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An Energy Efficient Wind Turbine Design Consideration

Additional submitted attachment is included below.

From: Kari Appa <ka@wtswind.com>
Sent: Monday, October 22, 2018 3:49 PM
To: Energy - Docket Optical System
Subject: An Energy Efficient Wind Turbine Design Consideration
Attachments: US9537371B2 - Contra rotor wind turbine system using a hydraulic power transmission device - Google Patents.html; AXIAL-FLOW-ROTOR (15).PDF

Three Radial Bladed Rotor Configuration has been the common practice. This leads to a massive rotor as the cubic power of the blade length. For example, the DOE anticipated, 50 MW rated rotor mass would be ~ 1200 tons. This is beyond the scope of the present consideration and hence limited to 12 MW/unit.

However, if we change the rotor configuration to the axial flow helical bladed configuration, we arrive at a light weighted rotor, as outlined in attachments 1 and 2. This seems to be a reasonable rotor. But, I dought my analysis.
I appreciate if any of you could point to me the mistake, in my analysis, attachment 2.

Thank you.
Best regards.

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Patents

Contra rotor wind turbine system using a hydraulic power transmission device

Abstract

The present invention provides a system for a contra rotor wind turbine system comprising of dual aerodynamic rotors composed of plurality of either radially extended blades or axially extended helically contoured blades. The blades on the upwind or the outer rotor are set to spin in the first direction about the outer shaft, while the blades on the downwind or inner rotor are set to spin in a second direction about the co-axially mounted center shaft. Each rotor drives a digitally controllable positive displacement pump unit to convert the kinetic energy of the rotor to the fluidic potential energy. The potential energy of each rotor is compounded to achieve net potential energy. The net potential energy is stored in a fluidic reservoir and used by a hydraulic motor to drive an electrical generator. The hydraulic pump and the motor units are provided to maintain uniform rotational speed and torque.

Images (13)

Classifications

H02K7/183 Rotary generators structurally associated with turbines or similar engines wherein the turbine is a wind turbine

F03D1/025 Wind motors with rotation axis substantially in wind direction having a plurality of rotors coaxially arranged

F03D11/02

F03D15/00 Transmission of mechanical power

US9537371B2
US Grant

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2014-12-10	US14565450	Active
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Info: Patent citations (11), Non-patent citations (5), Legal events, Similar documents, Priority and Related Applications

External links: USPTO, USPTO Assignment, Espacenet, Global Dossier, Discuss

Description

FIELD OF INVENTION

The present invention relates generally to turbines and specifically to an energy efficient contra rotor turbine that harnesses energy from a kinetic fluid flow medium to produce mechanical and electrical power thereof.

BACKGROUND OF THE INVENTION

The embodiments stated herein, generally relate to the field of electric power generation from the kinetic energy of a fluid flow medium, such as wind, steam or hydraulic fluid. More specifically, the embodiments described herein relate to the development of an energy efficient wind turbine (WT) system, having a pair of contra rotors (CR) coupled to an electrical power generating alternator by means of a hydraulic power transmission (HPT) device. According to the present innovation, the integration of the contra rotor wind turbine technology with the hydraulic power transmission device (CR-WT-HPT) results in a cost effective and an energy efficient wind turbine having the following features:

- reduced tower-top weight, since the low speed hydraulic pump unit need be mounted on the tower top, while the alternator could be placed on the ground level,
- the rotors could start easily and safely at any wind speed, because, the heavy duty alternator inertia load is not directly connected to the rotors and moreover, the torque required to drive the hydraulic pump units can be digitally controlled to match the rotor torque at any wind speed,
- increased annual energy yield per unit of rotor swept area,
- Significantly reduced noise level.

Said Contra Rotor Wind Turbine unit may comprise of conventional radially extended blades (FIG. 1*a*) having its axis of rotation in the direction of fluid flow, designated as CR-WT. Alternatively, each co-axial contra rotor unit may comprise of helically contoured blades having its axis of rotation, also positioned horizontally in the direction of fluid flow (FIG. 4) and designated as CR-HAWT. Still further, it may have an alternate configuration, wherein the axis of rotation of the helical bladed contra rotor may be positioned vertically up perpendicular to the flow field, designated as CR-VAWT.

As the need for energy continues to grow worldwide, the commitment to extract more of energy from the renewable sources increases. At present, the worldwide requirement is around 30 percent or more from solar and wind energy sources. For this reason, the offshore wind farm development is gaining popularity. According to the present technology, the cost of initial investment required on offshore wind turbine installations is nearly 3 to 4 times more expensive than that for the land based units. To minimize this cost, innovators are looking into several other technologies, which are more efficient and less expensive; such as:

a) The Contra Rotor Wind Turbine (CRWT, FIG. 1*a*), which is designed to yield nearly 30 to 50 percent more of annual energy per unit of rotor swept area, and

b) The Hydraulic Power Transmission (HPT, FIG. 1*c*) device that couples a rotor and an alternator. This HPT device permits the coupling of multiple rotors to a single alternator, which can be placed on the ground floor for easy access to installation and maintenance at minimal cost.

FIG. 2 shows the typical art of the present innovation, wherein the Contra Rotor (CR) technology and the hydraulic power transmission (HPT) technology are integrated to yield, a cost effective and an energy efficient wind turbine system.

SUMMARY

In view of the foregoing, an embodiment herein provides a contra rotor wind turbine system using a hydraulic power transmission device. The contra rotor wind turbine (CRWT) unit, depicted in FIG. 1*a* and described in Ref. 1, Ref. 2, and U.S. Pat. Nos. 6,127,739; 6,278,197 B1; 6,375,127; 7,679,249; 7,789,624, comprises of two rotors, set to spin in opposite direction to each other. The upwind rotor, while spinning in one direction generates aerodynamic torque and also imparts some kinetic energy to the vortex flow shed behind the upwind rotor. This kinetic energy contained in the vortex flow is utilized to turn the downwind rotor in opposite direction to the upwind rotor, so as to extract additional energy from the flow field swept behind the upwind rotor. Since, a certain amount of kinetic fluid energy is extracted by the downwind rotor, the downwind flow field will be rendered smooth, noise free and non-oscillatory and permits closer tower spacing than that required in the case of single rotor towers. For example the tower spacing in the case of the CRWT units may be as close as 4 times the rotor diameter versus 7 times for the conventional single rotor units. Thus, more of annual energy can be extracted in a given wind farm site.

According to an embodiment, the annual energy yield by the CRWT unit is seen to be 30 to 60 percent more than that of a conventional single rotor system of similar rotor swept area, according to our field tests reported in Ref. 1 and the CFD simulation study conducted at the Denmark Technical University (DTU) (Ref. 2). Furthermore, it has been observed, that the slower the rotor speed, higher is the percent of energy extraction (FIG. 1*b*). This is due to reduced blanketing effect on the downwind rotor. Hence, the CRWT technology is more applicable to the utility scale turbines, whose rotor speeds are less than 20 rpm or so.

