US 20080050234A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2008/0050234 A1
(43) Pub. Date: Feb. 28, 2008
Ingersoll et al.

(54) **WIND TURBINE SYSTEM**

(75) Inventors: **Eric Ingersoll**, Cambridge, MA (US); **David Ritvo Marcus**, West Newton, MA (US)

Correspondence Address:
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

(73) Assignee: **General Compression, Inc.**, Attleboro, MA (US)

(21) Appl. No.: **11/804,704**

(22) Filed: **May 19, 2007**

Related U.S. Application Data

(60) Provisional application No. 60/932,956, filed on May 19, 2006, provisional application No. 60/932,958, filed on May 19, 2006, provisional application No. 60/932,960, filed on May 19, 2006, provisional application No. 60/932,951, filed on May 19, 2006, provisional application No. 60/932,952, filed on May 19, 2006, provisional application No. 60/932,955, filed on May 19, 2006, provisional application No. 60/932,959, filed on May 19, 2006, provisional application No. 60/932,954, filed on May 19, 2006, provisional application No. 60/932,957, filed on May 19, 2006.

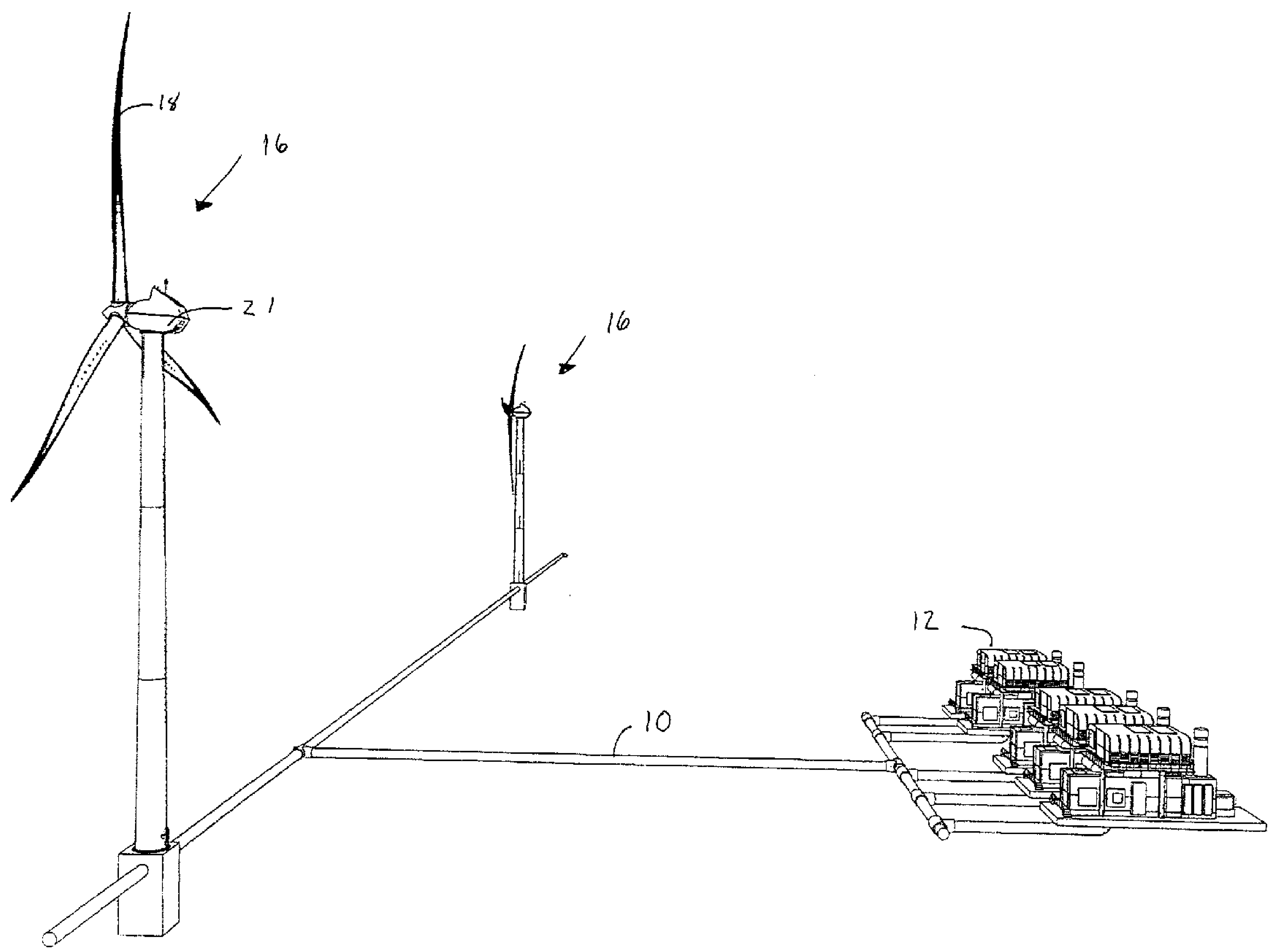
Publication Classification

(51) **Int. Cl.**
B63H 1/06 (2006.01)

(52) **U.S. Cl.** .... **416/132 B**; 290/55; 60/327; 60/670

(57) **ABSTRACT**

A wind turbine system for producing compressed air from wind energy. The wind turbine harvests energy from wind to produce mechanical energy. A compressor receives mechanical energy from the wind turbine to compress air to an elevated pressure. Thermal energy may be removed from the air, and the air is stored in a storage devices, such that the air may be released from the storage device on demand.



