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Наш знак:	СПИС-682	06.07.2022
Ваш знак:		ден месец година

Искане за проучване за
Новост на

**„Реверсивна енергоакумулационна система с обратими
пневматични и електрически силови машини с активно
термоелектрическо охлаждане“**

Патентното ведомство Ви уведомява, че във връзка с Ваше искане
СПИС-682 от 13.06.2022 г. е извършено проучване въз основа на:

- ☒ описанието, претенциите
- ☒ приложената фигура

Класове по МПК: H01L31/04; H01S10/00; H02J7/35; H02J3/38;
F24S20/20; F02C1/05; H01M10/46

Бази-данни: IPAS; Espacenet; Epoquenet; Internet

Приложения: становище; доклад от проучване и цитираните в него
документи.

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СТ А Н О В И Щ Е

ОТНОСНО: проучване за новост на

**“Реверсивна енергоакумулационна система с обратими
пневматични и електрически силови машини с активно
термоелектрическо охлаждане” с вх. № СпИС-682/13.06.2022**

Проучването е направено въз основа на представените патентни претенции 1 - 10, представеното описание и приложената към него фигура.

Съгласно патентна претенция 1, реверсивната енергоакумулационна система с обратими пневматични и електрически силови машини с активно термоелектрическо охлаждане съдържа въздушен компресор, резервоар за сгъстен въздух и електрически генератор, като компресорът е обратима пневматична силова машина мотор-компресор, а генераторът е обратима електрическа силова машина мотор-генератор, чийто захранващ вход е свързан през оптимизиращ енергопреобразователен интегратор и първи извод на електроразпределител с общ електрически извод от наклонени фотоволтаични панели, към чиито долни ръбове шарнирно са монтирани плоски отражатели. Втори извод на електроразпределителя е свързан със захранващ вход на група електрохимични акумулатори, чийто извод присъединен посредством кабел към вход на оптимизиращия енергопреобразователен интегратор. Обратимата пневматична машина мотор – компресор е механично свързана през регулируема трансмисия с обратимата електрическа силова машина мотор – генератор и е тръбно свързана през електрически регулируем двупосочен клапан с резервоара за сгъстен въздух. Първи изпълнителен извод от оптимизиращия интегратор през първи изпълнителен механизъм е свързан с регулиращ вход на регулируемата трансмисия, а втори изпълнителен извод от оптимизиращия интегратор през втори изпълнителен механизъм е свързан с регулиращ вход на електрически регулируем двупосочен клапан. От външните страни на корпусите на обратимата пневматична силова машина мотор – компресор, на регулируемата трансмисия и на обратимата електрическа силова машина мотор – генератор са монтирани активни термоелектрически генератори, чиито електрически изводи са съединени със съответните електрически входове на оптимизиращия интегратор.

Съгласно патентна претенция 2, плоските отражатели са от рециклируеми материали.

Съгласно зависима претенция 3, обратимата електрическа силова машина мотор – генератор е безчеткова машина с ротор от постоянни магнити.

Съгласно зависима претенция 4, електроразпределителят, електрически регулируемият двупосочен клапан и регулируемата трансмисия са програмируеми.

Съгласно зависима претенция 5, оптимизиращият енергопреобразователен интегратор е програмируем и дистанционно управляем.

Съгласно зависима претенция 6, обратимата силова машина мотор – компресор е многостепенна.

Съгласно зависима претенция 7, регулируемата трансмисия е механична скоростна кутия.

Съгласно зависима претенция 8, резервоарът за сгъстен въздух е естествена подземна кухня.

Съгласно зависима претенция 9, резервоарът за сгъстен въздух е подземен разклонен тунел в бивши мини.

Съгласно зависима претенция 10, резервоарът за сгъстен въздух са изоставени шахти и кладенци.

Ефектът, който се цели се състои в увеличена енергийна ефективност чрез реверсивно използване на едни и същи обратими пневматични и електрически силови машини с активно термоелектрическо охлаждане с цел автоматично балансиране на пиковите и падовете на електронатоварването в електрическата мрежа.

В резултат на извършеното проучване бяха намерени следните документи, отнасящи се до реверсивни енергоакумулиращи системи с пневматични и електрически силови машини с термоелектрическо охлаждане, които са отразени в доклада от проучването:

- В документ US2009/0230696 A1 е разкрита система за използване на слънчева енергия за повишаване на ефективността на система за съхранение на енергия със сгъстен въздух (и обратно). Системата включва фотоволтаичен панел за захранване на компресор, който осигурява енергия от сгъстен въздух във вътрешен съд, поместен в резервоар за съхранение. Два слънчеви приемни панела се използват за загряване на вода. Системата има още турборазширител и генераторен комплект. Общата ефективност на системата се подобрява от страничния продукт на охлаждания въздух от турборазширителя, който се използва за генериране на повече електрическа мощност от свързан генератор, задвижван с гориво, и/или от отпадната топлина от компресора и отработените газове на генераторния комплект, който се използва в комбинирана топлинна и енергийна система за захранване или на парогенераторна установка или на абсорбционен охладител.

- В документ CN202348587 U (реферат) е разкрита система за съхранение на електрическа енергия, което се състои от управляващо устройство, въздушен резервоар, управляващ клапан, въздушна помпа и малък турбинен генератор. Въздушната помпа е свързана с единия край на въздушния резервоар чрез тръбопровод, като другият край на въздушния резервоар е свързан с малкия турбогенератор през управляващия клапан, а управляващото устройство е свързано съответно с управляващия клапан, въздушната помпа и малкия турбогенератор чрез кабели, които се използват за предаване на управляващи сигнали. Въздушната помпа може да бъде заменена с въздушен компресор. Излишната произведена енергия може да се съхранява, когато електрическата енергия, генерирана от генератори на възобновяема енергия, например като слънчеви фотоволтаични генератори извън мрежата, вятърни генератори и други подобни, не се консумира.

-В документ US2016/0091000 A1 е разкрита система за съхранение и производство на електрическа енергия, включваща: поне един енергиен

източник, за предпочитане източник на възобновяема енергия; поне една помпа, захранвана от енергийния източник, пригодена да компресиращ въздуха вътре в резервоар за съхранение на сгъстен въздух, така че да го подава към поне един първичен пневматичен задвижващ механизъм, свързан към най-малко един вторичен пневматичен задвижващ механизъм, за предпочитане свързан към множество вторични пневматични задвижващи механизми, посредством тръби под налягане и електроклапи; поне един трансмисионен възел, адаптиран да преобразува възвратно-постъпателното въртливо движение на споменатите пневматични задвижващи механизми в постоянно въртливо движение; поне един електрически генератор, свързан към споменатия предавателен възел, адаптиран да произвежда електрическа енергия, когато е необходимо.

- В документ WO2021/113953 A1 е разкрита система за генериране на електрическа енергия, която включва фотоволтаична клетка, генератор, двигател, задвижван от въглеродороден газ, филтриран през филтър, непрекъсваемо захранване (UPS), включващо акумулаторна батерия, като UPS е свързано към фотоволтаичната клетка и към генератора чрез двупосочен инвертор за приемане, предаване и определяне на DC или AC захранване, както и интелигентен контролер, свързан към UPS за контролиране на изхода на DC или AC захранване към поне един въздушен компресор, доставящ сгъстен въздух на едно или повече пневматични устройства.

Анализът на обекта на проучването и извесните решения показва следното:

Новост

В нито един от намерените при проучването документи не е разкрита реверсивната енергоакумулационна система с обратими пневматични и електрически силови машини с активно термоелектрическо охлаждане, която да включва всички признаци на обекта на проучването, разкрит в претенциите от 1 до 10 вкл.

Следователно, реверсивната енергоакумулационна система с обратими пневматични и електрически силови машини с активно термоелектрическо охлаждане, разкрита в претенциите от 1 до 10 вкл. и която е обект на проучването, **отговаря на изискванията на чл. 8 от Закона за патентите и регистрацията на полезните модели (ЗПРПМ) за новост.**

06.07.2022 г

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ПАТЕНТНО ВЕДОМСТВО НА РЕПУБЛИКА БЪЛГАРИЯ

ДОКЛАД ОТ ПРОУЧВАНЕ

ПРОУЧВАНЕ ВХ. № СпИС - 682/13.06.2022

I. Уточнен класификационен индекс по МПК

H01L31/04; H01S10/00; H02J7/35; H02J3/38; F24S20/20; F02C1/05; H01M10/46

II. ОБЛАСТ НА ПРОУЧВАНЕ:

Минимален обхват на проучване

Вид класификация:

МПК

Класификационен индекс:

H01L31/04; H01S10/00; H02J7/35; H02J3/38; F24S20/20; F02C1/05; H01M10/46

Бази данни, в които е извършено проучването

Espacenet; Eropuonet; IPAS; Internet

III. Релевантни документи

Категория	Цитиране на документите с посочване на релевантните части	Релевантни претенции
A	US2009/230696 A1; (Enis et al.); 17.09.2009; описание, претенции, фигури и реферат	1-10
A	CN202348587 U; (Dalian Vocational and Tech.Col).; 25.07.2012; реферат	1-10
A	US2016/0091000 A1; (Swiss Green Systems SAGI); 31.03.2016; описание, претенции, реферат и фигури	1-10
A	WO2021/113953 A1; (Westgen Technologies Inc. et all), 17.06.2021; целият док-т	1-10

Категория на документа

X – документът е от особено значение; претендираното изобретение няма новост или изобретателска стъпка, когато документът се разглежда самостоятелно
A – документ, отразяващ нивото на техниката, който не е от особено значение

Y – документът е от особено значение; претендираното изобретение няма изобретателска стъпка, когато документът се комбинира с един или повече други документи и тази комбинация е очевидна за специалист в областта

Дата: 06.07.2022

Име: С. Демиревска

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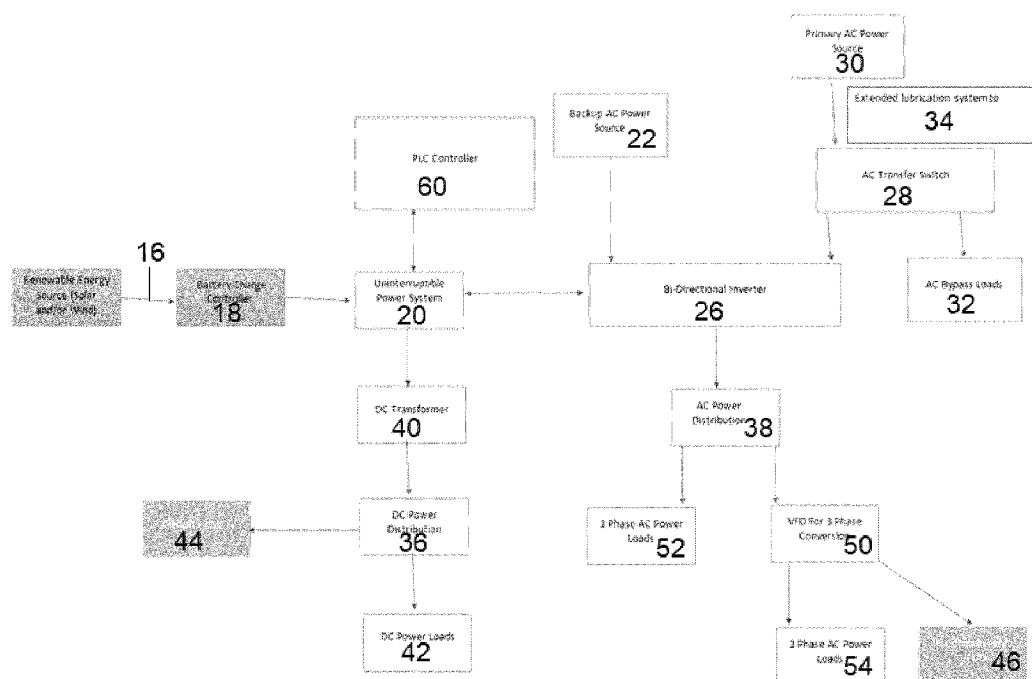
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(54) Title: ENGINEERED POWER ON DEMAND



(57) Abstract: A system, module, and method for generating reliable, high quality power on demand and off-grid includes a photovoltaic array for delivering DC power; a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an extended lubrication system; an uninterruptible power supply (UPS) comprising a storage battery, the UPS being coupled to the photovoltaic array for receiving the DC power, and to the generator by a bi-directional inverter for receiving, transmitting, and qualifying DC or AC power; and an intelligent controller coupled to the UPS for controlling output of the DC or AC power to at least one air compressor capable of providing compressed air to one or more pneumatic devices.



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Published:

- *with international search report (Art. 21(3))*

ENGINEERED POWER ON DEMAND

Cross Reference to Related Application

5 **[0001]** This application claims priority of United States Provisional Patent Application Serial No. 62/945,694, entitled “Engineered Power On Demand (EPOD)”, filed December 9, 2019, and hereby incorporated by reference herein in its entirety (where permitted).

Technical Field

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[0002] The present invention relates to a system, module, and method for providing power generation and compressed air using natural gas and renewable energy for off-grid locations.

Background of the Invention

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[0003] Remote wellsites often rely on fuel gas driven pneumatic systems which use the mechanical energy stored in high pressure gas from a well or fuel gas source to actuate valves in the open and closed positions to control well flow and to power injection pumps. Once spent, the gas is vented to the atmosphere. However, the gas is composed predominantly of methane, thus creating a safety hazard (i.e., explosion risks) and negatively impacting the environment. Further, wet gas may flood instruments.

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[0004] Methane has a greenhouse gas intensity twenty-five times greater than that of carbon dioxide. In Canada, 44% of methane emissions are from oil and gas. Venting gas through pneumatic devices makes up about 35% of the oil and gas industry’s total methane venting in Canada, which equates to about 18,000,000 tonnes of carbon dioxide annually. Goals have thus been set to reduce carbon emissions by 45%. New regulations aim to restrict the use of fuel gas pneumatic controllers, and existing high bleed pneumatic controllers (which emit 67 tonnes CO₂e annually) will need to be retrofitted or converted to instrument air pneumatic systems.

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[0005] Commercially available power generation systems to generate less than 5 kW of power for off-grid wellsites include, but are not limited to, solar, thermoelectric generators,

and fuel cells. For larger power demands, natural gas generators and microturbines are readily available to generate greater than 30 kW. However, there has been a gap in cost-effective remote power generation technology that has made it difficult to supply power in the 5 kW to 30 kW range required to run an adequately sized power generation system for use at remote wellsites.

Summary of the Invention

[0006] The present invention relates to a system, module, and method for providing power generation and compressed instrument air using hydrocarbon gas and renewable energy for off-grid locations. It was surprisingly discovered that by utilizing the system, module, and method of the present invention, one or more of the following benefits may be realized:

(1) The invention relates generally to a hybrid system powered by a renewable energy source in conjunction with DC and AC power distribution which enables a load to be powered from a battery, and a generator to be run intermittently on hydrocarbon gas to supply back-up power.

(2) The invention also provides an extended lubrication system to increase the service interval of the generator engine and to handle combustion byproducts. The extended lubrication system may comprise a filtration system which continuously slipstreams a portion of oil through a separate filter. The oil capacity is significantly increased to allow for dilution of any combustion byproducts from variable quality fuels. The invention also provides an electrical design providing battery back-up and electrical power conditioning to enable use of variable quality fuel sources.

(3) The invention may supply power in the 5 kW to 30 kW range required to run an adequately sized instrument air system.

(4) The invention may be suitable for any off-grid remote location. In an exemplary use, the invention may be suitable for a wellsite in providing a remote power generation and air compression system capable of providing sufficient power and instrument air to eliminate fuel gas pneumatics and methane venting on a wellsite. The invention may

be capable of burning hydrocarbon gas (for example, hydrocarbon gas directly from the wellhead), and generating power (in combination with solar energy) and instrument air to power the wellsite.

- 5 (5) The invention takes operators into consideration by providing proper heating, ventilation, air conditioning, and safety measures within the operators' work module; extended service intervals; remote monitoring capabilities; and air metering.

10 [0007] Thus, broadly stated, in one aspect of the invention, a system for generating power on demand and off-grid is provided, comprising: a power source using a renewable resource; an uninterruptible power supply (UPS) comprising a storage battery and coupled to the power source for receiving DC or AC power; and an intelligent controller coupled to the UPS for controlling output of the DC or AC power to one or more devices.

15 [0008] In the various embodiments, the power source for delivering the DC power may be a photovoltaic array. In the various embodiments, the system may further comprise a battery charge controller coupled to the power source for regulating the DC power.

20 [0009] In the various embodiments, the power source for delivering the AC power may be selected from a generator or a utility power connection. In the various embodiments, the power source may comprise a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas. In the various embodiments, the hydrocarbon gas is filtered through a coalescing filter to remove free liquid.

25 [00010] In the various embodiments, the engine comprises an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts.

30 [00011] In the various embodiments, the storage battery may be coupled to the generator by a bi-directional power inverter, the bi-directional power inverter being configured, in a first mode of operation, to receive and convert the DC power into AC power, and in a second mode of operation, to receive and convert AC power into DC power for charging the storage battery.

[00012] In the various embodiments, the bi-directional power inverter qualifies the DC or AC power and switches loads within a set timeframe to ensure uninterrupted transition from the storage battery to the generator.

5 **[00013]** In the various embodiments, the bi-directional power inverter may comprise an AC transfer switch for providing the AC power from one or more AC power sources.

[00014] In the various embodiments, the system may further comprise one or more of a DC power distribution unit and an AC power distribution unit for supplying power to one or
10 more devices. In the various embodiments, the one or more devices may comprise at least one air compressor capable of providing compressed air to one or more pneumatic devices.

[00015] In another aspect of the invention, a system for generating power on demand and off-grid comprises a photovoltaic array for delivering DC power; a generator having a
15 size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts; an uninterruptible power supply (UPS) comprising a storage
20 battery, the UPS being coupled to the photovoltaic array for receiving the DC power, and to the generator by a bi-directional inverter for receiving DC or AC power; and an intelligent controller coupled to the UPS for controlling output of the DC or AC power to at least one air compressor capable of providing compressed air to one or more pneumatic devices.

[00016] In another aspect of the invention, a system for generating power on demand
25 and off-grid comprises a photovoltaic array for delivering DC power; a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts; an uninterruptible power supply (UPS) comprising a storage
30 battery, the UPS being coupled to the photovoltaic array for receiving the DC power, and to the generator by a bi-directional inverter for receiving DC or AC power; and an intelligent controller coupled to the UPS for controlling output of the DC or AC power to one or more devices.

[00017] In another aspect of the invention, a system for generating power on demand and off-grid comprises a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts; a power storage device
5 coupled to the generator by a bi-directional power inverter for receiving DC or AC power; and an intelligent controller coupled to the storage battery for controlling output of the DC or AC power to one or more devices.

10 **[00018]** In another aspect of the invention, a system for generating power on demand and off-grid comprises an on-site power source for powering an air compressor capable of providing compressed air to one or more pneumatic devices; and an intelligent controller for collecting data in relation to carbon credit generation.

15 **[00019]** In another aspect of the invention, a module formed of a modified shipping container and comprising any of the above systems is provided.

[00020] In the various embodiments, the module further comprises one or more of a motion sensor, lighting system, smoke detector, space heater using renewable energy, and
20 heating, ventilation, and air conditioning system.

[00021] In another aspect of the invention, a method for generating power on demand and off-grid using the above system comprises: converting sunlight rays into DC power using a photovoltaic array; supplying hydrocarbon gas to operate an engine of a generator to
25 generate AC power; conditioning the DC or AC power using a bi-directional inverter to output conditioned DC or AC power; delivering the conditioned DC or AC power to a UPS comprising a storage battery; and controlling output of the DC or AC power to operate at least one air compressor for providing compressed air to one or more pneumatic devices.

30 **[00022]** In the various embodiments, the hydrocarbon gas is filtered through a coalescing filter. In the various embodiments, the engine comprises an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and

diluting combustion byproducts. In the various embodiments, conditioning the DC or AC power comprises converting the DC power to AC power, or the AC power to DC power.

[00023] In another aspect of the invention, a method for generating power on demand and off-grid using the above system comprises: converting sunlight rays into DC power using a photovoltaic array; supplying hydrocarbon gas recovered from a wellhead to operate an engine of a generator to generate AC power; conditioning the DC or AC power using a bi-directional inverter to output conditioned DC or AC power; delivering the conditioned DC or AC power to a UPS comprising a storage battery; and controlling output of the DC or AC power to operate one or more devices.

[00024] In another aspect of the invention, a method for generating power on demand and off-grid using the above system comprises: supplying hydrocarbon gas recovered from a wellhead to operate an engine of a generator to generate AC power; conditioning the DC or AC power using a bi-directional inverter to output conditioned DC or AC power; delivering the conditioned DC or AC power to a power storage device; and controlling output of the DC or AC power to operate one or more devices.

[00025] In another aspect of the invention, a method for generating power on demand and off-grid using the above system comprises supplying power from an on-site power source to an air compressor capable of providing compressed air to one or more pneumatic devices; and collecting data in relation to carbon credit generation.

[00026] Additional aspects and advantages of the present invention will be apparent in view of the description, which follows. It should be understood, however, that the detailed description and the specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the scope of the invention will become apparent to those skilled in the art from this detailed description.

Brief Description of Drawings

[00027] Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

[00028] FIG. 1 is a block diagram of a system form of the invention.

[00029] FIGS. 2A-B are perspective views of the system form of FIG. 1 integrated as a first embodiment of a self-contained module.

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[00030] FIG. 2C is a schematic plan view of the interior of the self-contained module of FIGS. 2A-B.

[00031] FIGS. 3A-C are schematic views of the system form of FIG. 1 integrated as a second embodiment of a self-contained module. FIG. 3A is a schematic plan view of the interior of the self-contained module. FIG. 3B is a schematic front view of the self-contained module of FIG. 3A. FIG. 3C is a schematic rear view of the self-contained module of FIG. 3C.

15 [00032] FIGS. 4A-E show embodiments of a user interface whereby a user can operate the system of FIG. 1.

Detailed Description

20 [00033] Unless defined otherwise in this specification, all technical and scientific terms are used herein according to their conventional definitions as they are commonly used and understood by those of ordinary skill in the art of engineering.

[00034] As used herein, the terms “comprises” or “comprising” should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced.

25 [00035] As used herein and in the appended claims, the singular forms “a”, “an,” and “the” include plural referents unless the context clearly dictates otherwise.

[00036] References in this document to orientations, to operating parameters, to ranges, to lower limits of ranges, and to upper limits of ranges are not intended to provide

strict boundaries for the scope of the invention, but should be construed to mean “approximately” or “about” or “substantially”, within the scope of the teachings of this document, unless expressly stated otherwise.

5 **[00037]** The present invention comprises a system, module, and method for providing power generation and compressed air using hydrocarbon gas and renewable energy for off-grid remote locations. As used herein, the term “off-grid” refers to locations which are not connected to one or more public utilities including, but not limited to, electricity, gas, and water. As used herein, the term “remote” refers to an area which is a distance away from a
10 city, town, or other residential area. In the various embodiments, the off-grid remote location may be a wellsite.

[00038] Referring to FIG. 1, the system form (1) of the invention may include various components which intercommunicate to perform selected functions. Referring to FIGS. 2A-
15 2C and 3A-3C, the components of the system form (1) of the invention may be integrated as an entirely self-contained module (2). Referring to FIGS. 4A-E, embodiments of a user interface whereby a user may operate the system (1) integrated within the module (2) are shown.

20 **[00039]** In general, the system form (1) of the invention comprises a combination of the following features: (a) a hybrid system powered by a renewable energy source (for example, solar power) in conjunction with DC and AC power distribution which enables a load to be powered from a battery, and a generator to be run intermittently on hydrocarbon gas (for example, natural gas on a wellsite) to supply back-up power and extend service
25 intervals; (b) an extended lubrication system to increase the service interval of the generator engine, and to dilute combustion byproducts from variable quality fuels; and (c) an electrical design providing battery back-up and electrical power conditioning to enable use of variable quality fuel sources, as further described herein.

30 **[00040]** **Power Generation**

[00041] In the various embodiments, power may be generated using a renewable energy source including, but not limited to, sunlight, wind, or both. In the various

embodiments, power may be generated using a solar photovoltaic array (10) or a wind-powered electricity generation unit. In the various embodiments, power may be generated using a solar photovoltaic array (10) comprising a linked collection of photovoltaic modules (12) (colloquially termed “solar panels”), each photovoltaic module (12) being formed of multiple interconnected photovoltaic cells (14). The photovoltaic cells (14) convert sunlight or solar energy into direct current (“DC”) electricity (16). The DC electricity (16) generated by the solar photovoltaic array (10) may be delivered continuously through a battery charge controller (18) to one or more batteries (20).

[00042] In the various embodiments, the battery charge controller (18) may regulate the voltage, current, or both being delivered to the battery (20) of an uninterruptible power supply (“UPS”). By continuously monitoring the charge state of the battery (20), the battery charge controller (18) prevents overcharge or damage to the battery (20). If the charge state of the battery (20) drops below a predetermined state, the system (1) includes a backup alternating current (“AC”) source including, but not limited to, a generator or utility power connection. In the various embodiments, a generator (22) may serve as a backup electrical power source which converts mechanical energy into electrical energy. The generator (22) is powered by an internal combustion engine (24) and is activated upon receipt of a transmitted start signal. In the various embodiments, the size of the generator (22) may range from about 5 kW to about 30 kW. In the various embodiments, the size of the generator (22) may be selected from about 6 kW, 20 kW, or 30 kW.

[00043] In the various embodiments, a power storage device (instead of a UPS) may be utilized including, but not limited to, a battery or an ultracapacitor.

[00044] Once running, the generator (22) may be programmed to operate at the desired constant revolutions per minute (“RPM”). As load increases, fuel is added (and consequently more air) to maintain the RPM. A suitable fuel may be a hydrocarbon gas. As used herein, the term “hydrocarbon gas” refers to any gas comprising molecules of carbon and hydrogen in various combinations. The term refers to untreated and treated hydrocarbon gas including, but not limited to, natural gas propane, and the like. In the various embodiments, the hydrocarbon gas may be natural gas from the well, pipeline, or other source. In the various

embodiments, the hydrocarbon gas may be natural gas sourced from the well at the off-grid remote location.

5 **[00045]** This allows the engine (24) to operate with variable heating value fuels as fuel flow for higher calorific value fuels is just reduced to maintain the constant RPM. In the event of a sudden change in calorific value and an RPM surge, a power inverter (26) detects a frequency or voltage change and disqualifies the load, protecting any electronics.

10 **[00046]** In the various embodiments, the fuel gas pressure regulator may ensure that the fuel gas pressure is maintained below about 50 psig in compliance with electrical area classification. In the various embodiments, the hydrocarbon gas is routed through a coalescing filter to remove any free liquids. In the various embodiments, a differential pressure switch may be positioned proximate to the coalescing filter to measure pressure drop and to emit an alert if the coalescing filter requires replacement.

15 **[00047]** In the various embodiments, the power inverter (26) may be connected to the generator (22) and the battery (20). In the various embodiments, the power inverter (26) may be a bi-directional power inverter. In the various embodiments, the bi-directional power inverter (26) may convert DC produced by the battery (20) to alternating current (“AC”), and controls the voltage and frequency of its output. In the various embodiments, the bi-directional power inverter (26) may be utilized to rectify AC to DC in order to charge the battery (20). In the various embodiments, the power inverter (26) may comprise an internal charge controller which continuously monitors the charge state of the battery (20) to prevent overcharging. Both functions may occur simultaneously.

25 **[00048]** In the various embodiments, the power inverter (26) may include an automatic AC transfer switch (28) that switches to whichever AC is providing power - either a primary AC source (30) or the backup AC power source such as the generator (22). The AC transfer switch (28) does not allow two AC sources (22, 30) to provide power simultaneously. In the various embodiments, the AC transfer switch (28) directs AC to AC bypass loads (32).

[00049] The power inverter (26) reviews any loads on the battery (20) and qualifies the voltage and frequency of the generator (22) to ensure that they match. Once the supply and

load of the generator (22) have been qualified, the power inverter (26) utilizes the supply of the generator (22) to power the load. The power inverter (26) is programmed with the maximum amperage of the generator (22) and utilizes the difference in current between the load and the maximum ampacity of the generator (22) to charge the battery (20). Once the
5 battery (20) has been fully charged, the generator (22) is turned off and the load switches to run off the battery (20) through the power inverter (26). The power inverter (26) can qualify and switch loads within one half cycle to ensure a smooth and uninterrupted transition from the battery (20) to the generator (22). In the various embodiments, multiple power inverters (26) may be added in parallel to increase the capacity of the system (1).

10

[00050] The generator (22) has a required cool down time and a shutdown signal is sent to the generator (22) prior to the battery (20) reaching full charge. This allows the generator (22) to cool down under a partial state of load to “top off” the battery (20) during the cool down cycle and avoid wasted engine run time and fuel.

15

[00051] Extended Lubrication System

[00052] Typical engine oil maintenance cycles generate operating issues for remote locations. Further, byproducts from the combustion of “dirty” natural gas (for example, well
20 gas including hydrocarbons heavier than methane and additional organic compounds) can foul the lubricating oil of the engine (24) from engine blow by. In the various embodiments, the engine (24) may be provided with an extended lubrication system (34) for increasing the maintenance life of the engine (24) and handling combustion byproducts from the well.

25 **[00053]** In the various embodiments, the extended lubrication system (34) may comprise a filtration system which continuously slipstreams a portion of oil through a separate filter. The oil capacity is significantly increased to allow for dilution of any combustion byproducts. Oil from the pressure side of the oil pump is diverted through an orifice meter to a secondary filtration system and routed back to the crankcase where oil is
30 typically stored within an oil pump.

[00054] In the various embodiments, a continuous feed system may be provided to increase further the maintenance life of the engine (24). In such a system, oil is continuously

drained off the crankcase through an orifice plate to a spent oil tank. The oil level is monitored when the oil in the crankcase hits a specified level, a solenoid opens, and gravity drains fresh oil to the crank until level is satisfied again.

5 **[00055] Air Compression**

[00056] In the various embodiments, the system (1) may include a DC power distribution system (36), an AC power distribution system (38), or both, thereby providing a centralized power supply for off-grid remote locations. The DC power distribution system
10 (36) receives DC from the battery (20) through a DC transformer (40) and distributes power to DC control systems and DC power loads (42) including, but not limited to, chemical pumps, a motor control system (44), and the like.

[00057] In the various embodiments, the system (1) may power one or more air
15 compressors (46). As used herein, the term “air compressor” refers to a device which converts power (using a motor or engine) into potential energy stored in pressurized air (i.e., compressed air) which is supplied to various equipment. In the various embodiments, the air compressor (46) may comprise a 3 HP to 20 HP duplex reciprocating air compressor or scroll air compressor. In the various embodiments, the air compressor (46) may comprise a 3, 5, or
20 7.5 HP duplex reciprocating air compressor or scroll air compressor. In the various embodiments, the air compressor (46) may include a fire eye (48) for fire safety protection.

[00058] In the various embodiments, the air compressor (46) may be used to provide compressed air to one or more pneumatic devices. As used herein, the term “pneumatic
25 device” means any instrument which generates and utilizes compressed air. Non-limiting examples of pneumatic devices include valve actuation devices, process control and sensing devices, pumps, water transfer pumps, small pump jacks, and block valves.

[00059] In the various embodiments, the air compressor (46) may be powered by a
30 variable frequency drive (VFD) (50). The VFD (50) controls AC motor speed and torque by varying motor input frequency and voltage. In the various embodiments, the VFD (30) may transform single phase power (52) from the power inverter (26) to three phase power (54) for the air compressor (46). In addition, the VFD (50) controls starting current. In the various

embodiments, the VFD (50) may convert a single phase 230 VAC source into a 230 VAC three phase source to power the air compressor (46).

[00060] In the various embodiments, a pair of air compressors (46) may be provided.

5 The air compressors (46) operate in a lead/lag fashion to maximize the run time of each air compressor (46), thereby maximizing time between maintenance. Under normal operation, only one air compressor (46) operates at a time by alternating the air compressors (46) at each start event, thereby allowing each air compressor (46) to cool off fully between operation and extending compressor life. In the various embodiments, the air compressors (46) may be
10 powered by individual VFD's or a single VFD with a relay that switches between the air compressors (46). In addition to phase conversion, the VFD (50) allows current inrush of the motor to be controlled to ensure any current limits on the power inverter (26) are not exceeded.

15 **[00061]** Compressed air from the air compressor (46) flows to a wet air receiver. As used herein, the term "wet air receiver" refers to a storage vessel or tank positioned after the air compressor (28). The wet air receiver provides additional storage capacity and reduces moisture by collecting liquid. The compressed air passes through a first filter before entering a regenerative desiccant dryer system (56) to remove water. Dried air then passes through a
20 second filter to removes any remaining particulates or oil. The cleaned dried air then flows through a mass flow meter (58) which continuously monitors air usage. The air compressor (46) may thus provide sufficient compressed air to allow one or more pneumatic devices to operate on compressed air rather than methane, thereby eliminating methane venting on off-grid remote locations such as, for example, wellsites. In various embodiments, the air usage
25 is recorded and trended by a programmable logic controller ("PLC") (60). This may allow for accurate monitoring of the air used; generating carbon credits; and setting high or low flow alarms.

[00062] A pressure transmitter (62) connected to the wet air receiver controls the
30 operation of the air compressor (46). When the pressure transmitter (62) falls below a setpoint, the air compressor (46) is activated by a start command. Once the setpoint is reached, the air compressor (46) is deactivated by a stop command. The run time of the air compressor (46) is monitored by the PLC (60) to alert the operator when scheduled

maintenance is required. If an air compressor (46) fails to run following a start command, it is placed in fault mode and removed from operation. A fault call out is logged in a programmable logic controller ("PLC") (60) and the operator is alerted.