At present, the contra rotor wind turbine technology uses direct coupling of the aerodynamic rotor assemblies with the alternator units. Hence, the entire power generating alternator unit need be assembled on the tower top. In the case of multi-megawatt (>10 MW) units, the tower-top weight could be as heavy as 500 tons or more. This leads to very expensive installation and maintenance cost. To overcome this problem, innovators (References 3 to 7) have developed an economical hydraulic power transmission (HPT) device (FIG. 1*c*), to couple the rotors and the alternator, that could be mounted at the tower base.

Now, it is the object of this innovation to develop a method of integrating the contra rotor (CR) technology with the hydraulic power transmission (HPT) technology to drive an alternator which can be mounted on ground level for the convenience of offshore wind turbine installation and maintenance. Thus, an efficient and cost effective utility scale contra rotor wind turbine is developed for installation in either the land based or the offshore based wind farms. Furthermore, the integration concept put forth here becomes applicable for all types of wind turbines, whether it is a vertical axis or a horizontal axis model, and whether having radial bladed rotor or helical bladed rotor. The method of compounding the potential energies of the helical bladed rotors, described in FIG. 4 and FIG. 5 is similar, even in the case of vertical axis rotors, wherein the kinetic energy of each rotor is transformed into fluidic potential energy and compounded to achieve the net effect in a stepwise manner.

These and other aspects of the embodiments herein will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be understood, however, that the following descriptions, while indicating preferred embodiments and numerous specific details thereof, are given by way of illustration and not of limitation. Many changes and modifications may be made within the scope of the embodiments herein without departing from the spirit thereof, and the embodiments herein include all such modifications.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is set forth with reference to the accompanying figures. In the figures the use of the same reference numbers in different figures indicates similar or identical items.

FIG. 1*a* presents a typical assembly of a contra rotor wind turbine of a prior art (U.S. Pat. No. 6,127,739, Ref. 1). The contra rotor wind turbine comprises of a dual rotor assembly, having a direct drive coupling device with an electricity generating alternator, according to an embodiment therein;

FIG. 1*b* shows the Cp performance characteristics of the upwind rotor and the downwind rotor in low rotor speed situations, according to an embodiment therein;

FIG. 1*c* presents a typical assembly of another prior art wind turbine technology, (described in Refs. 3 to 7) comprising of a rotor assembly, a low speed hydraulic pump unit, a high speed digital displacement hydraulic motor and an electricity generating alternator, according to an embodiment therein;

FIG. 2 illustrates a sectional view of an exemplary embodiment of the present innovation of a typical utility scale contra rotor wind turbine comprising of two radial bladed rotors set to spin in opposite direction to each other. Each rotor shaft is coupled to drive a digitally controlled positive displacement pump, such that the kinetic energy of the rotor is transformed into fluidic potential energy, according to an embodiment herein;

FIG. 3 illustrates a method of compounding the potential energies of plurality of radial bladed contra rotors installed in a wind farm. This approach leads to storage of the net potential energy in a fluid reservoir (accumulator) and requiring a single alternator to generate electric power from the stored fluidic potential energy source, according to an embodiment therein;

FIG. 4 illustrates a sectional view of an exemplary embodiment of the present innovation of a typical utility scale contra rotor wind turbine comprising of two helical bladed axial flow rotors set to spin in opposite direction to each other. Each rotor shaft is coupled to drive a digitally controlled positive displacement pump unit, such that the kinetic energy of the rotors is transformed into fluidic potential energy, according to an embodiment herein;

FIG. 4*a* illustrates the airfoil chord setting, a with respect to the resultant velocity vector VR and also the velocity vector VN normal to the helically contoured blade leading edge, according to an embodiment therein;

FIG. 4*b* illustrates the airfoil chord setting α with respect to the resultant velocity vector VR and also the airfoil section tilt angle ψ with respect to the normal to the cylindrical surface swept by the tangent velocity vector $VT=\omega\cdot R$, according to an embodiment therein;

FIG. 4*c* illustrates the pump assemblies connected to the inner and outer helical bladed rotors of the axial flow turbine, according to an embodiment therein;

FIG. 5 illustrates a method of compounding the potential energies of plurality of helically bladed contra rotors installed in a wind farm. This approach leads to storage of the net potential energy in a reservoir and requiring a single alternator to generate electric power from the stored fluidic potential energy source, according to an embodiment therein;

FIG. 6 illustrates the typical performance characteristics of a conventional radial bladed rotor, according to an embodiment therein; and

FIG. 7 illustrates the typical performance characteristics of a helical bladed rotor of the present innovation, specially intended for offshore wind farms due to its geometrical simplicity and light weight rotors requiring inexpensive installation and maintenance cost and also due to its superior aerodynamic performance, according to an embodiment therein.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments herein and the various features and advantageous details thereof are explained more fully with reference to the non-limiting embodiments and detailed in the following description. Descriptions of well-known components and processing techniques are omitted so as to not unnecessarily obscure the embodiments herein. The examples used herein are intended merely to facilitate an understanding of ways in which the embodiments herein may be practiced and to further enable those of skill in the art to practice the embodiments herein. Accordingly, the examples should not be construed as limiting the scope of the embodiments herein.

As mentioned above, there remains a need for a contra rotor wind turbine system using a hydraulic power transmission device. Referring now to drawings, and more particularly to FIGS. 1 through 7, where similar reference characters denote corresponding features consistently throughout the figures, there are shown preferred embodiments.

According to an embodiment, the detailed description of the integration of the contra rotor wind turbine concept with a hydraulic power transmission device is first presented with respect to the conventional radial bladed wind turbine (CRWT). In addition, an alternate wind turbine configuration comprising of axial flow helical bladed rotors is presented.

Contra Rotor Wind Turbine with Hydraulic Power Transmission Device

Here we consider two configurations of the contra rotors, namely the radial bladed rotor and the axial flow helical bladed rotor.

Case A: Radial Bladed Contra Rotor Wind Turbine

According to an embodiment, depicted in FIG. 2, a horizontal axis contra rotor wind turbine system **100** is provided, wherein the system comprises of a pair of aerodynamic torque producing rotors such as an upwind rotor **101** and a downwind rotor **102**, wherein each rotor having plurality of radially extended blades. Said upwind rotor is fixed to the upwind rotor shaft **114** and its blades **101** are set to spin the rotor in a first direction. Likewise, said downwind rotor is fixed to the downwind rotor shaft **115** and its blades are set to spin the rotor in a second direction, opposite to the first direction. Furthermore, each rotor shaft is coupled to plurality of low speed digital displacement hydraulic pump units **103**, **104**, such that the kinetic energy of each rotor is transformed into potential energy in a compounded manner.

According to an embodiment, said upwind rotor and said downwind rotor shafts are supported on bearing units **112** *a,* **112** *b,* **112** *c,* which are in turn supported on bulkheads of the cylindrical shell **122**. The plurality of piston units are connected in series such that the kinetic energy of each rotor is converted as potential energy in a hydraulic fluid media and compounded as net potential energy. FIG. 2 shows an outline of the fluid conduits.