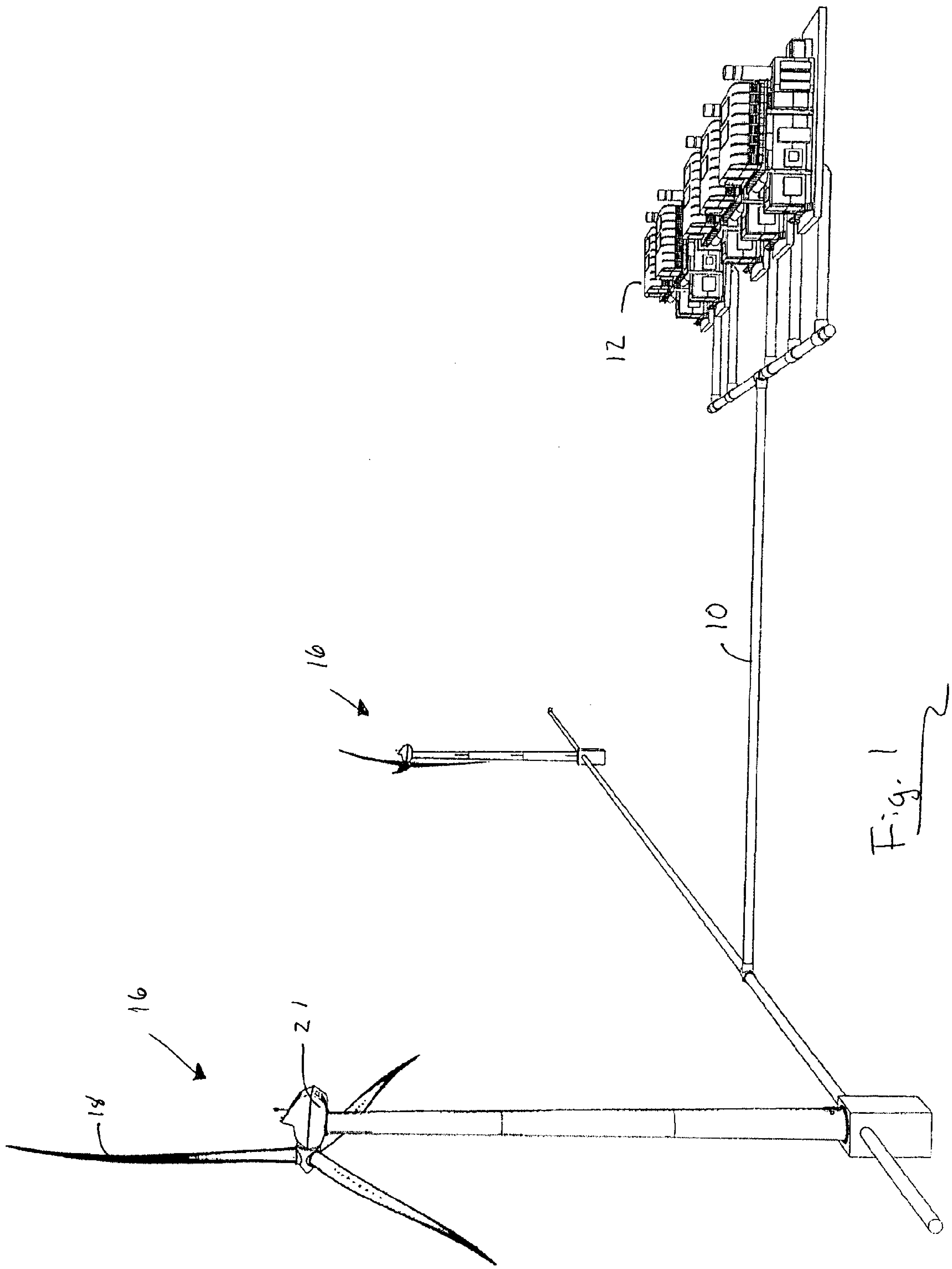


Fig. 1

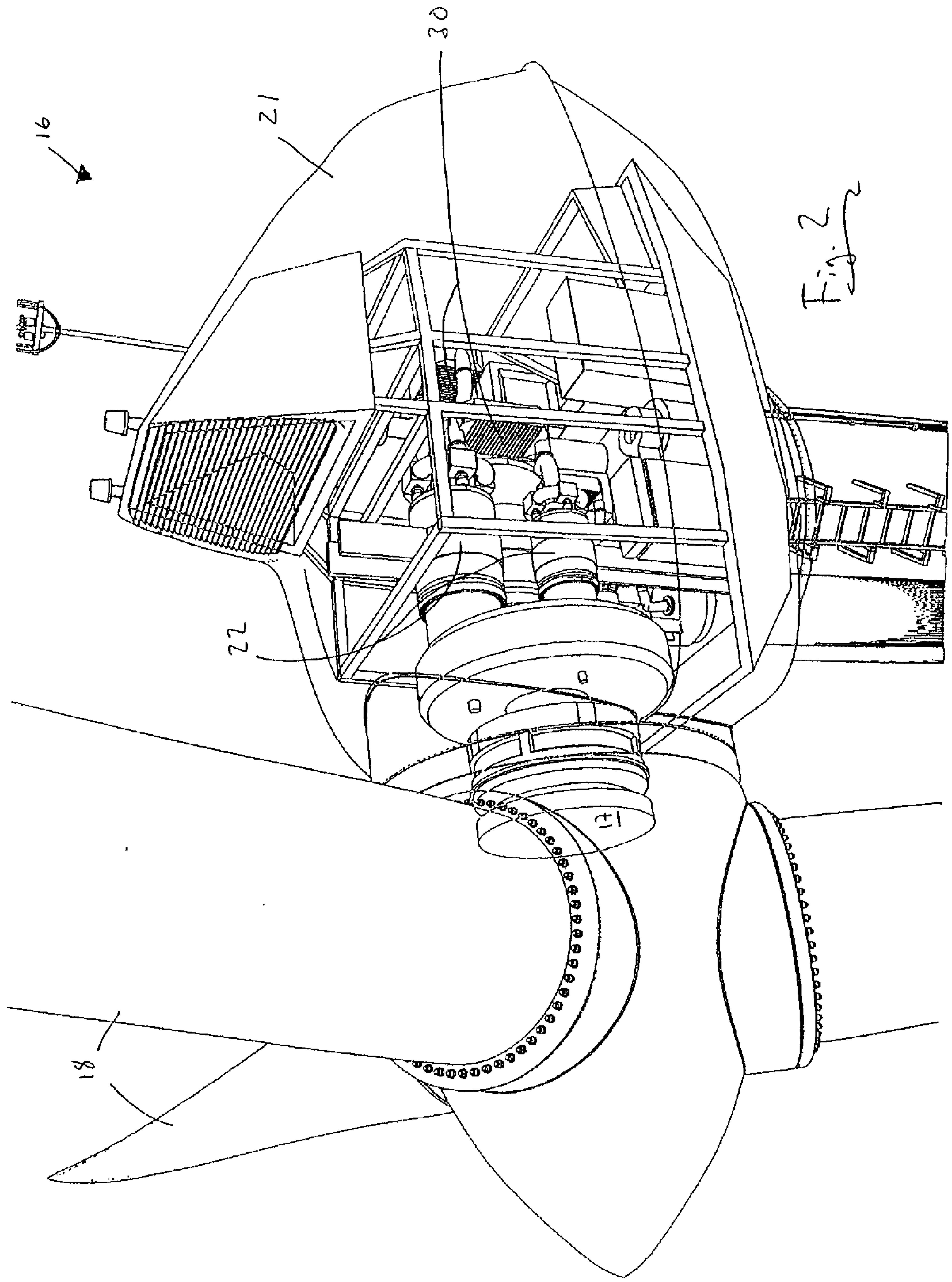


Fig. 2

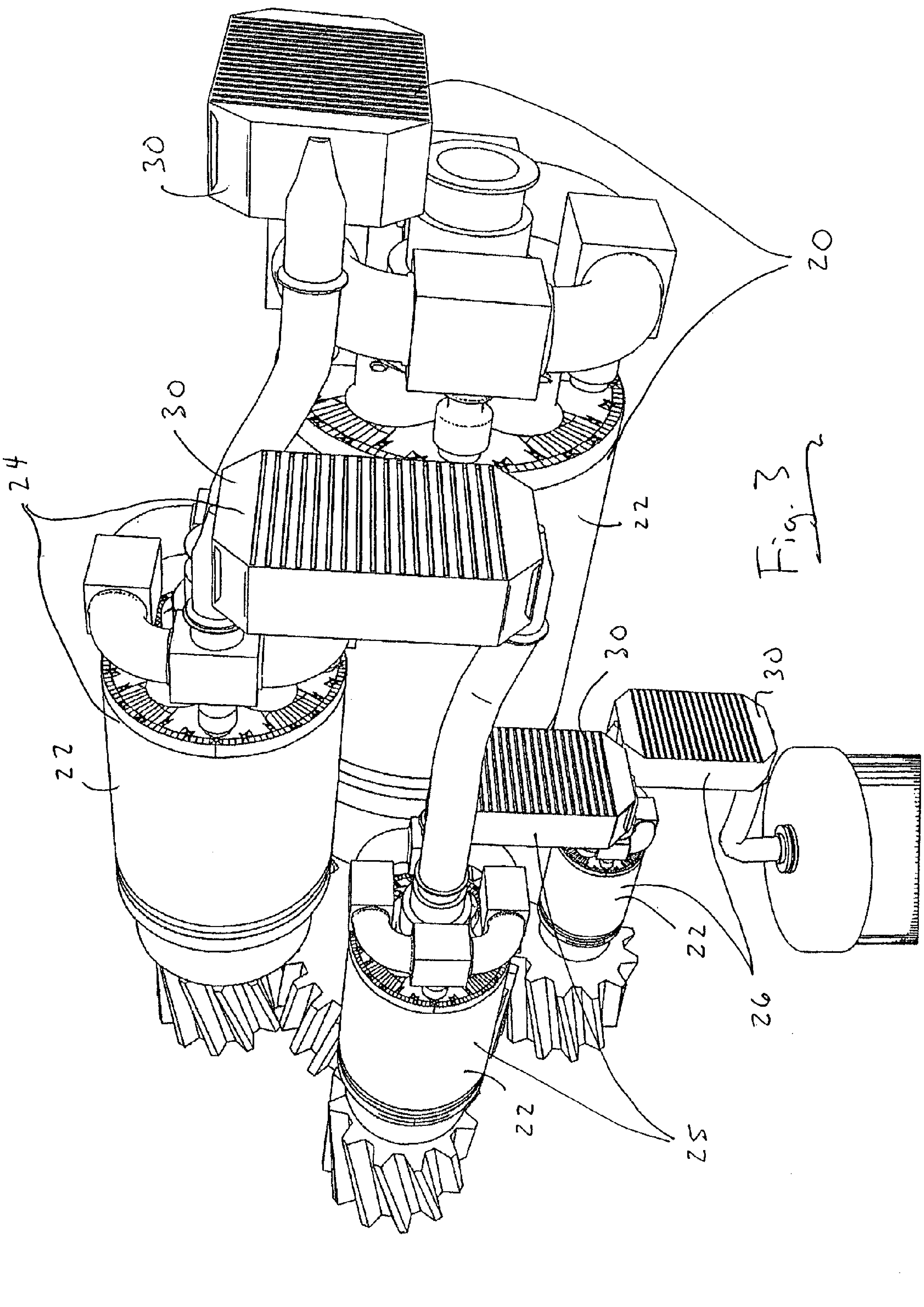


Fig. 3

WIND TURBINE SYSTEM

RELATED APPLICATIONS

[0001] This Application claims the benefit of U.S. application Ser. No. 11/437419 filed on May 19, 2006, U.S. application Ser. No. 11/437424 filed on May 19, 2006; U.S. application Ser. No. 11/438132 filed on May 19, 2006; U.S. application Ser. No. 11/437261 filed on May 19, 2006; U.S. application Ser. No. 11/437407 filed on May 19, 2006; U.S. application Ser. No. 11/437408 filed on May 19, 2006; U.S. application Ser. No. 11/437836 filed on May 19, 2006; U.S. application Ser. No. 11/437406 filed on May 19, 2006; and U.S. application Ser. No. 11/437423 filed on May 19, 2006, each of which are hereby incorporated by reference in their entirety.