5 **[00063] Programmable Logic Controller**

10 **[00064]** In the various embodiments, a PLC (60) may control the functions of the system (1), performs datalogging, and communicates with any site master controller. The PLC (60) may allow monitoring and trending of system process conditions including, but not limited to, run status of the generator (22), run time, voltage and current, charge and voltage state of the battery (20), input from the photovoltaic modules (12), temperature, run time of the air compressor (46), and volume of air used. The PLC (60) may be integrated into a Supervisory Control and Data Acquisition ("SCADA") system which allows for remote operation and monitoring of the system (1); emits alerts in the event of a fault; and enables
15 generation of carbon credits through reporting of required data in compliance with government regulations.

[00065] Integration of System in a Module

20 **[00066]** Referring to FIGS. 2A-2C and 3A-C, the components of the system form (1) of the invention may be integrated within an entirely self-contained module (2) in order to provide uninterruptible power generation and air compression at off-grid remote locations. In the various embodiments, the module (2) may be pre-constructed, tested, and commissioned at a manufacturer or machine shop before being shipped to the desired off-grid remote
25 location. In this manner, components do not have to be purchased from separate vendors, hastily engineered into the required configuration, and fabricated on site. Rather, the fully fabricated module (2) may be purchased by a sole vendor and shipped to the location in one easily transportable unit. Once at the location, installation requires only connecting the fuel gas inlet, compressed air outlet, and wiring other wellsite components to the DC and AC
30 power distribution systems (36, 38). This may save costs and reduce supply chain and operational problems.

[00067] In the various embodiments, the module (2) may be constructed from a conventional shipping container (for example, a Sea-Can™ Container as manufactured by Sea-Can Containers, Ltd., Alberta, Canada). In the various embodiments, the container may be modified by replacing wooden flooring with aluminum non-slip flooring, and installing insulated paneling (for example, galvalume) to the walls, doors, and ceiling. In the various embodiments, a wall of the container may be replaced by the insulated paneling and a man door (116). Installing the man door (116) within the insulated paneling (as opposed to cutting a man door through the original wall of the container) ensures a proper tight fit and avoids development of rust. In the various embodiments, a ladder (64) may be attached to an end wall (66) of the module (2) to provide access to the roof (68) of the module (2).

[00068] In the various embodiments, one or more photovoltaic modules or solar panels (12) may be mounted to a side wall (70), roof (68), or both of the module (2) using suitable attachment means including, but not limited to, extendable telescoping struts (72). As shown in FIGS. 2A-B, the telescoping struts (72) are adjustable to enable the solar panels (12) to be positioned flush to the side wall (70) or roof (68) for shipping to the off-grid remote location, and outwardly to a desired angle once the module (2) has been deployed at the off-grid remote location. In the various embodiments, the telescoping struts (72) may define one or more apertures for receiving suitable locking means (for example, pins and the like) to lock the solar panels (12) in position at the desired angle relative to the side wall (70) or roof (68) of the module (1). The angle may be adjusted accordingly depending on the season and latitude in order to gather sufficient solar energy.

[00069] In the various embodiments, the module (2) may include a control system (74) comprising the PLC (30), a touchscreen human machine interface (HMI), and associated breakers (for example, a generator breaker (118) as shown in FIG. 3A) and contactors. Provision of the control system (74) conveniently removes the requirement for additional electrical buildings at the off-grid remote location. In the various embodiments, the generator (22) and engine (24) may be positioned beside a side wall (76) opposite the air compressor (46) to allow sufficient space for the control system (74), DC control panel (78), and AC control panel (80). In the various embodiments, the DC control panel (78) and AC control panel (80) may be provided in the form of a single control unit (120) as shown in FIG. 3A. The generator (22) and engine (24) are mounted on a skid for easy access and maintenance.

In the various embodiments, the UPS including the battery (20) is contained within the control panels (78, 80) mounted to the side wall (70) of the module (2).

[00070] In the various embodiments, the module (2) may include a motion sensor (82) which is connected to the control system (74) for providing security and controlling a lighting system (122). In the various embodiments, the lighting system (122) may comprise light-emitting diodes (LEDs). If motion is detected within the module (2), the lighting system (122) turns on and a passcode must be entered within a preset timeframe via the HMI, or an alarm is triggered and an alert transmitted to the operator. After a set period of no motion, the motion sensor (82) automatically turns off the lights to avoid unnecessary power draw. In the various embodiments, an exterior lighting system (124) may be maintained during hours of low light, as set by a clock connected to the control system (74) (FIG. 3B). In the various embodiments, the exterior lighting system (124) may comprise LEDs. In the various embodiments, a smoke detector (84) may be provided to detect smoke and emit an alarm.

[00071] In the various embodiments, the module (2) may include a heating, ventilation, and air conditioning (“HVAC”) system. In the various embodiments, exhaust from the generator (22) may exit the module (2) through a generator exhaust (86). In the various embodiments, hot air emitted from the radiator of the generator (22) may pass through an exhaust duct (88) including an exhaust louvre to exit the module (2). A modulating damper (90) is positioned upstream of the exhaust louvre, and is controlled by a temperature sensor (92) in the module (2). If the temperature falls below a setpoint, the modulating damper (90) closes, increasing static pressure in the exhaust duct (88) and causing a weighted backdraft damper (94) positioned upstream on a ducted “T” to recirculate hot air through a recirculation duct (96) back into the module (2) as the primary source of heating.

[00072] When the temperature rises above the setpoint, the modulating damper (90) opens fully, and one or more exhaust fans (98a, 98b) are activated at low speed. If the temperature continues to rise, or if an explosive environment is detected using a suitable sensor including, but not limited to, a lower explosive limit and gas sensor, the exhaust fans (98a, 98b) are activated at high speed. In the various embodiments, the exhaust fans (98a, 98b) may be positioned on opposite end walls (66, 100) of the module (2). At a setpoint, a high temperature alarm emits an alert to the operator.

[00073] If the modulating damper (90) is fully closed and the set temperature cannot be satisfied, a space heater (110) is activated. In the various embodiments, the space heater (110) may be connected to an inlet (112) for receiving fuel (for example, natural gas) from the exterior of the module (2) and to an exhaust outlet (114) extending to the exterior of the module (2). Suitable space heaters (110) include, but are not limited to, explosion-proof infrared gas catalytic heaters and the like (for example, a Cata-Dyne™ heater, Thermon Heating Systems).

[00074] In the various embodiments, fresh air may be supplied by one or more intake louvres (126) proximate the air compressor (46) to ensure that the air compressor (46) is provided with cooler air during compression, optimizing efficiency of the air compressor (46); to minimize pulling cold air across the module (2) while the air compressor (46) is running; and to avoid formation of a vacuum in the module (2). In the various embodiments, the one or more intake louvres (126) may be positioned close to the floor proximate the air compressor (46) (FIG. 3B). In the various embodiments, the intake louvres (126) may be selected to be of a desired size to ensure that water or moisture is not pulled into the module (2) while the exhaust fans (98a, 98b) and the engine (24) are running.

[00075] Embodiments of the present invention are described in the following Examples, which are set forth to aid in the understanding of the invention, and should not be construed to limit in any way the scope of the invention as defined in the claims which follow thereafter.

[00076] Example 1 – Specifications of an exemplary system

[00077] The specifications of an exemplary engineered power on demand solar hybrid system capable of generating power at 6, 20, and 30 kW are set out in the following Tables 1-9.

TABLE 1 - GENERAL	
Make	Westgen Technologies
Model	EPOD – 6 kW / 20 kW / 30 kW
Engine	Kubota DG972 (6 kW) Kubota WG2503 (20 kW) Kubota WG3800 (30 kW)

	Yanmar Y-EGG19A1 Yanmar Y-EGG23A1
Engine Type	Reciprocating Engine
Engine Controller	Local PLC

TABLE 2 - ELECTRICAL SYSTEM	
System Power Output	6,000 W / 20,000 W / 30,000 W
Power Distribution	24 VDC & 120/240 VAC
Battery System	Sealed Gel Integrated Battery UPS
Battery Capacity	980 AH @ 24 V (Option to Increase)
Battery Cycle Life	2300 Cycles @ 50% Depth of Discharge
Battery Type	Sealed Tubular Gel SOPzV Block
Battery Bank Weight	1,520 lbs
Power Back up	30 A 120/240 V Backup Generator Receptacle
Panels	PLC/ RTU/ MCC
RTU	PLC with Embedded IO and SCADA System
Hybrid Inverter/ Charger	Conext XW+ NA
Inverter	A510 Inverter(6,800 W) / (13,600 W) / (27,200 W)
DC Voltage Transducer	CR5300 Series
Line Reactor	KDRD25L

TABLE 3 - SOLAR SYSTEM	
Power Generation	3800 W Solar Generation (Option to Increase)
Solar Panel Brand	Canadian Solar
Linear power output Warranty	25 Years
Solar Panel Type	60-Cell Monocrystalline Module
Solar & Battery System Diagnostic Monitor	Conext ComBox
Solar Charge Controller	Conext MPPT 80 600
Hybrid Inverter/ Charger	Conext XW+ NA

TABLE 4 - EPOD GENERATOR SPECIFICATIONS	
Make	Kubota
Model (Power Output)	Kubota DG972 (6 kW) Kubota WG2503 (20 kW) Kubota WG3800 (30 kW) Yanmar Y-EGG19A1 Yanmar Y-EGG23A1
Engine Type	Reciprocating Engine
Lubrication	Long Run Oil System with Reservoir
Oil/ Filter Change Interval	2500 Hours
Oil Type	10w30 Torq-Guard Engine Oil
Full System Oil Capacity	80 Liters
Generator Weight with Stand	550 lbs

TABLE 5 - COMMUNICATION

Logic Controller	Controller M221 24 IO Transistor PNP Ethernet
Control Panel	Magelis HMI STU 655/855 (Option to Increase)
Sensor Switch	CM-PDT-10 Series Switch

TABLE 6 - FUEL OPERATIONAL SPECIFICATIONS	
Fuel Type	Natural Gas, Propane, (Wellhead Gas Capable)
Fuel Gas Conditioning	Inlet Fuel Gas Coalescing Filter and Regulator
Fuel Pressure Range	0.5 – 150 PSIG
Fuel Gas Consumption	1.9 CFM Max (6 kW)
Fuel Propane Consumption	0.6 CFM Max (6 kW)
BTU Requirements	900-2500 BTU

TABLE 7 - STRUCTURAL	
Containment	Steel Shipping Container
Dimensions	20' L x 8' W x 8.5' H
Access/Egress	Man Door with Window and Panic Hardware/ Sea Can Double Door Entrance
Walls/ Insulation	Insulated Aluminum Foam Panels
Insulation Value	R12
Flooring	Aluminum Diamond Plate Non-Slip Flooring
EPOD Weight	11,600 lbs
Design Temperature	-45°C to +35°C

TABLE 8 - UTILITY	
Heating	5 kW Forced Air Heater
Ventilation	Exhaust Fan & Ducting with Adjustable Dampers
Exhaust Fan	120 VAC ¼ HP Fan
Smoke Detection	Smoke Detector with Alarm Contacts
Security	Interior Motion Detector with Call Outs
Lighting	Philips FluxStream LED Lights
Convenience Receptacle	120 VAC Supplied Inside

5

TABLE 9 - INSTRUMENT AIR SPECIFICATIONS	
Compressor	Duplex 5 HP (Option to Increase)
Compressor Make	Champion (Other Options Available)
Compressor Type	Reciprocating (Other Options Available)
Wet Air Receiver	120 Gallon
Wet Air Receiver Tank Drain	Electric Auto-Drain
Instrument Air Filtration	Pre & Post Air Filter
In-line Flow Meter	CDI 5100
Desiccant Air Dryer	Trident Dryspell PD238 (Other Options

	Available)
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[00078] Example 2 – Specifications of an exemplary control panel

[00079] The specifications of an exemplary control panel for the system described in Example 1 are set out below. The control panel is a micro-PLC based control system with a 10” color operator touchscreen designed and programmed to monitor and control instrument air compressors, dryer and outlet flow measurement to customer connections; natural gas/propane generator; building ambient temperature; building lighting and security system; and solar and battery system. The control panel features include:

- 10 • CSA approved for use in general purpose NEMA 12 environment;
- Pure sine wave 120/240vac, 1ph, 60hz customer output power;
- UPS 24VDC customer output power;
- Equipment and alarm status (dry NC or NO contact for customer connection);
- Motion detection control for interior lighting and security;
- 15 • Customer back-up generator 120/240vac, 1ph, 60hz, 30A exterior connection with 10ft portable cable (L14-30 twist-lock outlet. Min. 5000W customer generator);
- Clearly identified covered and lockable (breaker lock) circuit breakers. No internal panel fuses. All accessible to the operator with no exposure to live electrical parts;
- 20 • 10” color touchscreen including an alarm banner with description, time & date (Logs up to 100 alarms); security password protected (default – security disabled); HAND / OFF / AUTO operation of compressors, exhaust fan and generator; adjustable equipment maintenance alarms; and data-logging.

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[00080] Example 3 – Exemplary control panel touchscreen instructions and controls

[00081] FIG. 4A shows a main panel screen having the following instructions and controls:

30

- Pressing the “RESET” button resets all non-active alarms. (NOTE: Displayed on all pages).

- “INTERIOR LIGHTS OFF/ON” display indicates status of EPOD interior lights.
(NOTE: Displayed on all pages).
- “SECURITY OFF/ON” displays EPOD motion sensor security system status.
(NOTE: Displayed on all pages).
- 5 • “BUILDING TEMP” displays current EPOD ambient temperature (NOTE:
Displayed on all pages).
- “BUILDING TEMP SET” displays current EPOD ambient temperature setpoint.
A pop-up keypad will appear when pressed. Enter desired set-point & press
enter. (NOTE: Displayed on all pages).
- 10 • HMI pages are displayed at the bottom of the page. Pressing the page will take
you to the page indicated. (NOTE: Displayed on all pages).
- Displays current time, year, month and day. Pressing the current time, year,
month and day display for 3 seconds takes you to the configuration page
allowing you to make changes to the current time, year, month and day.

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[00082] FIG. 4B shows a “Process PG. 1” panel screen having the following instructions and controls:

- 20 • “HAND/OFF/AUTO” controls for both compressors. HAND or AUTO will turn
green upon pressing to indicate they are enabled. Red indicates disabled. HAND
will bypass PLC controls with exception of an ESD, smoke or fire alarm. OFF
disables HAND & AUTO. AUTO enables PLC controls.
- 25 • “HAND/OFF/AUTO” controls for the generator. HAND or AUTO will turn
green upon pressing to indicate they are enabled. Red indicates disabled. HAND
will bypass PLC controls with exception of an ESD, smoke or fire alarm. OFF
disables HAND & AUTO. AUTO enables PLC controls.
- 30 • “HAND/OFF/AUTO” controls for the generator exhaust recirculation louver.
HAND or AUTO will turn green upon pressing to indicate they are enabled. Red
indicates disabled. HAND will bypass PLC controls with exception of an ESD,
smoke or fire alarm. OFF disables HAND & AUTO. AUTO enables PLC
controls.
- ACT-1000 closed position is displayed. “CLOSED MANUAL SET” displays the
manual position setpoint. A pop-up keypad will appear when pressed. Enter

desired set-point & press enter. “ACT-1000 % closed displays the auto position of the actuator.

- “RUNNING” green display for running equipment. “STOPPED” red display for stopped equipment.
- 5 • Red blinking “FAULT” displays appear during an equipment fault. The fault display will be visible until the fault has been cleared and RESET button has been pressed. If a compressor VFD fault occurs, a green “RESET VFD-XXXXX button will appear. If the VFD fault is clear, pressing RESET VFDXXXXX button for 3 sec will reset the VFD. NOTE: After a VFD reset. If the faulted
- 10 VFD initiated a fail to start alarm and the lag compressor is running. The lead VFD compressor will start again when the IA pressure drops below the START setpoint.
- PT-1000 is displayed (PSI). “COMP. START” displays current PT-1000 start setpoint. A pop-up keypad will appear when pressed. Enter desired set-point & press enter. “COMP. STOP” displays current PT-1000 stop setpoint. A pop-up
- 15 keypad will appear when pressed. Enter desired set-point & press enter.
- “LEAD” control for both compressors. LEAD will turn green upon pressing to indicate it’s enabled. The LEAD compressor will run as per the above COMP. START/STOP setpoints. NOTE: When compressors ALTERNATE is enabled,
- 20 the LEAD buttons are disabled. If the lead compressor fails to start, the lag compressor will start when the IA pressure drops below the START setpoint.
- “ALTERNATE TIME SET” displays current compressor A & B alternating duration. A pop-up keypad will appear when pressed. Enter desired set-point & press enter.
- 25 • FT-1000 is displayed (SCFM).

[00083] FIG. 4C shows a “Process PG. 2” panel screen having the following instructions and controls:

- “HAND/OFF/AUTO” controls exhaust fans, generator & interior lights. HAND or AUTO will turn green upon pressing to indicate they are enabled. Red indicates disabled. HAND will bypass PLC controls with exception of an ESD, smoke or fire alarm. OFF disables HAND & AUTO. AUTO enables PLC controls.
- 30

- “RUNNING” green display for running equipment. “STOPPED” red display for stopped equipment.
- Red blinking “FAULT” displays appear during an equipment fault. The fault display will be visible until the fault has been cleared and RESET button has been pressed.
- “OFF DELAY SET” displays current EPOD interior lights off (Time after a motion is detected) setpoint. A pop-up keypad will appear when pressed. Enter desired set-point & press enter.
- “START SET” displays current EPOD catadyne heater start time (Required time to start catadyne heater) setpoint. A pop-up keypad will appear when pressed. Enter desired set-point & press enter. START will turn green upon pressing to indicate it’s enabled. When the START SET time has elapsed, the START button will turn Red indicating its disabled. Pressing OFF at any time will disable the START enable.
- Pressing Security “ON” or “OFF” will open the security screen. Enter the USER & PASSWORD (DEFAULT: USER = ADMIN PASSWORD = 1234), press UNLOCK button & then the HOME button. You will be re-directed to the home page. Navigate back to the PROCESS PG.2 page. To enable the security system press security ON button. It will turn green upon pressing to indicate it’s enabled. A pop-up display will blink on all screens indicating the amount of time remaining to exit the EPOD. The non-adjustable time to exit is 60 sec.
- If a motion is detected when the security system is enabled, the OFF button must be pressed (after security screen) within 60sec or an alarm email or output is enabled.

[00084] FIG. 4D shows a “LOGGING” panel screen having the following instructions and controls:

- FT-1000 “ON” will turn green upon pressing to indicate it’s enabled. Red indicates disabled. “TOTAL HRS” displays the amount of time elapsed since enabled. “TOTAL SCF” displays the total SCF of FT-1000 since enabled. Both totals can be reset by pressing the “RESET LOGGING” for 3 seconds. “AVERAGE SCFM” displays the average SCFM (TOTAL SCF/TOTAL HRS/60).

- Compressors and generator “TOTAL HRS” are displayed. Pressing the “RESET TOTAL HRS” opens a pop-up screen asking “ARE YOU SURE” you want to reset the totals. Hold the “RESET TOTAL HRS” for 5 seconds to reset the total. Press “CLOSE” to exit the pop-up screen.
- 5 • Compressor and generator “TOTAL MAINTENANCE HRS” are displayed. Pressing the “RESET THE MAINTENANCE HRS” for 3 seconds will reset the totals.
- “TOTAL MAINTENANCE HRS SET” displays the time setpoint for the (Required time to start Cata-Dyne™ heater) setpoint. A pop-up keypad will
10 appear when pressed. Enter desired set-point & press enter.

[00085] FIG. 4E shows an “ALARMS” panel screen having the following instructions and controls:

- All EPOD alarms are displayed on the Alarm page including the message, date
15 & time. All active alarms will be displayed with a red background. All non-active reset alarms will be displayed with a green background. Alarms are Reset by pressing the RESET button.
- Pressing the UP/DOWN buttons scrolls through the alarms. Pressing the GARBAGE button will delete the alarm.
- 20 • A maximum of 100 alarms can be displayed at once.
- The following are the nEPOD alarms with descriptions:
 - DR-1000 FAULT ALARM (Active alarm when Dryer DR-1000 is de-energized or initiates a fault condition).
 - VFD-K1000A FAULT ALARM (Active alarm when VFD VFD-K1000A
25 initiates a fault condition).
 - VFD-K1000B FAULT ALARM (Active alarm when VFD VFD-K1000B initiates a fault condition)
 - G-1000 FAULT ALARM (Active alarm when Generator G-1000 initiates a fault alarm).
 - 30 • MANUAL ESD ALARM (Active alarm when EPOD manual ESD button is pressed).
 - SD-1000 SMOKE DETECTOR ALARM (Active alarm when EPOD smoke detector initiates a smoke alarm).

- FT-1000 LOSS OF SIGNAL ALARM (Active alarm when FT-1000 loses signal to EPOD PLC).
- PT-1000 LOSS OF SIGNAL ALARM (Active alarm when PT-1000 loses signal to EPOD PLC).
- 5 • TT-1000 LOSS OF SIGNAL ALARM (Active alarm when TT-1000 loses signal to EPOD PLC).
- MD-1000 SECURITY MOTION ALARM (Active alarm 60 sec. (non-adjustable) after MD-1000 detects a motion when the security system is enabled.
- 10 • K-1000A FAIL TO START ALARM (Active alarm when IA motor K-1000A fails to start in LEAD after 5 sec. (non-adjustable).
- K-1000B FAIL TO START ALARM (Active alarm when IA motor K-1000B fails to start in LEAD after 5 sec. (non-adjustable).
- G-1000 FAIL TO START ALARM (Active alarm when Generator G-1000 fails to start in LEAD after 5 sec. (non-adjustable).
- 15 • K-1000A MAINTENANCE ALARM (Active alarm when the K-1000A TOTAL MAINTENANCE HRS is equal to the TOTAL MAINTENANCE HRS SETPOINT).
- K-1000B MAINTENANCE ALARM (Active alarm when the K-1000B TOTAL MAINTENANCE HRS is equal to the TOTAL MAINTENANCE HRS SETPOINT).
- 20 • G-1000 MAINTENANCE ALARM (Active alarm when the K-1000B TOTAL MAINTENANCE HRS is equal to the TOTAL MAINTENANCE HRS SETPOINT).
- 25 • AT-1000 FIRE DETECTOR ALARM (Active alarm when EPOD fire detector initiates a fire alarm).
- AT-1000 LOSS OF SIGNAL ALARM (Active alarm when AT-1000 loses signal to EPOD PLC).

30 **[00086]** **Example 4 – Exemplary mode of operating the generator**

[00087] An exemplary mode of operating the generator in automatic mode or manual mode may involve the following steps:

[00088] TABLE 10 – STEPS FOR AUTOMATIC MODE

<u>Starting:</u> 1. Check Engine Coolant and Oil Levels. 2. Check unit over for signs of damage or missing parts. 3. Check block heater operation. 4. Check battery connection. 5. Check battery charger Operation. 6. Open fuel valve. 7. Turn Key switch on Control panel to on, wait for screen to load. 8. Ensure the main breaker is open. 9. Press the Green Start Button. 10. Unit will crank and come up to speed. 11. Check unit Voltage, frequency to make sure they are correct. 12. Press the Red Stop Button, allow unit to come to complete stop. 13. Press the White Auto Button. 14. Auto Mode Icon will display on screen. 15. Close main breaker.
<u>When the start contacts close:</u> a. Start Delay Timer begins. b. Once start delay timer ends, crank relay is engaged. c. Unit will now run at rated speed until Start Contacts open. d. Start Contacts open. e. Cool down timer begins. f. Once cool down timer ends, unit is stopped. g. Unit stays in ready mode for next start command.
<u>Removing unit from Auto Mode:</u> 1. Press the Red Stop button. 2. Open the main breaker. 3. Turn key switch to off, ensure power has been removed from panel. 4. Close fuel valve.
<u>Note:</u> When unit is in Auto Mode ensure that: 1. Fuel valve remains open. 2. Main breaker remains closed. 3. Battery charger is on. 4. Block heater is on.

[00089] TABLE 11 – STEPS FOR MANUAL MODE

<u>Starting:</u> 1. Check Engine Coolant and Oil Levels 2. Check unit over for signs of damage or missing parts 3. Check block heater operation 4. Check battery connection 5. Check battery charger Operation 6. Open fuel valve 7. Turn Key switch on Control panel to on, wait for screen to load

8. Ensure the main breaker is open 9. Press the Green Start Button 10. Unit will crank and come up to speed 11. Check unit Voltage, frequency to make sure they are correct 12. Close main breaker
<u>Stopping:</u> 1. Press the Red Stop button 2. Open the main breaker 3. Turn key switch to off, ensure power has been removed from panel 4. Close Fuel valve

[00090] Example 5 – Exemplary mode of operation of a duplex 5 HP air compressor

- 5 **[00091]** An exemplary mode of operating a duplex 5 HP air compressor may involve the following steps:

[00092] TABLE 12 – Steps for Operating Duplex 5 HP Air Compressor

1. Inspect unit for any visible signs of damage that would have occurred in shipment or during installation. 2. Pull main disconnect switch to unit to assure that no power is coming into the unit. “Lock Out” or “Tag Out” switch. Connect power leads to start. 3. Check compressor oil level. Add oil as required 4. Activate main disconnect switch. 5. “Jog” motor and check for proper rotation by direction arrow. If rotation is wrong, reverse input connections on the magnetic starter. 6. Close receiver outlet hand valve and start. 7. With receiver hand valve closed, let machine pump up to operating pressure. At this stage the automatic controls will take over. Check for proper cycling operation. 8. Check for proper operation of any options. 9. When the initial run period has shown no operating problems, shut unit down and recheck oil level. 10. Open receiver hand valve. The air compressor unit is now ready for use.

10 **[00093] Example 6 – Exemplary mode of operation**

- [00094]** An exemplary mode of operation for the unit is to minimize engine run time. Ideally average annual run time should be around 30-40%, with the remainder of site load (including air compressor load) handled by solar and/or wind. Since maintenance cycles on the air compressor and generator are similar at approximately 2500 hours between oil changes, the air compressor should be sized for approximately 30% duty cycle per
- 15

compressor (60% duty cycle if using a duplex compressor system). Note that further reduced instrument air run time can sometimes be beneficial if it reduces total engine runtime.

[00095] Additional Disclosures

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[00096] The following are non-limiting, specific embodiments of the system, module, and methods of generating power on demand and off-grid:

[00097] Embodiment A. A system for generating power on demand and off-grid comprising: a power source using a renewable resource; an uninterruptible power supply (UPS) comprising a storage battery and coupled to the power source for receiving DC or AC power; and an intelligent controller coupled to the UPS for controlling output of the DC or AC power to one or more devices.

10
[00098] Embodiment B. The system of Embodiment A, wherein the power source for delivering the DC power is a photovoltaic array.

[00099] Embodiment C. The system of Embodiment A or B, further comprising a battery charge controller coupled to the power source for regulating the DC power.

20

[000100] Embodiment D. The system of any one of Embodiments A through C, wherein the power source for delivering the AC power is selected from a generator or a utility power connection.

25 **[000101]** Embodiment E. The system of any one of Embodiments A through D, wherein the power source comprises a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas.

[000102] Embodiment F. The system of Embodiment E, wherein the hydrocarbon gas
30 is filtered through a coalescing filter to remove free liquid.

[000103] Embodiment G. The system of Embodiment E or F, wherein the engine comprises an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts.

5 **[000104]** Embodiment H. The system of any one of Embodiments A through G, wherein the storage battery is coupled to the generator by a bi-directional power inverter, the bi-directional power inverter being configured, in a first mode of operation, to receive and convert the DC power into AC power, and in a second mode of operation, to receive and convert AC power into DC power for charging the storage battery.

10

[000105] Embodiment I. The system of Embodiment H, wherein the bi-directional power inverter qualifies the DC or AC power and switches loads within a set timeframe to ensure uninterrupted transition from the storage battery to the generator.

15 **[000106]** Embodiment J. The system of Embodiment H, wherein the bi-directional power inverter comprises an AC transfer switch for providing the AC power from one or more AC power sources.

[000107] Embodiment K. The system of any one of Embodiments A through J, further
20 comprising one or more of a DC power distribution unit and an AC power distribution unit for supplying power to one or more devices.

[000108] Embodiment L. The system of any one of Embodiments A through K,
25 wherein the one or more devices comprises at least one air compressor capable of providing compressed air to one or more pneumatic devices.

[000109] Embodiment M. A system for generating power on demand and off-grid comprising: a photovoltaic array for delivering DC power; a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas
30 filtered through a coalescing filter and comprising an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts; an uninterruptible power supply (UPS) comprising a storage battery, the UPS being coupled to the photovoltaic array for receiving the DC power, and to the

generator by a bi-directional inverter for receiving DC or AC power; and an intelligent controller coupled to the UPS for controlling output of the DC or AC power to at least one air compressor capable of providing compressed air to one or more pneumatic devices.

5 **[000110]** Embodiment N. A system for generating power on demand and off-grid comprising: a photovoltaic array for delivering DC power; a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting
10 combustion byproducts; an uninterruptible power supply (UPS) comprising a storage battery, the UPS being coupled to the photovoltaic array for receiving the DC power, and to the generator by a bi-directional inverter for receiving DC or AC power; and an intelligent controller coupled to the UPS for controlling output of the DC or AC power to one or more devices.

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[000111] Embodiment O. A system for generating power on demand and off-grid comprising: a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an extended lubrication system for slipstreaming a portion of oil through a filter
20 to extend service intervals, and diluting combustion byproducts; a power storage device coupled to the generator by a bi-directional power inverter for receiving DC or AC power; and an intelligent controller coupled to the storage battery for controlling output of the DC or AC power to one or more devices.

25 **[000112]** Embodiment P. A system for generating power on demand and off-grid comprising: an on-site power source for powering an air compressor capable of providing compressed air to one or more pneumatic devices; and an intelligent controller for collecting data in relation to carbon credit generation.

30 **[000113]** Embodiment Q. A module formed of a modified shipping container and comprising the system of any one of Embodiments A-P.

[000114] Embodiment R. The module of Embodiment Q, further comprising one or more of a motion sensor, lighting system, smoke detector, space heater using renewable energy, and heating, ventilation, and air conditioning system.

5 **[000115]** Embodiment S. A method for generating power on demand and off-grid using the system or module of any one of embodiments A through R, the method comprising: converting sunlight rays into DC power using a photovoltaic array; supplying hydrocarbon gas recovered from a wellhead to operate an engine of a generator to generate AC power; conditioning the DC or AC power using a bi-directional inverter to output conditioned DC or
10 AC power; delivering the conditioned DC or AC power to a UPS comprising a storage battery; and controlling output of the DC or AC power to operate at least one air compressor for providing compressed air to one or more pneumatic devices.

[000116] Embodiment T. The method of Embodiment S, wherein the hydrocarbon gas
15 is filtered through a coalescing filter.

[000117] Embodiment U. The method of Embodiment S or T, wherein the engine comprises an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts.
20

[000118] Embodiment V. The method of any one of Embodiments S through U, wherein conditioning the DC or AC power comprises converting the DC power to AC power, or the AC power to DC power.

25 **[000119]** Embodiment W. A method for generating power on demand and off-grid using the system or module of any one of embodiments A through R, the method comprising: converting sunlight rays into DC power using a photovoltaic array; supplying hydrocarbon gas to operate an engine of a generator to generate AC power; conditioning the DC or AC power using a bi-directional inverter to output conditioned DC or AC power; delivering the
30 conditioned DC or AC power to a UPS comprising a storage battery; and controlling output of the DC or AC power to operate one or more devices.

[000120] Embodiment X. A method for generating power on demand and off-grid using the system or module of any one of embodiments A through R, the method comprising: supplying hydrocarbon gas to operate an engine of a generator to generate AC power; conditioning the DC or AC power using a bi-directional inverter to output conditioned DC or AC power; delivering the conditioned DC or AC power to a power storage device; and
5 controlling output of the DC or AC power to operate one or more devices.

[000121] Embodiment Y. A method for generating power on demand and off-grid using the system or module of any one of embodiments A through R, the method comprising:
10 supplying power from an on-site power source to an air compressor capable of providing compressed air to one or more pneumatic devices; and collecting data in relation to carbon credit generation.

[000122] Additional embodiments which result from combining, integrating and/or omitting features of the embodiments explicitly described herein are not intended to be
15 precluded. Although various embodiments have been shown and described, the invention is not limited to such embodiments and will be understood to include all modifications and variations as would be apparent to one skilled in the art. It should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the intention
20 is to cover all modifications, equivalents and alternatives falling within the scope of the invention as defined by the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A system for generating power on demand and off-grid comprising:
5 a power source using a renewable resource;
an uninterruptible power supply (UPS) comprising a storage battery and coupled to the power source for receiving DC or AC power; and
an intelligent controller coupled to the UPS for controlling output of the DC or AC power to one or more devices.
10
2. The system of claim 1, wherein the power source for delivering the DC power is a photovoltaic array.
3. The system of claim 2, further comprising a battery charge controller coupled to the
15 power source for regulating the DC power.
4. The system of claim 1, wherein the power source for delivering the AC power is selected from a generator or a utility power connection.
- 20 5. The system of claim 4, wherein the power source comprises a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas.
6. The system of claim 5, wherein the hydrocarbon gas is filtered through a coalescing
25 filter to remove free liquid.
7. The system of claim 5, wherein the engine comprises an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts.
30
8. The system of claim 1, wherein the storage battery is coupled to the generator by a bi-directional power inverter, the bi-directional power inverter being configured, in a first mode

of operation, to receive and convert the DC power into AC power, and in a second mode of operation, to receive and convert AC power into DC power for charging the storage battery.

9. The system of claim 8, wherein the bi-directional power inverter qualifies the DC
5 power or the AC power and switches loads within a set timeframe to ensure uninterrupted transition from the storage battery to the generator.

10. The system of claim 8, wherein the bi-directional power inverter comprises an AC transfer switch for providing the AC power from one or more AC power sources.

10

11. The system of claim 1, further comprising one or more of a DC power distribution unit and an AC power distribution unit for supplying power to one or more devices.