In an embodiment, the incoming low pressure fluid conduit **111**, enters the inlet port **110** *a* of the downwind rotor pump **104**. Its outlet **110** *b* at higher pressure is fed into the inlet port **110** *c* of the upwind rotor pump **103**. Thus, the pair of pump units is connected in series, so as to compound the potential energies of each pump unit, which is equivalent of compounding the power (kinetic energy) generated by two rotors and exits at the output port **110** *d.* The primary objective of these pumps is to convert the kinetic energies of said rotors, as the net potential energy. The net potential energy fluid line **113** is next connected to the fluid accumulator (reservoir) **107**, comprising certain volume of gas **108** at high pressure and a certain volume of liquid medium **109**. Said accumulator can serve as a load balancer in varying wind state. Furthermore, said accumulator along with said hydraulic motor and said alternator can be housed in a cabin 141, below the ground level in the case of a land based unit or below the water surface (cabin deck) in the case of an offshore installation using floating platforms.

In an embodiment, the contra rotor wind turbine tower top canopy assembly **122** containing said pump unit assembly, is rotatably mounted on a swivel bearing unit **123** fastened to an up-right tower **121**, while the digitally controlled hydraulic motor **106** and the electrical power generating unit **105** can be installed on the ground near the tower base. Thus, the cost of installation and maintenance can be significantly reduced. Furthermore, the rotors can now start easily since the light weight high speed alternator inertia load is not directly connected to the rotors, but indirectly through digitally controllable pump units **103**, **104**. For easy start, the inlet valve **110** *a* and the outlet valve **110** *d* of the hydraulic fluid lines can digitally be activated to achieve required torque to match the rotor generated aerodynamic torque at any wind speed, within the range of its operational limits.

In an embodiment, the net potential energy stored in the fluidic reservoir **107**, is next used by a high speed hydraulic motor **106** to drive the alternator **105**, which generates the dispatchable quality electric power **131**. To maintain voltage and frequency compatibility with the alternator output **131** and the grid line **132**, the pump unit inlet and outlet valves **116** and **117** can be digitally controlled to maintain the motor speed and torque, such that there would be no need for electronic power converter and transformer units. This method of compounding of the kinetic energies can be applied to a cluster of rotors in a wind farm, wherein multiple pairs of contra rotors are interconnected in series to compound the potential energies and store the net energy in a reservoir.

FIG. 3 illustrates a method of interconnecting multiple pairs of radial bladed contra rotors **200**, according to an embodiment. For sake of convenience, we assume three towers having subscripts a, b, and c. The low pressure fluid line **211** *a* enters the inlet of the downwind rotor side pump unit of tower top assembly **203** *a* and exits at the upwind rotor side pump of said tower as the compounded potential energy **213** *a*. Likewise, the net compounded potential fluid line exists as **213** *c* and enters the compressed air chamber **208** of the reservoir **207**. Thus, the total sum of all kinetic energies of the air mass swept by the plurality of said contra rotors is stored as the net potential energy of the fluid media contained in the reservoir **207**. The electrical power generating alternator **205** can be driven by two hydraulic motors **206** *a* and **206** *b,* which can be set to spin either in the same direction or in the contra rotor concept. Said hydraulic motors are fed by the same high potential fluid media **209** contained in the reservoir **207**. Once again, to maintain voltage and frequency compatibility between alternator output **231** and the grid line **232**, said motor inlet valves **216**, **217** and outlet valves **219**, **220** are digitally controlled

The art of integrating the contra rotor technology and the hydraulic power transmission device can equally be applied to either the vertical axis wind turbine, or the horizontal axis wind turbine. FIG. 4 outlines the concept for the case of a single tower and FIG. 5 for multiple towers, comprising plurality of light weight helical blades.

Case B: Axial Flow Helical Bladed Contra Rotor Wind Turbine:

According to an embodiment depicted in FIG. 4, the horizontal axis contra rotor wind turbine system **300** is provided, wherein the system comprising a pair of aerodynamic torque producing helical bladed rotors such as an outer rotor **301** and an inner rotor **302**, wherein each rotor having plurality of helical blades, uniformly spaced around the cylindrical surface of each rotor. FIG. 4*a* shows the aerofoil setting of a helical blade with respect to resultant wind speed vector VR, at an angle of incidence α. Generally at a design rotor speed, the blade leading edge is set normal to the resultant velocity vector VR forming a helix angle. However, at varying rotor speeds, the wind velocity normal to the leading edge is given by VN.

Furthermore, FIG. 4*b* illustrates the blade configuration, which is required to produce efficient torque load. For this reason, the airfoil is tilted at angle ψ with respect to the tangent velocity vector, $Vt=\omega\cdot R$, wherein ω is the angular velocity of the rotor and R is the radius of said rotor.

In an embodiment, said outer rotor is rotatably coupled to the outer rotor shaft **315** (FIG. 4) and its plurality of blades **301** are set to spin the rotor in a first direction. Whereas, said inner rotor is rotatably coupled to the inner rotor shaft **314** and its plurality of blades are set to spin the rotor in a second direction, opposite to the first direction. Furthermore, each rotor shaft is coupled to low speed digital displacement hydraulic pump units **303**, **304**, (FIG. 4*c*) such that the kinetic energy of each rotor is transformed compoundedly into the net potential energy.

In an embodiment, said outer rotor shaft **315** and said inner rotor shaft **314** are supported on an assembly (FIG. 4*c*) of coaxial bearing units **312** *a,* **312** *b,* which are in turn supported on two upright columns **322** *a* and **322** *b.* The entire helical bladed contra rotor assembly is mounted on the upright tower unit **321** by means of an assembly of yaw bearing **323**. Thus the rotor assembly can self align into the wind direction without the need of any yaw controlling device. The pump units are connected in series such that the kinetic energy of each rotor is converted as potential energy in a hydraulic fluid media and compounded as net potential energy. FIG. 4 and FIG. 4*c* show an outline of the fluid conduits.

The incoming low pressure fluid conduit **311** enters the inlet port **310** *a* of the inner rotor pump **303**. Its outlet **310** *b* at higher pressure is fed into the inlet port **310** *c* of the outer rotor pump **304**. Thus, the pair of pump units is connected in series, so as to compound the potential energies of each pump, which is equivalent of compounding the power (kinetic energy) generated by two rotors. The primary objective of these pumps is to convert the kinetic energies of the rotors or the air mass swept by the rotors, as the net potential energy. The net potential energy, exiting at the outlet port **310** *d* is conveyed via the fluid conduit **313** and is connected to the fluid potential energy accumulator **307**, comprising of certain volume of gas chamber **308** at high pressure and certain volume of liquid **309**.

FIG. 4 further describes the housing of the high potential energy filled fluid accumulator, the high speed hydraulic motor and an electrical alternator in a cabin **341** of a floating platform. The geometric design of said cabin will be such as to maintain stability of the floating platform at all wind conditions.

