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(54) METHOD FOR SITE SPECIFIC ENERGY CAPTURE OPTIMIZATION THROUGH MODULAR ROTOR BLADE TIP EXTENSION

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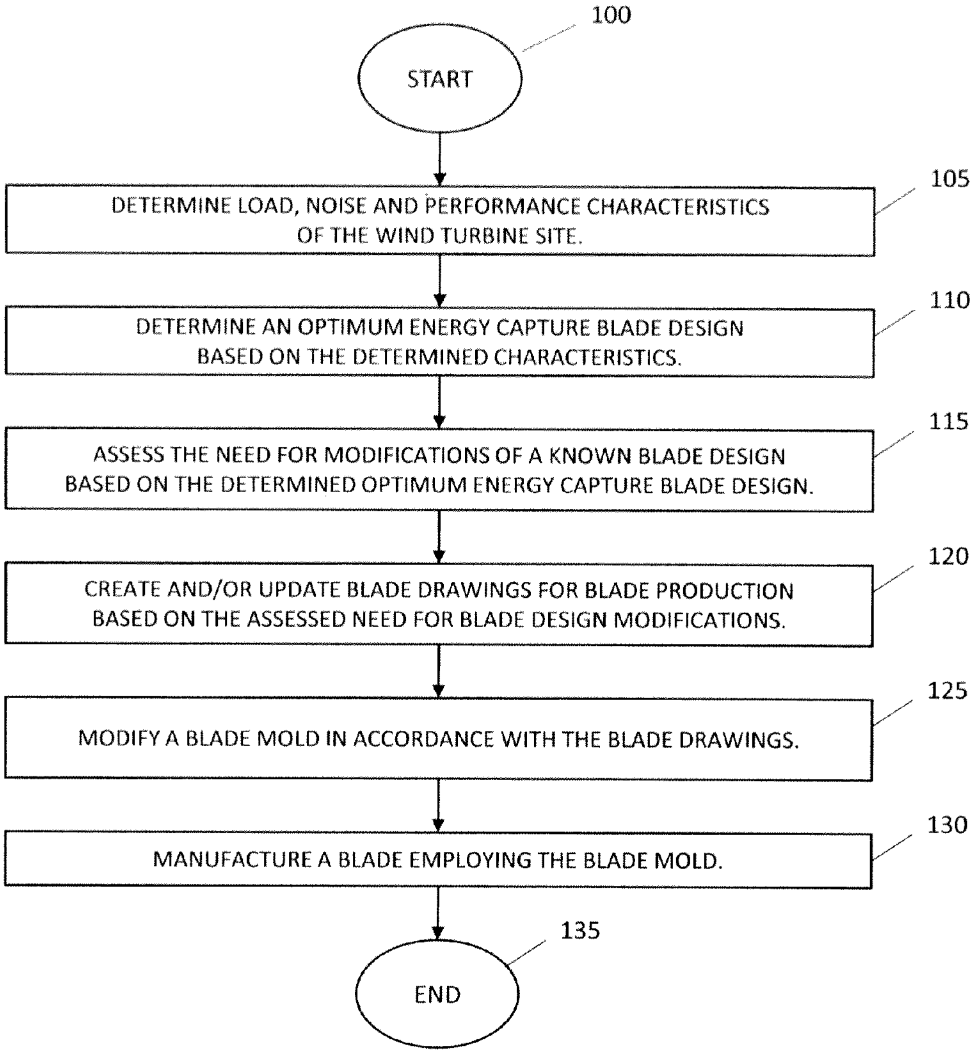
(57) ABSTRACT

A power generating system wherein a turbine (**34**) is mounted on top of a tower (**30**) or tethered underwater. The turbine (**34**) includes a rotor having a main blade (**20**) connected to a rotor hub (**40**) and an extender blade tip (**22**, **22'**) attached to the main blade (**20**). During manufacture, the optimum energy-capture is determined using site-specific conditions of one or more of air density, wind speed, extreme wind, wind shear, noise and turbulence intensity. The extender blade tip (**22**, **22'**) is chosen from a number of extender blade tips having a length that is the closest to the determined optimum energy-capture. The chosen extender blade tip is attached to the main blade either during manufacture or on-site. Alternatively, a one piece blade is produced based on information determined from the site specific conditions. The tip of such one piece blade can be customized based on the information obtained.