12. The system of claim 11, wherein the one or more devices comprises at least one air
15 compressor capable of providing compressed air to one or more pneumatic devices.

13. A system for generating power on demand and off-grid comprising:
a photovoltaic array for delivering DC power;
a generator having a size ranging from about 5 kW to about 30 kW, and comprising
20 an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts;
an uninterruptible power supply (UPS) comprising a storage battery, the UPS being coupled to the photovoltaic array for receiving the DC power, and to the generator by a bi-
25 directional inverter for receiving DC or AC power; and
an intelligent controller coupled to the UPS for controlling output of the DC or AC power to at least one air compressor capable of providing compressed air to one or more pneumatic devices.

30 14. A system for generating power on demand and off-grid comprising:
a photovoltaic array for delivering DC power;
a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an

extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts;

an uninterruptible power supply (UPS) comprising a storage battery, the UPS being coupled to the photovoltaic array for receiving the DC power, and to the generator by a bi-directional inverter for receiving DC or AC power; and

an intelligent controller coupled to the UPS for controlling output of the DC or AC power to one or more devices.

15. A system for generating power on demand and off-grid comprising:

10 a generator having a size ranging from about 5 kW to about 30 kW, and comprising an engine powered by hydrocarbon gas filtered through a coalescing filter and comprising an extended lubrication system for slipstreaming a portion of oil through a filter to extend service intervals, and diluting combustion byproducts;

a power storage device coupled to the generator by a bi-directional power inverter for receiving DC or AC power; and

an intelligent controller coupled to the storage battery for controlling output of the DC or AC power to one or more devices.

16. A system for generating power on demand and off-grid comprising:

20 an on-site power source for powering an air compressor capable of providing compressed air to one or more pneumatic devices; and

an intelligent controller for collecting data in relation to carbon credit generation.

17. A module formed of a modified shipping container and comprising the system of any one of claims 1-16.

18. The module of claim 17, further comprising one or more of a motion sensor, lighting system, smoke detector, space heater using renewable energy, and heating, ventilation, and air conditioning system.

19. A method for generating power on demand and off-grid using the system of claim 13, the method comprising:

converting sunlight rays into DC power using a photovoltaic array;

supplying hydrocarbon gas to operate an engine of a generator to generate AC power;
conditioning the DC or AC power using a bi-directional inverter to output conditioned
DC or AC power;

5 delivering the conditioned DC or AC power to a UPS comprising a storage battery;
and

controlling output of the DC or AC power to operate at least one air compressor for
providing compressed air to one or more pneumatic devices.

10 20. The method of claim 19, wherein the hydrocarbon gas is filtered through a coalescing
filter.

21. The method of claim 19, wherein the engine comprises an extended lubrication
system for slipstreaming a portion of oil through a filter to extend service intervals, and
diluting combustion byproducts.

15

22. The method of claim 19, wherein conditioning the DC or AC power comprises
converting the DC power to AC power, or the AC power to DC power.

20 23. A method for generating power on demand and off-grid using the system of claim 14,
the method comprising:

converting sunlight rays into DC power using a photovoltaic array;

supplying hydrocarbon gas to operate an engine of a generator to generate AC power;

conditioning the DC or AC power using a bi-directional inverter to output conditioned
DC or AC power;

25 delivering the conditioned DC or AC power to a UPS comprising a storage battery;
and

controlling output of the DC or AC power to operate one or more devices.

30 24. A method for generating power on demand and off-grid using the system of claim 15,
the method comprising:

supplying hydrocarbon gas to operate an engine of a generator to generate AC power;

conditioning the DC or AC power using a bi-directional inverter to output conditioned
DC or AC power;

delivering the conditioned DC or AC power to a power storage device; and
controlling output of the DC or AC power to operate one or more devices.

25. A method for generating power on demand and off-grid using the system of claim 16,
5 the method comprising:

supplying power from an on-site power source to an air compressor capable of
providing compressed air to one or more pneumatic devices; and
collecting data in relation to carbon credit generation.

10

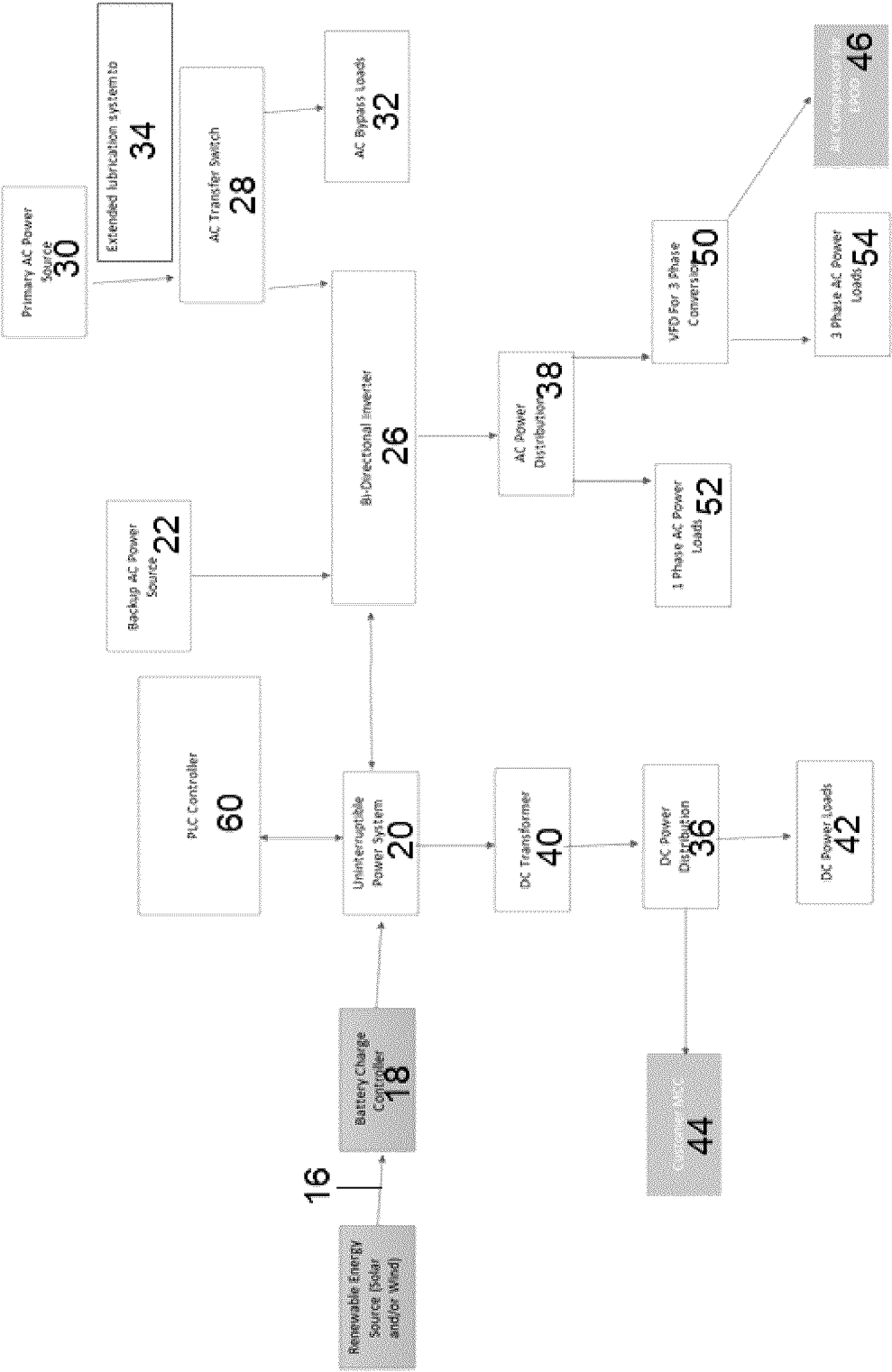


FIG. 1

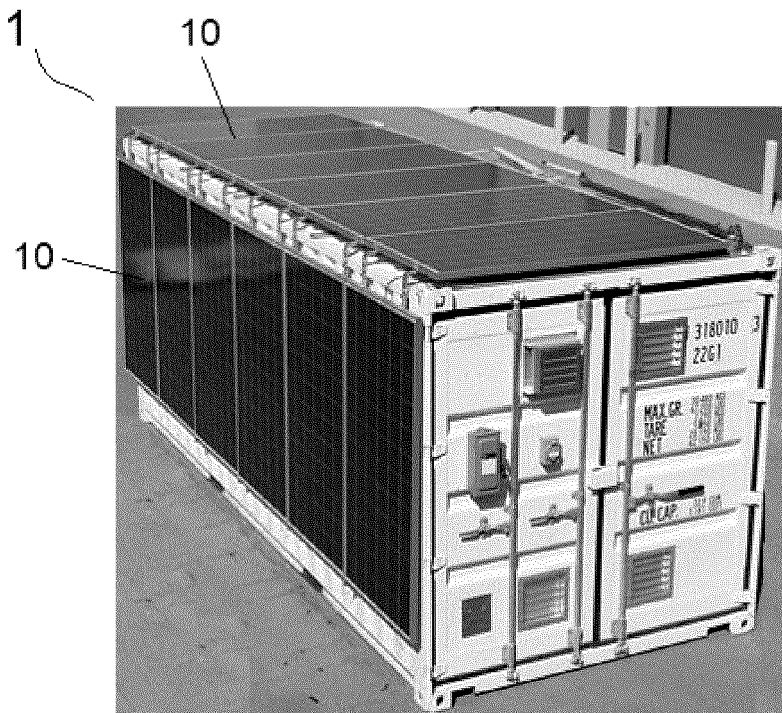


FIG. 2A

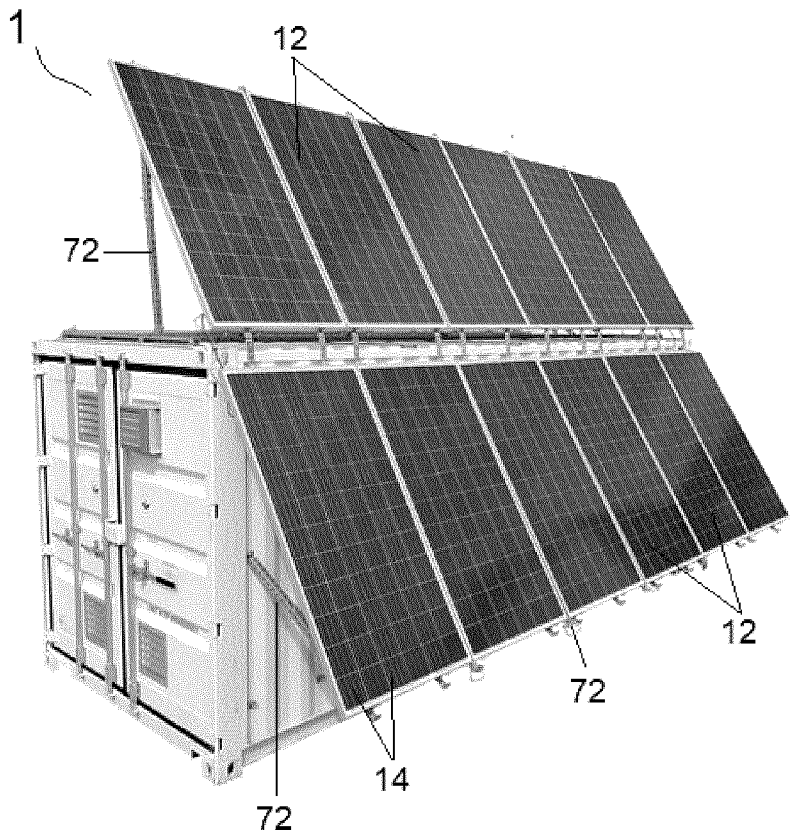


FIG. 2B

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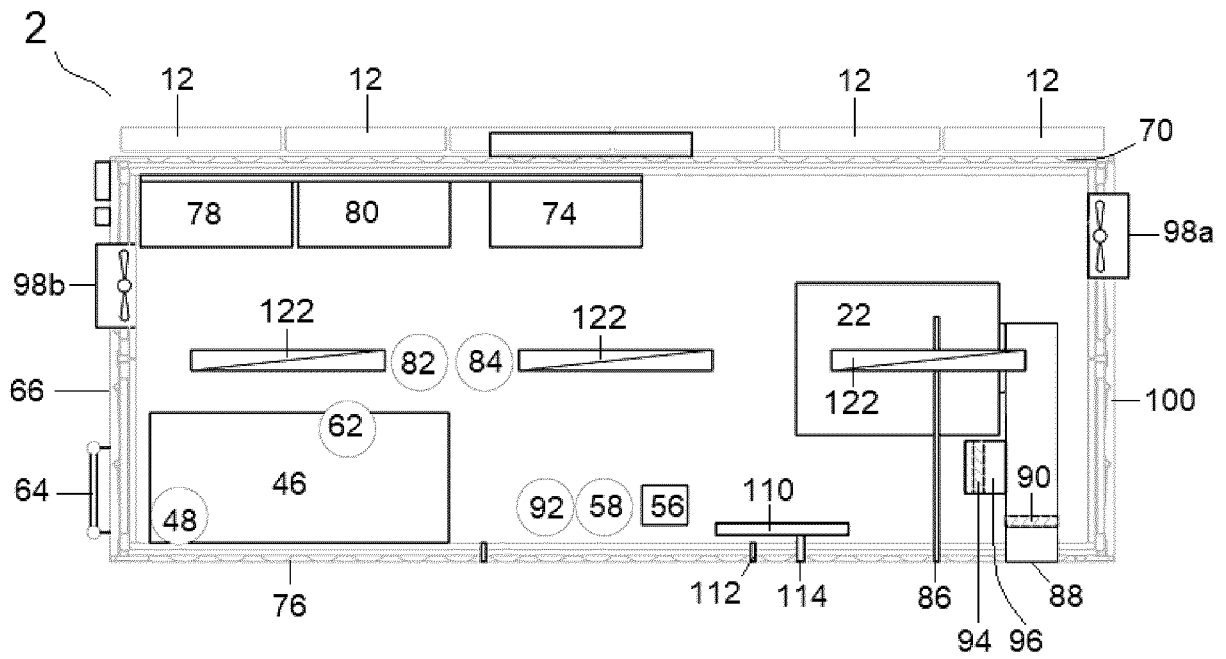


FIG. 2C

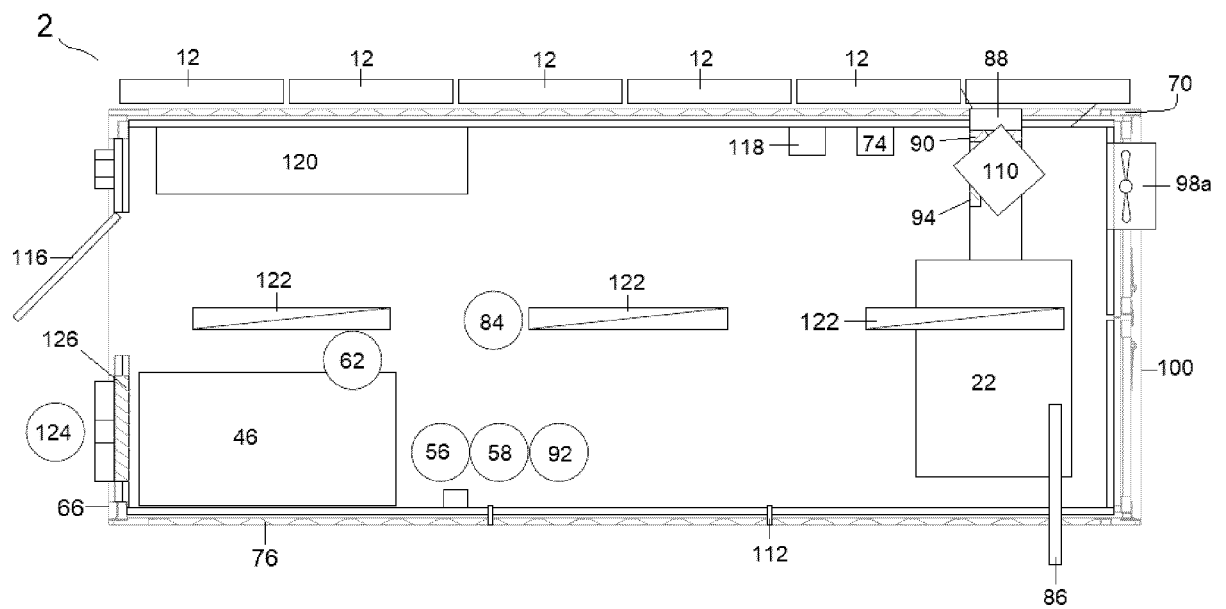


FIG. 3A

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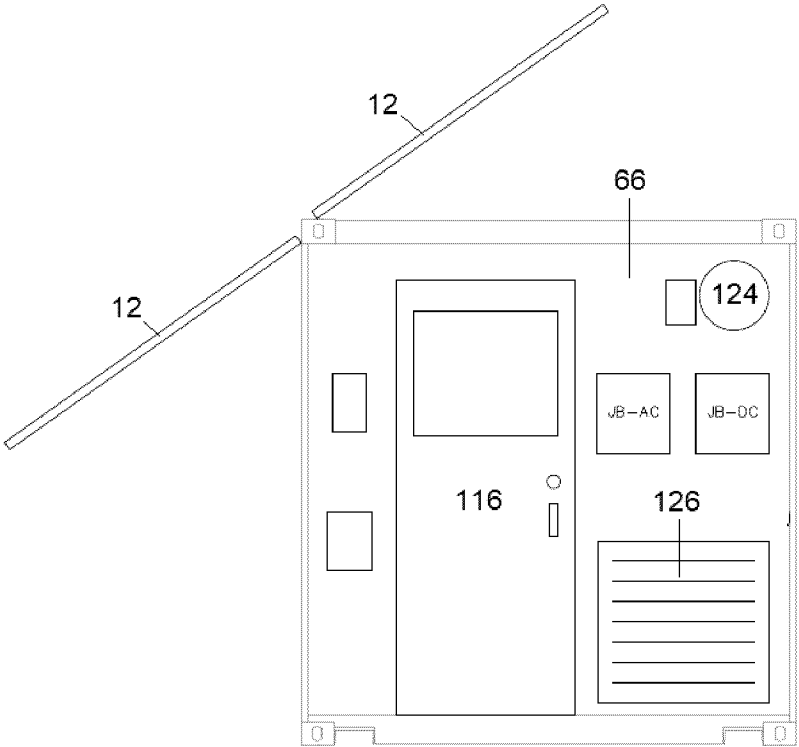


FIG. 3B

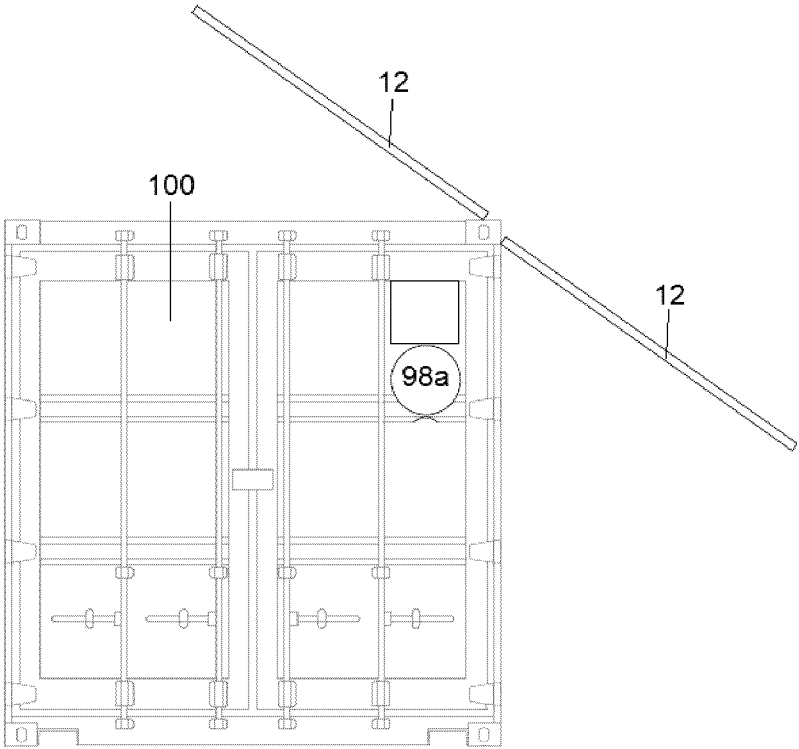


FIG. 3C

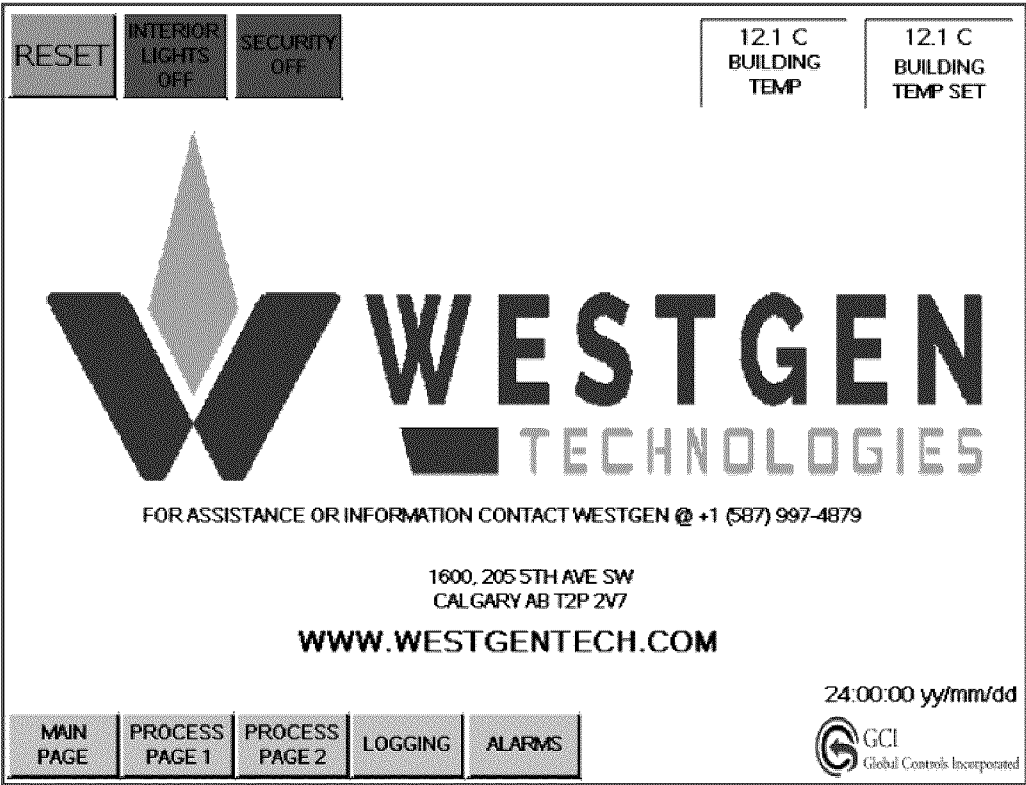


FIG. 4A

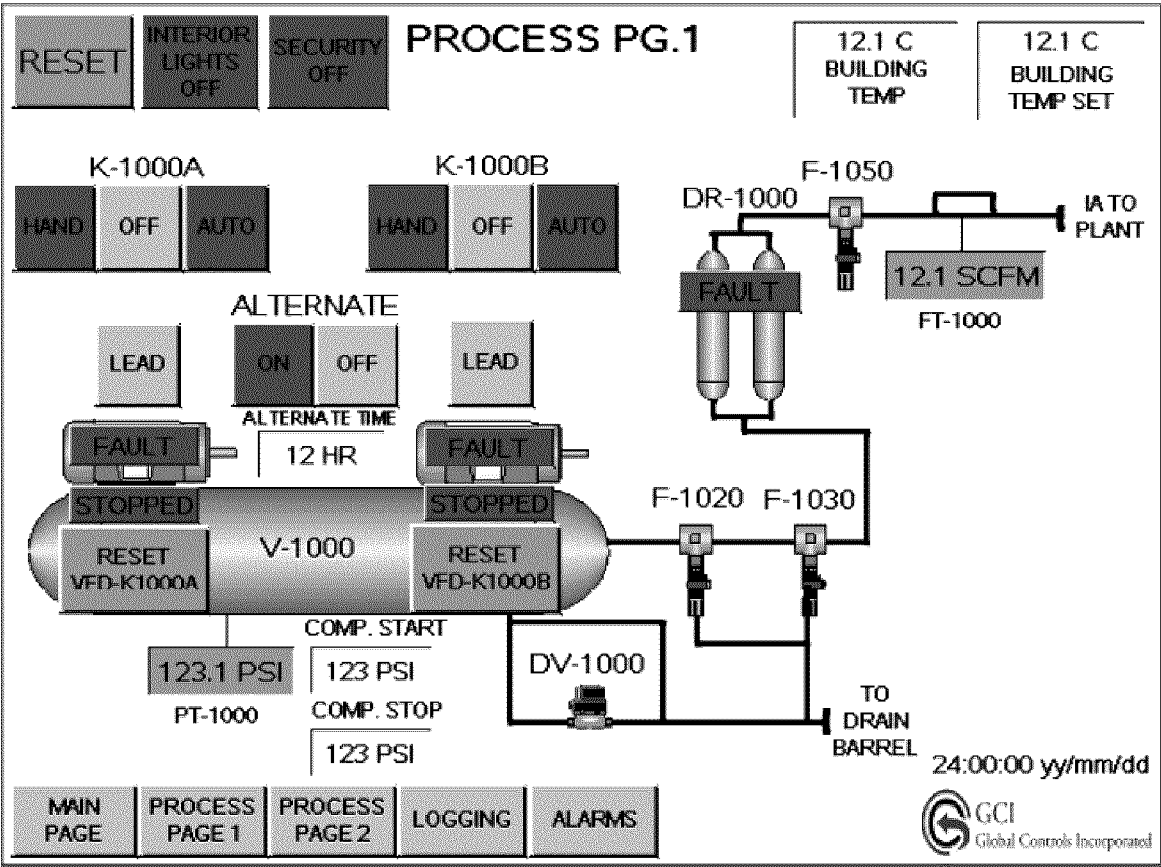


FIG. 4B

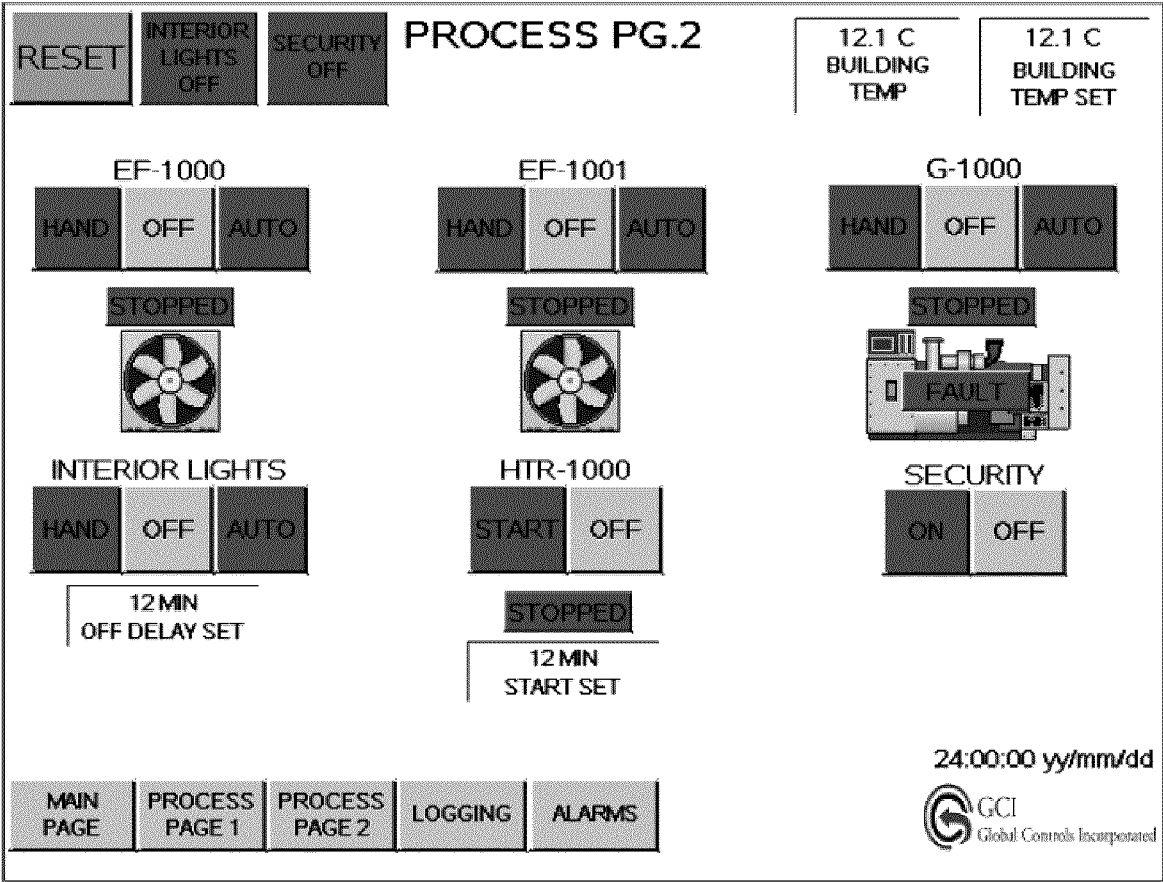
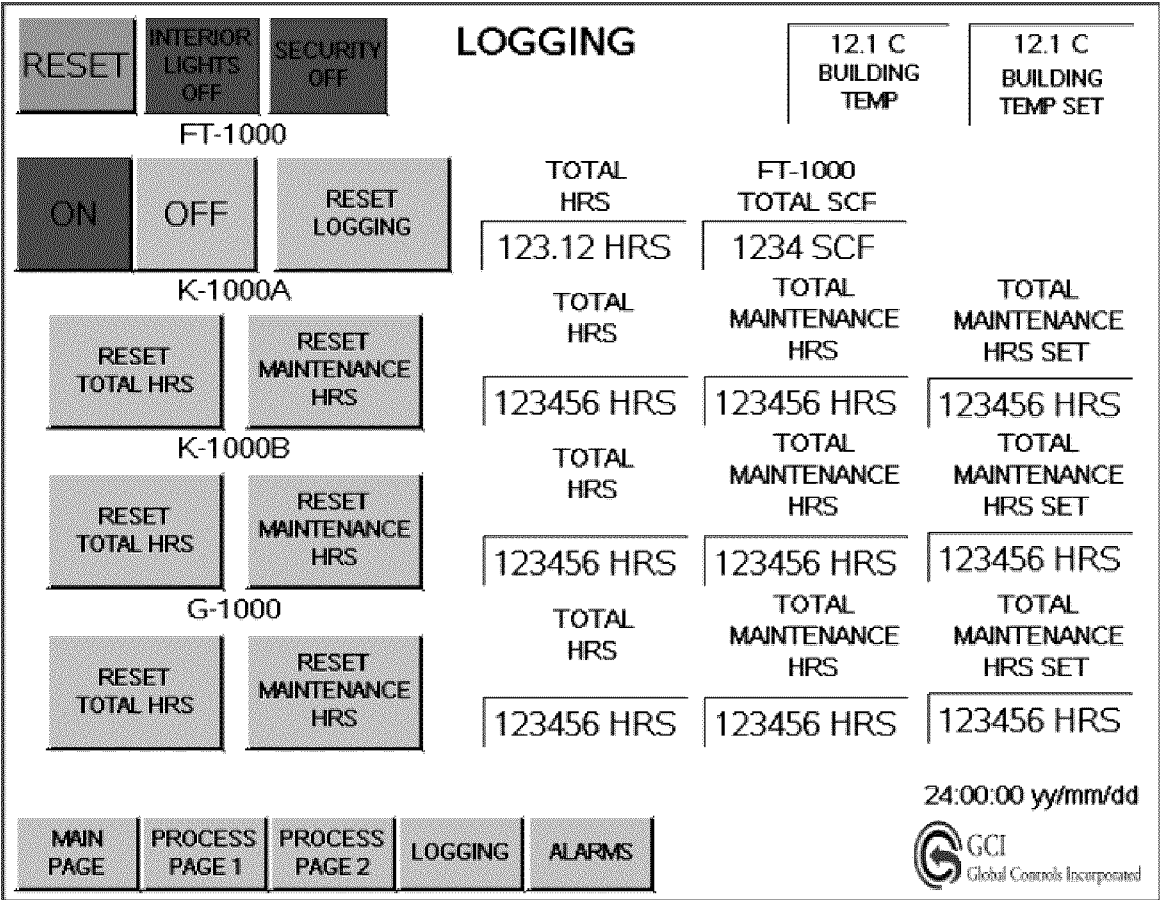


FIG. 4C



24:00:00 yy/mm/dd

MAIN PAGE

PROCESS PAGE 1

PROCESS PAGE 2

LOGGING

ALARMS

GCI

Global Controls Incorporated

FIG. 4D

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[illegible]

FIG. 4E



US 20160091000A1

(19) **United States**(12) **Patent Application Publication**
GALLINO(10) **Pub. No.: US 2016/0091000 A1**(43) **Pub. Date: Mar. 31, 2016**(54) **DEVICE FOR THE STORAGE AND
GENERATION OF POWER**(71) Applicant: **SWISS GREEN SYSTEMS SAGI,**
Lugano (CH)(72) Inventor: **Gianfranco GALLINO,** Bellinzona
(CH)(21) Appl. No.: **14/891,460**(22) PCT Filed: **May 2, 2014**(86) PCT No.: **PCT/IB2014/000650**

§ 371 (c)(1),

(2) Date: **Nov. 16, 2015**(30) **Foreign Application Priority Data**

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(2013.01); **F15B 21/14** (2013.01); **F15B**
2015/1495 (2013.01); **F15B 2211/7058**
(2013.01)

(57)

ABSTRACT

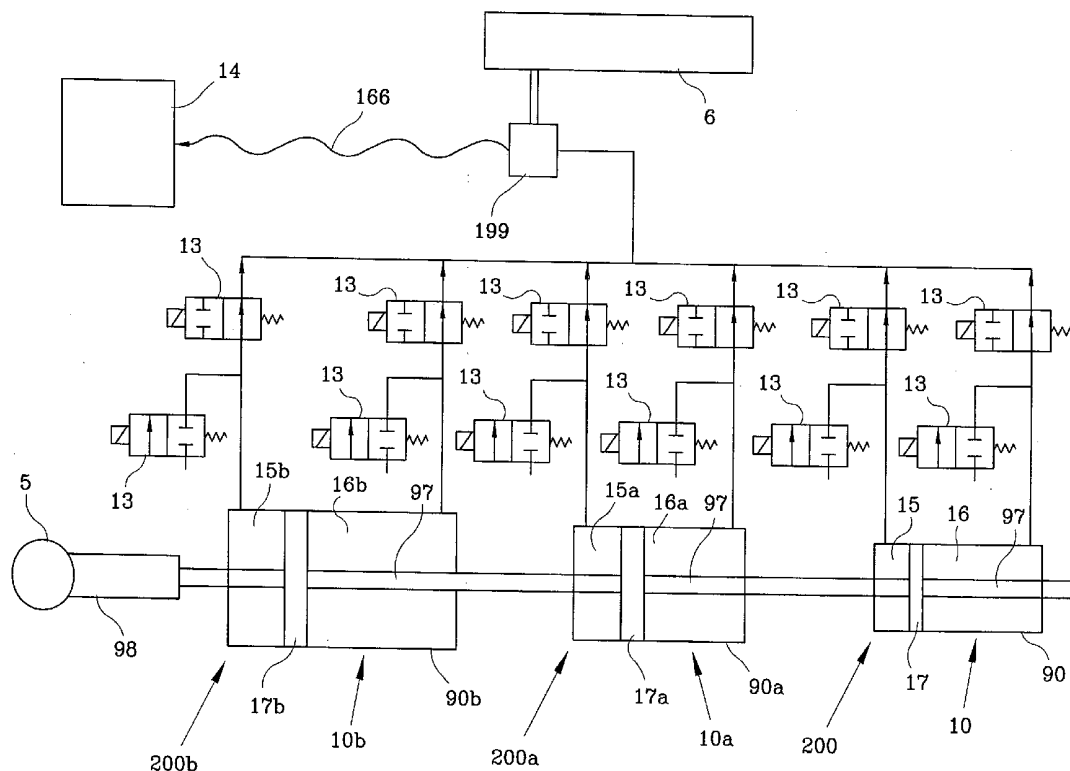
Device (100) for the storage and production of electric power includes:

at least one energy source, preferably a source (400) of renewable energy;

at least one pump (200), supplied by the energy source (400), adapted to compress the air inside a storage tank (6) of compressed air so that to feed it to at least one primary pneumatic actuator (1) connected to at least one secondary pneumatic actuator (1a), preferably connected to a plurality of secondary pneumatic actuators (1a, 1b, 1c), via pressurized pipings (3 and 4) and electrovalves (150 and 298);

at least one transmission assembly (21) adapted to transform the reciprocating rotary motion of the pneumatic actuators (1, 1a, 1b, 1c) in a constant rotary motion;

at least one electric generator connected to the transmission assembly (21) adapted to produce electric power when necessary.