FIG. 5 illustrates a method of interconnecting multiple pairs of helical bladed contra rotors **400**. For sake of convenience, we assume three towers having subscripts a, b, and c. The low pressure fluid conduit **411** *a* enters the inlet port of the inner rotor pump unit **403** *a* and exits at the outer rotor pump unit of said tower as the compounded potential energy conduit **413** *a*. Likewise, the net compounded potential fluid conduit exists as **413** *c* and enters the compressed air chamber **408** of the reservoir **407**. Thus, the total sum of all kinetic energies of the air mass swept by the plurality of said rotors is stored as the net potential energy of the fluid media contained in the reservoir **407**. The electrical power generating alternator **405** is driven by two hydraulic motors **406** *a* and **406** *b*, which are set to spin either in the contra rotor concept or in parallel. Said motors are fed by the same high potential energy fluid media **409** contained in the reservoir **407**. Once again, to maintain voltage and frequency compatibility between alternator output **431** and the grid line **432**, said motor inlet **416**, **417** and outlet valves **419**, **420** are digitally controlled.

To compare the merits of above said two types of rotors, analytical calculations were conducted for each rotor. FIG. 6 presents the power performance and the geometrical characteristics of a conventional radial bladed rotor, while FIG. 7 presents that of a helical bladed axial flow rotor. The specifications of each rotor are as follows:

	Conventional Radial Bladed HAWT	Axial Flow Helical Bladed HAWT		
Rated Wind speed	10	m/s	10	m/s
Tip Speed Ratio	6		2.5	
Rotor Speed	5.7	rpm	2.5	rpm
Rated Power	10	MW	10	MW
Blade Length	98	m	20	m
Number Blades	3		79	
Blade Tip Chord	4.8	m	1	m
Each Blade Weight	55	tons	0.38	ton
Rotor Diameter	196	m	188	m

	Conventional Radial Bladed HAWT	Axial Flow Helical Bladed HAWT		
Hub Height	130	m	120	m
Blade Helix Angle			68	deg
Rotor Weight	165	tons	30	tons

Although both rotor configurations extract the same amount of power from the same swept wind stream flow, there are two major differences, namely, the blade geometry and the rotor speed. In the case of the conventional radial bladed configuration, each blade length is 98 meter long and each blade weighs well over 55 tons. This requires special crane support to transport, install and maintain the turbine. Whereas, the helical configured rotor comprises of plurality of smaller blades, which are less than 20 m in length and weigh less than 0.4 ton each. Smaller light weight blades can be transported and installed inexpensively. Another interesting feature of the axial flow rotor is its rotor speed, which is around 2.8 rpm versus 8 rpm for the radial bladed rotor, meaning lightly stressed dynamic environment. Furthermore, the noise level will be far less than that of a conventional radial bladed rotor, since the sound level varies as the fifth power of the rotor speed. Hence, the helical bladed axial flow rotor configuration becomes a better choice for the offshore wind farms.

Since the helical blades are set at constant radial position, the remaining stream flow domain can be used to place another concentric rotor, which can be set to spin either in the same direction (mounted on the same shaft **314**) as the outer rotor or in the opposite direction (mounted on a coaxial shaft **315**).

In the case of conventional radial bladed rotors, the vortices shed at the blade tip are kinetically energized due to the centrifugal force exerted on the fluid mass distributed along the blade length. For this reason, the tower spacing is used as 6 to 8 times the rotor diameter. Whereas, in the case of the axial flow helical bladed rotors, the shed vortex strength is much weaker for two reasons: (1) The helical bladed rotors, for the same power rating, need to spin at lower rotational speeds than that of the conventional radial bladed rotor, (2) The shed vortices are distributed along the length of the blade, hence they are weaker in strength. Hence, the tower spacing can be closer than that for the radial bladed rotors.

The Benefits of the Contra Rotor Turbine Technology Using a Hydraulic Power Transmission Device are:

The aerodynamic rotors need not drive the massively geared alternator unit, which may weigh in excess of 200 to 400 tons. Instead, the rotors can start turning plurality of digitally controlled pump units in low wind speeds converting the kinetic energy of each rotor into compounded potential energy and stored in a hydraulic fluid media, which can be used to drive a high speed hydraulic motor coupled to a conventional light weight alternator.

With the advent of the digital displacement hydraulic power transmission units, the contra rotor technology has solved the massive inertial problem and will lead to better performance.

The tower top weight can be reduced, since only the digital displacement pump units need be on the tower top, while the high speed hydraulic motor and the light weight alternator could be placed on the ground level for the convenience of installation and reduced maintenance cost.

There is no need for power conversion units and slip rings which carry high amps, since the motor speed can be controlled to run a conventional alternator with fixed wound armature unit.

The flow behind each CRWT unit is seen to be nearly vortex free. Hence, tower spacing could be closer, leading to the placement of more towers in a given site and more of annual energy production.

The noise problem associated with higher power rated wind turbines is now reduced, because of the contra rotation of two rotors, wherein the vortex energy imparted by the upwind rotor is utilized by the downwind rotor to generate mechanical power.

In a wind farm, whether land based or offshore based, plurality of contra rotor units can be compounded to store the net potential energy in a single fluid reservoir and operate a single alternator, so as to enhance efficiency and minimize cost of maintenance.

For the same power rating, the axial flow helical bladed rotor runs at almost one third the speed as that of the conventional radial bladed rotor and hence it is much quieter than the conventional radial bladed rotor.

In the case of the axial flow helical bladed rotors, the shed vortex strength is much weaker for two reasons:

(1) The helical bladed rotors, for the same power rating, need to spin at lower rotational speed versus that of the conventional radial bladed rotor;

(2) The shed vortices are distributed along the length of the blade, hence they are weaker in strength versus that for said conventional rotors.

Hence, the tower spacing can be closer than that for said radial bladed rotors.

The foregoing description of the specific embodiments will so fully reveal the general nature of the embodiments herein that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation. Therefore, while the embodiments herein have been described in terms of preferred embodiments, those skilled in the art will recognize that the embodiments herein can be practiced with modification within the spirit and scope of the embodiments as described herein.

Claims (11)

The invention claimed is:

1. An electrical power generating contra rotor wind turbine system comprising:

   a canopy of frame work rotatably mounted on a tower top;

   a pair of coaxial contra rotating rotors, having plurality of radially extended blades, and set to spin in opposite direction to each other;

   an electrical power generating alternator;

   a system of digitally controlled hydraulic pump assembly mounted inside of said tower top canopy and suitably coupled to said rotors so as to convert the kinetic energy of said rotors into fluidic potential energy in a compounded manner and stored in a fluid accumulator;

   an underground mounted hydraulic power transmission system of hydraulic motor assembly suitably coupled to drive said alternator to generate electrical power;

   said hydraulic power transmission device having the ability to be programmed to play the role of a speed controller as well as an emergency braking system; and

   said alternator being configured to be driven by either a single high speed hydraulic motor or plurality of pairs of hydraulic motors, either in the same direction or in contra rotation, such that the magnetic flux speed increases due to the contra rotation of the magnetic field and wound armature of said electrical generator, leading to substantially increased annual energy production.

2. The system of claim 1 further comprises a system of bearing assembly which ensures unidirectional motion of each rotor and also ensures load carrying bearing assembly for satisfactory performance of said rotors coupled to said alternator.

3. The system of claim 1 further comprises a system of hydraulic pump assembly placed on said tower top and converts the kinetic energy of the contra rotors in a compounded manner into the potential energy stored in a fluid accumulator.