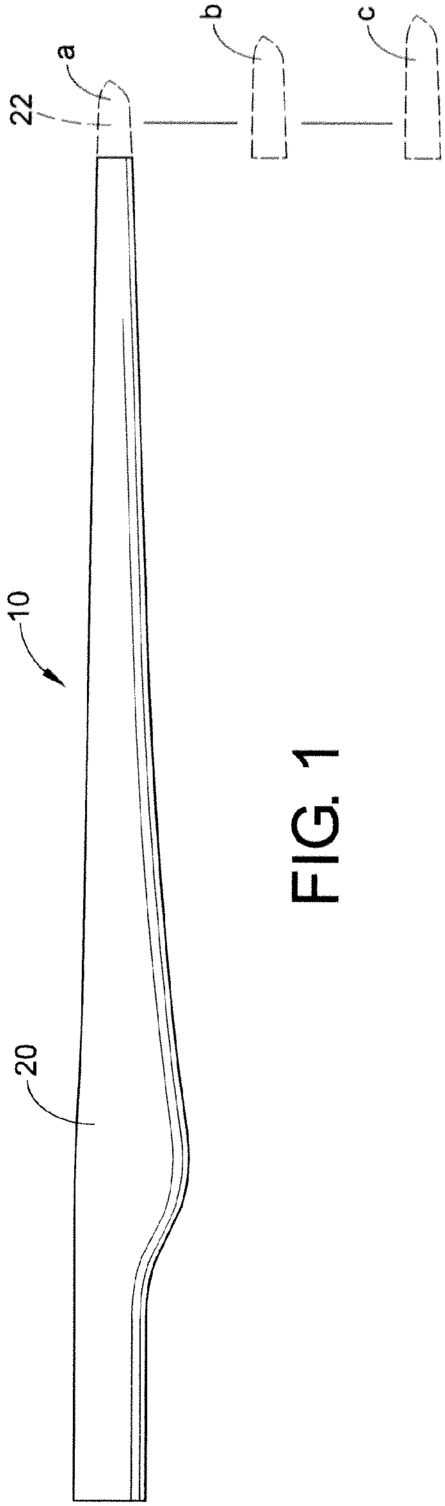


FIG. 1

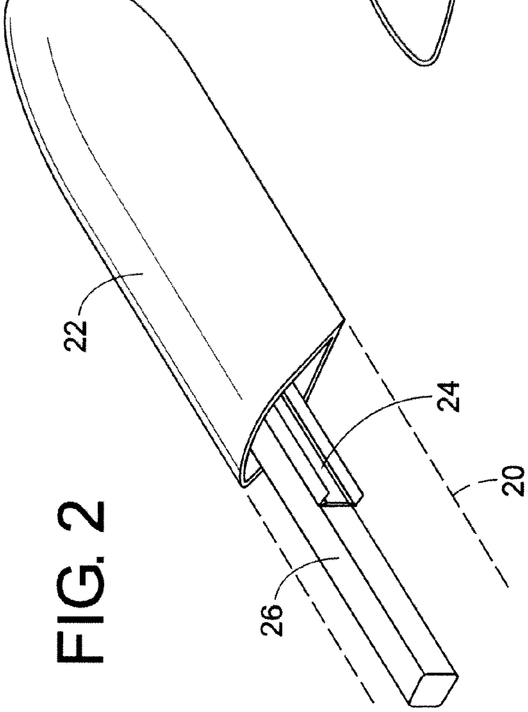


FIG. 2

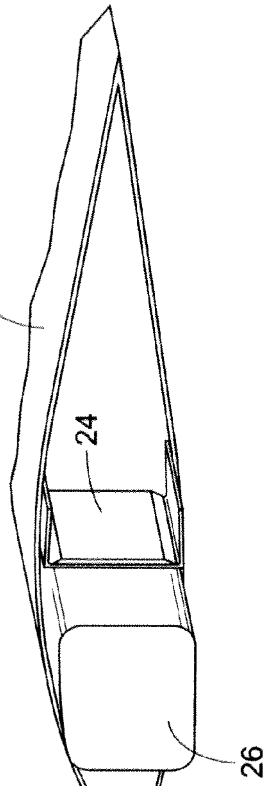


FIG. 3

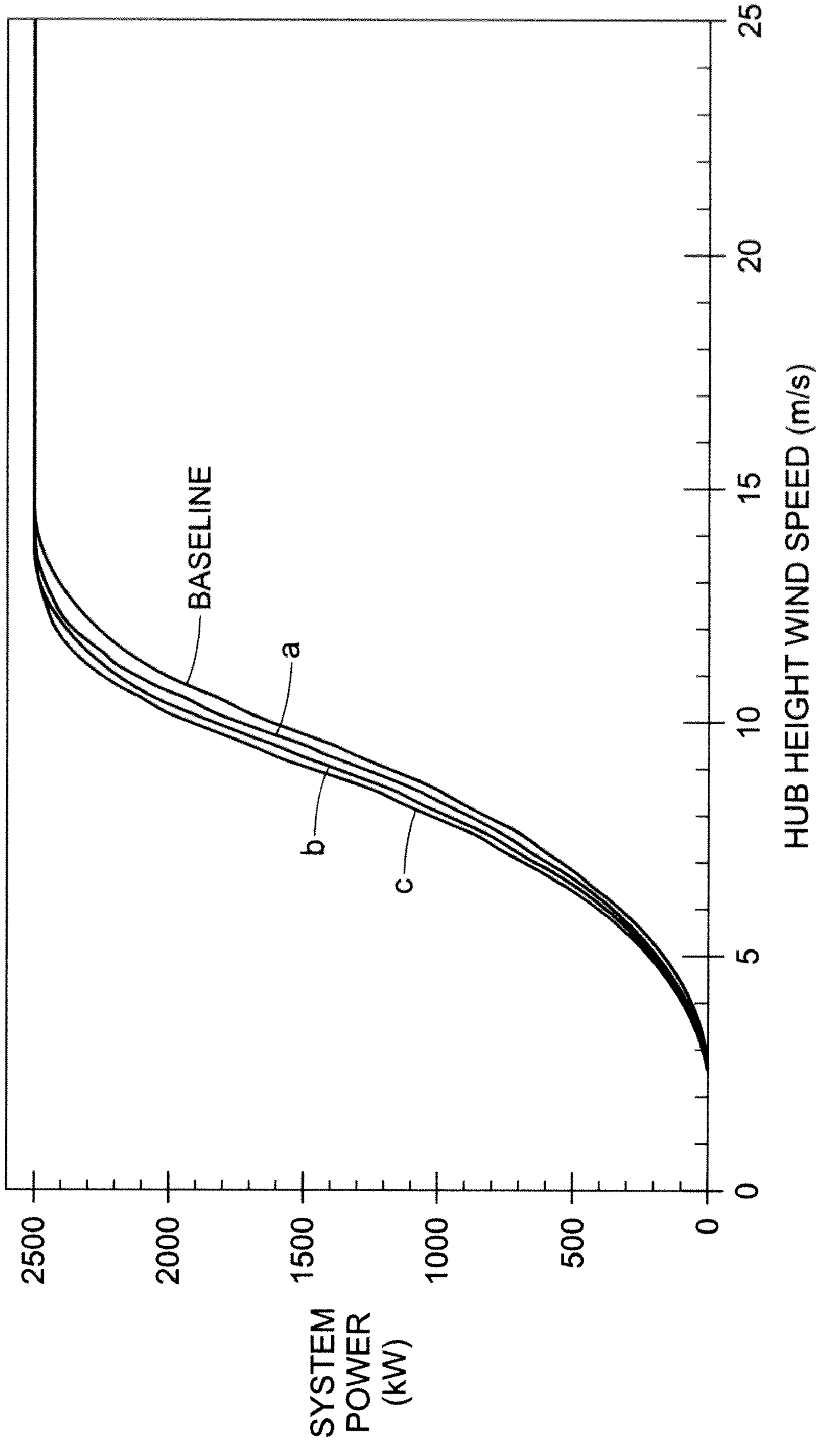

SYSTEM POWER (kW)
2500
2000
1500
1000
500
0
0
5
10
15
20
25
HUB HEIGHT WIND SPEED (m/s)