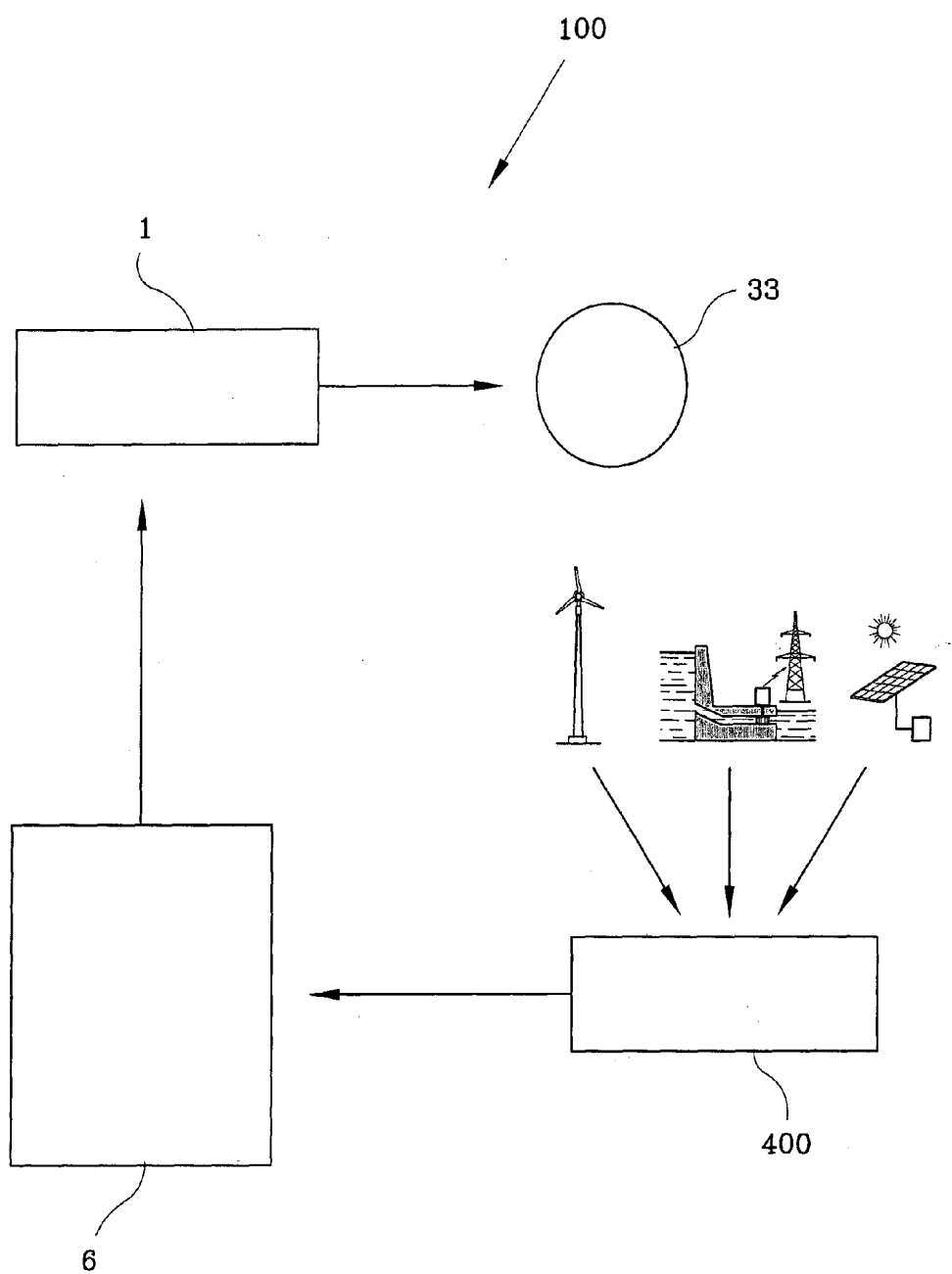
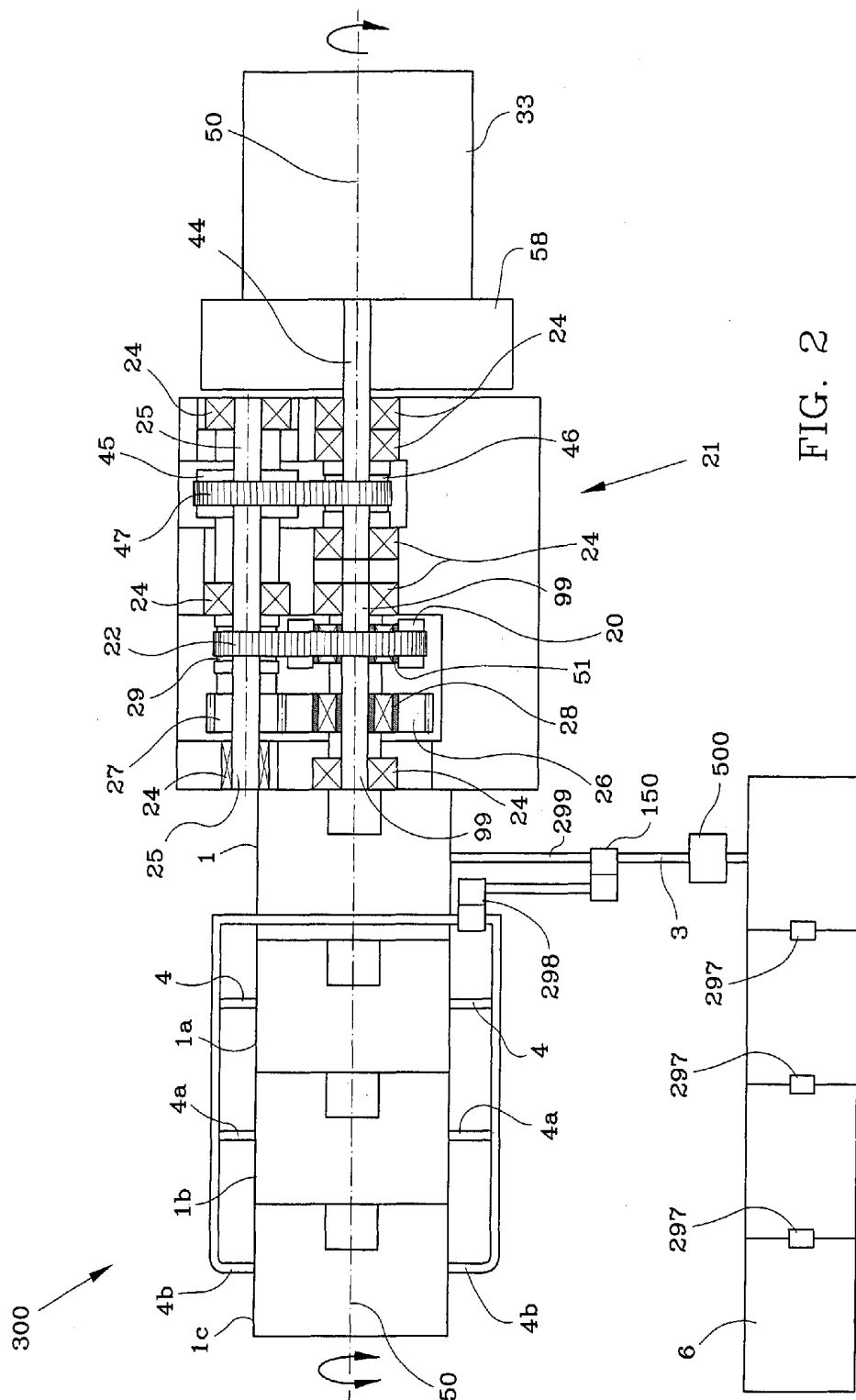


FIG. 1



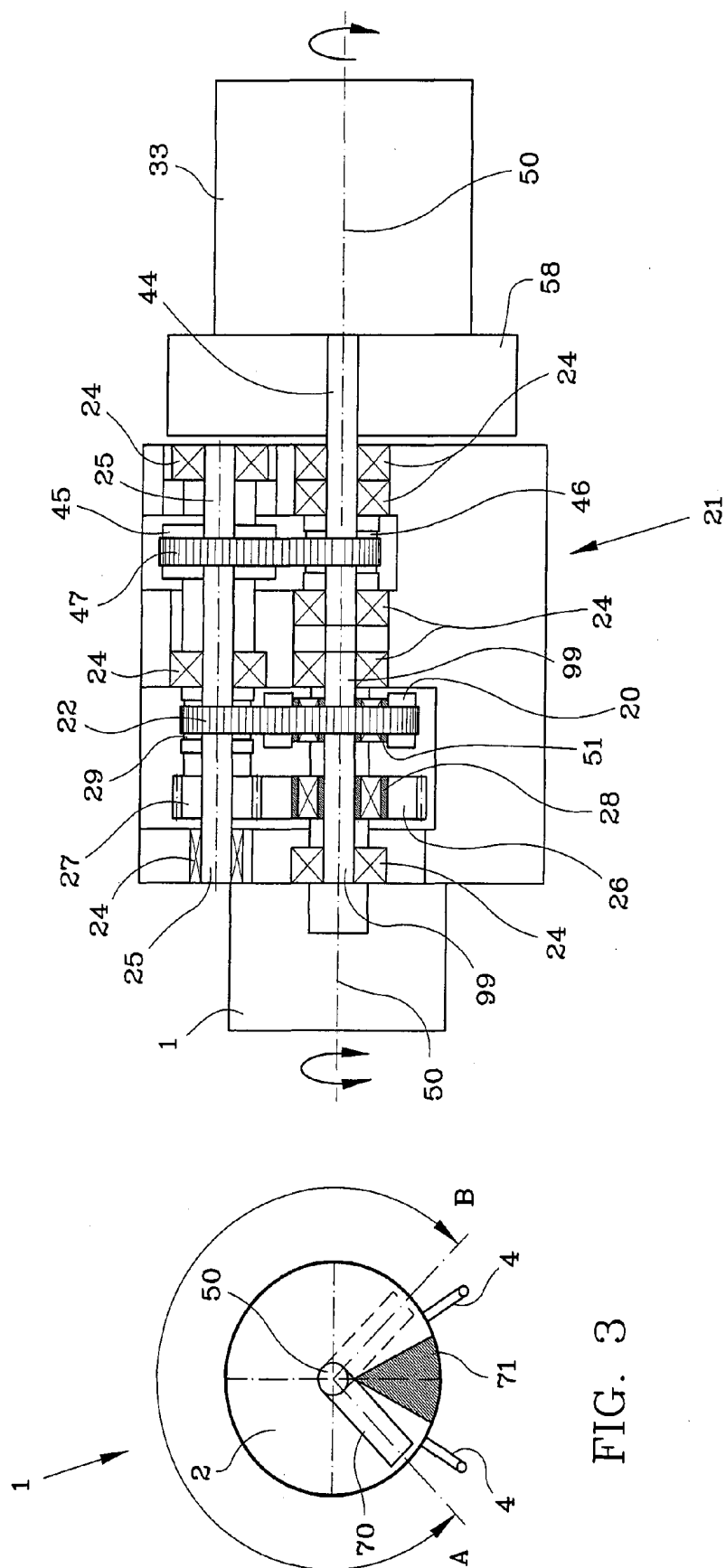


FIG. 4

FIG. 3

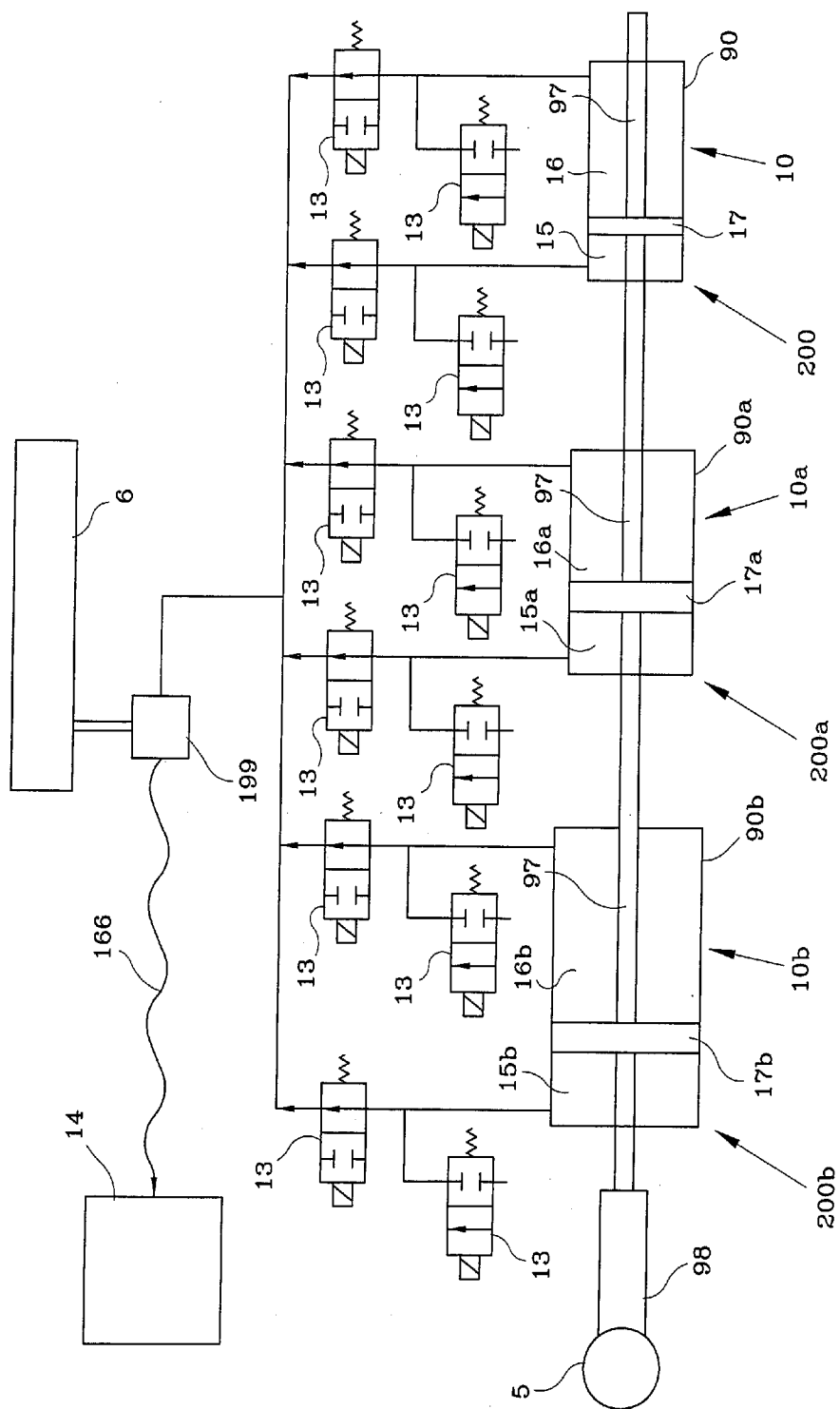


FIG. 5

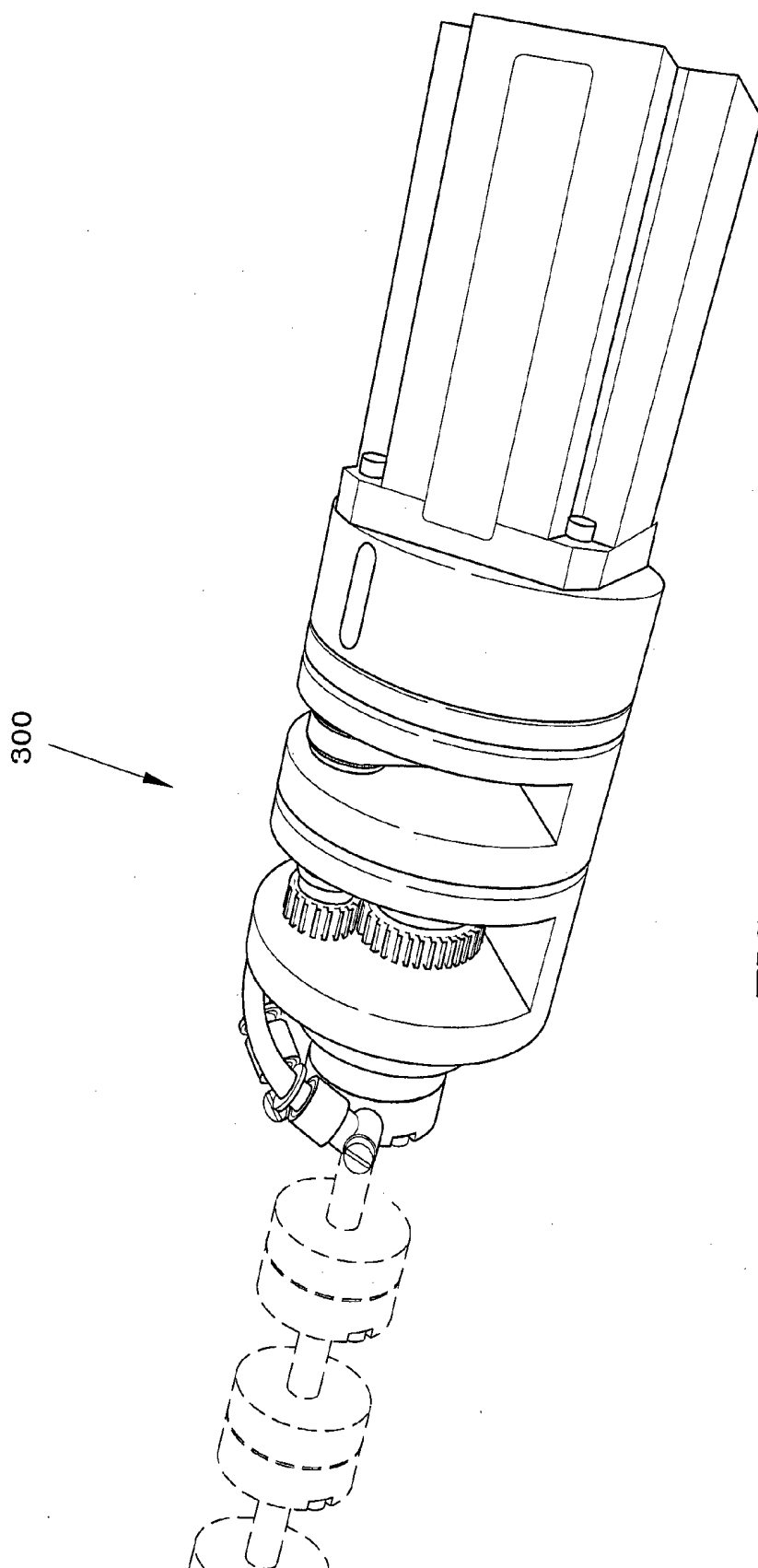


FIG. 6

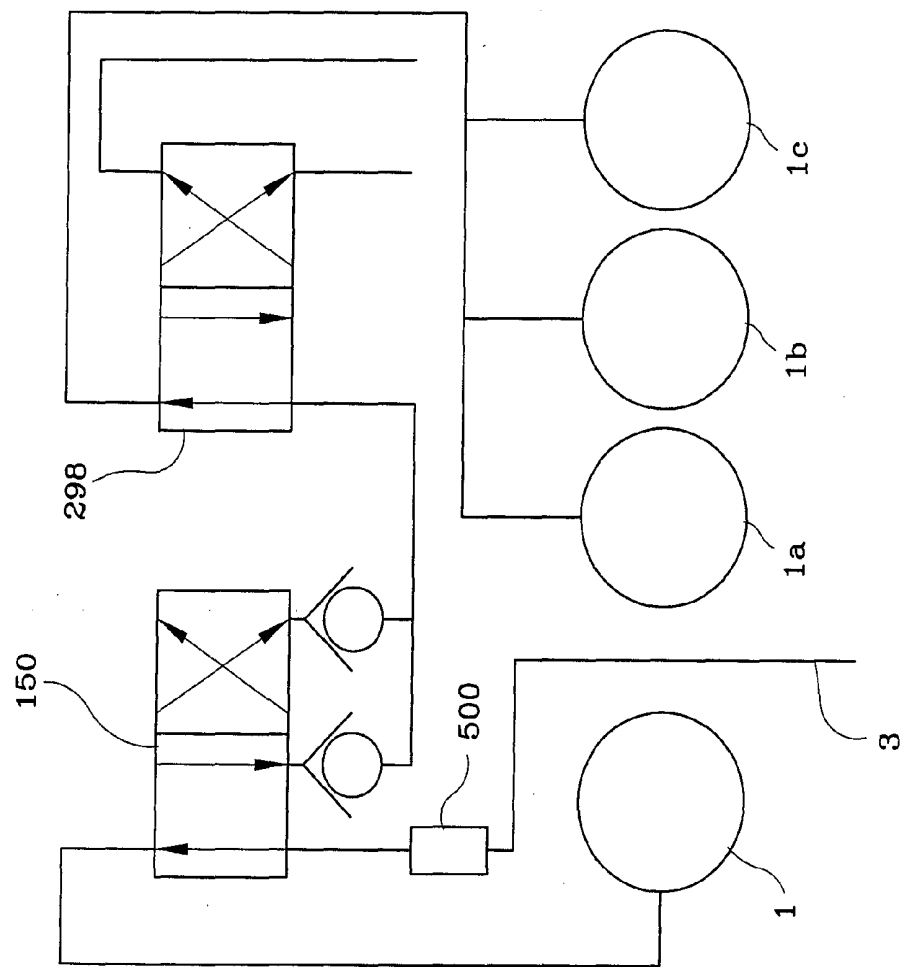


FIG. 7

DEVICE FOR THE STORAGE AND GENERATION OF POWER

STATE OF THE ART

[0001] At the present time all industrial devices adapted for the production of non-renewable electric power, independently from their size, are characterized by a poor thermodynamic efficiency. Classic internal combustion engines, independently from being two stroke or four stroke engines and independently from being fed with petrol, kerosene, methane, LPG or gas oil, have unfortunately a mechanical efficiency lower than 30%. The unsolved problem of all internal combustion devices currently available on the market is the extreme energy waste related to the intrinsic heat production typical of the structure and design itself of these engines. The speed, at which the combustion happens, together with their mechanical complexity, dissipates inevitably a high energy amount as heat. Obviously, in order to disperse in the environment the uselessly produced heat, every internal combustion engine is inevitably combined with bulky exchangers or radiators, adapted to dissipate the produced thermal power. In addition, toxic emissions are inevitably associated with the existing internal combustion engines, coming from the combustion of the used hydrocarbons themselves, which are harmful for both the environment and the human health. On the whole, also hydrogen engines demonstrated to have a very little energy efficiency, even lower than 40%. Similarly, all thermal power plants actually working have similar criticality. Poor thermodynamic efficiencies, emissions harmful for the environment and high heat production. Due to the size of this typology of industrial plants, the loss of produced heat is so high to recommend to locate these thermal power plants next to rivers, lakes or still better next to the sea. Speaking about energy: the situation is critical and anyway correlated to devices and plants which are conceptually outworn and provided with poor efficiency and little performance. The overall situation is even worse if criticalities related to the production of atomic energy are analyzed. In this case, in addition to the poor plant efficiency, high production costs and little operative duration of the same, unsolved problems relating the production of radioactive wastes, their management and safe disposal have to be added. As if all this was not enough, all dimensionally significant plants for the production of non-renewable energy, have the disadvantage of being little adaptable, i.e. they are plants that, because of their size and design, are not able at all to modulate their power production over time, or they can do it only partially. The power requirement of each country is very variable over 24 hours, as anyone knows. As a matter of fact, the consumption varies appreciably as a function of user requirements during twenty four hours, so that in Italy the consumption changes from 22 GW in the middle of the night to over 50 GW around noon. In conclusion, the energy consumption varies of 60% during the day, thereby assuming a high modulation ability of production plants. As previously mentioned, most of all the greatest thermal power plants and nuclear plants have great difficulties in reducing or increasing suddenly their power production. This situation causes an energy imbalance in domestic electric networks, thereby methods and devices adapted to allow the power storage when the requirements are lower become essential, i.e. during the night, making it again available when the requirements are greater such as, for example, during the day. In every country this intermittent requirement of electric power further decreases the efficiency of power systems,

revealing the need of having a new and efficient method adapted to allow the power storage when there are lower requirements, but allowing its sudden release at user needs. Desirably, all this is carried out with a high efficiency.

FIELD OF THE INVENTION

[0002] The present invention has the intention to solve all the afore said drawbacks, describing an innovative device for the storage and production of electric power that has to be safe, inexpensive and able to store high power amounts but, at the same time, being able to return it again on the electric network in a highly efficient way as requirements of electric power increase.

DESCRIPTION OF THE INVENTION

[0003] The present Application describes and claims an innovative electropneumatic device substantially composed of two independent sub-units, connected one to another through a common pressurized piping.

[0004] The first sub-unit is composed of a pump, preferably it is composed of a plurality of pumps, still more preferably it is composed of a series of three pumps, which are adapted to allow the potential energy to be stored as compressed air inside one or more apposite storage tanks of said compressed air, so that to be able to feed it to the second sub-unit through at least one pressurized piping.

[0005] Said second sub-unit is composed of at least one couple of motors or pneumatic actuators, preferably a plurality of pneumatic actuators, activated in an orderly sequence according to a precise scheduled scheme by the compressed air previously stored up in the storage tank and fed to the first of said pneumatic actuators through a pressurized piping. The reciprocating oscillatory motion, made by said activated pneumatic actuators, is transmitted to a transmission assembly adapted to transform the oscillatory motion typical of said pneumatic actuators in a continuous rotary movement, said transmission assembly being in turn connected to a conventional electric generator.

[0006] The first sub-unit of the present invention is provided with an appropriate storage tank, said storage tank of compressed air can be any tank sufficiently strong and safe for the containment of said air, alternatively, said tank can be made so as to have, in its inside, a plurality of sectors, preferably four sectors, adapted to delimit zones of compressed air characterized by different pressures. For example, a zone with maximum pressure at about 80, 100 bars, a zone of medium pressure at about 40, 60 bars, a zone of low pressure at about 25, 30 bars, and lastly a zone of maximum pressure at about 15, 20 bars. Said zones are connected one to another by at least one pressure reducer, independently from how many they are. Said devices for reducing the pressure can be electrically controlled conventional taps adapted to be opened and closed to create or prevent the connection among different independent zones of said tank, so as to distribute the compressed air among said zones according to what imposed by the control unit. The control unit analyzes data coming from the manometers placed in every independent zones, by processing them in order to optimize the distribution of compressed air inside every single zone and the whole tank, so as to maintain the desired pressure as a function of the instant consumption and the instant pumping capacity (related to the power available at that time). This differentiation in the inner structure of the storage tank of the compressed air allows to

store up great air amounts at high pressures in relatively little spaces. This is an essential feature in case renewable energy is available. These energy sources, as a matter of fact, being bound to the unforeseeability of weather conditions, independently from being wind or solar energy, must be necessarily stored up in great amounts as compressed air, when the nature makes them available. As a consequence the need of a multi-stage tank arises, which is relatively little and then able to be installed in every garden or roof of every building, and adapted to store up great amounts of high pressure compressed air, up to about 80, 100 bars. The described tank is equipped with a plurality of electrically controlled taps, as many as the compartments it is provided with, so as to feed the primary pneumatic actuators at a pressure of compressed air of about 10 bars. For plants having greater dimensions and for storing great amounts of compressed air, galleries and tunnels present on the territory but no longer in use can be employed. Thanks to the generous capacity of these cavities, great amounts of compressed air can be stored effectively just in hours in which the power requirement is minimum. The tightness, the management simplicity and the total absence of toxicity of this power storage technique allows economic saving, an optimum safe level and duration almost unlimited of these storage deposits. As it has no practical contraindication, the storage of compressed air inside said galleries and tunnels and its subsequent use, could be carried out infinitely, without damaging things or humans. If these galleries will have to be reconverted to other purposes, they would be immediately available and substantially ready for the new uses. The storage of compressed air, in order to increase its efficiency, is carried out preferably through a plurality of compressors. In fact, every compressor is provided with a specific capacity and compression efficiency and then it is used exclusively as a function of the pressure present in the storage tank in that moment. Substantially, when the pressure inside the storage tank is low, all compressors are activated, when it is medium the second compressor is activated, and when the maximum pressure has to be reached, the third compressor is activated. Alternatively, the plurality of compressors can operate individually or in combination, as a function of the power available in such a moment. Therefore, if for example the plant is fed by solar energy and a bright spell happens in a cloudy day, all pumps can be activated simultaneously also if this way is not the most efficient for the power storage. On the contrary, if the plant would have not much power available, only the most little pump would be activated that could operate also at reduced speed, because of being fed by direct current. Obviously, thanks to a conventional inverter, the alternating current can also be used. Alternatively the three compressors can operate in sequence, each one compressing the air up to a certain pressure. When the air pressure reaches about 10 atms, the air can be entered directly into the storage tank from the first air compressor through a piping provided with a check valve, or else it can be sent to the second compressor through a piping provided with a check valve. Said second compressor further comprises the air coming from the first compressor, up to reach a pressure of about 20 atmospheres. In its turn, the air compressed by the second compressor can be directly entered into the storage tank through a piping provided with a check valve, or else it can be sent to a third compressor, adapted to further compress the air coming from the second compressor, through an appropriate pipeline. The third compressor, when a pressure of about 30 atmospheres is reached, enters said air into the storage tank or

the gallery conveniently arranged for the so-compressed air containment. Obviously, the storage tank of compressed air, independently from the pressure in its inside, is provided with at least one check valve for compressed air that is placed on every single piping or pipeline feeding it. Substantially, thanks to the modularity of the control unit, all possible combinations can be achieved in order to exploit and optimize at best the single independent storage zones of compressed air.

[0007] By providing for a national use, it is necessary to provide for the use of a lot of galleries in order to have a sufficient number of tanks for the storage of compressed air. Every unexpected and accidental loss of compressed air, by being not toxic, would not cause any collateral damage if not the simple drop of system efficiency.

[0008] Therefore, the afore said storage system of compressed air allows, at first, to transform the electric power into mechanic power and then the mechanic power into pneumatic power in the guise of compressed air. Obviously, the afore said storage system of compressed air can be effective also for domestic use, i.e. by using a tank of compressed air having little size for family use, adapted to be automatically filled at the middle of the night, when the cost of electric power is greatly lower than the daily one. The system of compressed air, i.e. the various pumps, can be fed by the electric current of the network, by any generator, or else by any renewable energy source such as, for example and not limitatively, photovoltaic panels, aeroturbines or hydroelectric turbines. For illustration purposes, 1 cubic meter of compressed air at 30 bars, by adopting the scheme described in the present Application, can approximately produce about 2 KWh of electric power.