4. The system of claim 3 further comprises a system of digitally controllable high speed hydraulic motor driven by the potential energy of said fluid media and coupled to an electrical power generating alternator assembly housed in an underground cabin near said tower base.

5. The system of claim 4, wherein the magnetic field unit is driven by one motor, while a wound armature unit is driven by another motor in opposite direction to each other, leading to increased electrical efficiency and reduced alternator weight and reduced cost per unit of power generated.

6. The system of claim 1 can be applied to plurality of contra rotors so as to achieve net compounded potential energy that can be stored in a fluid accumulator and used to run a single alternator, resulting in reduced cost of energy and reduced maintenance.

7. The system of claim 1, wherein said contra rotor concept, minimizes the vortex strength in the downwind flow resulting in reduced noise and turbulence, permitting closer spacing of towers leading to enhancement of annual energy in a given wind farm site.

8. The system of claim 7, wherein said, vortex strength in the case of axial flow helical bladed rotor is weak, since the vortex shedding is distributed along the blade length, unlike in the case of conventional radial bladed rotor, wherein the concentrated vortex spills at the blade tip.

9. The system of claim 1, the aerodynamic rotors could start turning plurality of pump units in low wind speeds converting the kinetic energy of each rotor into potential energy in the compounded manner and stored in a hydraulic fluid accumulator, which can be used to drive a high speed hydraulic motor coupled to a conventional light weight alternator to generate grid quality electrical power, requiring no other power conversion unit.

10. The system of claim 1, the tower top weight can be reduced, since only the digital displacement pump units need be installed on the tower top, while the high speed hydraulic motor and the light weight alternator could be placed on the ground level for the convenience of installation and reduced maintenance cost.

11. The system of claim 1, requires no power conversion device, since the motor speed can be controlled to drive a conventional alternator with fixed armature unit to meet the grid quality power output.

Patent Citations (11)

Publication number	Priority date	Publication date	Assignee	Title
US6127739A *	1999-03-22	2000-10-03	Appa; Kari	Jet assisted counter rotating wind turbine
US6278197B1 *	2000-02-05	2001-08-21	Kari Appa	Contra-rotating wind turbine system
US6492743B1 *	2001-06-28	2002-12-10	Kari Appa	Jet assisted hybrid wind turbine system
US20040096327A1 *	2002-11-14	2004-05-20	Kari Appa	Method of increasing wind farm energy production
US7679249B2	2007-03-02	2010-03-16	Kari Appa	Contra rotating generator
US7789624B2	2006-03-03	2010-09-07	Kari Appa	Methods and devices for improving efficiency of wind turbines in low speed sites
US20130277971A1 *	2012-04-23	2013-10-24	Hanwoo Cho	Horizontal axis wind turbine systems and methods
US8875511B2 *	2012-03-30	2014-11-04	Larry C. Simpson	Geothermal wind system
US8938967B2 *	2007-01-30	2015-01-27	Thomas McMaster	Hybrid wind turbine
US20150159628A1 *	2013-12-09	2015-06-11	Kari Appa	Offshore contra rotor wind turbine system
US20160076519A1 *	2012-04-29	2016-03-17	LGT Advanced Technology Limited	Wind energy system and method for using same

Family To Family Citations

* Cited by examiner, † Cited by third party

Non-Patent Citations (5)

Title
Analysis of Counter-Rotating Wind Turbines, The Science of Making Torque from Wind IOP Publishing , Journal of Physics: Conference Series 75 (2007) 012003 doi:10.1088/1742-.
Appa Kari , 2002 Energy Innovations Small Grant (EISG) Program (Counter rotating wind turbine system) Technical Report, California, US. 00-09 FAR Appendix A.
ChapDrive, Hydraulic Transmission for Wind Turbine , VP Asmund Furuseth, Production Technique Conference 2012, Mar. 7, 2012.
Hydrostatic Transmission for Wind Power, Brad Bohlmann Sustainability Director CCEFP Adjunct Professor, Mechanical Engineering, University of Minnesota.
Rahul Dutta, Modeling and Analysis of Short Term Energy Storage for Mid-Size Hydrostatic Wind Turbine, a Graduate School Thesis, University of Minnesota, Aug. 2012.

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Similar Documents

Publication	Publication Date	Title
US6857846B2	2005-02-22	Stackable vertical axis windmill
US7098552B2	2006-08-29	Wind energy conversion system
US6015258A	2000-01-18	Wind turbine
US7329965B2	2008-02-12	Aerodynamic-hybrid vertical-axis wind turbine
US7488155B2	2009-02-10	Method and apparatus for wind turbine braking
US7008171B1	2006-03-07	Modified Savonius rotor
US20100140950A1	2010-06-10	Decorative wind turbine having flame-like appearance
US5599168A	1997-02-04	Wind turbine adaptable to wind direction and velocity
US20040247438A1	2004-12-09	Wind energy conversion system
US7345376B2	2008-03-18	Passively cooled direct drive wind turbine
US4710100A	1987-12-01	Wind machine
US20080159873A1	2008-07-03	Cross fluid-flow axis turbine
US7183665B2	2007-02-27	Direct drive wind turbine

Publication	Publication Date	Title
US20090148285A1	2009-06-11	Multi-section wind turbine rotor blades and wind turbines incorporating same
US20070132247A1	2007-06-14	Electric power generation system
US20080217925A1	2008-09-11	Vertical axis wind turbine with angled braces
US7802968B2	2010-09-28	Methods and apparatus for reducing load in a rotor blade
US7040859B2	2006-05-09	Wind turbine
GB2347976A	2000-09-20	Variable pitch water turbine.
US8492918B1	2013-07-23	Hybrid water pressure energy accumulating tower(s) connected to a wind turbine or power plants
US8030790B2	2011-10-04	Hybrid water pressure energy accumulating wind turbine and method
US20080145224A1	2008-06-19	Vertical axis wind turbine system
Kamoji et al.	2008	Experimental investigations on single stage, two stage and three stage conventional Savonius rotor
US20090110554A1	2009-04-30	Wind Turbine for Generating Electricity
US20100111697A1	2010-05-06	Wind energy generation device

Priority And Related Applications

Priority Applications (2)

Application	Priority date	Filing date	Title
US201461997734	2014-06-09	2014-06-09	*US Provisional Application*
US14565450	2014-06-09	2014-12-10	Contra rotor wind turbine system using a hydraulic power transmission device

Applications Claiming Priority (1)

Application	Filing date	Title
US14565450	2014-12-10	Contra rotor wind turbine system using a hydraulic power transmission device

Legal Events

Date	Code	Title	Description
2014-12-10	AS	Assignment	**Owner name**: APPA, RUPA, MS., CALIFORNIA **Free format text**: ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNORS:APPA, SURI, MR.;APPA, RUPA, MS.;REEL/FRAME:034445/0979 **Effective date**: 20141208 **Owner name**: APPA, SURI, MR., CALIFORNIA **Free format text**: ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNORS:APPA, SURI, MR.;APPA, RUPA, MS.;REEL/FRAME:034445/0979 **Effective date**: 20141208

Axial Flow Helical Bladed Rotor

Appa Technology Initiatives / Wind Turbine Systems

Dr. Kari Appa
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Phone: 949-396-4799, email ID: ka@wtswind.com,

Section I: Technical Merit & Lab Alignment:

1. Company Summary: ATI is a California based small business entity, primarily engaged in the development of high performance wind turbines. In FY 2001, ATI was funded by the California Energy Commission, to build and demonstrate a Contra Rotor Wind Turbine (CRWT) technology model. The field test study showed that the CRWT concept is able to extract in excess of 30 per cent more energy from the same wind stream.