BASELINE
a
b
c

FIG. 4

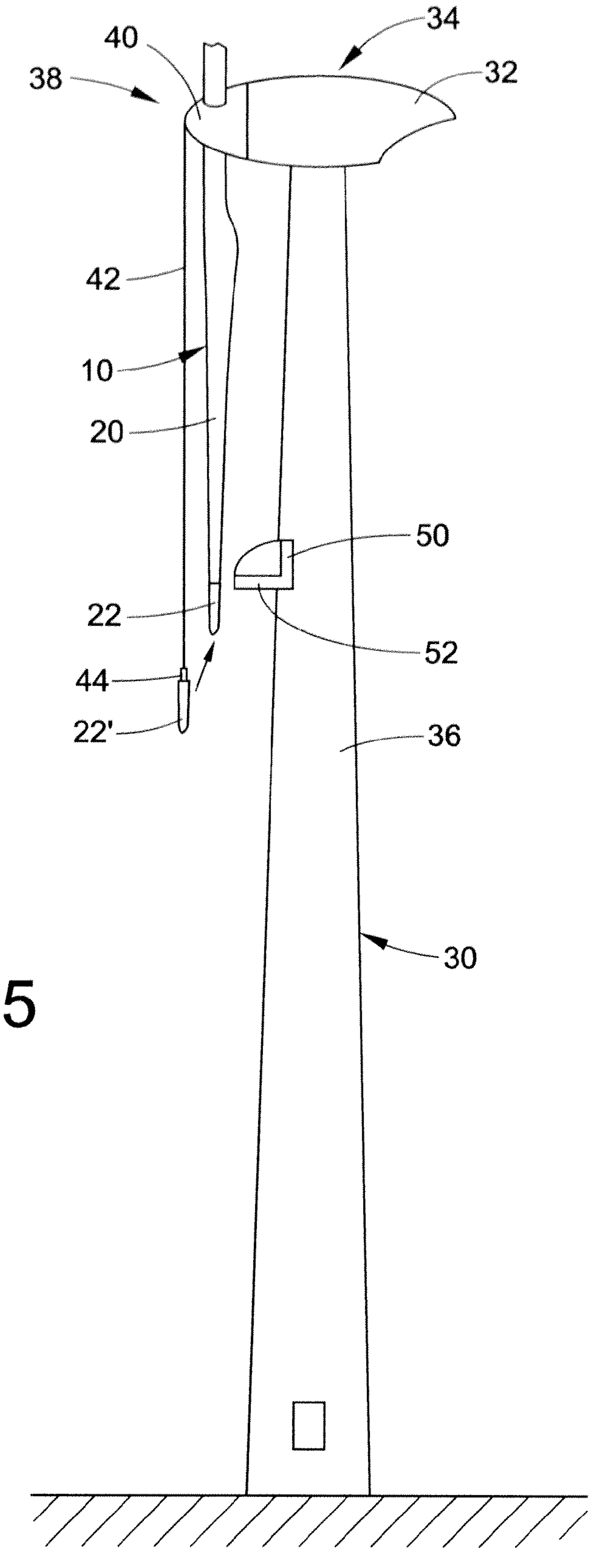


FIG. 5

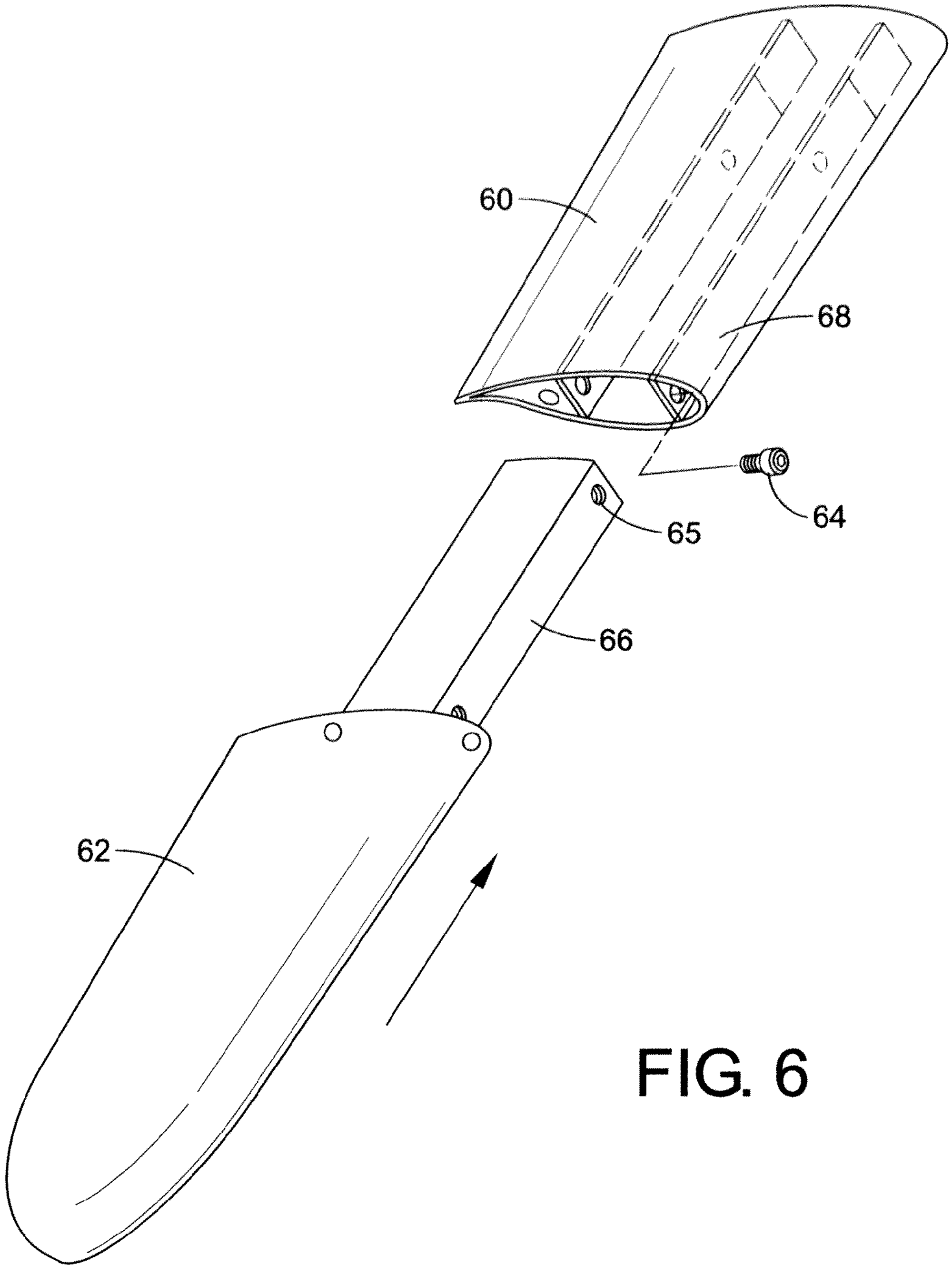


FIG. 6

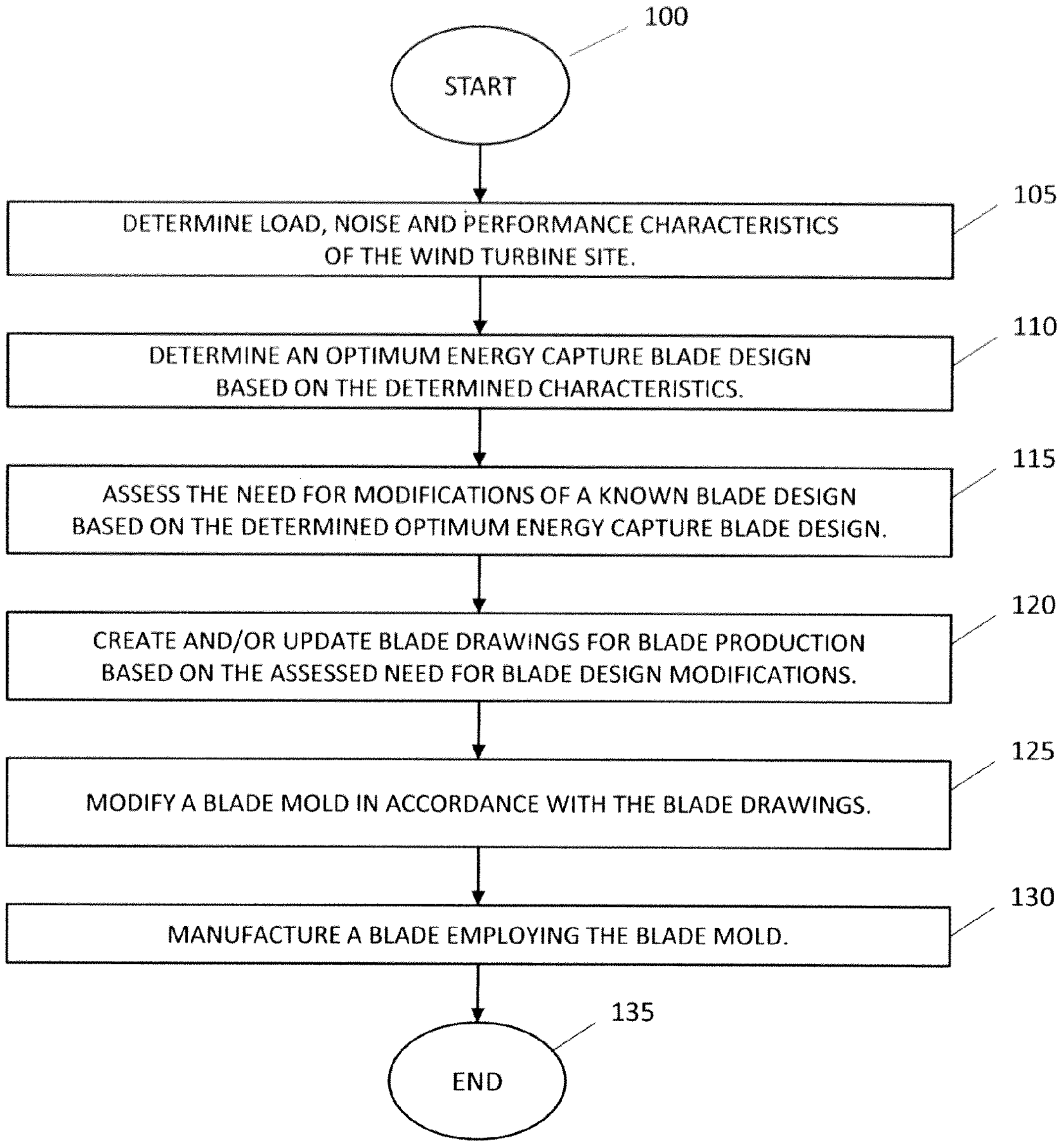

100
START
105
DETERMINE LOAD, NOISE AND PERFORMANCE CHARACTERISTICS OF THE WIND TURBINE SITE.
110