[0009] The second unit of said electropneumatic device is focused on the high operation efficiency of pneumatic actuators characterizing it. In the present invention, the motors or pneumatic actuators are used according to a precise scheme that is described in the following of the present Application. The operating scheme of the pneumatic actuators in the present Application provides for the feed of compressed air coming from the pressure reducer connected to the tank, at a final pressure of about 10 bars, to the pneumatic primary actuator. When then work has been carried out, the latter sends the emitted compressed air to at least one secondary pneumatic actuator, preferably to a plurality of secondary pneumatic actuators. Every pneumatic actuator is provided with a maximum travel of 270°, but it can be used in the most convenient range by also exploiting an oscillation with many degrees less. Substantially, every pneumatic actuator has to be considered as a compressed-air motor having an oscillating movement. At least one couple, preferably a plurality, of said pneumatic actuators are connected to a permanent-magnet three-phase electric generator. Said connection happens by means of a specific mechanical converting system, named as mechanical coupler or transmission assembly, adapted to transform the oscillating movement typical of said pneumatic actuators into the continuous rotary movement suitable to create electric power. The operating pressure and the air flow adapted to active said pneumatic actuators, conveniently arranged in the first and second stages as described in the following, are managed by electrovalves having adjustable frequency.

[0010] The primary pneumatic actuator of the second subunit, i.e. the pneumatic actuator arranged more upstream, is directly fed by the compressed air coming from the pressur-

ized piping at about 10 bars, extending from the storage tank of compressed air and ending directly into the feed duct of the first pneumatic actuator. The pneumatic actuators are arranged so as to integrally recover the air discharged from two side vents, during the normal operation of the first pneumatic actuator, by means of an appropriate couple of pipes for the air recovery. The air discharged from the two side vents of the first pneumatic actuator is, as a matter of fact, still provided with a pressure extremely higher than the atmospheric pressure and then it is still be used for carrying out a mechanical work. In order to prevent the useless dispersion of such an energy into the environment and to exploit said residual pressure differential at best, the air discharged from the two side vents of the primary pneumatic actuator is directly entered into the first couple of pipe for recovering the emitted air and is sent directly to the duct feeding the secondary pneumatic actuators. The high pressure the air still has, now activates said secondary pneumatic actuators arranged exactly on the same axis but downstream of the primary pneumatic actuator. The air coming out from the side vents of the last pneumatic actuator, being now unable of making any mechanical work, is simply released into the outer environment because of not having, by now, any pressure differential significant with respect to the atmospheric pressure. The sequence of pneumatic actuators, together with their direct connection and by being arranged on the same axis, allows to exploit the pressure drop at best, thereby achieving a very high efficiency in exploiting the compressed air previously stored in the storage tank. Obviously, if the starting pressures are higher than 10 bars, it is possible to sequentiate additional pneumatic actuators, till obtaining anyway a pressure, in the side vents, a little higher than the atmospheric pressure, i.e. higher than the atmospheric pressure of about 0.2-0.5 bars. Therefore, the distribution of the primary actuator and the secondary pneumatic actuator/s, forces the used compressed air to carry out all the mechanical work that can be obtained by exploiting its potential energy. On the contrary, if a very low pressure is available, it would be possible to use only one couple of pneumatic actuators as, in this case, the pressure exiting from the side vents of the secondary pneumatic actuator would already be just a little higher than the atmospheric pressure and then no more usable to carry out a work efficiently. The afore described different compressed-air motors, defined as pneumatic actuators, must all necessarily have the same size. This detail becomes necessary in that, differently, instabilities could arise. If a plant having great size has to be made, it is preferred having several main motors, that is a greater number of primary pneumatic actuators, instead of having only one great motor. This because, in this case, the pressure would be better distributed, thereby having the higher incoming pressure immediately. Obviously, every single outlet present in the primary pneumatic actuators according to the present invention, must be provided with at least one check valve.

DESCRIPTION OF THE DRAWINGS

[0011] Let's now proceed to the detailed description of the drawings the present invention is provided with, in which devices and apparatuses connected to the present invention are described for purposes of illustrations and not limitative, in which:

[0012] FIG. 1 is an overall view of the whole device 100 according to the present invention;

[0013] FIG. 2 is a partially exploded schematic view of the whole electropneumatic system 300 according to the present invention;

[0014] FIG. 3 is a plant view of the electropneumatic actuator 1 according to the present invention;

[0015] FIG. 4 is a side sectional view of the transmission assembly 21 alone, according to the present invention;

[0016] FIG. 5 is a general scheme only of the system for generating the compressed air according to the present invention;

[0017] FIG. 6 is a perspective view of the electropneumatic system 300 according to the present invention;

[0018] FIG. 7 is the operating scheme of the primary pneumatic actuator 1 and of the three secondary pneumatic actuators 1a, 1b, 1c arranged one in parallel to another.

DETAILED DESCRIPTION OF THE INVENTION

[0019] As evidently shown in FIG. 1, the present device is characterized by a plurality of components that, by operating synergistically, allows to achieve the object of the present invention. The operative scheme of the whole device 100 is composed of a system for the storage of compressed air and the production of electric power, by using compressed air as methodology for storing up the energy according to the present invention. In the scheme it can be noticed that the device is fed by any source of electric power 400, preferably any renewable energy source, adapted to feed at least one compressor 200 prearranged to compress the atmospheric air till a maximum pressure of about 100 bars, so that to be able to store it, as compressed air, into the tank 6. The air compression in the storage tank 6 of compressed air happens thanks to the system of high efficiency pumps 200. Therefore, said compressed air is sent to a plurality of pneumatic actuators 1, 1a, 1b, 1c through pressurized pipings 3. Said pneumatic actuators are adapted to transform said compressed air into mechanic power thanks to the transmission assembly 21 that transforms the oscillatory motion, made by said pneumatic actuators, into the continuous rotary motion and the latter into electric power ready to be used, thanks to the generator 33, or entered into the network. In FIG. 2, a schematic representation is shown in which there are four pneumatic devices or actuators 1, 1a, 1b, 1c, activated by the compressed air and all installed along the axis 50. Said axis 50 is, in its turn, connected to the transmission assembly 21, in its turn combined with an ordinary electric generator 33 adapted to produce the electric power at the desired voltage. FIG. 2 shows in detail an overall exploded view of the transmission assembly 21, adapted to transform the reciprocating rotary motion of a first element (specifically the plurality of pneumatic actuators 1, 1a, 1b, 1c), into the continuous rotary motion of a second element connected thereto (specifically the electric generator 33) through the transmission assembly 21 itself. The actuators 1, 1a, 1b, 1c are reverse-flow rotary pneumatic actuators. The presence of the transmission assembly 21 is essential for transforming the movement reversal, typical of these actuators, into the constant rotary motion indispensable for the production of electric power. The primary pneumatic actuator 1 is fed by the pressurized piping 3, coming from the tank 6. At least one pressure reducer 500 and one electrovalve 150, the latter being aided by two coils for its correct operation, are present on said pressurized piping 3. The opening and closing scheme of said electrovalve 150 is shown in detail in FIG. 7, from this one can infer that the compressed air coming from said electrovalve 150 feeds

alternately the two chambers A and B of the primary pneumatic actuator 1, then the air discharged from the pressurized ducts 4 feeds the sequence of secondary pneumatic actuators 1a, 1b, 1c mounted in parallel one to another. The pneumatic actuator 1c discharges directly into the environment the air fed by the pressurized pipe 4. Therefore, the compressed air coming from the storage tank 6 is fed to at least one pressure reducer 500 so that to feed it to the primary pneumatic cylinder/s 1 at a pressure of about 10 bars. The air emitted from said primary actuator 1 is sent, through a pressurized pipeline, to a second electrovalve 298 feeding, through the pressurized pipings 4, 4a and 4b, the secondary actuators placed in parallel one to another. It has to be outlined that the air emitted into the pipelines 4 by the primary pneumatic actuator 1 is not released into the atmosphere. Said air, having a pressure considerably higher than the atmospheric pressure, around 4 bars, is completely sent to the pressurized pipelines 4 and used to activate a plurality of secondary actuators 1a, 1b, 1c thanks to the second electrovalve 298. After said secondary actuators have been activated, the air is provided with a pressure a little higher than the atmospheric pressure and, as it cannot be used for any work, it is now released into the environment. The release of said exhausted air into the environment happens by the electrovalve 298 that is provided with appropriate vents. The number of secondary pneumatic actuators is such to reduce the pressure difference from the atmosphere to the air emitted by said secondary pneumatic actuators, in a range of about 0.2 bars.

[0020] The pneumatic actuator 1 is a reverse-flow rotary pneumatic actuators, specifically in FIG. 3 the pneumatic actuator is shown, in which the piston 70 is provided with an oscillatory motion of 270° (illustrated in FIG. 3 by the arrows A and B) and characterized by the presence of the separating zone 71 and the couple of pressurized pipings 4. The oscillation of 270° is made by the piston 70 in its regular working cycle around the axis 50. Said oscillation has a maximum amplitude of 270°, but the oscillation angle depends from the work frequency. Higher said frequency is, lower said oscillation angle will be. Independently from the oscillation angle, the transmission assembly 21 is anyway able to transform said reciprocating oscillatory movement into the continuous rotary movement essential for producing the electric power. The oscillatory frequency is directly correlated to the request of electric power in that moment. The two chambers A and B are separated one from another by the piston 70 and the separating zone 71, said chambers fill and empty with/from compressed air alternately, thanks to the action of the pressurized ducts 4 in their turn connected and controlled by the electrovalve 150, in case of the primary pneumatic actuator, or else 298, in case of secondary pneumatic actuators.

[0021] The transmission assembly 21 is adapted to transform the reciprocating rotary motion of a first element, i.e. the actuators 1, 1a, 1b, 1c, into the continuous rotary motion of a second element connected thereto, i.e., of the flywheel 58 and the electric generator 33. The pneumatic actuators 1, 1a, 1b, 1c are reverse-flow rotary pneumatic actuators, in order to transform the movement reversal typical of these actuators into a constant rotary motion, essential for adjusting the production of electric power, the transmission assembly 21 becomes necessary. It has to be noticed that all the pneumatic actuators 1, 1a, 1b, 1c are neatly arranged along an end of the axis 50. On the contrary, the central portion of the axis 50 is inside the transmission assembly 21 itself, on said portion of the axis 50 a gear wheel 26 is mounted. The first freewheel 28,

provided with only one and specified mesh way, is interposed between said gear wheel 26 and the shaft 99. A second gear wheel 27, adapted to engage with said first gear wheel 26, and a gear pulley 20, in its turn connected to the second gear pulley 29 through a first drive belt 22, are keyed on a second shaft 25 parallel to said first shaft 99. Said second gear pulley 29 is keyed on the second shaft 25 on which also the second gear wheel 27 is installed. The first gear pulley 20 is keyed on the first shaft 99 on which also the first gear wheel 26 is mounted with the respective first freewheel 28. A second freewheel 51, characterized by having a mesh way opposite with respect to that of the first freewheel 28, is installed between said first gear pulley 20 and said first shaft 99. The electric generator 33 must now rotate in a constant way because of the effect of the transmission system 21, being keyed on a third shaft 44 with which it rotates integrally always in the same way. The first shaft 99 and the third shaft 44 are on the same axis 50. This effect is possible thanks to the third shaft 44, having the longitudinal axis perfectly aligned to that of the first shaft 99, being placed side by side in parallel to the second shaft 25. The shaft 99 and the shaft 44, although being perfectly aligned, are not interconnected directly but they are separated and aligned one to another. The second shaft 25 and the third shaft 44 are connected one to another by means of a second toothed belt 47 placed between a third gear pulley 45 and a fourth gear pulley 46 keyed on the second shaft 25 and the third shaft 44, respectively. The third gear pulley 45 and the fourth gear pulley 46, thanks to the afore said kinematic systems, independently from the activation way of the pneumatic actuator 1, continue rotating in the same direction, thereby transmitting such a constant rotary movement to the electric generator 33. Obviously, the shafts 99, 25 and 44 will have to be installed on apposite bearings interposed among said shafts and the supports 24. The flywheel 58, placed on the shaft 44, is between the transmission assembly 21 and the electric generator 33.

[0022] In FIG. 5, it is clearly represented a schematic view of the system for generating compressed air according to the present invention, in which the pumps, in whose inside there are the three pistons 17, 17a, 17b respectively belonging to the three cylinders 90, 90a, 90b, are highlighted with the numerals 200, 200a, 200b. However, said pistons 17, 17a, 17b have different compression capacities and, therefore, when a lower pressure is sufficient to storage the compressed air, i.e. when for example the tank of compressed air 6 is half-empty, it will be sufficient to activate the piston 17b with a lower compressive capacity in order to fill it. But if the tank 6 of compressed air would be empty and great amounts of electric power could be available at reduced costs, or else if a significant solar irradiation could be available, it will be possible to make all pistons work simultaneously till the desired pressure of compressed air is reached. The activation mechanism is automatically managed by the control unit 14 that can activate the valves 13, which are adapted to provide the minimum pressure of compressed air necessary to allow said tank 6 to be filled by using the possible minimum power, by analyzing the pressure data received from the manometers placed in distinct zones of the tank 6 of compressed air. Every single pumping chamber 15 and 16, 15a and 16a, 15b and 16b, respectively of the cylinders 90, 90a, 90b, is connected to a couple of valves 13 controlled by the control unit 14. This distinctive feature allows to draw out the compressed air from every pumping chamber 15 and 16 of every cylinder 90, when the pistons 17, 17a, 17b are in both the back and forth steps, creating a double

pumping effect. The valves 13 open when electrically activated by the control given by the control unit 14, and they close automatically with a conventional spring-driven return mechanism, thereby avoiding the compressed air from flowing back through the valve 13 itself. As a matter of fact, the couple of valves 13 combined with every piston 17, 17a, 17b is managed by the electronic control unit 14 that analyzes the single pressure data, allowing the valves 13 connected to every single pumping chambers 15, 15a, 15b to be opened and closed alternately, thereby allowing to perfectly control both the flow of compressed air exiting from the pumping chambers 15 and 16 and the flow of incoming atmospheric air. Therefore, by way of explanation, in the forth step of the piston 17, the pumping portion 15 provides the compressed air to the tank 6, whereas during the back step of the piston 17, the pumping chamber 16 will provide said compressed air to the tank 6. All synergistically managed by the opening and closing of the valves 13, as mentioned above, which also avoid the reflux of compressed air. In short, the air compressors 10, 10a, 10b are activated by an electric motor 5 provided with a reducer, said electric motor 5 being preferably fed by renewable electric power. The electric motor 5 is provided with a screw mechanism 98 provided with ball bearings. The electric motor 5 is connected to at least one air compressor 10, preferably to three air compressors 10, 10a, 10b, all mounted along the same axis, represented in FIG. 5 by the drive shaft 97 itself. The pistons 17, 17a, 17b can therefore move alternately, inside the cylinders 90, 90a, 90b, when they are operated by the drive shaft 97. Therefore, it is the accurate opening and closing of the couple of valves 13, which are controlled by the control unit 14 and connected to every single pumping chamber 15 and 16, 15a and 16a, 15b and 16b, to determine which pump/s 10 must be operated, in every given moment, in order to optimize the energy consumption in the production of compressed air. The digital analog manometer 199 is adapted to provide the control unit 14 with data relative to the pressure inside the tank 6 so that to activate the valves 13 connected to the preferred pump 200 in order to optimize the distribution of compressed air inside the single zones of the tank 6. As previously described every independent zone is provided, in its inside, with a manometer and at least one electrically controlled tap managed by the control unit, in its turn directly connected to said manometers.

[0023] In FIG. 6 a schematic view of the whole electropneumatic system 300 is shown for better illustrating the present Application in which the pneumatic actuators can be noticed in a dotted line, which are perfectly arranged in-line with the transmission assembly in its turn directly connected with the generator. The efficiency of the device 300 object of the present Application, is about 80%. This excellent result has been detected by means of objective and incontestable measuring. The present device allows to produce electric power starting from a reserve of compressed air, previously stored in an apposite tank, thanks to the pumps preferably operated by renewable energy. In this latter case, the whole cycle has zero impact, i.e. it causes no damages to the environment, it does not release carbon dioxide into the environment and does not create any toxic waste.

1. Device (100) for the production of electric power comprising:

at least one energy source, (400) preferably of renewable energy, adapted to activate at least one electric motor (5) connected through a screw mechanism (98) adapted to operate the drive shaft (97) on whose axis at least one

pump (200) is arranged, preferably a plurality of pumps (200), (200a), (200b) adapted to compress the atmospheric air inside an appropriate storage tank (6) of said air, till a maximum pressure of 100 atmospheres is reached, thanks to the synchronous action of at least two couples of valves (13) connected to said pump (200) in such a way that every single pumping chamber (15) and (16) of each cylinder (90) is connected to said couple of valves (13) controlled by the control unit (14), which are adapted to open and close so as to exploit the compression action of the cylinder (17) during both the back and forth steps, and at least one pressurized piping (3) deriving from said storage tank (6) on which at least one pressure reducer (500) and one primary electrovalve (150) are placed, the latter being adapted to feed, at a pressure of about 10 bars, at least one pneumatic actuator (1) arranged on the axis (50) in turn connected, through at least one pressurized piping (4), to at least one secondary pneumatic actuator (1a), preferably a plurality of secondary pneumatic actuators (1a, 1b, 1c) connected in parallel one to another and arranged along said axis (50) too, which are adapted to be activated by the compressed air emitted by the primary pneumatic actuator (1) and entered into the pressurized piping (4), said pressurized piping (4) being provided with the secondary electrovalve (298) so as to allow said pneumatic actuators (1a, 1b, 1c) to be activated in parallel, these actuators also rotating, by their reciprocating rotary motion, the shaft (99) placed along said axis (50) with a reciprocating rotary motion, and said device (100) being provided with at least one transmission assembly (21) placed along said axis (50) and adapted to transform the reciprocating rotary motion of a first element, i.e. of the actuators (1), (1a), (1b), (1c), into the continuous rotary motion of a second element connected thereto, i.e. of the flywheel (58) connected to the electric generator (33).

2. Device (100) for the production of electric power according to claim 1, wherein the pneumatic actuators (1, 1a, 1b, 1c) are neatly aligned along an end of the axis (50), on the contrary the central portion of said axis (50) is within the transmission assembly (21) itself, the gear wheel (26) being mounted on said inner portion of the axis (50), the first free-wheel (28) is interposed between said gear wheel (26) and the shaft (99) and is provided with only one and fixed mesh way, a second gear wheel (27), adapted to engage with said first gear wheel (26) and a gear pulley (20), in its turn connected to the second gear pulley (29) by a first drive belt (22), are keyed on a second shaft (25) parallel to said first shaft (99), said second gear pulley (29) is keyed on the second shaft (25) on which also the second gear wheel (27) is installed, the first gear pulley (20) is keyed on the first shaft (99) on which also the first gear wheel (26) is mounted with the respective first freewheel (28), a second freewheel (51) is installed between said first gear pulley (20) and said first shaft (99) and comprises a mesh way opposite with respect to that of the first freewheel (28), the electric generator (33), being keyed on a third shaft (44) with which it rotates integrally always in the same way, has now to rotate in a constant way because of the effect of the transmission system (21), the first shaft (99) and the third shaft (44) are arranged on the same axis (50) thanks to the third shaft (44), having the longitudinal axis perfectly aligned to that of the first shaft (99) in its turn coincident to the axis (50), being placed side by side in parallel to the second shaft (25), the shaft (99) and the shaft (44), although being

perfectly aligned, are separated and aligned one to another, the second shaft (25) and the third shaft (44) are connected one to another by means of a second toothed belt (47) placed between a third gear pulley (45) and a fourth gear pulley (46) keyed on the second shaft (25) and the third shaft (44), respectively, the third gear pulley (45) and the fourth gear pulley (46) thanks to the afore said kinematic systems, independently from the activation way of the pneumatic actuator (1), continue rotating in the same direction, thereby transmitting such a constant rotary movement to the electric generator (33), the flywheel (58) placed on the shaft (44) being between the transmission assembly (21) and the electric generator (33).

3. Device (100) for the production of electric power according to claim 1, wherein by source of renewable energy is meant a wind, photovoltaic or hydroelectric energy source or a combination thereof.

4. Device (100) for the production of electric power according to claim 1, wherein the control unit (14) controlling the valves (13), is connected to at least one digital analog manometer (199), preferably a plurality of digital manometers (199), adapted to detect the pressure inside every single independent zone of the tank (6).

5. Device (100) for the production of electric power according to claim 1, wherein the electric motor (5) is connected to a screw mechanism (98) provided with ball bearings and adapted to operate the drive shaft (97).

6. Device (100) for the production of electric power according to claim 1, wherein the pneumatic actuator (1) is provided with reciprocating rotary motion with an oscillation angle of at least 270 degrees.

7. Device (100) for the production of electric power according to claim 1, wherein the pneumatic actuator (1) is provided with reciprocating rotary motion with an oscillation angle lower than 270 degrees.

8. Device (100) for the production of electric power according to claim 1, wherein the primary pneumatic actuator (1) is directly fed by the pressurized piping (3) through the primary electrovalve (150) and in that the air, emitted from said primary pneumatic actuator (1), feeds a plurality of secondary pneumatic actuators arranged in parallel one to another and adjusted by at least one secondary electrovalve (298) that is arranged on the pressurized pipings (4), through the pressurized pipings (4).

9. Device (100) for the production of electric power according to claim 1, wherein the storage tank (6) of the compressed air can be an ordinary tank conveniently sized, or preferably a gallery, or tunnel, or any other hermetic cavity no longer in use.

10. Device (100) for the production of electric power according to claim 1, wherein the storage tank (6) of the compressed air is a multistage tank composed of a plurality of separated zones, preferably four separated zones, connected one to another by at least one pressure reducer (297) represented by an electrically controlled ordinary tap adapted to electrically open and close by an ordinary spring mechanism.

11. Device (100) for the production of electric power according to claim 1, wherein the compressed air fed by the primary pneumatic actuator (1) has a pressure comprised between 5 and 20 bars, preferably 10 bars.

* * * * *



US 20090230696A1

(19) **United States**(12) **Patent Application Publication**
Enis et al.(10) **Pub. No.: US 2009/0230696 A1**(43) **Pub. Date: Sep. 17, 2009**(54) **METHOD AND APPARATUS FOR USING
SOLAR ENERGY TO ENHANCE THE
OPERATION OF A COMPRESSED AIR
ENERGY STORAGE SYSTEM****Publication Classification**(51) **Int. Cl.**
F01D 15/10 (2006.01)
H01L 31/042 (2006.01)
(52) **U.S. Cl.** **290/1 B; 290/52; 136/244**(76) **Inventors:** **Ben M. Enis**, Henderson, NV (US);
Paul Lieberman, Torrance, CA
(US)(57) **ABSTRACT**

The invention relates to a method and apparatus for using solar energy to enhance the efficiency of a compressed air energy storage system (and visa-versa). The apparatus comprises a photovoltaic panel to drive a compressor, which provides compressed air energy into an inner vessel housed within a storage tank. Two solar receiving panels are used to heat water which can be circulated and stored within an annulus surrounding the inner vessel, wherein the heated water can help regulate the temperature of the compressed air within the tank. This way, when air is released using a turbo expander, any excess temperature drops that can otherwise result from air expansion can be avoided. The overall system efficiency is enhanced by the chilled air by-product of the turbo expander which is used to generate more electrical power from an associated fuel-driven generator set, and/or by the waste heat from the compressor and from the generator set exhaust which is used in a Combined Heat and Power system (CHP) to power either a steam-driven generator set or an absorption chiller.

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(21) **Appl. No.: 12/321,794**(22) **Filed: Jan. 26, 2009****Related U.S. Application Data**

(60) Provisional application No. 61/062,149, filed on Jan. 24, 2008, provisional application No. 61/068,170, filed on Mar. 5, 2008, provisional application No. 61/195,418, filed on Oct. 7, 2008.

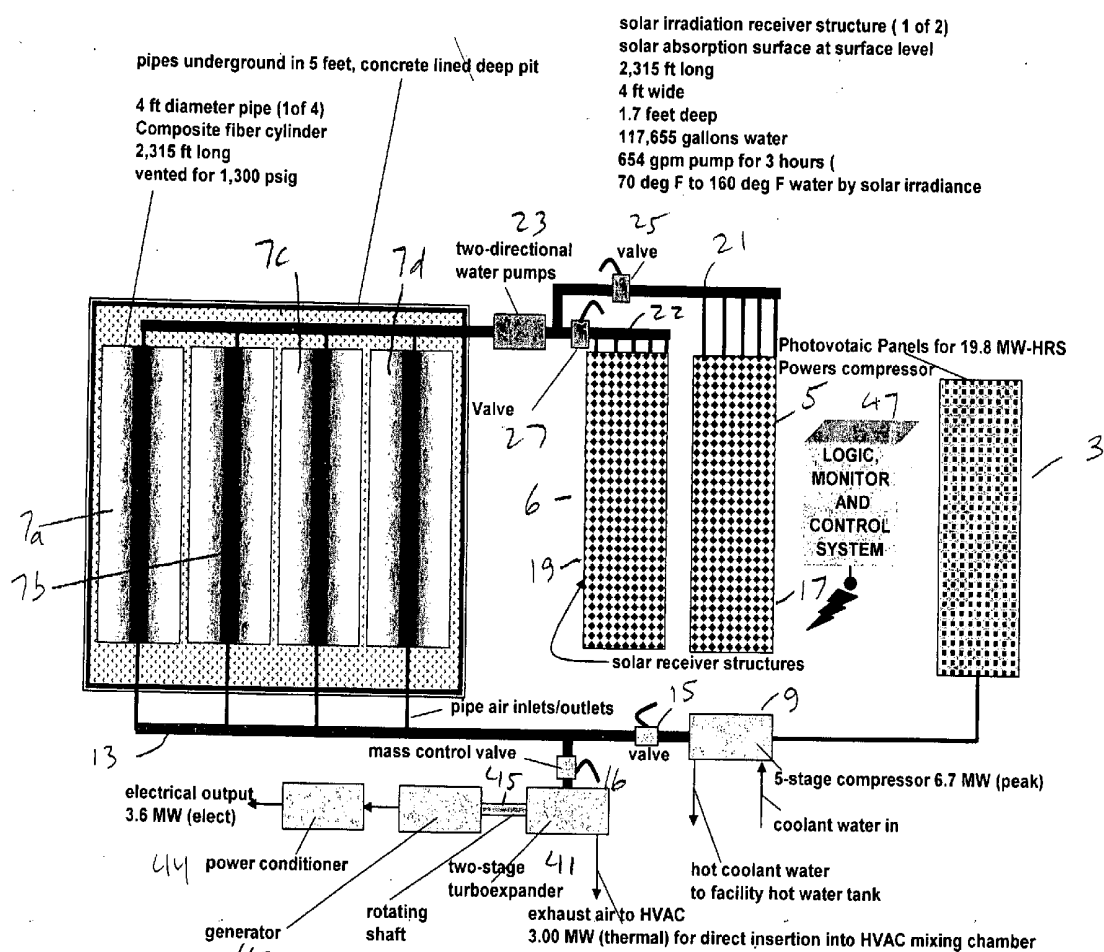
**Total System 3.6 MW(electrical) + 3.0 MW (thermal) = 6.66 MW for 3 hours**

FIGURE 1

pipes underground in 5 feet, concrete lined deep pit

4 ft diameter pipe (1 of 4)
Composite fiber cylinder
2,315 ft long
vented for 1,300 psig

solar irradiation receiver structure (1 of 2)
solar absorption surface at surface level
2,315 ft long
4 ft wide
1.7 feet deep
117,655 gallons water
654 gpm pump for 3 hours (
70 deg F to 160 deg F water by solar irradiance

two-directional water pumps

valve

Valve

Photovoltaic Panels for 19.8 MW-HRS Powers compressor

LOGIC, MONITOR AND CONTROL SYSTEM

solar receiver structures

pipe air inlets/outlets

mass control valve

valve

5-stage compressor 6.7 MW (peak)

coolant water in

hot coolant water to facility hot water tank

exhaust air to HVAC
3.00 MW (thermal) for direct insertion into HVAC mixing chamber

two-stage turboexpander

rotating shaft

generator

power conditioner

electrical output
3.6 MW (elect)