In this study, the rotors were directly coupled to the two components of the alternator. This concept could not be demonstrated on a utility scale model, due to extreme mass inertia of the alternator.

Today, due to the advent of the Hydraulic Power Transmission (HPT) device, it is possible to integrate the CRWT and HPT to function more economically and yield better energy in the case of offshore environment.

2. Problem Statement:
The geometric size and mass inertia of the conventional radial bladed rotors increase as the cube of the blade length. When the power rating of the rotor exceeds 8 MW, it becomes more expensive to transport, install and maintain in the offshore environment.

The proposed axial flow rotor system is based on our recent **US Patent 9,537,371 B2**:. The basic rotor design as shown in **Fig. 1a**, comprises of an inner rotor **62** and an outer rotor **62**, set to spin in opposite direction to each other.

Each rotor comprise of a number of small and light weighted helically contoured blades **70**. **Fig.1b** shows a typical 3-D view of the helical bladed contra rotors. Since the rotor is axis symmetric, the following design considerations are used to generate uniform torque:

2a. Tilted Aerofoil Sections:
The composite helical blades comprise of using tilted aerofoil sections. The corresponding tilted lift component is in the direction of the blade motion. The lift vector, L (which is parallel to the airfoil section) has a tangential component leading to torque generation (**Fig. 1c**).

2b. Tilted Flow Dividers/Deflectors:
A number of tilted airfoil shaped flow dividers **80 (Fig. 1a)** are used to deflect the flow stream, such that it is parallel to the airfoil section and generates tilted Lift ($\mathbf{C_L}$ **Fig. 1c**) on the blade, which in turn leads to torque. Furthermore, the airfoil shaped flow dividers produce starting torque. Once the rotor starts spinning, a helically contoured flow field $\mathbf{V_R}$ will be developed around the rotor. The primary objective of this construction is to generate uniform torque load by means of the axial flow rotors. **Fig. 1c** outlines the method of generating torque by the axial flow rotor.

2c. Torque Generating Supporting Rings.
The blade supporting rings 30 and 32 are also designed to generate torque. Thus every component of the axial flow rotor are optimized to convert aerodynamic energy into electrical energy.

A typical comparison of wind rotors (conventional versus the new) in terms of geometric size and mass are presented in Table 1 for a 10 MW unit and in Table 2 for a 50 MW unit. The suggested rotor is much lighter, since its lifting surface is located in high velocity flow domain.

3. Suggested Wind Turbine Design Approach:

An economical axial flow rotor design concept is presented in **FIG. 2**. The new contra rotor unit will be coupled to a hydraulic power transmission device to convert the kinetic energy of the rotor(s) into the potential energy stored in a hydraulic accumulator. The hydraulic accumulator together with associated hydraulic motor and the alternator units can be placed on the ground level for easy maintenance. The wind turbine rotors and the digitally controlled hydraulic pump units need be placed on the tower top.

4. Performance Verification Using a CFD simulation Software

Many Government Laboratories and Universities have developed highly reliable CFD simulation tools. This software will be used to model the suggested axial flow rotors (power rated at 10 MW or higher) including the hydraulic power transmission device, as outlined in **Fig 2**. To achieve optimal performance, the blade configuration and deflector sizing can be performed. After successful demonstration of the axial flow rotors, we may plan for a field demonstration model.

5. National Laboratory Alignment:
This suggested new rotor model design and performance can be simulated using a state-of-the-art Computational Fluid Dynamics (CFD) software, which is available with Government and Technical Universities. The study model could represent any 5 MW to 50 MW units, so as to compare the physical dimensions of the components, mass inertia and probable cost comparison versus the conventional radial bladed rotors.

ATI will work with a selected lab to define the model configuration and the flow parameters, so as to achieve power generation and the downwind flow characteristics as the vortex strength.

6. Environmental Energy & Energy Impact: If the new design performs as expected, the benefits are:

a. Cost savings – This is the major advantage – 50 to 60% cost reduction in the rotor assembly, due to light weight of components,
b. Increased Performance: This is another important factor associated with the blade configuration selected to operate,
f. More efficient energy generation,

7. Work Scope: Using ATI generated model configuration, and ATI defined flow configuration, the National Lab will generate the CFD model and perform the flow analysis to predict loads on blades and other components, so as to evaluate the torque loads and other important side loads on the rotor assembly.

8. Expected Outcomes from the Technical Assistance: The outcome of this CFD simulation, clearly demonstrates, how the vortex flow contributes to the generation of mechanical energy generation on a contra rotor, disproving the generally understood dynamic impact on a down wind component.

Moreover, the new rotor design will impact the present environment and may be replaced with the new rotor, due to its improved performance and cost reduction.