DETERMINE AN OPTIMUM ENERGY CAPTURE BLADE DESIGN BASED ON THE DETERMINED CHARACTERISTICS.
115
ASSESS THE NEED FOR MODIFICATIONS OF A KNOWN BLADE DESIGN BASED ON THE DETERMINED OPTIMUM ENERGY CAPTURE BLADE DESIGN.
120
CREATE AND/OR UPDATE BLADE DRAWINGS FOR BLADE PRODUCTION BASED ON THE ASSESSED NEED FOR BLADE DESIGN MODIFICATIONS.
125
MODIFY A BLADE MOLD IN ACCORDANCE WITH THE BLADE DRAWINGS.
130
MANUFACTURE A BLADE EMPLOYING THE BLADE MOLD.
135
END

FIG. 7

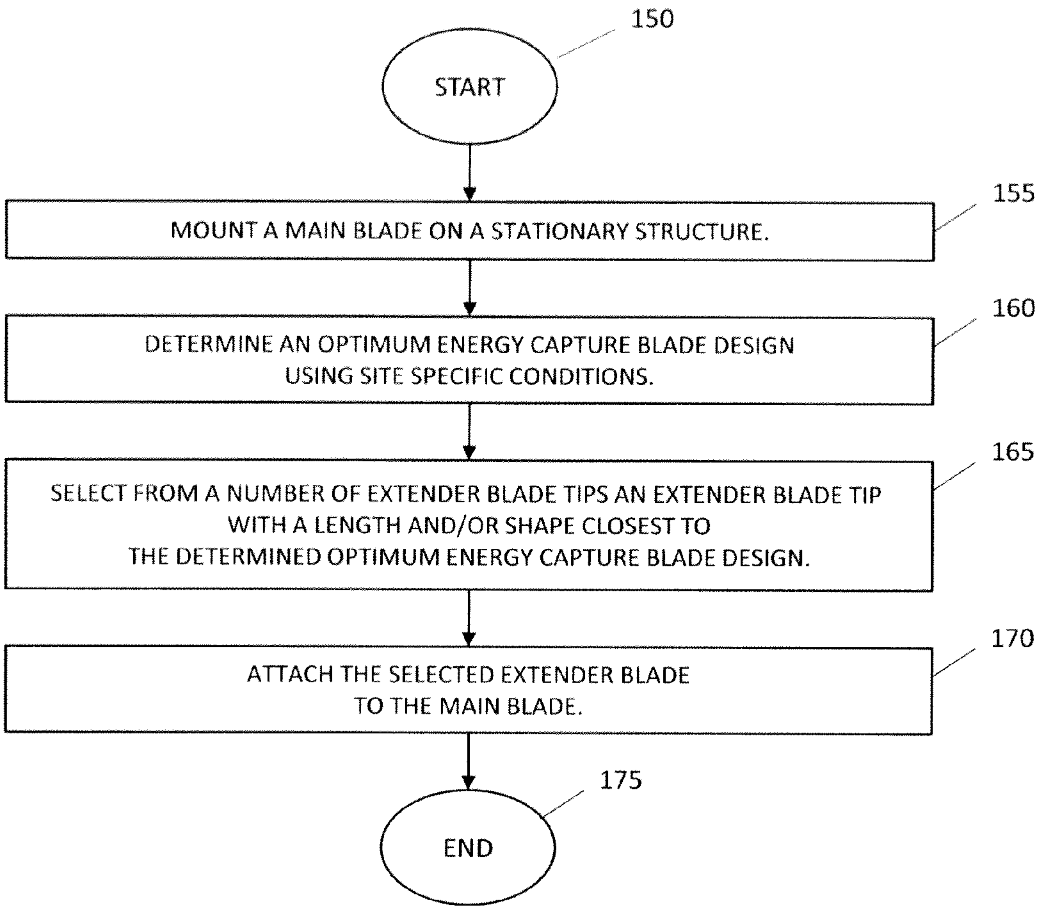

150
START
155
MOUNT A MAIN BLADE ON A STATIONARY STRUCTURE.
160
DETERMINE AN OPTIMUM ENERGY CAPTURE BLADE DESIGN USING SITE SPECIFIC CONDITIONS.
165
SELECT FROM A NUMBER OF EXTENDER BLADE TIPS AN EXTENDER BLADE TIP WITH A LENGTH AND/OR SHAPE CLOSEST TO THE DETERMINED OPTIMUM ENERGY CAPTURE BLADE DESIGN.
170
ATTACH THE SELECTED EXTENDER BLADE TO THE MAIN BLADE.
175
END