Total System 3.6 MW(electrical) + 3.0 MW (thermal) = 6.66 MW for 3 hours

7a

7b

7c

7d

13

19

21

22

23

25

27

41

43

44

47

5

6

9

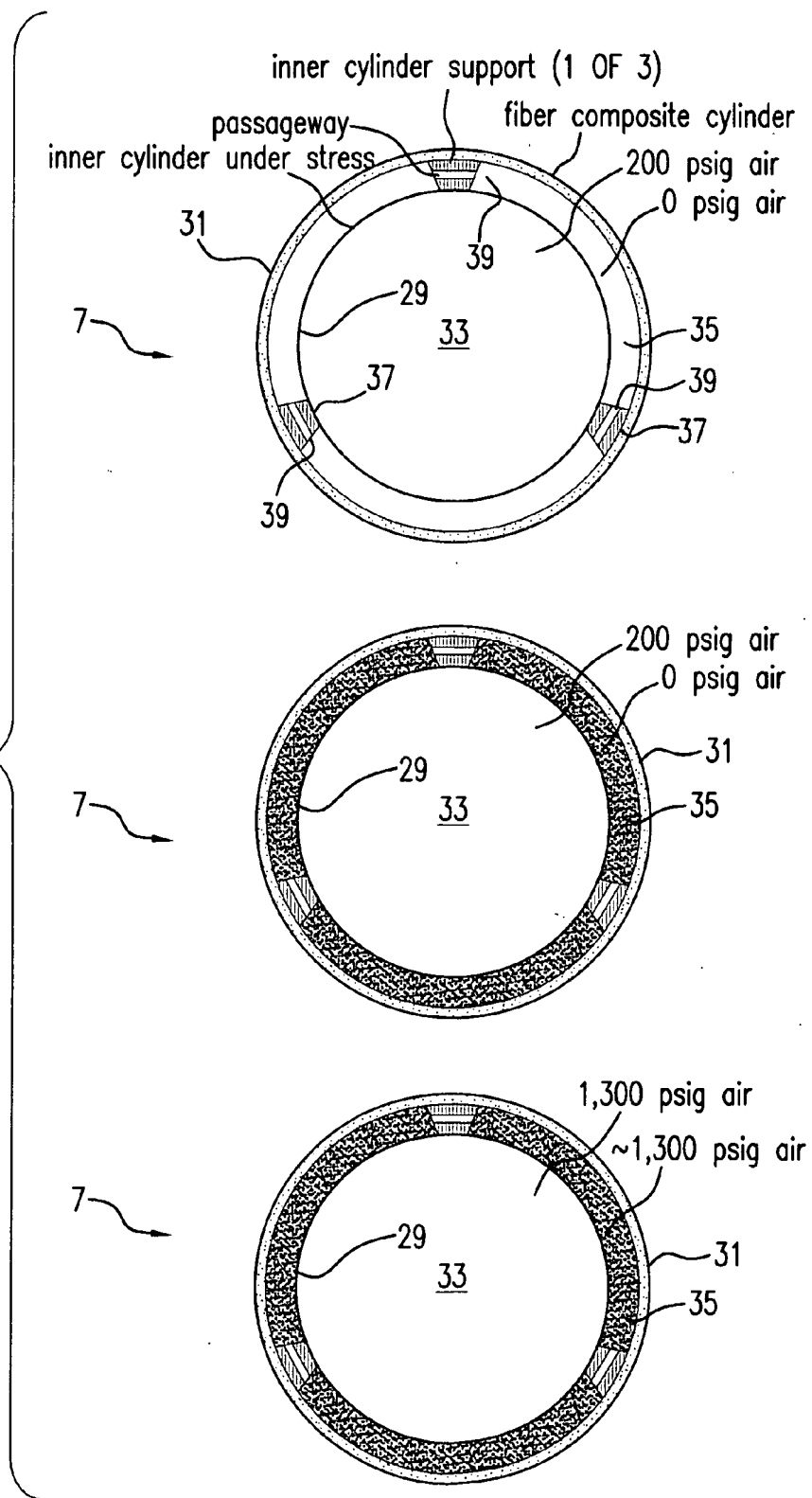
15

16

17

3

FIG. 2



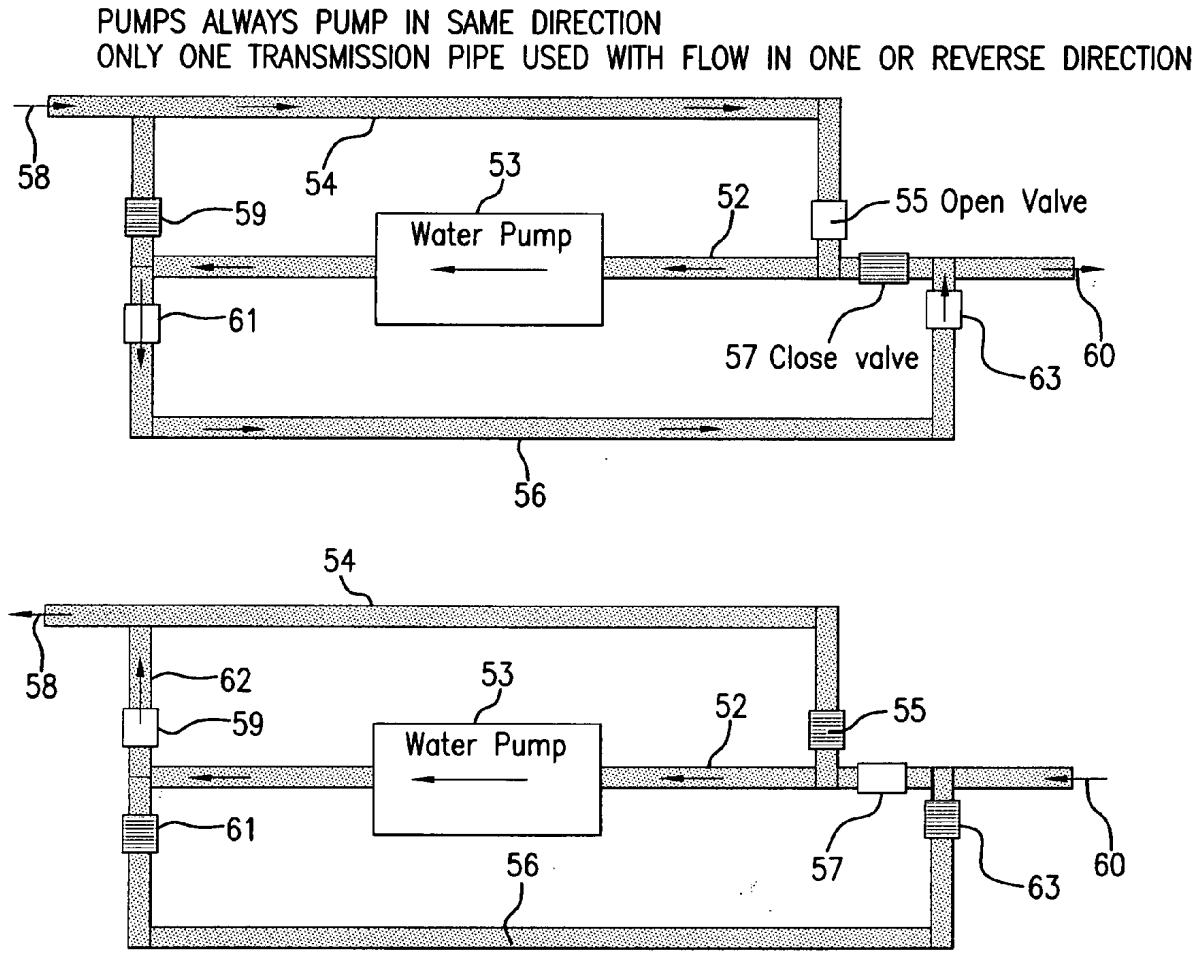


FIG.2A

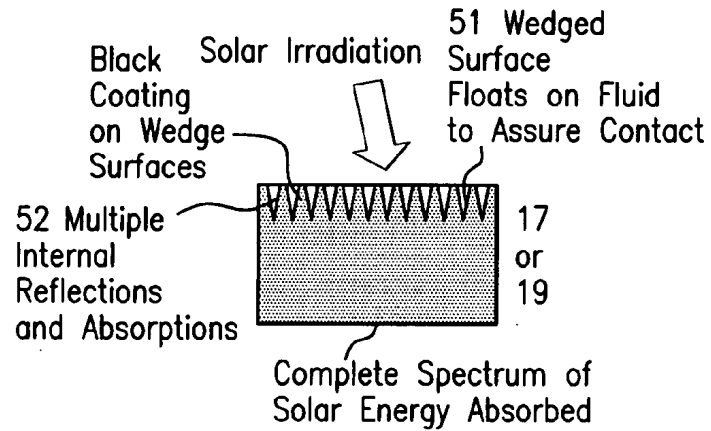


FIG. 3

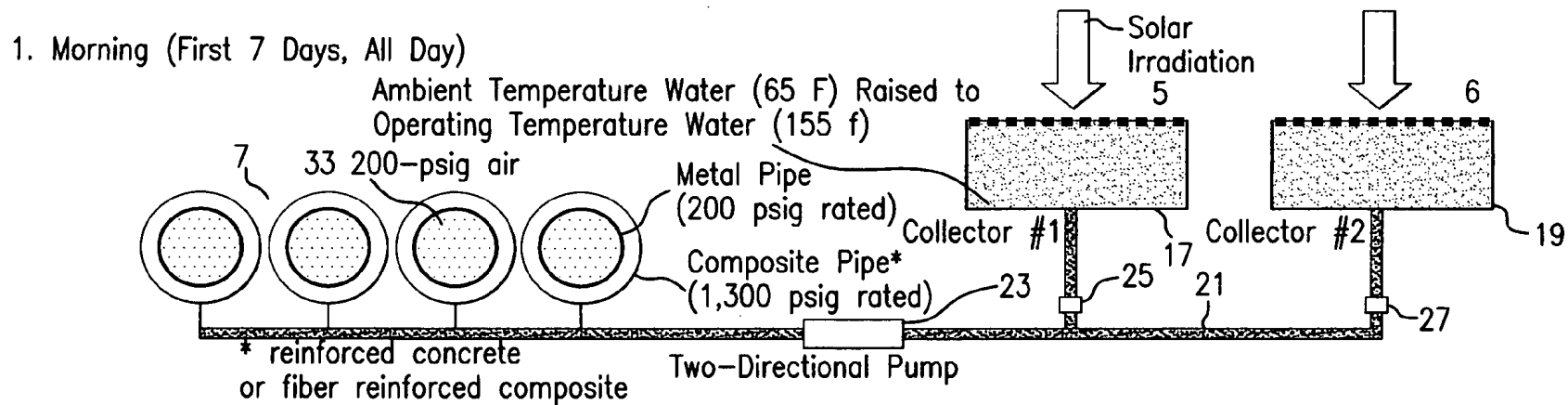


FIG. 4

2. Night (End of 7th Day)

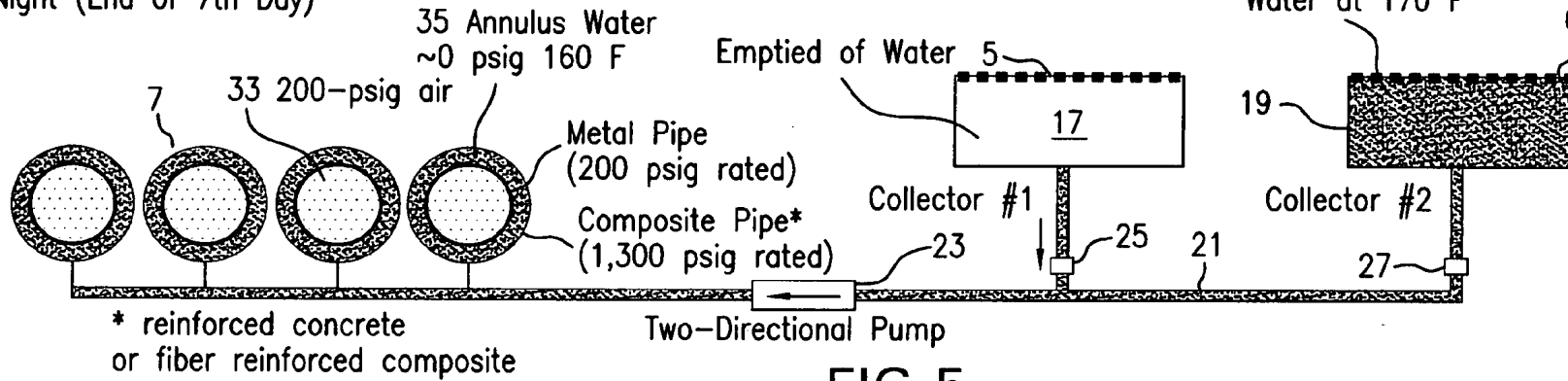


FIG.5

3 Morning (8th Day, During morning and early afternoon sunshine)

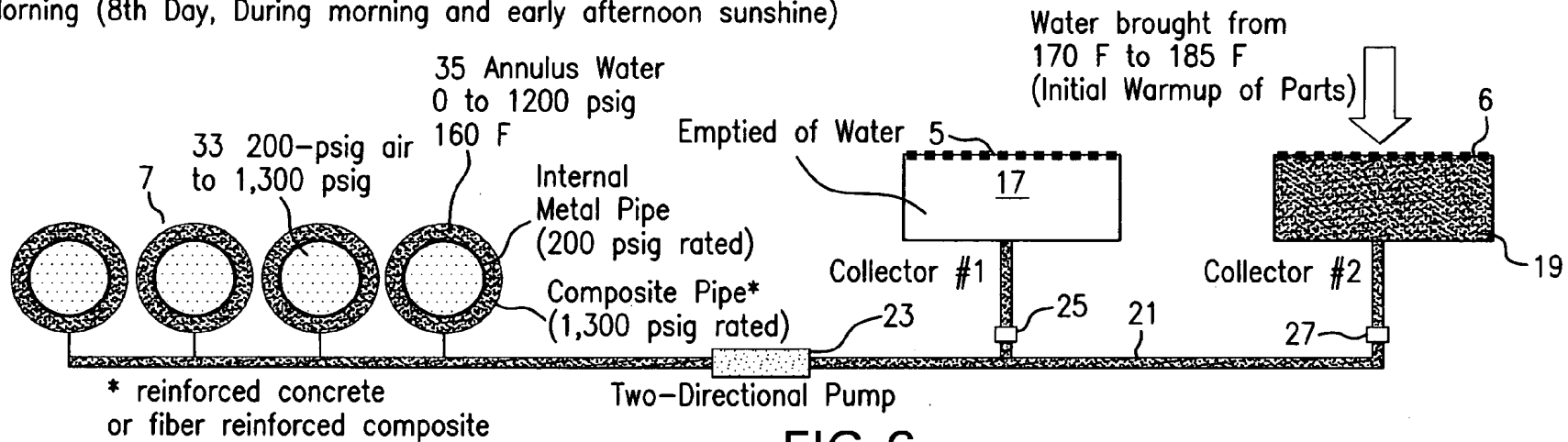


FIG.6

4. Morning (8th Day, During three hours of late afternoon sunshine)

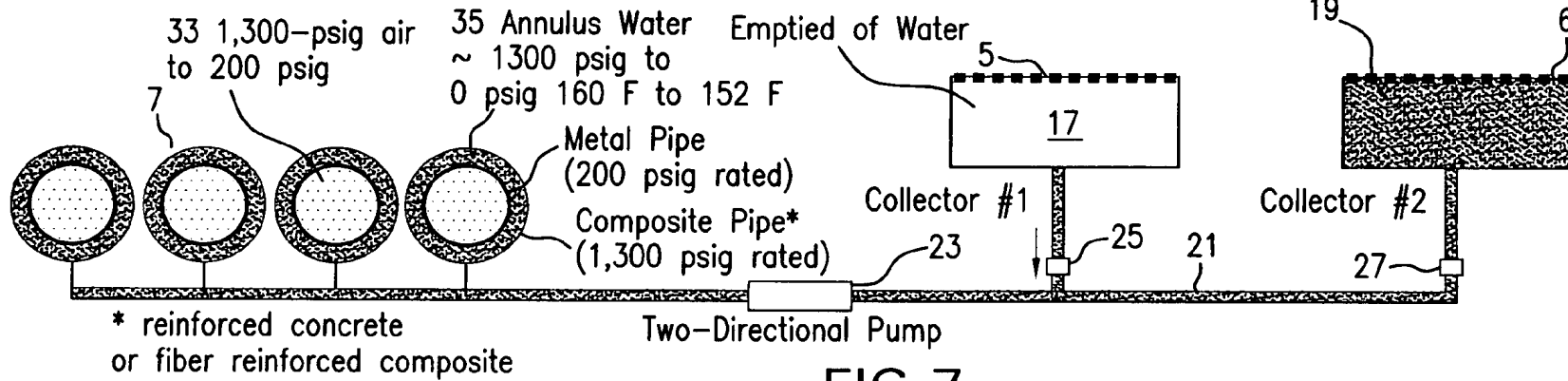


FIG. 7

5. Night (8th Day, During early part of night)

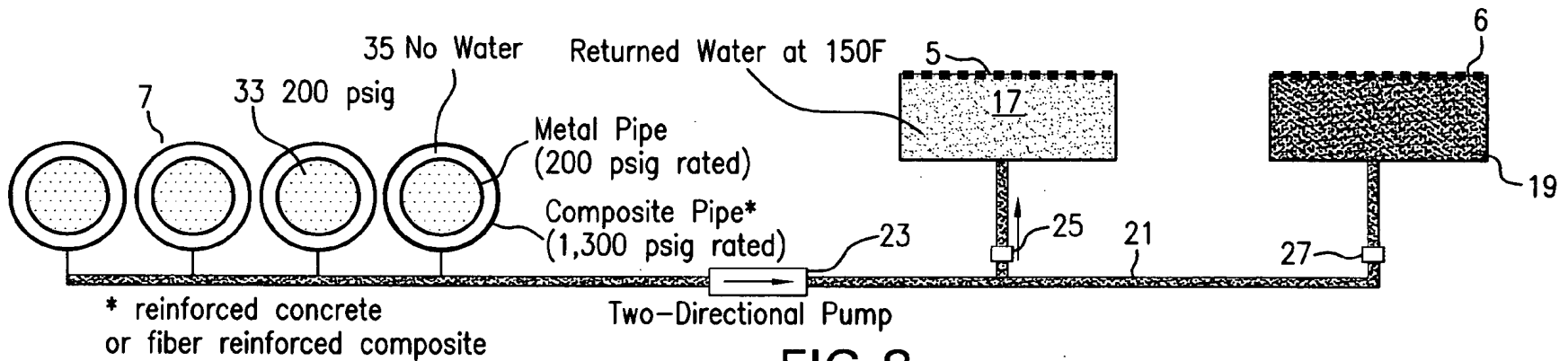


FIG. 8

6. Night (8th Day, late part of night)

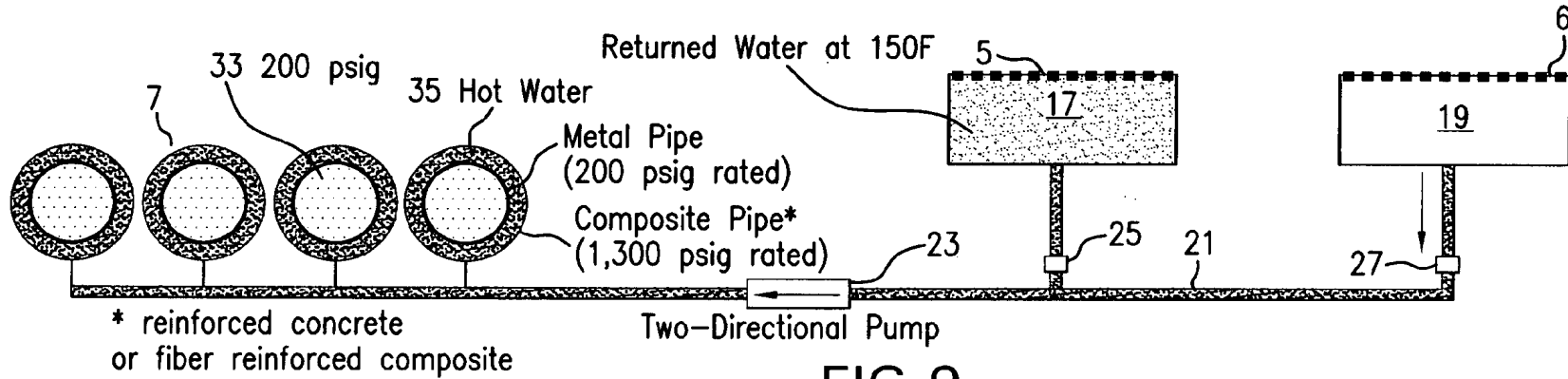


FIG.9

7. Day (9th Day, During sunshine, Morning and Early Afternoon)

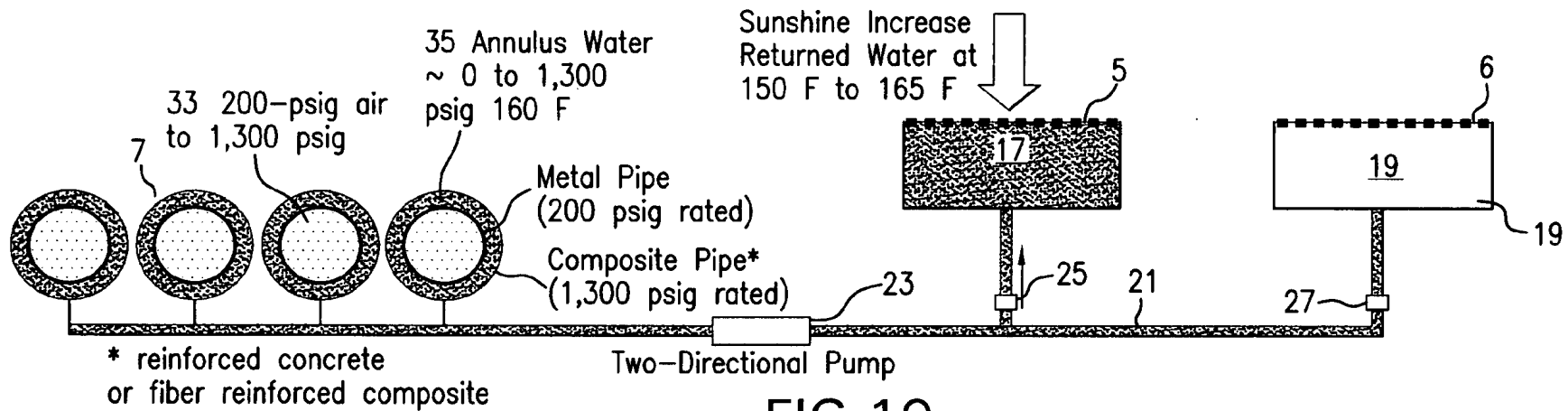


FIG.10

10. Night (9th Day, late part of night)

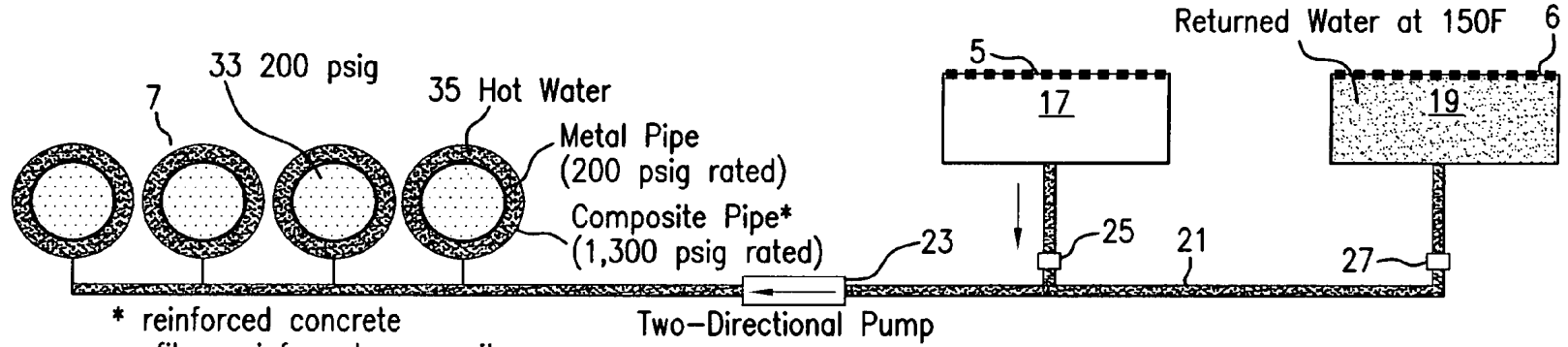


FIG. 13

11. Day (10th Day, During morning and early afternoon sunshine)

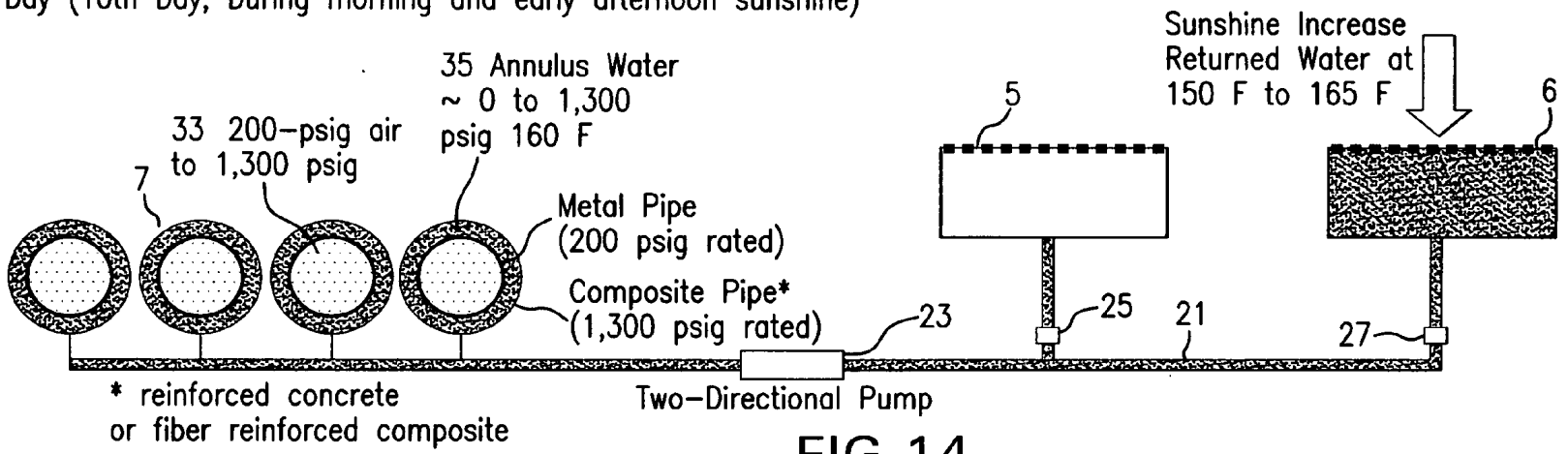


FIG. 14

WATER COOLED STAGE Stage 1	WATER COOLED STAGE Stage 2	WATER COOLED STAGE Stage 3	WATER COOLED STAGE Stage 4	NON-WATER COOLED STAGE Stage 5
14.7 psia	40.5 psia	112 psia	276.4 psia	600 psia
70 F	70 F	70 F	70 F	70 F
40.6 psia	112.1 psia	276.5 psia	600 psia	1200 psia
324.5 F	324.5 F	309.67 F	309.67 F	260.96 F
16,251 #/hr	16,251 #/hr	16,251 #/hr	16,251 #/hr	16,251 #/hr
9,479.75 SCFM	9,479.75 SCFM	9,479.75 SCFM	9,479.75 SCFM	9,479.75 SCFM
1,037.4 HP	1,037.4 HP	976.2 HP	976.2 HP	791.4 HP
9.14 SCFM/hp	9.14 SCFM/hp	9.71 SCFM/hp	9.71 SCFM/hp	11.98 SCFM/hp
75% efficiency	75% efficiency	70% efficiency	60% efficiency	60% efficiency
9.14 SCFM/hp	4.57 SCFM/hp	3.11 SCFM/hp	2.35 SCFM/hp	1.97 SCFM/hp

FIGURE 15

	RATED (HP)	EFFICIENCY (%)	HEATED WATER (%)	HEATED WATER (BTU/MIN)	OUTPUT AIR TEMPERATURE (F)	OUTPUT AIR (#/MIN)
STAGE 1	1,037.4	75	13	5,719		
STAGE 2	1,037.4	75	13	5,719		
STAGE 3	976.2	70	15	6,210		
STAGE 4	976.2	60	20	8,280		
STAGE 5	791.4	60			260.96	270.85
TOTAL	4,818.6			25,928		
TOTAL	3,595	KW				

FIGURE 16

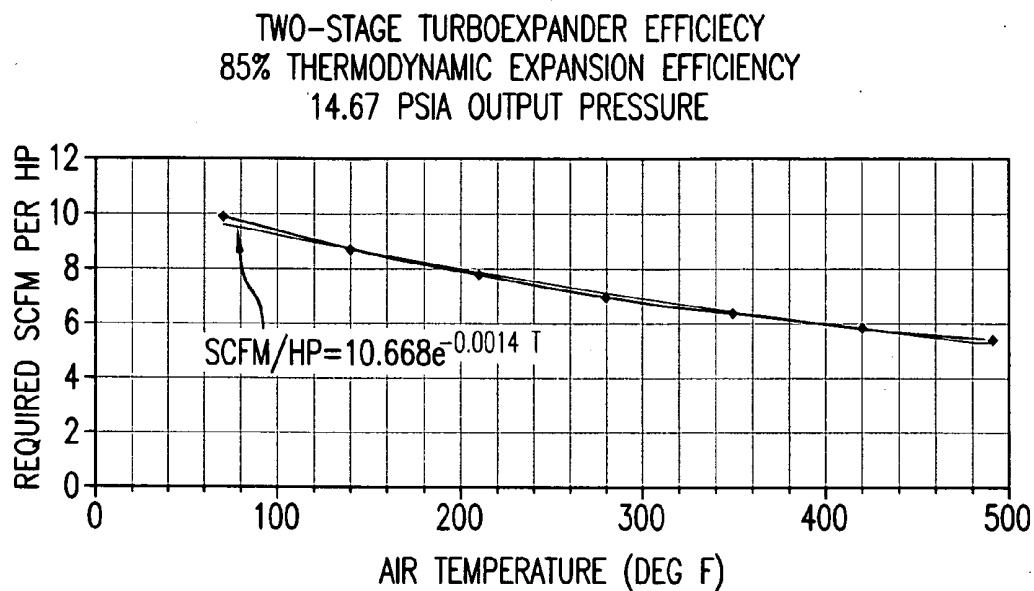


FIG.17

	STAGE 1 INPUT PRESSURE	STAGE 1 INPUT TEMPERATURE	STAGE 1 OUTPUT PRESSURE	STAGE 1 OUTPUT TEMPERATURE
	(PSIA)	(DEG F)	(PSIA)	(DEG F)
SCENARIO 1	200	70	90	*-23.2
SCENARIO 2	200	140	90	35.0
SCENARIO 3	250	300	50	61.6
SCENARIO 4	250	400	50	131.7

* OUTPUT AND INPUT AIR MUST BE DRY

	STAGE 2 INPUT PRESSURE	STAGE 2 INPUT TEMPERATURE	STAGE 2 OUTPUT PRESSURE	STAGE 2 OUTPUT TEMPERATURE
	(PSIA)	(DEG F)	(PSIA)	(DEG F)
SCENARIO 1	90	*-23.2	14.67	-175
SCENARIO 2	90	35.0	14.67	-136.3
SCENARIO 3	50	61.6	14.67	-70
SCENARIO 4	50	131.7	14.67	-43.4

	ELECTRICAL**	THERMAL	COMPRESSOR EFFICIENCY 200 TO 1200 PSIG	SYSTEM EFFICIENCY (WITHOUT HVAC)	SYSTEM EFFICIENCY (WITH HVAC)
	(SCFM/HP)	(SCFM/HP)	(SCFM/HP)		
SCENARIO 1	9.70	9.71	3.3	34.04%	68.02%
SCENARIO 2	8.53	11.28	3.3	38.70%	67.95%
SCENARIO 3	6.31	17.09	3.3	52.32%	71.63%
SCENARIO 4	5.55	27.66	3.3	59.46%	71.39%

FIGURE 18

3.60 MW (electrical) REPLACEMENT SHEET

3.00 MW (thermal)

6.60 MW (total)

3 Hrs

3,600 kW

4,826 hp

9.1 scfm/hp

43,914 scfm

180 minutes

7,904,558 scf required

4 ft diameter

9,250 ft length

116,239 cu ft (actual)

9,624,536 scf at 1,214.67 psia

1,700,955 scf at 214.67 psia

7,923,581 scf available

FIGURE 19

5 kW-Hrs/Sq M/day

2,313 ft long trench

4 ft wide trench

9,250 sq ft (footprint of pipe)

859 sq M

4,297 kW-Hrs/day

15,468,356 kW-sec/day

0.948 (BTU/sec)/kW

14,664,002 BTU available/day

FIGURE 20A

External Receiver

4 ft wide trench

1.7 ft deep trench

2,313 ft long

981,240 # water

117,655 gallons water

654 gpm water 3 hours

External Receiver Water Temperature Increase

1 BTU/(# F) water

981,240 # water

981,240 BTU/F water

15 F temperature change

14,718,600 BTU required per day (no losses)

FIGURE 20B

Jacket Size

4 ft inside diameter
 4.068 ft outside diameter
 9,250.0 ft length
 15,942.9 cu ft
 62.4 #/cu ft
 994,835 #
 1 BTU/(# F)
 994,835 BTU/F
 116,239 sq ft area

FIGURE 21

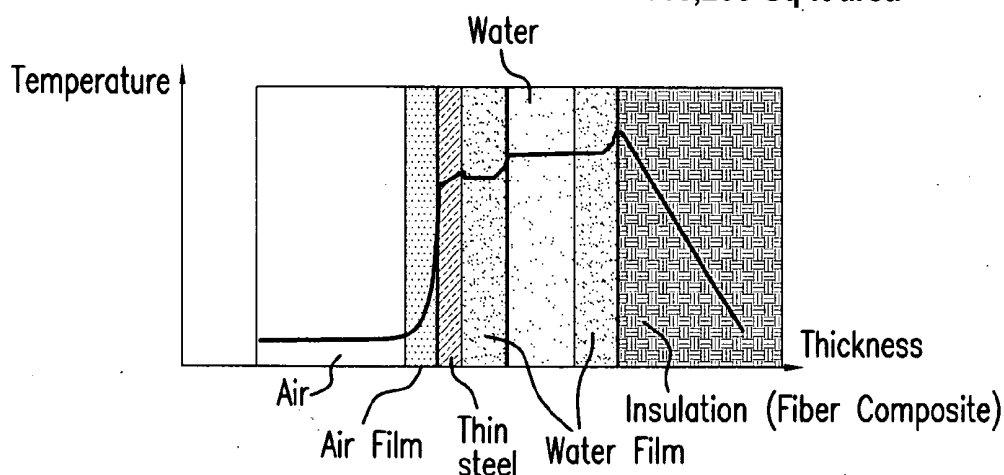


FIG.22

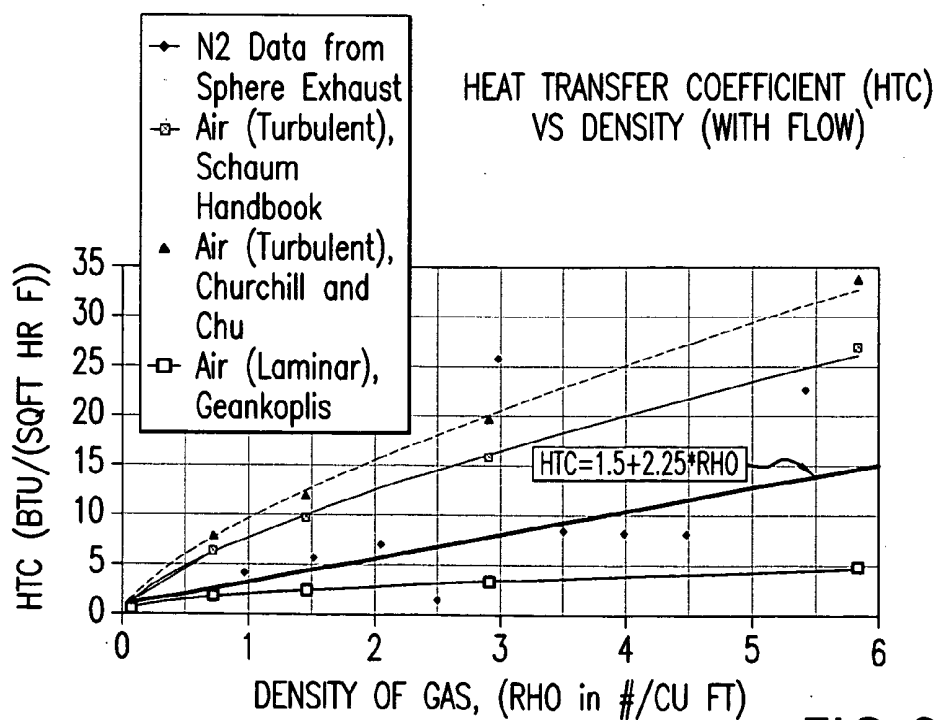


FIG.23

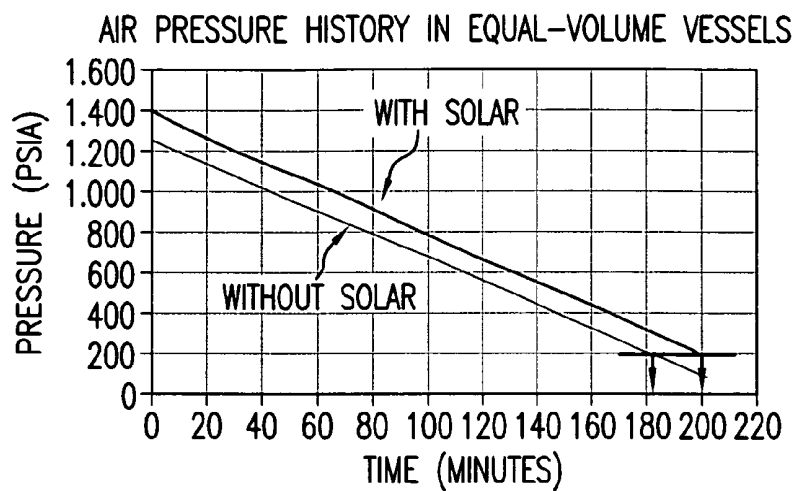


FIG.24

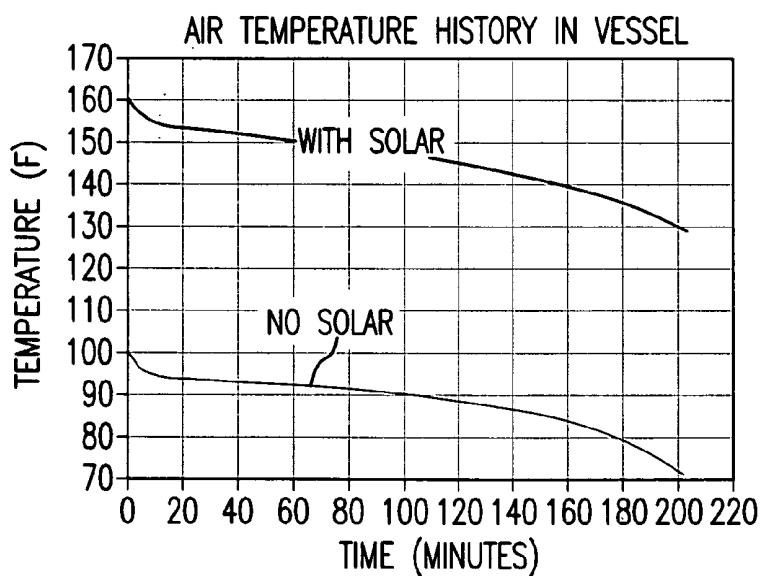


FIG.25

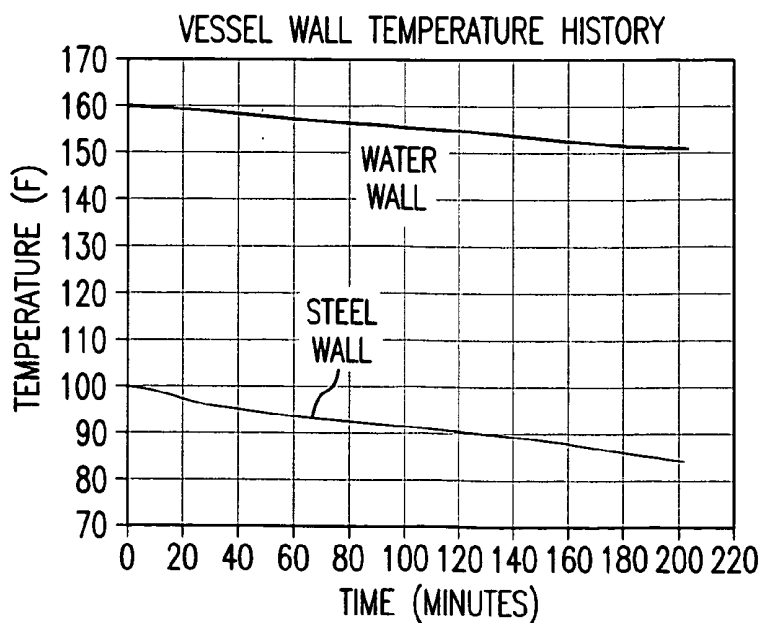


FIG.26

**METHOD AND APPARATUS FOR USING
SOLAR ENERGY TO ENHANCE THE
OPERATION OF A COMPRESSED AIR
ENERGY STORAGE SYSTEM**

RELATED APPLICATIONS

[0001] This application claims priority from U.S. Provisional Application Ser. Nos. 61/062,149, filed on Jan. 24, 2008, 61/068,170, filed on Mar. 5, 2008, and 61/195,418, filed on Oct. 7, 2008, all of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] Due to the growing demand for energy throughout the world, concerns have grown about the future of the world's energy supplies. Not only are there limited supplies of oil and coal reserves available within the earth's crust, but due to the ongoing security problems and concerns that now exist throughout the world today, there has been a growing desire to reduce our nation's reliance on foreign oil.