Appendix A

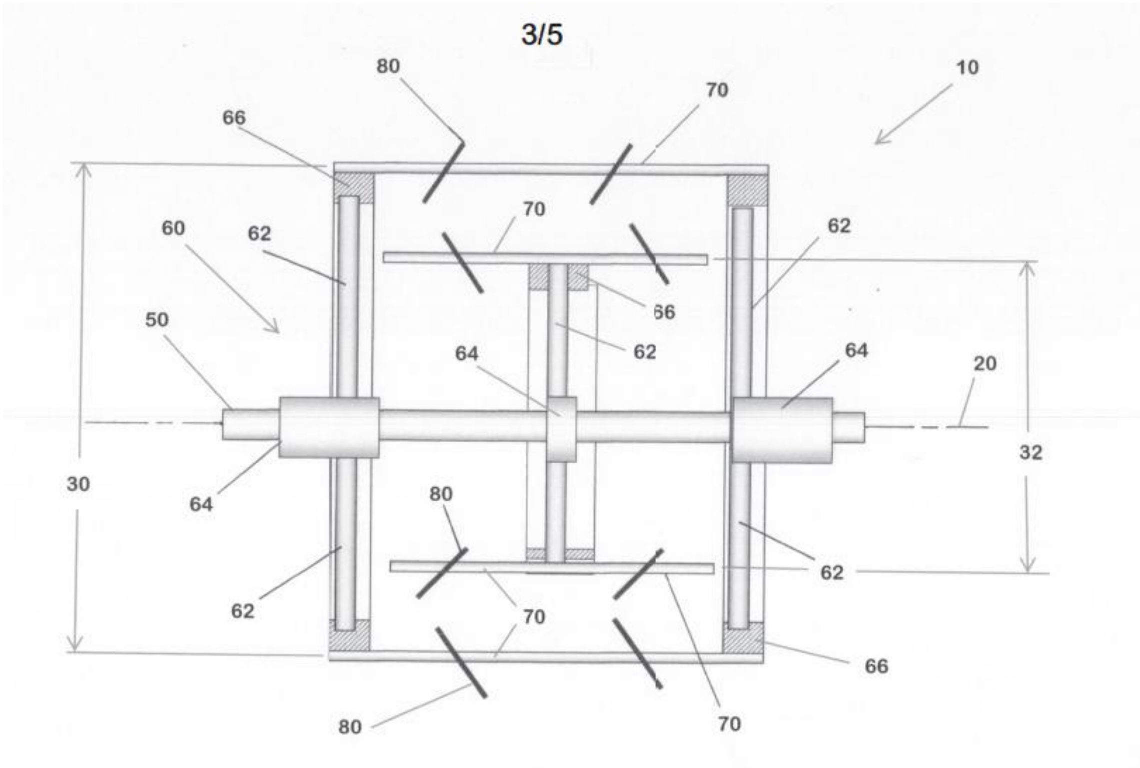

FIG. 1a Suggested Axial Flow Helical Bladed Rotor As Shown in FIG 1b

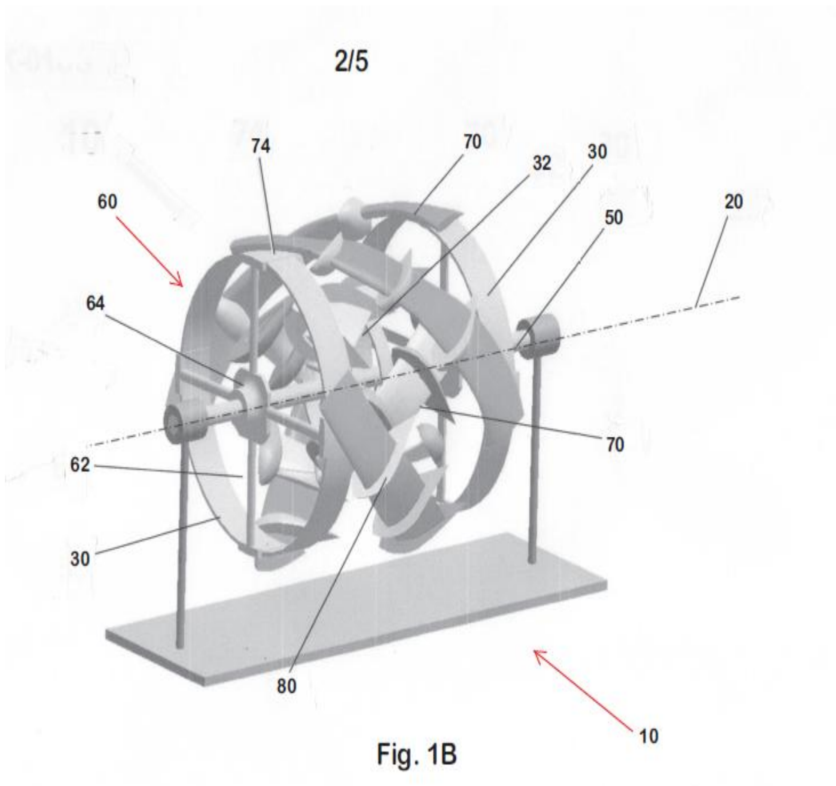

Fig. 1B

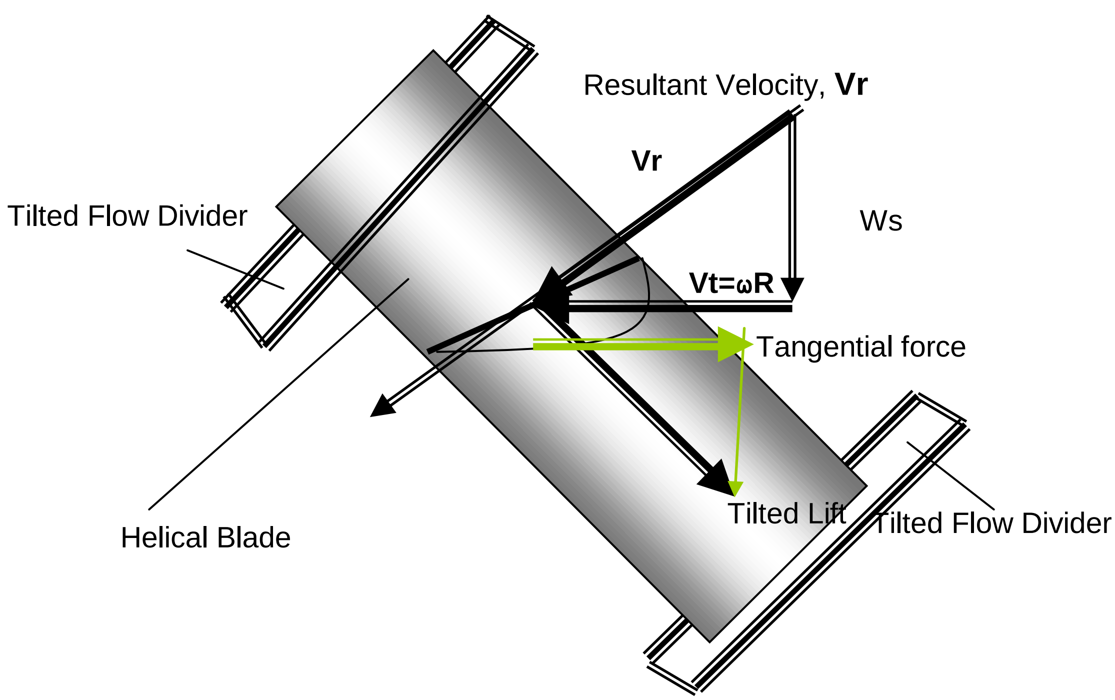

FIG. 1c Helical Blade with Tilted Airfoil and Tilted Flow Dividers

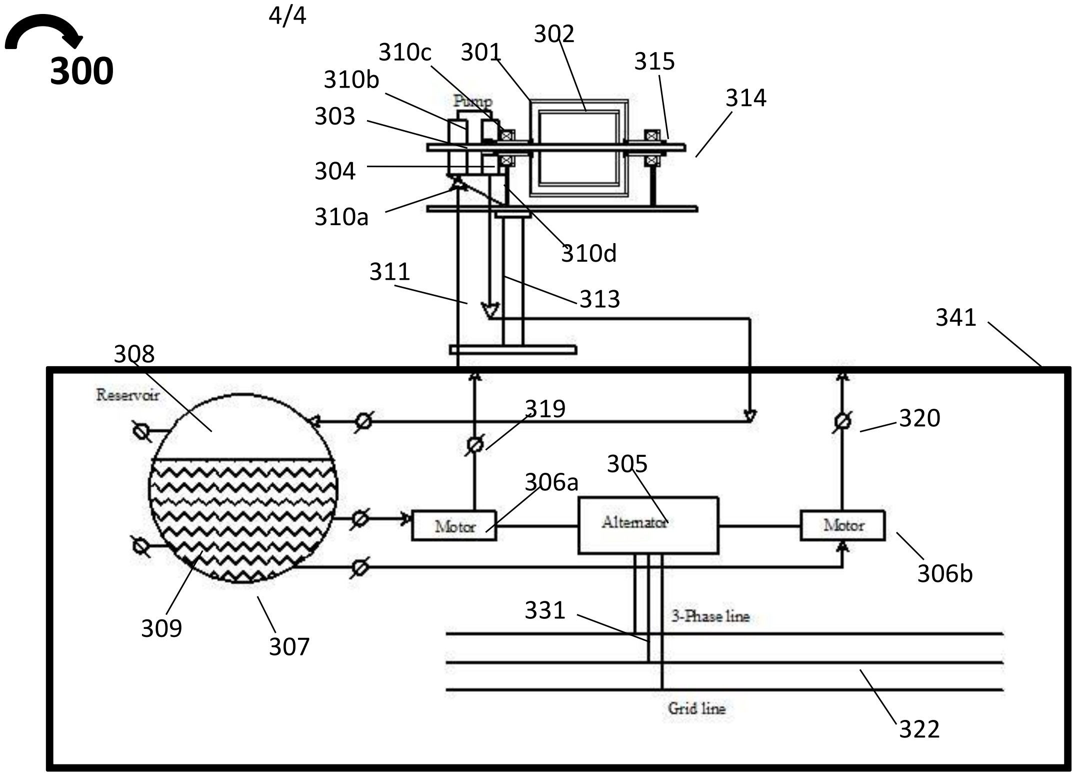

Fig 2

FIG 2. Proposed Axial Flow Helical Bladed Contra Rotor System Using Hydraulic Power Transmission Device

Table 1. 10 MW WIND TURBINE ROTORS

	Conventional Radial Bladed HAWT	**Suggested Rotor**
Rated Wind speed	10 m/s	10 m/s
Tip Speed Ratio	6	6.0
Rotor Speed	5.7 rpm	5.8 rpm
Rated Power	10 MW	10 MW
Blade Length	**98 m**	**15 m**
Number of Blades	3	252
Blade Tip Chord	**4.8 m**	**0.134m**
Each Blade Weight	**55 tons**	**0.05 ton**
Rotor Diameter	196 m	200 m
Hub Height	130 m	120 m
Blade Helix Angle		80 deg
Total Rotor Weight	**165 tons**	**12 tons**

Table 2. 50 MW WIND TURBINE ROTOR

	Conventional Radial Bladed HAWT	Suggested Rotor
Rated Wind speed	10 m/s	10 m/s
Tip Speed Ratio	6	6.0
Rotor Speed	2.6 rpm	2.6 rpm
Rated Power	50 MW	50 MW
Blade Length	**220 m**	**33 m**
Number of Blades	3	252
Blade Tip Chord	**10.5 m**	**0.29 m**
Each Blade Weight	**421 tons**	**0.25 ton**
Rotor Diameter	441 m	440 m
Hub Height	300 m	300 m
Blade Helix Angle		80 deg
Total Rotor Weight	**1263 tons**	**61.0 tons**

Appendix B

KEY PERSONNEL RESUME

Dr. Kari Appa:

Responsibility: Principal Investigator

He takes the responsibility to conduct, direct and manage technical activities of the project. He will also manage the financial aspects of the project. He will coordinate with the National Laboratory Program Administrator.

Education: M.S., Aerospace Eng. 1959, Indian Institute of Science, Bangalore, India;

Ph. D, Aerospace Eng., 1966, University of Stuttgart, Germany

1968-1977: Bell Aerospace, Niagara Falls, NY, Senior Design Engineer

1977-1979 Pratt & Whitney, West Palm beach, FL.

1979-1998: Northrop Grumman Corporation, California. As principal engineer, was responsible for research and methods development in structural dynamics, flight loads, aeroservoelasticity, multidisciplinary optimization, and smart structures innovations, steady and unsteady aerodynamics.

1998-Present: Started a small business entity, focusing on aircraft and wind energy R&D activities. Built and demonstrated several contra rotating wind turbine model. One 6 kW system was built and demonstrated under California Energy Commission funding (EISG Grant No. 51809A/00-09, FY2001-2002). Test result showed that nearly 30 percent of additional power could be extracted from leeward rotors of a Contra Rotor System. Further, it was learnt that slower the rotor speed, more efficient a contra rotor system could be. Dr. Appa is currently developing more efficient wind turbine rotors, specially meant for offshore wind farms.