BACKGROUND

[0002] 1. Field

[0003] This invention relates generally to a system for harvesting energy from the wind.

[0004] 2. Discussion of Related Art

[0005] From its commercial beginnings more than twenty years ago, wind energy has achieved rapid growth as a technology for the generation of electricity. The current generation of wind technology is considered mature enough by many of the world's largest economies to allow development of significant electrical power generation. By the end of 2005 more than 59,000 MW of windpower capacity had been installed worldwide, with annual industry growth rates of-greater than 25% experienced during the last five years.

[0006] Certain constraints to the widespread growth of wind power have been identified. One constraint relates to the difficulty in dispatching energy harvested from the wind when needed by customers. Relatively unpredictable wind speeds affect the hour-to-hour output of wind plants, and thus the ability of power aggregators to reliably supply a given amount of energy at any particular time. Additionally, interconnection costs based upon peak usage are spread over relatively fewer kwhs from intermittent technologies such as wind power as compared to other technologies.

[0007] The applicant appreciates that a need exists for improving wind turbine systems such that energy, when harvested, can be provided to appropriate markets at a desired time. The applicant also appreciates that a need exists to maximize the amount of energy that may be harvested from the wind at any given time.

SUMMARY OF INVENTION

[0008] According to one aspect of the invention, a system is disclosed for producing compressed air from wind energy. The system comprises a wind turbine that harvests energy from wind to produce mechanical energy A compressor receives mechanical energy from the wind turbine to compress air to an elevated pressure. A storage device receives the air from the compressor such that the air can be released from the storage device on demand. An expander for expanding air received from the storage device is used to generate electric energy. Thermal energy is removed from the air prior to being received by the storage device and thermal energy is added to the compressed air prior to being expanded to generate electric energy.

[0009] According to another aspect of the invention, a system is disclosed for producing desalinating water with the assistance of wind energy. The system comprises a wind turbine that harvests energy from wind to produce mechanical energy. A compressor receives mechanical energy from the wind turbine to compress air to an elevated pressure. A storage device receives the air from the compressor such that the air can be released from the storage device on demand. Air provided to the compressor is drawn from a fluid containing system of a desalination facility to promote the evaporation of sea water.

[0010] According to yet another aspect of the invention, a system for producing liquefied air products utilizing wind energy is disclosed. The system comprises a wind turbine that harvests energy from wind to produce mechanical energy. A compressor receives mechanical energy from the wind turbine to compress air to an elevated pressure. An expander expands air received from the compressor to produce liquefied air products from the compressed air.

[0011] According to still another aspect, a method of producing compressed air from wind energy is disclosed. The method comprises harvesting wind with a wind turbine to produce mechanical energy and compressing air to an elevated pressure with a compressor driven by the mechanical energy. The compressor also comprises removing thermal energy from the air and conveying the air to a storage device after thermal energy is removed from the air. Compressed air is stored in the storage device at a working pressure greater than 10 atmospheres. The compressed air is conveyed to an electric energy production facility. Thermal energy is added to the compressed air and the compressed air is expanded to drive a turbine to produce electric power.

[0012] According to another aspect, a method of producing desalinated water with the assistance of wind energy is disclosed. The method comprises harvesting wind with a wind turbine to produce mechanical energy and compressing air to an elevated pressure with a compressor driven by the mechanical energy. Air is conveyed to a storage device after thermal energy is removed from the air. The compressed air is stored in the storage device at a working pressure greater than 10 atmospheres. Air is drawn from a fluid containing system of a desalination facility to promote evaporation of sea water.

[0013] According to another aspect, a method for producing liquid air products utilizing wind energy is disclosed. The method comprises harvesting wind with a wind turbine to produce mechanical energy. Air is compressed to an elevated pressure with a compressor driven by the mechanical energy. Compressed air is then expanded to produce liquefied air products from the compressed air.

BRIEF DESCRIPTION OF DRAWINGS

[0014] The accompanying drawings are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing. In the drawings:

[0015] FIG. **1** is a perspective view of a wind turbine system and a power plant, according to one embodiment.

[0016] FIG. **2** is a perspective, cutaway representation of a wind turbine, according to one embodiment.

[0017] FIG. **3** is a shows representation of a multi-stage compression cycle, according to one embodiment.

DETAILED DESCRIPTION

[0018] This invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including", "comprising", or "having", "containing", "involving", and variations thereof herein, is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

[0019] Aspects of the invention relate to a system for producing compressed air from wind energy. The system includes one or more wind turbines that, when driven by the wind, provide mechanical energy to a compressor. The compressor, in turn, compresses a working fluid, such as air, to an elevated pressure. The compressed working fluids may then be released to accomplish a desired task, such as the production of electricity, the liquification of air, and other processes that require the input of energy.

[0020] According to one aspect of the invention, energy from the wind is stored as compressed air. A given system may have a finite amount of storage for compressed air. In this regard, it may be advantageous to compress the air in a manner that maximizes the amount of air that can be stored. To help accomplish this, heat may be removed from the compressed air prior to being conveyed to the storage device, which can help maximize the amount of compressed air that can be stored by a given storage device. Moreover, energy may be less expensive to store in a compressed working fluid that is closer to the ambient temperature than one that is at a higher temperature.

[0021] According to one aspect, air liquefaction may also be used as a mechanism for storing energy for later use. It is to be appreciated that liquefied air occupies a much smaller volume than air at a comparable pressure. Air stored as liquid may later be heated and expanded to drive a turbine, or for any of the other uses discussed herein. Liquid air may be produced with an expander that is closely coupled to the compressor. The expander may be positioned within the nacelle of a wind turbine, the tower of a wind turbine, or on the ground at a wind form, according to some embodiments. A common expander may receive compressed air from multiple wind turbines or each wind turbine may be associated with a single expander. It is to be appreciated that many of the methods and devices discussed herein that operate in association with energy stored as compressed air may also operate with energy stored as liquid air.

[0022] According to some embodiments, compressors may compress fluids other than air—such as various types of vapors, like CO2, refrigerants, water vapor, and the like. These vapors may act as working fluids in closed loop systems, such as closed loop systems used for refrigeration, drying, and distillation, to name a few. It is to be appreciated that many of the methods and devices discussed herein that operate in association with compressed air, may also operate with various types of vapors.

[0023] Turn now to the figures, and initially FIG. **1**, which shows a schematic representation of a system that may be used to produce compressed air for subsequent release on demand. As illustrated, the system includes a plurality of wind turbines **16** that may harvest energy from the wind. One or more wind turbines drive compressors that draw air from the ambient environment and compress the air to an elevated pressure. Heat that results from compression may be removed from the air prior to, during, or after the compression process. A multi-stage compression scheme may be used to facilitate the removal of heat from the air and/or to allow the system to compress the air to higher pressures. Once compressed, the air is conveyed to a storage device **10**, which as illustrated, includes a pipeline. The compressed air may be conveyed by the pipeline to a turbine at a power generation plant **12**, where heat may be added to the air and the air may be expanded to drive a turbine that produces electricity.

[0024] Embodiments of the invention facilitate storing energy received from the wind, such as in compressed air, so that the energy may be released later when needed or desired. In this regard, the system facilitates the production of "on demand" or "dispatchable" wind energy. This may allow wind energy to be harvested and stored during times when the demand, and thus price for energy, is low so that such energy may be released at a later time when the demand is higher. Additionally, facilities that can be relied upon to provide energy when needed may qualify as firm capacity. In this regard, these facilities may be capable of replacing other non-renewable power generation facilities that might otherwise be required to meet the peak demands of a particular grid.