FIG. 8

METHOD FOR SITE SPECIFIC ENERGY CAPTURE OPTIMIZATION THROUGH MODULAR ROTOR BLADE TIP EXTENSION

BACKGROUND

[0001] This disclosure relates to electric power-generating devices, such as wind turbines and ocean current turbines, and more particularly to a structural support for a wind turbine blade which has a detachable outer aerodynamic blade tip, which can be replaced with a longer blade tip that increases the rotor diameter and captures more wind energy or a shorter blade tip to reduce wind energy exposure.

[0002] Modern wind turbines are typically designed to a standard wind classification defining an average wind speed, turbulence intensity, extreme wind, and average air density. Current wind turbine design practice uses the wind classification to define extreme loads and fatigue loads that drive the design of the mechanical structure. However, wind turbines are typically deployed to sites or locations within an array of wind turbines at a particular site, which have lower average wind speeds, air density or turbulence intensities than that defined by the standard wind classification used for the design. This results in excess design margin in the machine design that can be leveraged by incrementally increasing the rotor diameter to the point at which the operational loads experienced by the machine will more fully utilize its structural capacity.

[0003] What is needed is a method to optimize the energy capture of an array of wind turbines at a given site, given the site-specific conditions each one will experience.

[0004] What is further needed is a method for wind or ocean current turbines which will facilitate an increase or a decrease of rotor blade lengths specific to the site at which the blades are deployed.

[0005] What is also needed is a rotor blade structure for wind or ocean current turbines, which is modular and detachable for easy access for servicing and maintenance, and which is lightweight, easily maintainable, and durable.

SUMMARY OF THE DISCLOSURE

[0006] According to one embodiment of the present disclosure, a fluid flow power generating method is provided. More particularly, the method comprises mounting a turbine on a structure which is held stationary with reference to a fluid flow. The turbine includes a rotor having a main blade connected to a rotor hub at a proximal end and including a distal end with provisions for attaching a modular extender blade tip to the main blade. An optimum energy capture is determined using site specific conditions including one or more of air density, wind speed, extreme wind, wind shear, noise and turbulence intensity. An extender blade tip is chosen from a number of extender blade tips. The chosen blade tip has a length which is the closest to the optimum energy capture determined in the previous step. The chosen extender blade tip is then attached to the main blade.

[0007] In accordance with another embodiment of the present disclosure, a method is provided for selecting a turbine blade for fluid flow power generation. According to this method, a blade base portion is formed, as are a plurality of blade tip portions of varying lengths and/or shapes. An optimum energy capture blade length and shape is determined for a site at which the blade will be employed using site specific conditions, including one or more of air density, wind speed, extreme wind, wind shear, noise and turbulence intensity. A blade tip is then selected from the plurality of blade tips formed, which blade tip when mounted to the blade base portion will most closely approach the determined optimum energy capture blade length and shape. The selected blade tip portion is then secured to the blade base portion.

[0008] According to a further embodiment of the present disclosure, a method is provided for selecting a turbine blade for a fluid flow power generation. In accordance with the method, a configuration is determined for a blade base portion. Then, an optimum energy capture blade length and shape is determined for a site at which the blade will be employed. This determination uses site specific conditions, including one or more of air density, wind speed, extreme wind, wind shear, noise and turbulence intensity. A configuration of the blade tip portion is then determined and the blade mold is configured based on the previous steps. A blade is then manufactured in a blade mold which is configured in accordance with the last step.

[0009] The present disclosure relates to a fluid flow (wind or water) power generating system, which includes a rotor blade with interchangeable blade tips in order to vary the radius of sweep of the rotor blade to increase or decrease a cross-sectional ea of fluid flow swept by the rotor blade.

[0010] To optimize the energy capture of an array of wind turbines at a given site, a method is provided to deploy rotor blades of different lengths to fully utilize the structural design capacity of the machine, given the site-specific conditions it will experience.

[0011] The method includes the utilization of modular blade tip extensions added to a baseline blade length to achieve the different rotor diameters necessary to maximize the energy capture from each individual machine, while staying within the allowable structural design envelope. This approach to energy capture optimization takes advantage of site specific conditions of air density, wind speed and turbulence intensity that are typically less than what was defined by the standard wind classification used for the machine design.