He is the author of seven US patents:

- Continuously deformable smart trailing edge and leading edge aerodynamic effectors. US Patent No. 5,887,828, March 30, 1999.
- Extendible leading edges to alleviate roll reversal speeds and to enhance flight maneuver capabilities of tactical aircraft. Us patent no. 5, 921, 506, July 13, 1999.
- Monolithic composite wing design and fabrication methodology, US patent no. 6,190,484 b1, February 20, 2001.
- Active control surface modal system for aircraft buffet and gust load alleviation and flutter suppression, US patent. No. 6,375,127, April 23, 2002.

US Patents on Wind Turbine Issued to Dr. Kari Appa:

1. Jet assisted counter rotating wind turbine- US Patent 6,127,739- October 3, 2000,
2. Contra-Rotating Wind Turbine System, US Patent No. 6,278,197 B1, August 21, 2001
3. US PTO , 6,375,127, April 23, 2002,
4. Jet Assisted Hybrid Wind Turbine System US Patent No. 6492743 , 12/10/2002
5. Contra Rotating Generator US Patent No. 7679249, 03/16/2010
6. US PTO, 7,789,624, September 7, 2010.: Methods and devices for improving efficiency of wind turbines in low speed sites

He is the author of well over 40 publications, a few are:

1. Appa, K., "Recent Advances in Maneuver Loads Analysis," Computer Methods in Applied Mechanics and Engineering, Vol.90, No.1- 3, 1991. North-Holland.
2. Appa, K. ' Maneuver Loads Analysis for Military Aircraft.' Section 6, Chapter 5, in Flight-Vehicle Materials, Structures, and Dynamics-Assessment and Future Directions Vol. 1, Editors; A. K. Noor and S. L. Venneri, Published by The American Society of Mechanical Engineers New York, N.Y. 10017, 1994.
3. Appa, K., Khot, N. S., and Ausman, J. Feasibility Assessment and Optimization Study of Smart Actuation Systems for Enhanced Aircraft Maneuver Performance, Air Force Report, WL-TR-97-3083, July 1997, Flight Dynamics Directorate, Wright Laboratory, Air Force Materiel Command, Wright-Paterson Air Force Base, OH 45433-7562.
4. Appa, K., Ausman, J., and Khot, N. S., "Smart Actuation Systems For Enhanced Aircraft Maneuver Performance," Flight Dynamics Directorate, AFRL-VA-WP-TR-1999-3047, October 1998.
5. Appa, K., Ausman, J., Khot, N. S., and Brenner, M. J., "Aircraft Dynamic Load Alleviation Using A Smart Actuation System," Air Vehicles Directorate, AFRL-VA-WP-TR-2000-3033, March 2000.
6. Appa, K., Counter Rotating Wind Turbine System, Appendix A to FAR 51809A/00-09, Energy Innovations Small Grant, (EISG) Program, EISG Final Report, April, 2002