[0003] Indeed, many energy experts believe that a successful energy solution must include the ability to harness energy from what are often called natural renewable resources, such as the sun and wind. The renewability and abundant availability of these resources make them well suited to the development of potentially viable long term solutions, and many believe that whatever efforts that are currently being made to use these resources must significantly be expanded before the world's oil and coal reserves eventually run out.

[0004] One problem associated with the use of renewable energy such as the sun and wind is that the energy is not always available when the energy is needed. Solar power, for example, is only available during the day, and is most effective when the sun is shining brightly, and therefore, the extent to which energy can be provided by the sun is not always predictable. Wind energy is also only available when the wind is blowing, and therefore, it is not a highly reliable source of energy. Another drawback to these resources is that even when energy is available, the amount of energy that they generate is not always consistent. For example, even when the wind blows, it does not always blow at the same speed, or at regular intervals, and therefore, the amount of energy that can be generated is not always consistent. The same is true of solar energy, i.e., the degree to which the sun is shining and available can be sporadic; it often depends on the weather, and therefore, it is never certain how much energy can be generated at any given moment in time.

[0005] One potential solution to these problems is to store the energy during times when the energy is available, and using the energy when it is needed most. This is often referred to as time-shifting. Nevertheless, one problem associated with time-shifting relates to the inherent inefficiencies that can result from having to store energy in one form, and then converting the energy into another form before it can be used. This is especially true of compressed air energy storage systems that store compressed air in high pressure storage tanks, wherein the energy must be converted by a generator to produce usable electricity. In such case, the energy used from storage can often end up costing more than the energy that was stored. These inefficiencies can significantly reduce the economic incentives that are needed to promote the installation of these potentially viable systems.

[0006] Notwithstanding these problems, because the sun represents a significant natural resource that will never run out, there is a strong desire to develop a system that can not only harness the sun's energy, i.e., to produce electricity, but to store the energy, and do so in a manner that is efficient and cost-effective, wherein the energy that is generated can then be made available on a continuous and uninterrupted basis, so that it can be used during peak demand periods, as well as when little or no sun is available. Moreover, while there has been a steady increase in the number of photovoltaic (PV) cell projects that have been initiated and developed in recent years, each of these projects has had a serious shortfall in electric power production particularly in the late afternoon and early evening when the power demand is high. Thus there is a need to install a PV panel system wherein the excess energy can be collected and stored during the high solar irradiation period and then used during the weaker solar irradiation period.

SUMMARY OF THE INVENTION

[0007] The present invention represents an improvement over past attempts to harness energy from renewable resources such as the sun and wind insofar as the present system preferably incorporates not only the advantages of using solar energy, but the advantages of using compressed air energy storage systems, wherein some of the previous inefficiencies of using compressed air are overcome by the heat generated by the sun, wherein the present system helps to reduce the inefficiencies and inconsistencies that have existed in past systems. Generally speaking, the invention relates to a method and apparatus that uses solar energy to enhance the efficiency of a compressed air energy storage system, and that can also use the compressed air energy storage system to enhance the efficiency of the solar energy generated thereby.

[0008] Preferably, the present invention comprises a photovoltaic cell panel that can collect solar energy and convert it into electrical energy, wherein at least a portion of the energy can be used to drive a compressor to produce compressed air energy, which in turn, can be stored in a high pressure storage tank. Two solar receiving panels are also preferably used to collect the sun's energy and use it to produce heated water which can, then be circulated and stored within an annulus surrounding the storage tank, wherein the heated water can then help to regulate the temperature of the compressed air within the tank, particularly when the compressed air is being released by a turbo expander, wherein not only is electricity generated, but chilled air is also produced as a by-product.

[0009] This way, when compressed air is released using the turbo expander, excessive temperature drops within the tank and compressed air can be avoided. And by maintaining and even increasing the temperature of the compressed air, the air pressure within the tank can also be maintained, which enhances the efficiency of the overall system. System efficiency can also be enhanced by making use of the chilled air by-product exhausted from the turbo expander to generate more electrical power from an associated fuel-driven generator set, and/or by using the waste heat from the compressor (and/or from the generator set exhaust) in a combined heat and power system (CHP) to power either a steam-driven generator set or an absorption chiller.

[0010] The various components of the system will now briefly be described.

[0011] The present invention preferably comprises at least two types of solar energy collecting means. First, a photovol-

taic cell panel is preferably used to collect solar energy and generate electricity when the sun is shining. In one embodiment, a large photovoltaic panel can be used to generate electricity that can be used to provide energy directly for an associated facility or small community, etc. But because the sun does not always shine in sufficient amounts to generate a consistent uninterrupted supply of energy, the present invention preferably comprises a means for storing the energy, such that it can be used later when the demand is high, and/or to reduce peak demand power spikes and surges, etc.

[0012] Accordingly, at least a portion of the electricity generated by the photovoltaic panel can be used to drive a compressor which in turn compresses air into a high pressure storage tank. This way, when the sun is shining, the system can be used to generate compressed air energy which can be used later. When the sun is not shining, the present system preferably enables the compressor to be operated using a conventional source, such as power from the grid, a utility plant, a wind farm or a wind turbine. In either case, the energy is preferably collected when the energy is most available and costs are relatively low, which, in the case of power grids and utility plants would be during the nighttime, and in the case of wind farms and wind turbines would be when the wind naturally blows.

[0013] Second, in addition to using a photovoltaic cell to generate energy, the present invention preferably uses at least one solar receiving panel connected to a container of water that can be used to heat the water contained therein. For purposes of this discussion, the term water shall include any water-like fluid or liquid that can be used as the conductor. Once the water is heated, it can then be transferred, stored and used to maintain the temperature of the compressed air within the tank. This is done by storing the heated water in an annulus surrounding the compressed air storage tank to maintain the temperature of the compressed air therein.

[0014] The receiving panel is preferably provided with an appropriate surface geometry to collect solar energy, wherein that energy can be used to heat the water contained within the container, such as up to 165 degrees F. or more. The solar receiving panels preferably comprise a wedge-shaped dimpled (egg-carton) surface covered with a black coating that essentially floats on top of the water contained within the containers, which helps to ensure that there is sufficient contact between the surface and the water stored therein to enable proper heat transfer to occur. This also helps to avoid the water from escaping from the container as a liquid or vapor. The wedge shaped surface also helps to ensure that a proper amount of solar irradiation is absorbed by the panels to generate heat regardless of the angle at which the sun's rays hit the surface. The sun's rays are preferably allowed to enter into the wedge shaped sections and because of the gaps or notches therein, the sun light can be reflected internally, thereby helping to make efficient use of the radiated energy from the sun. In addition to the geometry of the surface, the black coloring also helps to ensure that the sun's heat is absorbed properly by the panels. By using the heated water to maintain the temperature of the compressed air within the tank, not only can the air pressure be better maintained, but greater system efficiencies can also be achieved.

[0015] The design of the high pressure storage tank also plays a role in being able to improve the efficiencies of the system. The tank, in such case, is preferably designed with an inner pressure vessel and an outer wall that are concentrically oriented. This way, the compressed air can be stored within

the inner pressure vessel, and the heated water can be stored within an annulus that surrounds the inner vessel, wherein the heated water that surrounds the inner wall can help maintain the temperature of the compressed air in the tank.

[0016] It should be noted here that the materials and properties used to make the inner and outer walls of the storage tank are preferably different. For example, the inner wall is preferably made thin with a relatively strong elastic material such as steel that enables a sufficient amount of heat transfer to occur between the heated water and compressed air, whereas, the outer wall is preferably made thick and relatively strong with sufficient insulating properties to hold the heat in, such as reinforced concrete or fiber reinforced composite materials. This way, the conductivity of the inner wall can be used to help promote heat transfer between the heated water and compressed air, whereas, the outer wall can be strong and thick enough to withstand the pressures that are exerted against the tank, as will be discussed, as well as preserve the temperature of the air and water contained therein.

[0017] One problem overcome by the present system is achieving a happy medium between making the inner wall thin enough to provide sufficient heat transfer characteristics, while at the same time, making the tank strong enough to withstand the significant pressures that can exist within the vessel, such as up to 1,300 psia. This problem is complicated by the fact that under normal circumstances one way to improve conductivity is to make the inner wall that separates the two substances thinner, whereas, one way to increase the strength of the inner wall is to make it thicker. In the average case, for example, a compressed air energy storage tank may require pressures as high as 1,300 psia to produce an adequate supply of compressed air, but the question is whether the inner vessel in the present case with its conducting properties can be designed to maintain that kind of pressure on its own.

[0018] The present invention preferably solves this problem by making the inner wall elastic and relatively thin, and the outer wall relatively strong and thick, but also by introducing the heated water into an annulus that exists between the inner and outer walls, and then closing the annulus, thus allowing water pressure within the annulus to build up, such that, when the pressure within the inner wall is increased, water within the annulus (and the outer wall that holds it) serve to prevent the inner wall from bursting. That is, when the air pressure within the inner pressure vessel is increased beyond the capacity of the inner wall, the inner wall will expand and stretch, and therefore, the water pressure within the annulus will also increase, but because water is incompressible, and the outer wall is stronger, any pressure exerted against the inner wall will be maintained by the water in the annulus which exerts pressure against the outer wall. Therefore, it is the strength of the outer wall that will help dictate the maximum pressure amounts that can be maintained within the tank. Accordingly, even if the inner wall is designed to withstand only a nominal amount of air pressure, i.e., such as 200 psia in the preferred embodiment, the outer wall is preferably designed to withstand over 1,300 psia, and therefore, the system is preferably able to withstand overall internal air pressures of 1,300 psia or more.

[0019] Stated differently, when there is no water in the annulus there is no pressure, and therefore, when there is 200 psig in the pressure vessel, there is a 200-psig pressure differential across the inner wall. When the water is first sent to the annulus, the inner wall sustains the internal pressure so that the water can be transferred to the annulus with little or no

backpressure. But when the water fills the annulus, and the valve is closed, air within the pressure vessel can then be compressed above 200 psig, such as up to 1,300 psig, wherein the inner wall stretches, and because the water in the annulus is sealed by the valve, and is incompressible, and the outer wall is thicker and stronger than the inner wall, and able to withstand up to 1,300 psig, the internal pressure of 1,300 psig within the inner pressure vessel can be maintained. In such case, the expansion of the inner wall is limited because the water in the annulus is pressurized by the expanding inner wall, which acts like a balloon that is supported by the "incompressible" water that transmits its hydrostatic pressure to the outer wall.

[0020] The inner wall is preferably made of steel, or other metal, such as aluminum or copper, which can be made relatively thin in order for proper heat transfer to occur. Steel is also elastic and therefore allows the inner wall to expand and stretch as the pressure within is increased. Ideally, the inner wall is designed to stretch to within 10% of its elastic limit. On the other hand, the outer wall is preferably made of a thick fiber reinforced composite material or pre-stressed concrete or other strong material that can withstand the pressures that are exerted against it.

[0021] Based on the above, when the air pressure within the inner wall is increased to above its capacity, i.e., above 200 psia in the preferred embodiment, as long as the annulus between the inner and outer walls is filled with water, and sealed, and the water pressure in the annulus is increased, the inner wall will be able to withstand the higher air pressures amount, i.e., as high as 1,300 psia, or whatever the maximum capacity of the outer wall is. This would not be the case if no water was in the annulus, or the valve was open, or if the outer wall was not designed to withstand the greater pressure amounts. Since the elastic limit of the inner wall is much lower than the limit of the outer wall, it would not be able to withstand the added pressure on its own.

[0022] The present system also preferably incorporates a multi stage turbo expander that is associated with an electrical generator and power conditioner, wherein the compressed air can be released and expanded to produce electricity. Expanding the compressed air also creates chilled air as a by-product, and therefore, the present system preferably incorporates a means of using the chilled air to provide cooling for an ancillary device, such as HVAC, refrigeration, or desalination device. The cool air can also be used as the inlet into an associated fuel driven turbine generator set (GenSet). Heat derived from the compressor can also be used in ancillary systems, such as for showers, laundries, baths, steam-driven (GenSet), absorption chiller, etc., as well as to provide heat for the heated water in the annulus.

[0023] By being able to store the compressed air within the inner pressure vessel, and the heated water within the annulus that surrounds the inner wall, the temperature of the compressed air can be maintained when the turbo expander is operated to release the compressed air, which would otherwise cause the air to become significantly chilled. Accordingly, the present system helps to maintain the temperature and pressure of the compressed air within the storage tank, and therefore, improve the overall efficiency of the compressed air energy storage system.

[0024] Based on the above features and components, the present method preferably operates in the following manner:

[0025] Preferably, two solar receiving panels are initially exposed to the sun's rays during the daytime hours wherein

the water contained in the associated containers begins to heat up. This can, for example, go on for several days, or up to a week or more, to ensure that enough sunshine is available and provided to increase the temperature of the water in the containers, i.e., which in the preferred embodiment is about 165 degrees F. Preferably, the system is able to collect solar energy for at least eight hours each day, such as during the morning, noon and early afternoon.

[0026] When the sun is not available to drive the photovoltaic panel, the present method preferably contemplates being able to use an auxiliary source of energy, such as the power grid, or nearby utility plant, or a wind farm, or wind turbine, to produce compressed air energy that could be transferred into the pressure vessel in the tank. And preferably, to reduce the cost of using this energy, this is preferably done when energy demands and costs are relatively low, such as during the nighttime hours, or when the sun shines or the wind naturally blows.

[0027] At the same time, or otherwise when the sun is shining, such as during the morning, noon and afternoon hours, the photovoltaic panel is preferably used to produce electricity, which in turn, can be used to drive the compressor to produce compressed air energy, which can then be transferred to the pressure vessel of the tank and stored. Initially, the compressor should only be activated to increase the pressure within the vessel to the low pressure amount, which, in the preferred embodiment is 200 psia. This is based on the capacity of the inner wall, since at this point there is no water or pressure within the annulus to support more pressure in the vessel.

[0028] Once the water in one of the containers has reached the predetermined temperature, such as 165 degrees F., the heated water can be transferred into the annulus of the storage tank. This can be done by shutting the valve to one of the containers and opening the valve to the other container, and operating the pump to begin pumping the water into the tank. Preferably, the annulus has no air pressure and is vented so that as the water fills the annulus, there is no back pressure exerted on the pump. And preferably, this is done at night before the morning sun begins to shine so that the valves can be shut before the compressor begins to increase the pressure of the compressed air in the tank. Note that there can be more than one storage tank, in which case, the heated water can be distributed into the annuluses of all the tanks, but for convenience, this summary will mention only a single tank.

[0029] Then, once the annulus is completely filled with heated water, and the valve is closed, such as during the next morning when the sun is shining, the photovoltaic panel is preferably used to increase the pressure of the compressed air to its maximum pressure. The pressure is preferably increased until the maximum pressure reached is about 1,300 psia.

[0030] As discussed above, even though the inner wall does not have the capacity to withstand that kind of pressure on its own, the total pressure rating of the tank can be determined by the strength of the outer wall. That is, as the pressure within the inner vessel is increased, the inner wall will begin to expand, but because the annulus is completely filled with water, and water is incompressible, pressure within the annulus will help to maintain the air pressure within the inner wall. Moreover, when the internal air pressure is 1,300 psia, the tensile resistance in the stretched cylindrical inner wall is preferably able to impose a 200 psid (psi "difference"). Thus the outermost wall needs to only withstand an equivalent 1,100 psia air pressure, which is a built in safety feature.

[0031] Once the tank is filled with air pressure, such as to the maximum degree possible, the compressed air is ready to be released, which can occur during the late afternoon. This allows the system to provide backup energy during the peak daytime hours. At this point, the compressed air is preferably at about room temperature, although not necessarily so, and, the compressed air is preferably released by a turbo expander, which is combined with a generator and power conditioner to produce electricity. At the same time, the heated water in the annulus transfers its heat to the air in the vessel so that excessive temperature drops can be avoided.

[0032] And, as the compressed air is released via the turbo expander impeller, the chilled air by-product exhausted from the turbo expander can be used to drive an associated cooling device, such as an HVAC, refrigerator, or desalination device, or a related fuel driven generator set. The temperature of the heated water within the annulus is also reduced as the compressed air in the pressure vessel is decompressed and tends to drop in temperature as it drop in pressure.

[0033] Once the air pressure within the inner wall is reduced to below its capacity, i.e., to below 200 psia in the preferred embodiment, the valve can be opened and the water within the annulus can be transferred back to the first container, which preferably occurs before the sun comes up, such that the sun can begin to heat the water in the container again after the water is fully transferred. The temperature of the water at this point can be lower than it was before, although not substantially lower, i.e., the temperature could drop from 165 degrees F. down to 152 degrees F., for example, as the compressed air is released. This leaves the annulus empty of water, i.e., at zero psig (or 14.67 psia), whereas, the pressure vessel may still have an internal pressure of 200 psia (or 186.3 psig), wherein the inner wall preferably stretches elastically to contain the pressure difference.

[0034] Next, such as later that same night, the heated water in the second container is preferably transferred into the annulus of the tank. This can be done by shutting the valve to the first container and opening the valve to the second container, and operating the pump to begin pumping the water toward the tank.

[0035] Once the annulus of the tank is completely filled again, and the tank valve is closed again, which can be done by the next morning, the photovoltaic panel can begin operating again to supply energy to the compressor to increase the pressure of the air within the pressure vessel again. This is preferably done until the maximum air pressure of 1,300 psia is reached within the inner wall. At the same time, such as during the day, the water in the first container is heated again.

[0036] Once the air pressure in the pressure vessel is increased to a specified maximum, the compressed air is ready to be released by the turbo expander to produce electricity. Chilled air can also be produced as a by-product which can be used to drive an associated cooling device, such as an HVAC, refrigerator, or desalination device, or a related fuel driven generator set. Next, as the air pressure within the inner pressure vessel is reduced to below its capacity, i.e., 200 psia, the valve can be opened again and the heated water can be transferred back to the second container. This preferably occurs before the morning, so that the sun can begin to heat the water again.

[0037] The next day, when the water in the first container is heated again, the cycle can repeat, i.e., the heated water in the first container can be transferred back to the annulus of the

tank, and the compressor can be operated again to begin filling the pressure vessel with more pressure.

[0038] At any given time, when the sun is not available to drive the photovoltaic panel to compress the air, the present method preferably contemplates being able to use an auxiliary source of energy, such as the power grid, or nearby utility plant, or wind farm, or wind turbine, to produce compressed air energy that could be transferred into the pressure vessel of the tank. And preferably, to reduce the cost of using this energy, this is preferably done when energy demands and costs are relatively low, such as during the nighttime hours, or when the sun shines or the wind naturally blows.

[0039] Again, the main advantages of the present system is that the energy derived from the sun (and/or wind) can be used and stored so that the energy can be used when it is most needed, which may or may not coincide with when the energy is available. And, in doing so, the present system makes efficient use of not only the electricity produced from the use of solar photovoltaic and thermal energies, but the energy storage capacity of a compressed air energy storage system, including the heat input from the sun which enhances the energy provided by the system, as well as the chilled air thermal output which can be used to provide cooling for associated devices.

BRIEF DESCRIPTION OF THE DRAWINGS

[0040] FIG. 1 is a schematic drawing showing the various components of the solar enhancement system of the present invention, including the photovoltaic panel, the two solar receiving panels, the storage tanks, and the turbo expander set with generator;

[0041] FIG. 2 show cross sections of the high pressure storage tank used in connection with the present system showing the concentrically oriented inner vessel and outer wall, wherein three different pressure states are shown;

[0042] FIG. 2A is a schematic drawing showing the various components of an alternate pump with one direction-two way layout;

[0043] FIG. 3 is a schematic drawing showing a cross section of the wedged surface of the solar receiving panels capable of heating the water contained therein, wherein the wedged surface helps to ensure that most of the solar irradiation is absorbed and proper contact is made between the surface and water contained therein;

[0044] FIG. 4 is a schematic drawing showing the various components of the solar enhancement system of the present invention, including the two solar receiving panels with containers of water and the high pressure storage tanks, wherein the first phase of the process is shown in which the sun is allowed to heat the water within the containers and the air pressure within the tanks is increased to about 200 psia;

[0045] FIG. 5 shows the second phase during which the heated water from the first container fills the tanks, and in particular, the annulus between the inner and outer walls, wherein the valve is closed;

[0046] FIG. 6 shows the third phase during which the air pressure within the tanks and in particular the inner pressure vessel can be increased to the high pressure amount, wherein the water pressure in the annulus can also be increased;

[0047] FIG. 7 shows the fourth phase during which the air pressure within the pressure vessel can be released by the turbo expander, from the high pressure amount to the low pressure amount, which in turn causes the water pressure in the annulus to be decreased to zero (gage pressure);

[0048] FIG. 8 shows the fifth phase during which the water within the tanks is transferred back to the first solar receiving container;

[0049] FIG. 9 shows the sixth phase during which the heated water from the second container is pumped to fill the annulus, wherein the valve is closed;

[0050] FIG. 10 shows the seventh phase during which the air pressure within the inner pressure vessel is increased up to the high pressure amount, wherein the water pressure within the annulus can be increased;

[0051] FIG. 11 shows the eighth phase during which the air pressure within the vessel can be released by the turbo expander, which in turn causes the water pressure to be decreased to zero (gage pressure);

[0052] FIG. 12 shows the ninth phase during which the water within the annulus is transferred back to the second container;

[0053] FIG. 13 shows the tenth phase during which the heated water from the first container is pumped to fill the annulus again, wherein the valve is closed again;

[0054] FIG. 14 shows the eleventh phase during which the air pressure within the vessel can be increased to the high pressure amount, and the water pressure within the annulus can be increased to the high pressure amount, wherein the cycle is repeated again;

[0055] FIG. 15 is a chart showing the properties of a water-cooled five stage air compressor;

[0056] FIG. 16 is a chart showing a summary of the compressor outputs for heating water as well as the air in the pressure vessel;

[0057] FIG. 17 is a chart showing the required air flow from the pressure vessel to produce a unit of power (HP) as a function of air temperature at 200 psia;

[0058] FIG. 18 is a chart showing four scenarios of input pressure and input temperature for a two stage turbo expander;

[0059] FIG. 19 is a chart showing the requirements for producing power using a turbo expander;

[0060] FIG. 20A is a chart showing how much power is provided by the solar panel;

[0061] FIG. 20B is a chart showing how much the water temperature increases (15° F.) as a result of the energy provided by the solar panel;

[0062] FIG. 21 is a chart showing the annular radial gap (4.068 ft -4.000 ft) for water in the pressure vessel;

[0063] FIG. 22 is a chart showing the temperature profile between compressed air and outer insulator cylinder (Note that the insulation can be fiber composite as indicated or reinforced concrete);

[0064] FIG. 23 is a chart showing the total heat transfer coefficient between the air and inner wall;

[0065] FIG. 24 is a chart showing the air pressure history in the pressure vessel;

[0066] FIG. 25 is a chart showing the air temperature history in the pressure vessel; and

[0067] FIG. 26 is a chart comparing the air temperature histories of a steel wall vessel and the water filled annulus of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0068] FIG. 1 shows the main components of the present system 1, including a photovoltaic cell panel 3, two solar receiving panels 5, 6, and several high pressure storage tanks 7a, 7b, 7c, and 7d, among other components.

[0069] Photovoltaic panel 3 is preferably capable of collecting solar photovoltaic energy from the sun's rays and converting it into electricity. Preferably, there are two different configurations that can be used in connection with the present system, including 1) highly transmissive photovoltaic solar cells, and 2) highly reflective photovoltaic solar cells. In either case, the solar cell will use a portion of the irradiated solar energy received by the panel for conversion to electricity, wherein the remainder is preferably either transmitted to a back-plate that conducts the energy away or reflected from the front surface to avoid overheating. The electricity produced by panel 3 can be used directly, such as when a large panel that can supply energy for immediate use to a facility or small community is provided.

[0070] Panel 3 is preferably connected to a compressor 9 so that the solar energy generated by panel 3 can be used to drive compressor 9. Compressor 9 is preferably a multi-stage compressor that can be used to compress air into tanks 7a, 7b, 7c and 7d, via pipe 13. Compressor 9, for example, can be a five stage compressor with water cooling steps between each stage, wherein the fifth stage can produce compressed air that is relatively hot, as shown in FIG. 15. The discharge of compressed air from compressor 9 preferably produces air at a relatively high temperature, which can be helpful in being able to recover the overall efficiencies of the system. Heat exchangers can, nevertheless, be used to recover heat generated by compressor 9, as shown in FIG. 16, wherein the heated coolant can then be transferred to an associated site, for use in a laundry, shower, bath facility, steam-driven generator set or absorption chiller etc. The heated water can also be used to supply heated water to containers 17, 19. Note that the heated water in this case can be a key element in recovering the waste heat from the compressor so that the high efficiencies of the combined heat and power (CHP) systems are achieved. Thus a 75% efficient compressor stage can become a 75%+13%=88% efficient.

[0071] Compressor 9 is preferably connected to tanks 7a, 7b, 7c and 7d, via one or more pipes 13, through which compressed air generated by compressor 9 can be transferred. A valve 15 is preferably provided along pipe 13 that controls the flow of compressed air from compressor 9 to tanks 7a, 7b, 7c, 7d, while at the same time, mass control valve 16 is preferably provided to close off the flow of air to turbo expander 41. This way, when valve 15 is open, and valve 16 is closed, air will flow from compressor 9 to tanks 7a, 7b, 7c, 7d. On the other hand, when valve 15 is closed, and valve 16 is open, air can flow to turbo expander 41. It should be noted here that while four tanks are shown, any number of tanks can be used, including just one tank or multiple tanks.

[0072] Preferably, solar thermal energy receiving panels 5, 6 are provided with first and second containers 17, 19, respectively, associated therewith underneath as shown in FIGS. 4-14. The entire spectrum (ultraviolet, visible and near infrared wavelengths) of solar irradiation is preferably converted to thermal energy by the dimpled cover surface that floats atop the containers of water. Containers 17, 19 are preferably positioned underneath receiving panels 5, 6, and adapted such that the solar thermal energy collected by receiving panels 5, 6 can be used to heat the water contained therein. Although the term water will be used throughout, it should be understood that the term shall include other water-like fluids or

liquids that can also be used, such as those that have a high heat capacity with no tendency to introduce bio-fouling or corrosion, and which are able to store heat and rapidly release the heat to the compressed air as it is being stored or expanded.

[0073] Receiving panels 5, 6 are preferably provided with a dimpled solar energy receiving surface 51 with wedged-shaped indentations and black coating, as shown in FIG. 3. Dimpled surface 51 preferably has wedge shaped sections 52 and floats atop the water contained within containers 17, 19 so that direct contact between surface 51, which is exposed to the sun, and water, is ensured, and so that none of the water is allowed to escape as a liquid or vapor. Dimpled surface 51 preferably allows the sun's rays to enter into each wedge shaped section 52 at virtually any angle, wherein the light can be reflected (multiple times) internally and then absorbed by surface 51 to provide heat to the water contained therein. Dimpled surface 51 preferably helps to ensure that a proper amount of incident ultraviolet, visible and infrared solar irradiation is absorbed by panels 5, 6 to generate heat. The deeply corrugated surface as well as the black color preferably captures all the solar wavelengths of the energy emitted by the sun. The black coloring also helps to ensure that the sun's heat is absorbed properly by panels 5, 6.

[0074] Containers 17, 19 are preferably connected to and communicate with tanks 7a, 7b, 7c, 7d, via one or more pipes, 21, 22, through which heated water from containers 17, 19 can be transferred to tanks 7a, 7b, 7c, 7d. In one embodiment, a two directional pump 23 is preferably provided to pump water from containers 17, 19 to tanks 7a, 7b, 7c, 7d and vice versa. Preferably, valves 25, 27, are provided on pipes 21, 22, respectively, wherein valve 25 controls the flow of water to and from container 17, and valve 27 controls the flow of water to and from container 19. When valves 25, 27 are both closed, the annuluses 35 in the tanks can be sealed so that water pressure within tanks 7a, 7b, 7c, and 7d can be increased, as will be discussed.

[0075] As shown in FIG. 2, each tank 7 is preferably configured in the shape of a cylindrical pipe, with an inner wall 29 located concentrically inside an outer wall 31. This arrangement preferably enables one inner pressure vessel and one distinct outer annulus to be formed within each tank, including an inner pressure vessel 33 formed by inner wall 29, and annulus 35 extended between inner wall 29 and outer wall 31. This way, heated water from containers 17, 19 can be transferred to and stored within annulus 35, and compressed air from compressor 9 can be transferred to and stored within pressure vessel 33, wherein the compressed air within pressure vessel 33 can be surrounded by the heated water within annulus 35. Tank 7 can be located above ground, or partially or fully buried. Preferably, annulus 35 has no air pressure and is vented so that as the water fills the annulus, there is no back pressure exerted on pump 23.

[0076] Preferably, inner wall 29 is made of a relatively strong and elastic material such as certain types of metal including steel, copper or aluminum to ensure that adequate heat transfer occurs between the heated water within annulus 35 and compressed air within pressure vessel 33. Inner wall 29 is preferably made relatively thin, especially when metals such as stainless steel are used, since stainless steel has relatively low thermal conductive properties when compared to other metals such as copper or aluminum which can also be used.

Thermal Conductivity of Certain Materials

[0077]

Material	Btu/(hr ° F. ft)
Admiralty Brass	64
Aluminum	118
Beryllium	126
Copper	223
Tungsten	97
Stainless Steel	7 to 26

[0078] Inner wall 29 is preferably manufactured to withstand a predetermined amount of pressure, which in the preferred embodiment is about 200 psia, although this amount can be higher or lower. At the same time, inner wall 29 is preferably made elastic, which allows inner wall 29 to expand and stretch, such as up to 10% of its elastic limit, such as when air pressures in excess of the predetermined low pressure amount, i.e., 200 psia, is introduced into pressure vessel 33.

[0079] Several intermittent supports 37, with a passageway 39 in each one, are preferably provided and secured between inner wall 29 and outer wall 31 to secure inner wall 29 and outer wall 31 together, thereby helping to form a dual pipe-like structure. Passageways 39 are preferably provided within each support 37 to allow water within annulus 35 to pass between the sections formed by supports 37.

[0080] Outer wall 31 is preferably made of a strong and durable material, such as fiber reinforced composite materials or pre-stressed concrete, etc., which can withstand the significant air pressures that can be applied against outer wall 31, which in the preferred embodiment, can exceed 1,300 psia, as will be discussed. Outer wall 31 is preferably made relatively thick and has adequate insulating properties (low thermal conductivity).

[0081] Common fiber reinforced composites are typically composed of fibers along with a matrix. Fibers are the reinforcement and the main source of strength, while the matrix 'glues' all of the fibers together and transfers stresses between the reinforcing fibers. Sometimes, fillers or modifiers might be added to smooth out the manufacturing process, impart special properties, and/or reduce costs. The composites of interest in connection with the present invention include without limitation: (1) carbon fiber, (2) Polyamide (Aromatic polyamide, Aramid), e.g., Kevlar 29 and Kevlar 49 and (3) Glass (E-glass, S-glass, D-glass). These materials have a combination of strength and insulator properties that are suitable for the outer wall of this application. Another important characteristic of fiber composite materials are their robust performance in humid and corrosive atmospheres.