[0025] FIG. **2** shows a schematic representation of one embodiment of a wind turbine **16**. The turbine includes multiple blades **18** mounted to a shaft **17**. The blades are configured to receive energy from the wind, and in turn, to rotate the shaft. The shaft provides energy to compressors **22** located within the nacelle **21** of the turbine.

[0026] The turbine of FIG. **2** is a "direct drive" device, as the term is used herein—that is, the energy from the wind is not converted to electrical energy prior to being conveyed to the air compressor(s) of the system. It is to be appreciated that direct drive turbines may include various types of belts, chains, friction drives, gearings, shafts, clutches, and other mechanical, pneumatic, and/or hydraulic devices, which may be used to convey energy to the compressor. According to one embodiment, the rotor of the turbine may drive a hydraulic clutch that is selectively engaged to drive the compressor(s). Similarly, direct drive turbines may also include electronic devices for measuring or controlling the conveyance of wind energy to the compressor with the turbine still being considered a direct drive device.

[0027] The compressor(s) that receive energy from a given turbine may be located in the nacelle of the turbine itself. Such configurations may help improve the reliability of the wind turbine by reducing the length and/or complexity of any linkage between the rotor and the compressor(s). It is to be appreciated, however, that some embodiments may not incorporate all compressors into the nacelle, as some systems may use secondary compressors that are located in the tower, the ground, or underground. Other embodiments may incorporated all or a portion of the compressors directly in the tower structure that supports the nacelle, or elsewhere. Still, some embodiments may not have any compressors located in nacelles of the wind turbines, as aspects of the invention are not limited in this respect.

[0028] Various systems may be used to store compressed air. As shown in FIG. 1, the system may comprise a pipeline that conveys the compressed air to a desired destination. These pipelines may be constructed according to guidelines similar to those used in the construction of natural gas pipelines. Larger pipelines may cost more to install, but may be capable of storing greater quantities of compressed air, such that the additional cost may be justifiable. Larger pipelines may also be capable of conveying compressed air at lower flow rates with lower frictional losses. Aspects of the invention, however, are not limited to any particular type of storage device, such as gas pipelines, as other devices may also be used to store compressed air.

[0029] Natural or man-made vessels may also be used as storage devices for compressed air. According to some embodiments, geographic features, such as salt-domes or exhausted natural gas cavities may be used to store compressed air. Similarly, man-made devices, such as pressure vessels, bladders, and underground or underwater facilities may be used as the sole storage device for a particular system, or may augment the amount of storage provided by the pipelines of a particular system.

[0030] Embodiments of the system may store compressed air at various different operating Pressures. Generally speaking, systems that can store higher pressures may be more costly to produce, but can allow greater amounts of energy to be stored in a given volume of space. According to some embodiments, such as those that utilize pipelines constructed along guidelines normally used for natural gas systems, compressed air is stored at pressures up to 100 atmospheres. According to other embodiments, maximum storage pressures may be lower than 100 atmospheres, although maximum system pressures are generally greater than 10 atmospheres—a pressure that is higher than that normally associated with "shop air" systems. Still, other embodiments may store compressed air at pressures much greater than 100 atmospheres, as aspects of the invention are not limited in this respect. By way of example, systems may be capable of achieving maximum storage pressures of 240 atmospheres are greater. Recently developed composite reinforced pipes may facilitate achieving these pressures.

[0031] Systems may operated with different ranges of operating pressures. According to some systems, the operating pressure may vary widely between maximum pressures as high as 240 atmospheres, and lower pressure near ambient. However, according to some embodiments, smaller pressure ranges may prove beneficial, such as by minimizing stress on storage facilities and minimize the temperature swings in storage facilities during charging and discharging. Accordingly some operating pressures are targeted to vary not more than 100 atmospheres, 80 atmospheres, 50 atmospheres, or even less, as aspects of the invention are not limited in this respect.

[0032] The compression of a working fluid, such as air, typically results in a temperature increase. In fact, compressing air from atmospheric pressure to 100 atmospheres, as discussed above, may cause an about 550 degree Celsius or greater increase in air temperature, if the compression occurs adiabatically. Such high temperatures may pose design challenges for the compressor and other portions of the system that must accommodate such temperatures.

[0033] Heat (i.e., thermal energy) may be removed from air prior to, during, or after compression. Removing heat in this manner may reduce the maximum temperature that a system may be designed to accommodate. Additionally, increasing density at a given pressure and removing heat from compressed air (or any other working fluid) may increase the mass of air that can be stored in a given volume of space, as it is to be appreciated that a given mass of air occupies less space when at a lower temperature. In this regard, providing relatively cooler air to a storage device may increase the total mass of air that may be stored by the device.

[0034] Thermal energy that is removed from the air prior to storage is energy that may prove more costly to store or transport than the energy associated with the additional mass of air that may be provided to storage when the compressed air is at a lower temperature. Storing greater quantities of relatively cooler air may allow systems to be configured without as much, or no insulation surrounding the storage device. Additionally, thermal energy may be added back to the compressed air prior to, during, or shortly after expansion of the compressed air at a relatively low cost, particularly when compared to the costs of retaining the thermal energy that results directly from compression. Although embodiments may include removing thermal energy from compressed air at compression, it is to be appreciated that aspects of the invention are not limited in this respect.

[0035] Aspects of the invention may also facilitate separation of the energy associated with the compression of air, the energy associated with the heating of air that occurs upon compression. The energy associated with the compressed air may be utilized upon expansion of the compressed air to perform useful work, and may be stored in a pipeline or vessel until such work needs to be performed. The thermal energy may be used for any type of process that requires heat, and may be stored for later use in a medium, such as a cooling fluid, until such heat is required.

[0036] Thermal energy may be removed from air prior to compression. According to some embodiments, an evaporative cooler is used to accomplish this effect. Air may be passed through a wet or damp medium, such as a fibrous medium that promotes the wicking of water. Water may evaporate from the medium and into air prior to the air entering the compressor(s). This evaporation may draw thermal energy away from the air in quantities associated with the latent heat of vaporization for water, and the amount of water that evaporates. Some sensible heat exchange of thermal energy may also occur from the air to the water, which may further reduce the air temperature. It is to be appreciated that sensible heat exchange refers to thermal energy that results in a change of temperature. It is to be appreciated that cooling fluids other than water may also be used in evaporative coolers, as aspects of the invention are not limited in this respect.

[0037] Other types of heat exchangers may be used to cool air prior to compression. According to some embodiments, air may be passed through a bank of plates that are cooled by a working fluid. A plurality of cooling fins may extend into the airflow path to remove heat from the air. The working fluid provided to the heat exchanger may be evaporated during the heat exchange process, or may remain in a constant liquid or gaseous state, as aspects of the invention are not limited in this respect. It is to be appreciated that the above listed types of heat exchangers is merely exemplary, as other types of heat exchangers may also be used.

[0038] As discussed above, thermal energy may be removed from air at any point during the compression process. According to some embodiments, a cooling fluid is introduced directly into the air that is compressed. The cooling fluid may remove thermal energy from the air due to sensible heat exchange, although some evaporative cooling may also occur. This cooling fluid may be introduced to the air at any point prior the compressed air being delivered to storage. The cooling fluid may follow the air into the compression chamber of the compressor(s), and any other portions of the compression process. In this respect, the cooling fluid may be subjected to the same pressures as the air that progresses through the compression process. As discussed herein, the cooling fluid is typically removed from the compressed air prior to the air being delivered to the storage medium.

[0039] The temperature of the cooling fluid will not typically increase due to the increase in pressure that is experienced as the air and cooling fluid are compressed. This is due to the generally incompressible nature of cooling fluids, such as water. Instead, the cooling fluid remains at a temperature similar to that of the fluid prior to compression. As the compressed air is heated due to compression, the difference in temperature between the air and cooling fluid increases, thus causing heat in the air to move to the cooling fluid in efforts to reach equilibrium. The cooling fluid is then heated, primarily due to sensible heat exchange from the hotter, compressed air, although some evaporative cooling may also take place.

