN 104612765 A	13-05-2015
		EP 2157317 A2	24-02-2010
		ES 2424137 T3	27-09-2013
		RU 2011110424 A	27-09-2012
		US 2011139407 A1	16-06-2011
		WO 2010020480 A2	25-02-2010