[0082] The outer wall can also be made of inexpensive materials (such as reinforced concrete) that will sustain the internal pressure and mitigate corrosion effects, especially if the pressure vessel (tank or pipeline) is underground. Concrete is less expensive than fiber reinforced composite materials and therefore is the preferred choice. Nevertheless, when concrete is used, it must be pre-stressed to ensure that the proper tension strength can be achieved. Prestressing is a method used to overcome the concrete's natural weakness in tension. It can be used to produce high internal compression forces within the structure of the walls, such that regardless of the tension applied the concrete will be in compression. Prestressing steel tendons (generally high tensile steel cable or

rods) are typically used to provide a clamping and therefore compression load that produces an initial compressive stress that offsets the tensile stress that the concrete would otherwise experience due to the outward pressure of the compressed fluid. Prestressing is usually accomplished in three ways: (1) Pre-tensioned concrete, (2) Bonded post-tensioned concrete, or (3) Unbonded post-tensioned concrete.

[0083] In one example, the concrete portion of the wall is covered by an outer steel shell that can be shrunk (such as by heat) onto the concrete to compress and strengthen it against tension and therefore higher pressures. Such a pre-stressed concrete pressure tank is shown in U.S. Pat. No. 4,313,902, which is incorporated herein by reference. The pre-stressed concrete pressure-containment vessel is preferably contained by pre-stressing tendons, which apply forces to contain various high pressures within the structure. By permitting and actually inducing controlled cracking of the vessel in the outer portions of the thick shell wall, one embodiment of a pressure-containment vessel relieves stresses and enhances resistance to very high internal pressures and stresses due to high internal temperatures and steep temperature gradients.

[0084] Pressure vessels can have end covers which are discussed in U.S. Pat. No. 4,479,336, which is incorporated herein by reference. Such a closure comprises an anchoring ring surrounding the opening of the pre-stressed concrete pressure vessel, a plurality of axial stressing cables and a plurality of cover stressing cables. The cover is separately pre-stressed and simultaneously anchored to the pre-stressed concrete. The anchoring rings on the concrete are used to release the axial stressing cables of the vessel.

[0085] The internal pressures considered in connection with the tank are on the order of 1,300 psig. In this respect, a pre-stressed concrete pressure vessel capable of containing extremely high pressures in an internal cavity, such as 10,000 psi and higher, is shown in U.S. Pat. No. 4,389,825, which is incorporated herein by reference. The pressure vessel is constructed in such a way as to enable the application of extremely high circumferential pre-stressing forces at the outer cylindrical surface. The extreme circumferential post-tensioning force, much greater than previously known in pre-stressed concrete pressure vessels, provides for containment of extreme pressures in the internal cavity, using a relatively thin-wall vessel. In order to accommodate high circumferential post-tensioning without structural damage at the interior of the vessel, the vessel preferably includes vertical stress relieving slots extending radially outwardly from the internal cavity surface, effective to lower peak tangential compressive stress at the cavity surface and to relocate peak stress inside the vessel wall where the concrete is confined.

[0086] As shown in FIG. 2, tank 7 is preferably placed into one of three different pressure states. The state shown in the top drawing has about 200 psia of air pressure contained within pressure vessel 33, which is preferably the maximum pressure capacity of inner wall 29. At the same time, there is no water and no pressure in annulus 35 at that state. The second state shown in the middle drawing preferably has the same amount of pressure in vessel 33, but water has been introduced into annulus 35, which still has no pressure. The third state shown in the bottom drawing comprises about 1,300 psia of air pressure within vessel 33, which is the maximum capacity of tank 7, and about the same water pressure in annulus 35. Because inner wall 29 is elastic and expands, about the same amount of water pressure is contained within annulus 35 as there is air pressure contained

within vessel 33. Note, however, that when the internal air pressure of vessel 33 is 1,300 psia, the tensile resistance in the stretched cylindrical inner wall is preferably able to impose a 200 psid (psi “difference”). Thus outer wall 31 only needs to withstand an equivalent 1,100 psia air pressure, which is a built in safety feature.

[0087] As shown in FIG. 1, along pipe 13, a turbo expander device, such as two stage turbo expander 41, is preferably provided which is adapted to release the compressed air stored within tanks 7a, 7b, 7c, 7d, or more specifically, within pressure vessel 33. Turbo expander 41 can be any conventional type designed to expand the compressed air to drive an electrical generator 43, which preferably rotates around shaft 45. This way, as the compressed air is expanded and released, electricity can be generated by generator 43, wherein a power conditioner 44 is preferably provided. At the same time, chilled air produced by turbo expander 41 as a by-product can then be used to provide cooling for associated devices, such as an HVAC, refrigerator, or desalination device, or provide cool inlet air for a fuel driven turbine generator set (GenSet), which further improves the efficiency of the GenSet system.

[0088] In this last respect, the present invention preferably incorporates the method and system described in related U.S. Provisional Application Ser. No. 61/195,418, entitled “Method and Apparatus for Using Compressed Air to Increase the Efficiency of a Fuel Driven Turbine Generator,” which is incorporated herein by reference. In that patent application, an improved method and system for increasing the efficiency of a fuel driven turbine generator is shown and described, wherein the system preferably uses super chilled air from a turbo expander device and mixes it with ambient air to produce cool inlet air that can be injected into the compressor turbine for more efficient operation thereof. Unlike previous devices for cooling the inlet air, the system utilizes compressed air expanded by a turbo expander to generate the super chilled air, wherein the system produces not only cool air that can be drawn into the fuel driven generator, but “dry” inlet air. And, by removing the moisture from the inlet air using a centrifuge, when the inlet air is accelerated through the nacelle and into the compressor turbine, no ice particles that could damage the turbine blades are formed.

[0089] FIG. 17 shows that the required air flow from pressure vessel 33 to drive turbo expander 41 to produce a unit of power is greater when the air temperature of the compressed air is lower, and that concomitantly, less air flow from pressure vessel 33 is needed to drive turbo expander 41 to produce the same unit of power when the temperature of the compressed air is relatively high. What this shows is that when the temperature of the compressed air is kept relatively high, i.e., within pressure vessel 33, more power can be produced using the same amount of air flow when the temperature of the compressed air is higher. For example, if the air temperature of the intake to turbo expander 41 from pressure vessel 33 is 40 degrees F., the pressure vessel 33 would typically exhaust about 10.09 SCFM for every horse power of electrical power (and also a little more than 1 hp of thermal power) used. On the other hand, if the air temperature of the intake to turbo expander 41 from pressure vessel 33 is higher, such as at 160 degrees F., the pressure vessel would typically exhaust only about 8.53 SCFM for every hp of electrical power (and also a little less than 1 hp of thermal power) used. And since less air flow is required in the second instance to produce the same

amount of power, more electrical power can then be generated per unit of air flow generated by the system using higher temperature air.

[0090] FIG. 18 compares four scenarios of the compressed air energy storage system used herein. The first two scenarios, 1 and 2, show the sensitivities of the compressed air energy storage system to temperature differences of interest. Note that the percentages shown for the over-all system efficiency do not include the beneficial effects of (1) Waste heat recovery from the compressor that can be used by a nearby steam-driven generator set or by a nearby absorption chiller as is done in some Combined Heat and Power (CHP) facilities, and (2) Chilled air from the turbo expander that can be transmitted as intake air to a fuel-driven generator set. These changes will alter the system efficiencies so that 100% would be exceeded, as is the case for the Coefficient of Performance for heat pumps.

[0091] In this respect, scenarios 1 and 2 show small differences in overall system efficiency (bottom chart, last column). The motivation for changing from scenario 1 to scenario 2 is the elimination of the need for an expensive thick-walled steel pressure vessel that is replaced by a high technology fiber composite pressure vessel or by a more inexpensive commercial pre-stressed concrete vessel. This strongly influences the initial investment cost for the installation of the system since the pressure vessel is the major cost of the system. Furthermore, the daily use of the sun to provide solar energy will produce more electrical power in scenario 2 than in scenario 1. Scenarios 3 and 4 show that higher temperature air inputs result in higher efficiency of electrical power output, although the super-chilled air used for thermal power is reduced so that the combination of electrical power and thermal power outputs are increased by 6%.

[0092] Note the progression of the final exhaust temperatures (minus 175 degrees F. to minus 43.4 degrees F.), the progression of system overall efficiency without HVAC of 34.04% to 59.46%, the progression of system overall efficiency with HVAC of 68.02% to 71.39%, and if the waste heat is recovered from the compressor coolant water there is an additional 15% increase in efficiency.

[0093] The value of the thermal chill power is important to emphasize here. For example, if one considers an HVAC application, 1 unit of thermal chill power is achieved by using less than 1 unit of electrical power. This is a simple system to install. On the other hand, if one considers using a MARS 100 GenSet, for example, 1 unit of thermal chill power produces much greater than 1 unit of electrical power. The GenSet is notoriously sensitive to input air temperature, and there is about a 33% increase in electrical power output from the GenSet when the intake air is chilled from 95 degrees F. to minus 22 degrees F. At the same fuel consumption the electrical power would then increase from about 10 MW to about 13 MW. In the Combined Heat and Power (CHP) configuration where the waste heat is recovered, the 3 additional MW are obtained with about 2 MW input.

[0094] Preferably, there is a logic monitor and control system 47 associated with system 1, to control the operation of compressor 9 and turbo expander 41, and valves 15, 16, as shown in FIG. 1. In this respect, when the sun is shining, photovoltaic panel 3 is preferably used to drive compressor 9, but when the sun is not shining, or not enough solar energy is available, system 1 preferably has back-up power sources connected to compressor 9, such as energy from the power grid, or utility plant (such as hydro, geothermal or nuclear,

etc.). In such case, the present system preferably uses the energy during the low demand periods, such as during the nighttime, so that the rates that are charged can be kept to a minimum. Energy to drive compressor 9 can also come from an associated wind farm or wind turbine which can be operated where and when the wind blows. In such case, the energy used to drive compressor 9 is preferably provided during times when the wind naturally blows at a sufficient and consistent rate, although additional back up power from the grid or power plant would still be needed for periods when neither the sun nor wind is sufficiently available. Control system 47 preferably controls these systems automatically depending on which source is able to provide the energy most efficiently at any given moment in time. The accurate weather forecasting capability available today, for example, can permit useful input to the control system 47 over a two day period.

[0095] Control system 47 also preferably controls the release of compressed air through turbo expander 41, via valve 16, wherein valve 15 is required to be closed when valve 16 is open and the compressed air is being released. It also controls the extent to which electricity is generated by generator 43, and conditioned by power conditioner 44, as well as the extent to which chilled air is produced by turbo expander 41, and where the chilled air is distributed to, etc.

[0096] Control system 47 is also preferably adapted to control the flow of heated water to and from containers 17, 19, using pump 23 and valves 25, 27, which can also be automatically controlled. For example, when water in container 17 is sufficiently heated by the sun, i.e., it reaches a predetermined temperature, valve 25 can be opened, and valve 27 can be closed, and pump 23 can be used to transfer the heated water from container 17 into tanks 7a, 7b, 7c, and 7d. Then, once the tanks are completely filled, both valves 25, 27 can be closed, such that the annulus in the tanks are sealed to prevent heated water from flowing in the reverse direction. This also allows the water pressure within annulus 35 of tanks 7a, 7b, 7c and 7d, to be increased.

[0097] Likewise, when water in container 19 is sufficiently heated by the sun, and ready to be used, valve 27 can be opened, and valve 25 can be closed, and then pump 23 can be used to transfer heated water to and from container 19. Again, once the tanks are completely filled, both valves 25, 27 are preferably closed, such that the water pressure within annulus 35 can be increased at the appropriate time.

[0098] It should be noted that an alternate one directional pump 53 or other pump can be used as shown in FIG. 2A which can be used in place of two directional pump 23. Pump 53 is preferably adapted to pump water in one direction only, but the configuration of the pipes and valves preferably allows the water to flow in two directions simply by opening and closing the appropriate valves at the appropriate times. For example, as shown in the top drawing of FIG. 2A, when water is intended to flow in a first direction, i.e., from inlet 58 to outlet 60, valves 55, 61 and 63 are preferably opened, and valves 57 and 59 are preferably closed. This way, when water enters through inlet 58 and travels through pipe 54, it will pass through open valve 55 and into pipe 52, where it can be acted upon by pump 53. Then, as the water is pumped, because valve 61 is open, and valve 59 is closed, water will travel through pipe 56, and because valve 63 is open, and valve 57 closed, the water will eventually flow out outlet 60.

[0099] Likewise, as shown in the bottom drawing of FIG. 2A, when water is intended to flow in the opposite direction, i.e., from inlet 60 to outlet 58, valves 55, 61 and 63 are

preferably closed, and valves 57 and 59 are preferably opened. This way, when water enters through inlet 60 and travels through open valve 57, it will pass through pipe 52 and into pump 53 because valves 55 and 63 are also closed. Then, because valve 61 is closed, and valve 59 is open, as the water is acted upon by pump 53, the water will travel through pipe 62 toward outlet 58. And because valve 55 is closed, the water will eventually flow out outlet 58.

[0100] The method steps involved using the above components and features will now be discussed in association with FIGS. 4 through 14:

[0101] The first phase is shown in FIG. 4 wherein solar receiving panels 5, 6 are initially exposed to the sun's rays during the daytime. This helps to cause the water contained in associated first and second containers 17, 19, respectively, to begin to heat up. This can, for example, go on for several days, or up to a week or more, and preferably, the system is able to collect energy for at least eight hours per day, such as during the morning and early afternoon. The objective in this case is to increase the temperature of the water in containers 17, 19 to a certain degree, which in the preferred embodiment is 165 degrees F. Because two solar receiving panels 5, 6 are used, the water in one of the containers, such as 17, can be heated, while the water in the other container, such as 19, can be used to keep the compressed air warm, and vice versa.

[0102] During the same phase, the present method preferably contemplates being able to use the solar energy derived from photovoltaic panel 3 to drive compressor 9, to increase the air pressure within pressure vessel 33 to the predetermined low pressure amount, which in the preferred embodiment is 200 psia. Until water is introduced into annulus 35 and sealed, it is important that air pressure within vessel 33 not be increased to above the low pressure capacity, since that is the capacity of inner wall 29. Note that four tanks are shown in FIGS. 4 to 14; however, for simplicity purposes, this discussion will refer to only a single tank 7. Although there can be more than one storage tank, such as tanks 7a, 7b, 7c and 7d, for convenience, this discussion will refer to only tank 7.

[0103] An auxiliary source of energy is preferably available, such as from the power grid, or a nearby utility plant, or wind farm, or wind turbine, to produce compressed air energy when little or no solar energy is available. The system preferably takes that into account by using control system 47 to have the appropriate source connected at the appropriate time. When other sources of energy are used, the appropriate time is when the demands and costs for that source is relatively low, such as during the nighttime hours when the grid or power plant are used, or when the sun shines or the wind naturally blows when those resources are being used.

[0104] The second phase is shown in FIG. 5 wherein once the water in first container 17 has reached the predetermined temperature, such as 150 to 165 degrees F., the heated water can then be transferred into annulus 35 of tank 7 by opening valve 25 and keeping valve 27 closed. This can be accomplished during the nighttime, and is preferably done before the morning sun begins to shine so that valve 25 can be closed before compressor 9 begins to increase pressure in pressure vessel 33, as will be discussed. Heated water can be introduced into annulus 35 by shutting valve 27 of second container 19 and opening valve 25 of first container 17, and operating pump 23 which begins pumping water from first container 17 to annulus 35 through pipe 21. Preferably, annulus 35 has no air pressure inside and is vented so that as the water fills annulus 35, there is no back pressure exerted on

pump 23. Once annulus 35 is completely filled with water, both valves 25, 27 are preferably closed, to seal off annulus 35 and prevent water from escaping. Air pressure within vessel 33 preferably remains the same throughout the second phase. One way pump 53, as shown in FIG. 2A, along with the associated pipes and valves, can also be used rather than pump 23.

[0105] The third phase is shown in FIG. 6 wherein when the sun is shining, such as during the morning hours, photovoltaic panel 3 is preferably used to produce electricity, which in turn can be used to drive compressor 9 to produce compressed air which can be transferred to and stored within vessel 33. Initially, as discussed above, during the first phase, compressor 9 is activated to increase air pressure to the inner wall capacity, which in the preferred embodiment is 200 psia, but once annulus 35 is filled with water, and valves 25, 27 are closed, water pressure within annulus 35 can be increased, and therefore, photovoltaic panel 3 is preferably used again to increase the air pressure within vessel 33 until the maximum amount is reached, which in the preferred embodiment is 1,300 psia.

[0106] As discussed above, while inner wall 29 does not have the capacity on its own to withstand the maximum pressure of 1,300 psia, as long as annulus 35 is filled with water, and valves 25, 27 are closed, water pressure within annulus 35 can be increased to help maintain air pressure within vessel 33 at the maximum level.

[0107] Again, at any given time, when the sun is not available to drive photovoltaic panel 3, the present method preferably contemplates using an auxiliary source of energy, such as the power grid, or nearby utility plant, or wind farm, or wind turbine, to produce compressed air energy for pressure vessel 33.

[0108] The fourth phase is shown in FIG. 7 wherein once tank 7 is filled with compressed air, such as to the maximum degree possible, which in the preferred embodiment is 1,300 psia, the compressed air can be released, such as during the late afternoon hours when energy demand is high, wherein the system can provide backup energy during the peak day-time hours. At this point, the compressed air is preferably at about room temperature, although not necessarily so, and can be released by turbo expander 41, which along with electrical generator 43, and power conditioner 44, produces electricity. At the same time, the heated water in annulus 35 preferably transfers heat to the compressed air within vessel 33 so that excessive temperature drops resulting from air expansion can be avoided. And, as the compressed air is released, the chilled air by-product can be used to drive an associated cooling device, such as an HVAC, refrigerator, or desalination device, or a related fuel driven generator set, as discussed.

[0109] The fifth phase is shown in FIG. 8 wherein once the air pressure within pressure vessel 33 is reduced to at or below its capacity, i.e., 200 psia in the preferred embodiment, valve 25 can be opened again to enable the heated water within annulus 35 to be transferred back to first container 17, which preferably occurs before the sun comes up, such that the water can be fully transferred to container 17 before the sun begins to heat the water again. The temperature of the water at this point can be lower than it was before, although not substantially lower, i.e., the temperature could drop from 165 degrees F. to 150 degrees F., for example, as the compressed air is released. Once all the water is transferred, this leaves annulus 35 empty, i.e., at zero psig (14.67 psia), whereas, pressure vessel 33 may still have an air pressure of 200 psia.

[0110] The sixth phase is shown in FIG. 9 wherein later that same night the heated water in second container 19 is preferably transferred into annulus 35. This can be done by shutting valve 25 of first container 17 and opening valve 27 of second container 19, and operating pump 23 which pumps the water to annulus 35. This phase is similar to phase two except that heated water from second container 19 is transferred into annulus 35, rather than water from first container 17.

[0111] The seventh phase is shown in FIG. 10 wherein when the sun is shining, such as during the morning hours, photovoltaic panel 3 is preferably used again to produce electricity, which in turn, can be used to drive compressor 9, to produce additional compressed air energy, which can be transferred to and stored within vessel 33. This is done once annulus 35 is completely filled, and the valves 25, 27 are closed, which can be done by the next morning, wherein photovoltaic panel 3 can begin operating again to supply electrical energy to compressor 9 and increase air pressure within vessel 33, such as to the maximum amount, which in the preferred embodiment is 1,300 psia. Again, when the sun is not available, the present method preferably contemplates using an auxiliary source, such as the power grid, or utility plant, or wind farm, or wind turbine. This phase is similar to phase three in that the air pressure is increased within vessel 33 to about the same level—the maximum pressure amount.

[0112] The eighth phase is shown in FIG. 11 wherein once vessel 33 is filled with air pressure, such as to the maximum degree possible, which in the preferred embodiment is 1,300 psia, the compressed air can be released, such as during the late afternoon hours when energy demand is high. At this point, the compressed air is preferably at about room temperature, although not necessarily so, and can be released by turbo expander 41, which along with electrical generator 43, and power conditioner 44, produces electricity. At the same time, the heated water in annulus 35 preferably transfers heat to the compressed air within vessel 33 so that excessive temperature drops resulting from air expansion can be avoided. This phase is similar to phase four in that the compressed air in vessel 33 is released to about the same extent.

[0113] The ninth phase is shown in FIG. 12 wherein once the air pressure within pressure vessel 33 is reduced to at or below its capacity, i.e., 200 psia in the preferred embodiment, valve 27 can be opened again to enable the heated water within annulus 35 to be transferred back to second container 19, which preferably occurs before the sun comes up, such that the water can be fully transferred into container 19 before the sun begins to heat the water again. The temperature of the water at this point can be lower than it was before, although not substantially lower, i.e., the temperature could drop from 165 degrees F. down to 150 degrees F., for example, as the compressed air is released. Once all the water is transferred, this leaves annulus 35 empty, i.e., at zero psig (14.67 psia), whereas, pressure vessel 33 can still have an air pressure of 200 psia. This phase is similar to phase five except that heated water from annulus 35 is returned to second container 19, rather than first container 17.

[0114] The tenth phase is shown in FIG. 13 wherein later that same night the heated water in first container 17 is preferably transferred back into annulus 35. As with phase two, this can be done by shutting valve 27 of second container 19 and opening valve 25 of first container 17, and operating pump 23 which pumps the water to annulus 35. Then, once annulus 35 of tank 7 is completely filled again, and valves 25, 27 are closed, which can be done by the next morning, photo-

voltaic panel 3 can begin operating to supply energy to compressor 9 and compressed air to vessel 33. This phase is similar to phase two, and is also similar to phase six except that heated water from first container 17 is transferred into annulus 35, rather than from second container 19.

[0115] The eleventh phase is shown in FIG. 14 wherein when the sun is shining, such as during the morning hours, photovoltaic panel 3 is preferably used again to produce electricity, which in turn, can be used to drive compressor 9, to produce additional compressed air energy, which can then be transferred to and stored within vessel 33. This is done after annulus 35 is completely filled with water, and valves 25, 27 are closed, wherein air pressure within vessel 33 can be increased, such as to the maximum amount, which in the preferred embodiment is 1,300 psia. Again, when the sun is not available, the present method contemplates being able to use an auxiliary source of energy, such as the power grid, or utility plant, or wind farm, or wind turbine. This phase is similar to phase three as well as phase seven in that the air pressure is increased within vessel 33 to about the same extent—the maximum pressure amount. The cycle can then continue.

[0116] The following sample scenarios are provided to show how the present system may operate.

[0117] In a sample site, there is a proposed 550 MW solar photovoltaic power plant built on 9.5 square miles (25 km²) of ranchland. The system utilizes thin-film photovoltaic panels designed and manufactured by OptiSolar in Hayward and Sacramento Calif. The project delivers approximately 1,100 gigawatt-hours (GW·h) annually of renewable energy.

[0118] The proposed solution uses a T-CAES system to support a 33 MW photovoltaic array since this is consistent with the trend for similar solar arrays as shown in FIG. 1. This array has been oversized so there is 20% excess power (or 0.2*33 MW=6.6 MW) that is not immediately used but stored.

[0119] The calculations shown in FIG. 19 use scenarios 1 and 2 of FIG. 18 to derive the 3.6 MW (electrical) and 3.00 MW (thermal) requirements as specified in FIGS. 20a and 20b. FIGS. 20a and 20b show that a 4 feet diameter and 9,250 ft long pressure vessel may be required for the compressed air in the sample system. The result will permit the generation of 3.6 MW of electrical power with the co-generation of 3.0 MW of super chilled air for HVAC or other ancillary devices (and electrical power savings). FIG. 20A assumes that the single 250 feet long pressure vessel will be replaced by four 2,313 feet long tanks. Therefore a 2,313 feet long and 4 feet wide pipe at 5 (kW-Hrs)/(Sq M)/day will supply 14,664,000 BTU to the 981,240 pounds of water (FIG. 20A). This will result in a 15 degrees F. temperature rise in the water temperature each day and will require 14,718,600 BTU (sufficiently close to the available 14,664,000 BTU available). Five kW-Hr/Sq M/day of sunshine is the average.

[0120] FIG. 21 shows the mass of heated water that fills the 0.82 inch annular gap in the tank. There is a low heat transfer coefficient for the air compared to the high heat transfer coefficient (high conductivity of steel and its thin plate) across the steel and the high heat transfer coefficient across the steel and water interface, wherein FIG. 22 displays the resulting temperature profile. The lowest heat transfer coefficient controls the overall heat transfer across the interfaces. FIG. 23 shows the heat transfer coefficient between the com-

pressed air and the thin steel plate backed by the annulus of water. This is based upon the considerations shown in FIG. 22.

[0121] Two additional cases were considered with identical pressure vessel lengths and diameters. In one case, the usual thick walled steel tank of the prior art was used that was independent of solar energy input. In the other case, the steel wall was replaced with a water annulus outer wall of composite material as disclosed herein.

[0122] FIG. 24 shows that by using the solar energy enhancement method of the present system an increase in pressure can be obtained within pressure vessel 33. Also, an extra 40 minutes (compared to 180 minutes of power discharge time) of 3.6 MW (electrical) was achieved using the solar energy. Likewise, FIG. 25 shows that by using the solar energy enhancement method of the present system an increase in air temperature can be obtained within vessel 33. For example, it can be seen that with the solar enhancement the air temperature remained consistently about 60 degrees F. higher throughout the history of the usage.

[0123] FIG. 26 shows a comparison between using a conventional steel tank in which to store the compressed air (the lower line), and using the water annulus outer walled tank of the present system (the upper line). In the present system, note that the conventional steel wall tank is replaced by a thin walled steel cylindrical inner pressure vessel and a larger diameter thick walled inexpensive reinforced concrete or fiber composite cylindrical outer vessel. The annulus in between these cylinders is filled with water or water-like fluid that has a high heat capacity with no tendency to introduce bio-fouling or corrosion. The water (water-like) fluid is able to store heat and to rapidly release heat to the compressed air within the pressure vessel as it is stored or is expanded. The outermost thick walled cylinder is designed to contain the pressure.

[0124] As can be seen, the temperature of the vessel remained consistently higher when using the water annulus tank of the present system, i.e., the temperature remained at least about 60 degrees F. higher throughout the history of the usage than the steel walled standard tank. Moreover, FIG. 25 shows that there was a slight reduction in the rate at which the temperature in the tank decreased. For example, it can be seen that by using the present system, the temperature within pressure vessel 33 dropped from about 160 degrees F. at zero hour to about 152 degrees F. 200 minutes later which is a difference of about 8 degrees F. On the other hand, when using a conventional steel tank, the temperature began at about 100 degrees F. and dropped down to about 86 degrees F., which is a drop of about 14 degrees.

What is claimed is:

1. A solar energy storage and enhancement system comprising:

- a photovoltaic cell panel for collecting energy from the sun;
- at least one compressor capable of being powered by the energy derived from said photovoltaic panel;
- at least one tank having an inner wall and an outer wall, wherein a pressure vessel is formed inside said inner wall, and an annulus is formed between said inner and outer walls, wherein said at least one compressor is adapted to compress air into said pressure vessel,
- at least one solar receiving panel with a container for heating water therein, wherein the water is allowed to communicate between said container and said annulus;

at least one valve and pump that control the flow of water from said container to said annulus, and vice versa;

at least one expander for releasing the compressed air within said pressure vessel; and

a generator for generating electricity as the compressed air is being released.

2. The system of claim 1, wherein said inner wall is located concentrically inside said outer wall, and said outer wall is adapted to be stronger and thicker than said inner wall, wherein said outer wall is designed to withstand the maximum pressure exerted within said tank, and said inner wall is made with relatively high heat transfer properties.

3. The system of claim 2, wherein when said annulus is filled with water and said valve is closed, the amount of pressure that can be maintained within said pressure vessel is substantially determined by the amount of pressure that can be maintained by said outer wall.

4. The system of claim 3, wherein a control mechanism is provided that controls said valve and pump to coordinate the flow of water between said container and said annulus.

5. The system of claim 1, wherein said compressor is also adapted to be powered by at least one other source of energy taken from the group consisting of: the power grid, geothermal plant, nuclear plant, a wind farm, and wind turbine generator.

6. The system of claim 1, wherein the expander comprises a turbo expander that generates chilled air as a by-product, wherein in addition to generating electricity using said generator, the system is adapted to transfer the chilled air exhausted from said turbo expander to provide cooling for an associated device, such as an HVAC, refrigerator or desalination device, or fuel driven generator set.

7. The system of claim 1, wherein the system comprises a fuel-driven generator set capable of using the chilled air downstream of the turbo expander, and/or a combined heat and power system for use of the waste heat generated by the compressor and generator set to enhance overall system efficiency.

8. The system of claim 1, wherein there are at least two solar receiving panels with containers for heating water therein, and each of said receiving panels comprises a wedged surface that essentially floats on the water within said containers, wherein said wedged surface has internal gaps or notches therein that allow the sun's ray to be internally reflected as the sun's rays strike said surface at different angles.

9. The system of claim 1, wherein the photovoltaic panel is large enough to collect solar energy for direct use by the end user, wherein a portion of the energy generated thereby is used to power said compressor.

10. A method of using and storing solar energy and enhancing the efficiency of a compressed air energy storage system, comprising:

- providing at least one photovoltaic panel for collecting energy from the sun;
- providing at least one compressor capable of being powered by the energy derived from said photovoltaic panel as well as at least one other energy source;
- providing at least two solar receiving panels with containers for heating water contained therein;
- providing at least one tank having an inner wall and an outer wall concentrically located therein, wherein a pressure vessel is formed within said inner wall for

storing the compressed air, and an annulus is formed between said inner wall and said outer wall for storing water;

adapting said at least one compressor to communicate with and increase the pressure of the air within said pressure vessel;

adapting said containers to communicate with said annulus to allow water from said containers to flow into said annulus, and vice versa;

providing at least one first valve for closing said pressure vessel and at least one second valve for closing said annulus;

providing at least one turbo expander for releasing the compressed air within said pressure vessel;

providing at least one generator for generating electricity as the compressed air is being released from said pressure vessel; and

providing a fuel-driven generator set capable of using the chilled air exhausted downstream of said turbo expander, and/or a combined heat and power system for use of the waste heat generated by said at least one compressor and/or generator set to enhance overall efficiency of said system.

11. The method of claim 10, comprising exposing said solar receiving panels to the sun and collecting solar energy with said solar receiving panels and using the solar energy to heat the water contained within said containers.

12. The method of claim 11, comprising compressing air into said vessel with said at least one compressor, wherein the pressure within said vessel is initially increased up to a predetermined low pressure amount.

13. The method of claim 12, wherein when solar energy is available, the power to operate said at least one compressor is derived from said at least one photovoltaic panel, and when solar energy is not available, the power to operate said at least one compressor can be derived from said at least one other source.

14. The method of claim 13, wherein after the water is heated, the method comprises transferring the heated water

from one of said containers into said annulus, and after completely filling up said annulus, closing said second valve to seal said annulus.

15. The method of claim 14, comprising increasing the pressure within said vessel with said at least one compressor, wherein the pressure within said vessel is increased up to a predetermined high pressure amount.

16. The method of claim 15, comprising releasing the compressed air within said pressure vessel using said turbo expander and generating electricity using said generator, wherein the chilled air produced as a by-product can be used in connection with an associated cooling device, such as an HVAC, refrigerator or desalination device, or fuel driven generator set.

17. The method of claim 16, wherein after the pressure within said pressure vessel is reduced to at least said low pressure amount, the method comprises opening said second valve and allowing the water within said annulus to be transferred back into said one of said containers.

18. The method of claim 17, further comprising transferring the heated water from a second of said containers into said annulus, and after filling up said annulus, sealing said annulus, and wherein the method comprises increasing the pressure within said pressure vessel with said at least one compressor, wherein the pressure within said vessel is increased back up to about the predetermined high pressure amount.

19. The method of claim 18, comprising releasing the compressed air within said pressure vessel using said turbo expander and generating electricity using said generator, wherein the chilled air produced as a by-product can be used in connection with an associated cooling device, such as an HVAC, refrigerator or desalination device, or fuel driven generator set.

20. The method of claim 19, wherein after the pressure within said pressure vessel is reduced down to at least about said low pressure amount, the method comprises opening said annulus and allowing the water within said annulus to be transferred back into said second of said containers.

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**Espacenet****Библиографски данни: CN202348587 (U) — 2012-07-25**

Electric energy storing device**Изобретател(и):** CHUNLI DONG ± (DONG CHUNLI)**Заявител(и):** DALIAN VOCATIONAL & TECH COL ± (DALIAN VOCATIONAL & TECHNICAL COLLEGE)**Класификационен индекс:** - международни: **F03D9/02**
- кооперативна: Y02E10/72 (EP); Y02P70/50 (EP)**Номер на заявка:** CN201120512742U 20111212**Приоритетен(ни) номер(а):** CN201120512742U 20111212**Реферат на CN202348587 (U)**

An electric energy storing device comprises a controlling device, an air storing bag, a controlling valve, an air pump and a small-sized turbine generator. The air pump is connected with one end of the air storing bag by a pipeline, the other end of the air storing bag is connected with the small-sized turbine generator through the controlling valve, and the controlling device is respectively connected with the controlling valve, the air pump and the small-sized turbine generator through cables which are used for transmitting control signals. During usage, the air pump can be replaced by an air compressor, excess energy can be stored when electric power generated by renewable energy generators such as off-grid solar photovoltaic power generators, wind power generators and the like is incapable of being consumed, and electric power can be regenerated to serve as a supplement when electric power generated by the renewable energy generators can not meet requirements. The electric energy storing device has the advantages that functions of prior storage batteries are replaced, emission of harmful substances is reduced, the manufacture is simple, the cost is low, and the electric energy storing device is suitable for being matched with renewable energy generator sets such as photovoltaic power generator sets, wind power generator sets and the like and capable of meeting environment-friendly requirements and conforming to the energy saving trend.