[0040] The system may include features to increase the contact area between the cooling fluid and the air that is being compressed. This increased contact area may promote heat transfer between the cooling fluid and the air. According to some embodiments, the cooling fluid may be sprayed into the air, such that the cooling fluid, at least initially, is introduced to the air as water droplets. Increased contact area may be achieved through other mechanisms as well, such as with turbulators or other features within the system that may cause the cooling fluid to be agitated while passing thereby.

[0041] Cooling fluid may be introduced at directly into the compression system at different times. By way of example, cooling fluid introduced during a pre-cooling phase, primarily for evaporative cooling, may then serve to sensibly cool the air as the air is compressed. Cooling fluid may also be introduced to the air just prior to the air being compressed, during compression, and/or immediately after compression, as aspects of the invention are not limited in this respect.

[0042] The process of compressing air may result in a net production of water. As may be appreciated, the relative humidity of air increases as the air is compressed. Once a relative humidity of 100% is reached, further compression will result in water falling out of the air. By way of example, a 1.8 Megawatt wind turbine compressing 10,000 cubic feet per minute or air at 30% relative humidity may produce upward of several hundred gallons of water per day, when discharge pressures of the compressor are at or about 100 atmospheres. This water and/or cooling fluids may be removed from the compressed air prior to storage, although it is not required to be.

[0043] The compressed air may be cooled by mechanisms other than through cooling fluid injected directly into the air. By way of example, compressed air may be directed through any type of heat exchanger, such as a thin-plate heat exchanger, a shell and tube heat exchanger, a bank of cooling fins, and the like, as aspects of the invention are not limited in this respect. Such heat exchanger may be positioned about the compressor itself, so that cooling occurs during compression. These devices may also be positioned to cool air prior to compression, as discussed above, or after compression, as aspects of the invention are not limited in this respect. It is also to be appreciated that embodiments of the invention may incorporate any combination of approaches for cooling compressed air, or no techniques at all.

[0044] According to some embodiments, it is desirable to achieve isothermal, or near isothermal compression, such that compressed air exits the compressor at approximately ambient temperature. Minimal cooling of the compressed air would occur when the air is resident in the storage device, assuming the storage device is also at ambient temperature. In this respect, the capacity of a storage device may be better utilized, particularly during periods when the prevailing winds are strong, and there is much wind energy to be harvested and stored.

[0045] Various types and sizes of compressors may be employed to compress the air. By way of example, scroll type compressors, reciprocating or oscillating compressor, axial and/or centrifugal compressor may be used in various embodiments of wind turbines. Some examples include a toroidal intersecting vane compressor, as disclosed in US Publication No. US2005/0135934, or an oscillating vane compressor. The compressor(s) may act continuously, such as with a scroll type compressor or a centrifugal compressor, or may act in discrete phases, such as with many reciprocating or oscillating type compressors. Reciprocating and oscillating compressors, when employed, may be configured to have multiple compression chambers that act in parallel, in efforts to maximize flow rates and to reduce any pulsations in the flow of compressed air through the system. It is to be appreciated that the above listing of compressor types is merely exemplary, as aspects of the invention are not limited to any one type of compressor.

[0046] Embodiments of the compressors may compress air to a predetermined pressure, at which point the air and any cooling fluid may be released from the compression chamber. Alternately, compressors may be configured to release the compressed contents when a predetermined clearance volume is attained. Additionally, according to some embodiments, the volume or pressure at which compressed air is released may be varied during operation.

[0047] According to some embodiments, the compression may be carried out in multiple stages. Multi-stage compression may facilitate obtaining higher compressor outlet pressures. Additionally, multi-stage compressor may provide an opportunity to cool compressed air between compression stages. Intercooling the air in this manner may help reduce the maximum temperature that air experiences for any given discharge pressure of the overall compression system. According to some embodiment, dividing the compression among multiple stages and multiple compressors may facilitate an overall increase in the volumetric efficiency of each compressor, a reduction in the size of each compressor, a reduction in the flow rates that each compressor may have to accommodate, and/or reduction in the pressure differential that each compressor may accommodate.

[0048] Multi-stage compression may be accomplished according to various, different strategies. As represented in FIG. **3**, one embodiment includes four separate stages of compression. The first stage **20** may comprise one or more compressors (two are shown). The compressors may be four chamber, double acting **22** compressors. In such compressors, all four chambers are acting to compress air at any given time. As discussed herein, such a configuration may help decrease the size and cost may be reduced while the amount of mass flow may be increased.

[0049] The second stage **24**, as illustrated in FIG. **3**, includes a single, double acting, four chamber compressor **22** that receives the compressed air output from each of the first stage compressors. Due to the increased pressure of the air and the corresponding reduction in volumetric flow rate, the second stage may comprise a single compressor. Similar reductions in volumetric flow rates may also occur at the third **26**, **28** and fourth stages, which may comprise compressors **22** of a similar design, sized accordingly, or different types of compressors, as aspects of the invention are not limited in this respect. Also represented in FIG. **3** are intercoolers **30** that may be incorporated into each stage of the compressor.

[0050] Each stage of compression in the embodiment shown in FIG. **3** may increase the pressure of the air by a factor of between 3 and 3.5 in some operating modes, and in some instances by a factor of 3.16. This ratio of compressor outlet pressure to compressor inlet pressure is defined as a "pressure ratio". The pressure ratio of 3.16 evenly distributes the work across each stage of compression, and results in a discharge pressure of about 100 atmospheres. Discharge pressure, as the term is used herein, describes the pressure at which the overall compression system releases air, such as to a storage device. Distributing the pressure ratio evenly, in this manner, may in turn, allow the temperature rise associated with each stage of compression to be more evenly distributed, which can help increase the amount of heat that is removed from the compressed air, according to some embodiments.

[0051] According to other embodiments, the pressure ratios of various compression stages may differ. By way of example, according to one embodiment, the pressure ratio declines at each subsequent compression stage. In this sense, each successive compression stage increases the pressure of the air by a smaller amount. Such a scheme may help reduce the pressure differential experienced by the later stages, since later stages in the compression process will be dealing with greater absolute pressures, but with smaller pressure ratios. It is to be appreciated that in other embodiments of multi-stage compressors, that pressures ratios may differ from stage to stage according to different schemes, as aspects of the invention are not limited to those described above.

[0052] The compressors illustrated in FIG. **3** are each configured to receive air or air and cooling fluid, and to compress the contents to a defined outlet pressure. Upon reaching the defined pressure, the air or air and cooling fluid is then output from the compressor. According to some embodiments, the outlet pressure is defined by a valve positioned at the compressor outlet. Embodiments may have compressors with such valves set to a constant release pressure, or may include valves with release pressures that may be varied during operation of the compression system. The valve may be mechanical, such as a spring activated shuttle valve, or may be an electronically operated valve, as aspects of the invention are not limited in this respect.

[0053] The compressor may be operated to prevent the waste of mechanical energy. It is to be appreciated that pressure levels in a storage device may not be constant through all phases of operation. Compressing air to pressure much higher than that present in the storage device may require additional work that is difficult to recover when the compressed air expands upon entry into the storage device. Accordingly, some embodiments are configured to control discharge pressure of the compression system to be equal to or just slightly greater than the pressure in the storage device. Controlling the system in this manner may help improve the overall efficiency of the system. According to some embodiments, the discharge pressure is controlled to be ¼ atm greater than the storage pressure, ½ atm greater than the storage pressure, 2 atm greater than the storage pressure, or 5 atm greater than the storage pressure. Other controlled differences between discharge and storage pressures are also possible, as aspects of the invention are not limited in this respect.

[0054] In one embodiment, discharge pressures may be controlled by altering the pressure ratio(s) of the compressor. In embodiments that employ multi-stage compression, the pressure ratio of each stage may be reduced by a proportional amount until the desired discharge pressure is obtained. However, it is to be appreciated that the pressure ratios of multi-stage compressors may be altered in different manners to achieve a desired discharge pressure, as aspects of the invention are not limited in this manner.

[0055] Multi-stage compression may facilitate removal of heat between successive stages of compression. According to some embodiments, intercoolers may be positioned between compressors of each stage. In this regard, the amount of heat removed from the system may be increased. Intercoolers may also help reduce the maximum temperature that the air attains throughout the entire compression process. Cooling fluid may also be introduced between each of the compression stages, either in combination or in place of the intercoolers, as aspects of the invention are not limited to any one type of cooling.

[0056] Embodiments of the wind turbine may include features for cooling the compressors themselves. According to some embodiments, the compressors may include a coolant jacket through which cooling fluid is run to remove heat from the compressor. Cooling fins may be positioned about the external surface of the compressor to aid in the removal of heat. Still, other methods and devices may be used to cool the compressor itself, or the compressor may lack such features altogether, as aspects of the invention are not limited in this respect.

[0057] Embodiments may include features to protect the compressor and/or other components from cold weather conditions. By way of example, embodiments that include coolant jackets may include heaters to prevent compressor damage that might otherwise occur if cooling fluids were to freeze in the coolant jacket. Additionally, or in place of anti-freeze, the cooling system may be used to circulate warming fluids to prevent freezing damage. It is to be appreciated that protection for freezing may be implemented in cold weather conditions when the turbine is not operating, as normal heat rejection during operation may be sufficient to prevent freezing and any associated damage.

[0058] Embodiments of the invention may use different approaches to removing heat from cooling fluid that is used to cool the compressed air and/or the compressor itself. According to one embodiment, the cooling fluid is circulated from the nacelle, down the tower, and into the earth. The earth may act as a heat sink, removing enough heat from the cooling fluid to bring the cooling fluid back to or near the ground temperature. The cooling fluid may be stored in a relatively large underground tank to increase the average time that the cooling fluid is resident underground before returning to the nacelle. The surface area of the tank may also be maximized to promote heat transfer between the earth and the cooling fluid, such as through the use of ground loops.

[0059] According to one embodiment, water retrieved from air that is being compressed may help remove heat from the cooling fluid. The process of compressing air may result in a net production of water as at least a portion of the water vapor present in the air received by the turbine is removed during compression, as discussed above. This water may typically be cooler than the maximum temperature obtained by the air during compression, and thus may serve to cool the air and/or the cooling fluid itself. It is to be appreciated that embodiments of the invention may include features to remove heat from a cooling fluid other than those described above, such as traditional air to water radiators, evaporative cooling towers or ponds, nearby bodies of water, and the like, as aspects of the invention are not limited in this respect.

[0060] According to some approaches, a primary cooling fluid may receives thermal energy from the compressed air or compressor and may, in turn, reject this heat to a secondary cooling fluid. Here, the first cooling fluid may be optimized for temperatures and conditions at the compressor or in the nacelle of a turbine, while the secondary coolant is optimized for conditions elsewhere, such as at the ground where the secondary cooling fluid resides. A heat exchanger may be used to transfer heat between the primary and secondary cooling fluids. In other embodiments, only a single cooling fluid or no cooling fluids may be used, as aspects of the invention are not limited in this respect.

[0061] Various types of coolants may be used to cool the compressed air and the compressor itself. According to some embodiments, it may be desirable to use an environmentally friendly coolant, such as ethanol. In this regard, coolant that may escape to the environment may be less likely to cause environmental harm. Ethanol may also prevent freezing of the coolant, which may be advantageous for wind turbines situated in colder environments. Ethanol and other environmentally safe coolants may prove particularly useful for direct introduction into the compressed air for cooling, as such fluids may prove to be more likely to escape into the environment. Closed loop cooling systems, such as those used in heat exchangers for performing pre-cooling, inter-cooling, or for feeding a coolant jacket to cool the compressors themselves may be chosen such that the coolant is evaporated when receiving heat, returning to a liquid state for heat rejection. According to other embodiments, coolants may receive heat, and later reject heat without changing phases, as aspects of the invention are not limited in this respect, or to any one type of cooling fluid.

[0062] Compressed air, provided to the storage device, may be utilized in various different types of applications. According to some embodiments, the compressed air may be used to drive turbines that, in turn, provide electric power when needed.

[0063] According to some embodiments, the compressed air may be expanded from a storage device at operating pressure and fed directly to a turbine or any other type of expander, where the expanding air may produce electrical power. Large combustion turbines typically receive air that has been compressed to between about 30 and about 40 atmospheres, although other pressures are possible. The work associated with compressing air to such pressures often represents between roughly one half to three quarters of the gross power that the turbine may produce. In this respect, providing compressed air from a storage device in such a manner as to reduce or substantially eliminate the compressor work may double or triple the net output of the turbine, according to some embodiments.

[0064] Compressed air may be provided to power generation turbines in different manners. According to some embodiments, air is expanded from operating storage pressure and temperature and is fed directly to a turbine. As discussed herein, operating storage pressures may typically range between 10 atmospheres and 100 atmospheres, although higher and lower pressures are possible. The stored air will typically also be at roughly ambient temperature. It is to be appreciated that the stored air, through the process of expansion, may reach cryogenic temperatures upon discharge from the expander, particularly for air that is stored at the higher pressures, such as those up to and greater than 100 atmospheres, 200 atmospheres, or even 250 atmospheres.

[0065] Heat may be added to the compressed air prior to feeding the air to a turbine. The added heat may increase the energy that may be derived from the turbine to create electricity. Turbines in existing power plants may be constructed to operate with air at particular working temperatures, and in this respect, additional efficiencies may be realized by matching the temperature of the air provided to a turbine to that which is normally provided. According to some embodiments, the compressed air is heated to between about 1100 and 1500 Celsius and expanded to between about 30 and about 40 atmospheres prior to being fed to the turbine, although other temperature and pressure levels are possible, as the invention is not limited in this respect. By way example, the temperatures that turbines may accommodate are being increased through ongoing research, and it is contemplated that the temperatures provided by aspects of the invention may be as high as those that turbines can accommodate.

[0066] Adding heat to compressed air that is provided to a turbine may result in exhaust heat from the turbine that can be recuperated to perform useful work. By way of example, in some embodiments, the exhaust from a turbine may be used to preheat compressed air that is being provided to the turbine. The exhaust gases may be used to directly heat the compressed air, either before any expansion occurs, or during the expansion process but prior to the air being fed to the turbine. In other embodiments, heat from turbine exhaust gases may be used in a remunerator, or to heat the working fluid of a heat exchanger, that in turn, preheats compressed air prior to the air being fed to the turbine. It is to be appreciated, however, that aspects of the invention do not require the recuperation of heat from the turbine, as the invention is not limited in this respect.

[0067] Compressed air may be heated by various different means before being fed to a turbine. According to some embodiments, heat is added by combusting fuel directly in the compressed air. This is typically accomplished with liquid or gaseous fuels, such as natural gas, among other choices. According to other embodiments, steam may be injected directly into the compressed air. Other methods may also be available for directly heating the air prior to the air being introduced to the turbine. According to some embodiments, the air is heated directly by a solar concentrator, which may prove particularly advantageous as such devices are capable of attaining very high air temperatures. Still, other methods of directly heating the compressed air are possible, as aspects of the invention are not limited to those described above.

[0068] Embodiments may also use methods of indirectly heating the compressed air, such as with a heat exchanger that receives thermal energy from a working fluid. The working fluid, in turn, may be heated by multiple different types of sources, including biomass, coal, waste heat from other production or power plant facilities, solar heat from a collector, such as a trough style collector, and the like. According to some embodiments, the source of heat that is used to provide thermal energy to the compressed air may be a renewable energy source. In this respect, an energy provider may obtain additional government benefits for energy that is produced.

[0069] Air may be fed to turbines at various, different pressures. As discussed above, according to some embodiments, the air is fed to the turbine at the operating pressure of the storage device. Here, the pressure of air fed to the turbine may vary according to the operating pressure of the system. In other embodiments, the pressure may be controlled to a single pressure, or range of pressures, such as between 30 and 40 atmospheres, before being introduced to the turbine. It is noted that expanding the air from 100 atmospheres to 40 atmospheres typically only incurs an approximately 45 degree Celsius decrease in temperature, such that the thermal energy required to bring such expanded air to a desired temperature is not significantly increased.

[0070] Turbines that receive compressed air from a storage device may be configured in different manners. According to some embodiments, the turbines may be of similar construction to those that are found in existing, natural gas power plants. Such turbines are typically coupled to a compressor that may be used to compress air provided to the turbine when compressed air is not provided by the storage device. When compressed air is provided by the storage device, the compressor may be mechanically disconnected from the turbine, such that energy is not expended to rotate the compressor and compress additional air. Twin shaft compressor/turbine arrangements are also suitable for such embodiments. According to some embodiments, the compressor may be isolated from the atmosphere, such that rotation of the compressor does not compress air and minimizes any energy consumption by the pressure stages of the compressor/turbine.

[0071] According to other embodiments, compressed air may be expanded and fed through a steam turbine directly from storage, as such turbines are typically configured to operate with greater efficiencies over a wider range of operating pressures.

[0072] According to some embodiments, the air compressed by the wind turbine may be expanded to produce liquid air. The compressed air may be released from a storage device may, or may be released directly from compressor discharge. Expansion of compressed air is accompanied by a cooling of the air. In some embodiments, the air may be cooled such that at least a portion of the expanded air changes phase and become liquid.

[0073] Techniques may be used to increase the percentage of compressed air that is liquefied upon expansion. As may be appreciated, increasing the reduction in pressure that occurs upon expansion may increase the amount of thermal energy that is released as the air expands to atmospheric pressure, such that greater cooling and more liquefied air is obtained. Additionally, according to some embodiments, expanded and cooled air that is not converted to the liquid phase may be used to pre-cool compressed air. In this regard, energy may be removed from the compressed air such that upon expansion, a greater percentage of the air is converted to liquid. Other methods may be used to pre-cool the compressed air, either alone or in combination with air that has been expanded, as aspects of the invention are not limited to any one method or device for pre-cooling compressed air.

[0074] Compressing air to higher pressures may allow liquid air to be produced and stored at higher temperatures. According to some embodiments compressed air may be received from a storage device and compressed further to produce liquid air, either in addition to or in place of creating liquid air upon expanding the stored compressed air. Still, other methods may be used to increase the amount of liquid air that is derived from the compressed air, as aspects of the invention are not limited to those discussed above.

[0075] Products, such as industrial grade or even laboratory grade oxygen and nitrogen, may be produced with liquid air produced by various embodiments of the system. According to some approaches, fractional distillation may be used to isolate oxygen, nitrogen, or any other particular components from the air.

[0076] According to some embodiments, the compressed air may be used to produce oxygen or nitrogen directly through methods like pressure swing adsorption. In such embodiments, compressed air from a storage device is exposed to a substance that adsorbs oxygen, or some other constituent of air, at higher pressures. After exposure in the compressed air, the substance is exposed to a lower pressure environment, where oxygen (or another constituent of air) is released and collected.

[0077] Isolated air products, like laboratory grade or industrial grade oxygen, have many existing and growing markets. By way of example, oxygen may be used in the gasification and combustion of gasified solid fuels, by oxygen fired coal plants, integrated gasification combined cycle plants, natural gas plants, combined cycle plants, and the like.

[0078] Air liquefaction may also be used as a mechanism for storing energy for later use. It is to be appreciated that liquefied air occupies a much smaller volume than air at a comparable pressure. By way of example, liquid air occupies approximately _b /**1;80**th of the volume of gaseous air at 100 atmospheres. Air stored as liquid may later be heated and expanded to drive a turbine, or for any of the other uses discussed herein.

[0079] According to some embodiments, air liquefaction for energy storage occurs in place of storing energy as compressed air. Liquefaction may occur at a wind farm, and in some embodiments, within the nacelle of a turbine. In one embodiment, the expander comprises a turbine connected mechanically to the compressor(s), such that the turbine may help drive the compressor(s) as the compressed air is expanded. In some embodiments, the turbine and compressor may be mounted to a common shaft. The reduction in storage volume for liquefied air may facilitate transportation of energy harvested by a wind farm through means other than a pipeline. By way of example, ships, trucks, and rail may be used to transport liquid air containers from a wind farm or single wind turbine to various destinations. In the case of a pipeline, the size, cost, and losses associated with moving the fluid through the pipeline may be reduce.

[0080] The manner in which compressed air released from a storage device may utilize heat energy allows for numerous synergies with other types of processes. By way of example, Aluminum production facilities typically produce great amounts of waste heat that is typically output to the environment, often at great costs. According to some embodiments, this heat may be transferred, either directly or through a working medium, to compressed air before the compressed air is expanded through a turbine to produce electricity. This electricity, in turn, could, be provided to the Aluminum plant to power internal processes that may require energy.

[0081] Co-located facilities may benefit from other synergies as well. By way of example, plants often expend large amounts of energy to compress air for internal uses, such as powering tools, materials handling, robots and the like. Plants may receive compressed air directly from a storage device, such that electricity does not need to be used to compress air on-site. Cooling may also be provided directly to production, processing, or plants by the expansion of compressed air. Such cooling may be used for any processes internal to a plant that may require cooling, such as industrial process, including refrigeration, and the like.

[0082] According to some embodiments, a turbine that utilizes air provided from a storage device may be co-located with a peak power production plant to provide synergistic benefits. Peak power production facilities typically incur additional power production requirements during the hottest times of day, when consumers are operating air conditioners at maximum power. At such times, heat is more readily available, such as in a solar collector, for pre-heating compressed air before being fed to a turbine for electric power generation. The correlation between energy demand by consumers and solar energy availability for pre-heating compressed air allows for increased synergistic benefits.

[0083] Embodiments of the system may also be constructed to take advantage of synergies that may exist with facilities that require sub-atmospheric pressure. By way of example, the compressors of one or more wind turbines may be used to draw a vacuum to help evaporate fluids, such as salt water. The may prove particularly beneficial for desalination plants, where the evaporated water may later be condensed to provide fresh water.

[0084] Wind turbines, according to aspects of the present invention, may be positioned as solitary turbines, or may be grouped together in wind farms. Wind turbines may also be positioned anywhere, particularly where prevailing winds are typically strong. By way of example, turbines may be positioned in wide open plains and or in bodies of water, standing on the bottom of floating atop supporting structures. Such embodiments may provide a readily accessible source of cooling in the waters of a large inland lake or ocean.

[0085] Other types of plants that may find synergies with embodiments of the present invention may include but are not limited to, an aluminum production facility, a fertilizer, ammonia, or urea production facility, a liquid air product production facility that can be used in manufacturing liquid air, liquid oxygen, liquid nitrogen, and other liquid air products, a fresh water from desalination production facility, a ferrosilicon production facility, an electricity intensive chemical process or manufacturing facility, a tire recycling plant, coal burning facility, biomass burning facility, medical facility, cryogenic cooling process, or any plant that gasifies liquid oxygen, nitrogen, argon, CO2, an ethanol production facility, a food processing facility. Examples of food processing facilities include but are not limited to, dairy or meat processing facilities and the like.

[0086] Aspects of the invention also relate to obtaining renewable energy credits with wind generated energy. As may be appreciated, electricity may be provided to consumers by retailers, often known as load serving entities. Load serving entities, in turn, purchase the electricity they provide from wholesale suppliers of electricity. In deregulated control areas, an independent system operator may be responsible for the administration of the wholesale power markets and network reliability.

[0087] Some governments choose to establish and administer renewable energy portfolio standard (RPS) to promote power generation fuel diversity. Under the RPS, load serving entities may be obligated to purchase a defined percentage of their annual retail sales from qualified wholesale suppliers to comply with the RPS or provide so called compliance or penalty payments if they are unable to procure a sufficient amount of qualified supply. The compliance obligation typically increases annually by a defined increment set in advance by a governmental entity. The RPS may act to incent wholesale suppliers to develop new power plants that will generate electricity in certain government-preferred ways. In return suppliers may become eligible to receive renewable-energy credits (REC). According to some embodiments, the preferred ways may relate to the technology used to create the electricity, such as by the type of fuel burned to produce the electricity. The preferred ways may also relate to the nature of the emissions that result from a particular electricity generating process.

[0088] At least a portion of the electricity is available for sale to a wholesale or retail customer or on the open market. Renewable energy credits can be associated with the electricity produced, associated with electricity produced from the wind energy systems and the thermal energy systems, like those discussed herein. In one embodiment, the renewable energy credits are associated with a value placed on the produced electricity.

[0089] It is envisioned that the power generation system described herein creates opportunities for novel approaches to: increasing existing power generation efficiency, improving pollution abatement, and enabling pollution sequestration; and thereby may incent governments to craft novel forms of renewable-energy credits that said power system would qualify to obtain. For example, the wind energy system can be coupled to a thermal energy system and the wind energy and thermal energy from the thermal energy system is collected and stored. The renewable energy credits can be among the following: sulfur dioxide credits, nitrous oxide (NOX) credits, mercury reduction credits, cap and trade pollution credits, renewable obligation certificate (ROCs) credits, renewable energy credits (RECs), carbon credits, green energy credits, CO2 credits, financially valuable environmental attributes, power purchase agreements and the like. The thermal energy system can be selected from, biomass, geothermal, solar, coal, natural gas, oil, industrial process heat, nuclear, heat from a chemical or manufacturing process, a wind compressor intercooler, a body of water and the like. At least a portion of the wind power can be used convert at least a portion of the thermal energy to electricity to increase efficiency of conversion. The thermal portion of the wind energy can be stored, managed, and enhanced by a solar thermal collector, thermal inertial mass, thin walled tubing with anti-freeze distributed inside the tank, fossil fuel, or biomass, or bio fuel burner, a circulation device for using hot air, and the like.

[0090] In one embodiment, green credits are provided for the production of electricity from the wind energy system alone or in combination with the thermal energy system. The renewable energy credits attributed to wind power can receive green energy credit. In another embodiment, those renewable energy credits attributed to the thermal energy system, with attributes that qualify them as green energy credits, such as but not limited to thermal inputs derived from biomass combustion or gasification, also receive green energy credits. In one embodiment, a green energy credit of the thermal energy is increased in response to utilizing the wind power to covert the thermal energy into electricity.

[0091] All or a portion of the renewable energy credits can be sold to third parties. The sale to third parties can occur through a variety of mechanisms, including but not limited to, through a broker, a sales organization, an auction, directly from the wind energy system owner or manager, from a contracted owner of the renewable energy credit and the like.

[0092] The delivery of wind energy can be coordinated and stabilized. An energy delivery schedule can be created from the wind energy system in response to predictions for wind speed, wind power availability levels, historical, current and anticipated power and green energy prices, and historical, current and anticipated transmission availability. The delivery schedule can be used to match a customer's anticipated demand. The delivery schedule can manage updates and corrections to schedules on very short notice. The delivery schedule can be used to set a reduced number of constant power output periods during an upcoming period of time. By way of illustration, during the upcoming period of time energy, delivery levels can remain substantially constant despite fluctuations and oscillations in wind speed and wind power availability levels.

[0093] The upcoming period of time can be any period of time, including but not limited to the next 24 hour period. In one embodiment, no more than seven constant power output periods occur during any given 24 hour period.

[0094] The delivery schedule can take into account the amount of energy that can be supplied directly from the wind power system as well as stored energy. In one embodiment, the delivery schedule is utilized to determine an amount of energy that can be provided from storage, and an amount of power expected to be used and withdrawn by a power grid. In another embodiment, the delivery schedule is utilized to assist in ensuring that wind energy is available at constant power output levels even when the wind energy availability levels drop below a demand for power needed by a power grid.

[0095] In another embodiment, at least one demand history is created for a location to help forecast and predict how much energy will be used at the location during an upcoming period of time. Energy availability from the wind energy system can be determined. The demand history can be used for delivery of wind energy to the location to manage load, offset spikes, sags, and surges, and meet the needs of the grid and the customer.

[0096] Embodiments of the wind energy system can be coupled to a power grid that can be accessed to supply energy into storage by using electricity to run the generator/expanders backwards as motor/compressors to pressurize the system, which will then be expanded on demand to make electricity. An energy usage schedule can be developed using forecasts and predictions to for the upcoming time period to determine how energy from storage should be used to achieve a desired cost savings. A demand charge can be determined that may be applied based on spikes or surges that can occur during the upcoming time period, and an energy usage schedule then developed to reduce and/or offset the spikes or surges in a manner that achieves cost savings at a location. The location can be a commercial property end-user of energy and storage of energy is used to lower overall costs of energy at the commercial property end-use, and the like.

[0097] In one embodiment, an estimated cost savings for the upcoming time period is determined, and then that determination is repeated for an extended period of time, to help determine an overall cost savings that can be achieved during the extended period of time.

[0098] Having thus described several aspects of at least one embodiment of this invention, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description and drawings are by way of example only.

What is claimed is:

1. A system for producing compressed air from wind energy, the system comprising:

a wind turbine that harvests energy from wind to produce mechanical energy;

a compressor that receives mechanical energy from the wind turbine to compress air to an elevated pressure;

a storage device that receives the air from the compressor such that the air can be released from the storage device on demand; and

an expander for expanding air received from the storage device to generate electric energy;

wherein thermal energy is removed from the air prior to being received by the storage device, further wherein thermal energy is added to the compressed air prior to being expanded to generate electric energy.

2. The system according to claim **1**, wherein the thermal energy added to the compressed air is provided by a renewable energy source.

3. The system according to claim **2**, wherein the renewable energy source comprises one or more of solar energy, biomass energy, and geothermal energy.

4. The system according to claim **1**, wherein the thermal energy is added via a fluid medium into the compressed air.

5. The system according to claim **4**, wherein the fluid medium is a heated vapor.

6. The system according to claim **5**, wherein the heated vapor is steam.

7. The system according to claim **4**, wherein the fluid medium is a combustible gas that provides thermal energy to the compressed air as the fluid medium is combusted.

8. The system according to claim **1**, wherein the thermal energy is added via a working fluid that is heated remotely from the compressed air.

9. The system according to claim **8**, wherein the working fluid is heated by a renewable energy source.

10. The system according to claim **1**, used to create renewable energy credits.

11. A system for producing desalinated water with the assistance of wind energy, the system comprising:
- a wind turbine that harvests energy from wind to produce mechanical energy;
- a compressor that receives mechanical energy from the wind turbine to compress water vapor to an elevated pressure and temperature;
- wherein water vapor provided to the compressor is drawn from a fluid containing system of a desalination facility to promote the evaporation of feed water.

12. The system of claim **11**, further comprising:
- a heat exchanger that transfers heat of the compressed water vapor so the feed water to promote evaporation.

13. A system for producing liquefied air products utilizing wind energy, the system comprising:
- a wind turbine that harvests energy from wind to produce mechanical energy;
- a compressor that receives mechanical energy from the wind turbine to compress air to an elevated pressure; and
- an expander to expand air received from the compressor to produce liquefied air products from the compressed air.

14. The system according to claim **13**, further comprising:
- a heat exchanger positioned to cool compressed air prior to the compressed air being expanded.

15. The system according to claim **14**, wherein the heat exchanger is configured to receive air expanded by the expander to pre-cool compressed air.

16. The system according to claim **13**, wherein the compressor and the expander are positioned in a nacelle of the wind turbine.

17. The system according to claim **16**, wherein the expander comprises a expander that derives mechanical work from air that is expanded therein.

18. The system according to claim **17**, wherein the compressor and the expander are mechanically coupled, and work produced by the turbine helps drive the compressor.

19. A method of producing compressed air from wind energy, the method comprising:
- harvesting wind with a wind turbine to produce mechanical energy;
- compressing air to an elevated pressure with a compressor driven by the mechanical energy;
- removing thermal energy from the air;
- conveying the air to a storage device after thermal energy is removed from the air;
- storing the compressed air in the storage device at a working pressure greater than 10 atmospheres;
- conveying the compressed air to an electric energy production facility;
- adding thermal energy to the compressed air; and
- expanding the compressed air to drive a turbine to produce electric power.

20. The method according to claim **19**, wherein adding thermal energy comprises adding a thermal energy from a renewable energy source.

21. The method according to claim **20**, wherein the renewable energy source comprises one or more of solar energy, biomass energy, and geothermal energy.

22. The method according to claim **19**, wherein adding thermal energy comprises adding thermal energy via a fluid medium into the compressed air.

23. The method according to claim **22**, wherein adding thermal energy comprises adding thermal energy via a working fluid that is heated remotely from the compressed air.

24. The method according to claim **19**, further comprising:
- creating renewable energy credits.

25. A method of producing desalinated water with the assistance of wind energy, the method comprising:
- harvesting wind with a wind turbine to produce mechanical energy;
- compressing water vapor to an elevated pressure with a compressor driven by the mechanical energy;
- drawing water vapor from a fluid containing system a desalination facility to promote evaporation of a feed water.

26. A method for producing liquid air products utilizing wind energy, the method comprising:
- harvesting wind with a wind turbine to produce mechanical energy;
- compressing air to an elevated pressure with a compressor driven by the mechanical energy;
- expanding the compressed air to produce liquefied air products from the compressed air.

27. The method according to claim **26**, further comprising:
- cooling the compressed air prior to expanding the compressed air.

28. The method according to claim **26**, further comprising:
- cooling the air during the process of compressing the air.

29. The method according to claim **28**, further comprising:
- driving the compressor with energy received by the expander as the compressed air is expanded.

* * * * *