[0012] In accordance with an aspect of the disclosure, a turbine is mounted on a structure (such as a tall wind tower or a tethered underwater nacelle) that is held stationary in the horizontal axis with reference to the fluid flow. The turbine includes a rotor having a main blade connected to a rotor hub and interchangeable modular blade tips. The blade tips vary in length relative to the main blade to expose more or less of the rotor diameter to fluid flow. A generator is connected to the turbine for generating electrical energy.

[0013] In accordance with a further aspect of the disclosure, the modular blade tips are detachable from the main blade for easy access for servicing and maintenance.

[0014] In accordance with a further aspect of the disclosure, a calculation methodology is used to establish what increase in rotor diameter is possible on a site specific, or pad specific location within a site, while still staying within the design envelope for the wind turbine machine.

[0015] In accordance with a further aspect of the disclosure, a joining method is provided for simple connection to and removal of the modular blade tips from a baseline blade during the manufacturing process or the site setup process.

[0016] Significant value is provided by the disclosed process through increased energy capture at a given site. For the owner/operator of a wind turbine, increased energy capture equates to increased revenue and profit.

[0017] This disclosure has the advantage that it increases energy capture at a given site by utilizing larger rotor diameters across the site, or at individual locations within a site array.

[0018] The modular method of the disclosure results in lower tooling costs, and allows for changing the blade lengths should on-site conditions change after on-site installation of the blades. An alternative approach is to capture more energy through longer blades by manufacturing a new blade design for each incremental increase in length for the given on-site conditions. This results in much higher tooling costs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The invention will be described in detail with reference to the drawings in which:

[0020] FIG. **1** is a top plan view of a rotor blade according to one embodiment of the present disclosure comprising a base section and modular blade tips of three different and increasing lengths a, b, and c;

[0021] FIG. **2** is a perspective view of an extender blade tip beam within the base blade, showing the base blade beam with the attachment end of the extender blade tip attached thereto;

[0022] FIG. **3** is an enlarged sectional view of the extender blade tip beam and the base blade beam (spar) of FIG. **2** with the blade tip beam bolted to the blade spar;

[0023] FIG. **4** is a chart of system power versus rotor hub height divided by wind speed plotted for a baseline blade length and the three blade extensions shown in FIG. **1**;

[0024] FIG. **5** is a schematic view of a wind turbine tower illustrating how an extended blade tip can be lifted by a hoist in a nacelle of the tower;

[0025] FIG. **6** is a diagram of a quick-release attachment structure for the extender blade;

[0026] FIG. **7** is a flow chart concerning the construction of a rotor blade according to another embodiment of the present disclosure; and

[0027] FIG. **8** is a flow chart concerning the construction of a rotor blade in accordance with a further embodiment of the present disclosure.

[0028] In these figures, similar numerals refer to similar elements in the drawings. It should be understood that the sizes of the different components in the figures may not be to scale, or in exact proportion, and are shown for visual clarity and for the purpose of explanation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0029] Referring to FIG. **1**, it is a perspective view of a rotor blade **10** of the present disclosure comprising a main blade body **20** and a detachable outer aerodynamic extender blade tip **22**, chosen from several blade lengths, such as three blade lengths, a, b, and c, illustrated by broken lines. A rotor has a root blade (base main blade **20**) and an extender blade tip **22** resulting in a blade **10** of fixed length. The extender blade tip **22** provides a modular feature, which increases or decreases the rotor diameter depending upon which blade tip, a, b or c, is attached to the main blade section **10**.

[0030] As to FIG. **2**, it is a perspective view of an extender blade beam **24** of the extender blade **22** within the base blade **20**. It shows one embodiment of a base blade beam **26** with the attachment end **24** of the extender blade beam attached to the base blade beam **26**.

[0031] With reference to FIG. **3**, it is a sectional view of the extender blade beam **24** of extender blade **22** and the base blade beam **26** of FIG. **2**. The base blade beam or spar **26** can be bolted inside the blade spar. The spar can be made from a composite material or a metal. Another embodiment is disclosed in FIG. **6**.

[0032] FIG. **4** illustrates a chart of system power versus rotor hub height divided by wind speed, plotted for a baseline blade length and the three blade tip extension lengths a, b and c shown in FIG. **1**. It is evident from FIG. **4** that the longest blade tip extension c will provide the most system power at a given wind speed, whereas the shortest blade tip extension a will provide the least system power for that given wind speed.

[0033] With reference now to FIG. **5**, shown is a schematic view of a wind turbine tower **30** illustrating how a hoist (not shown) in a nacelle **32** can lift an extender blade tip **22'** into locking position with the main blade **10**. As is known, a wind power-generating device includes an electric generator (not visible) housed in the nacelle **32** forming a turbine **34**, which is mounted atop a tall tower structure **36** anchored to the ground. The turbine **34** is free to rotate in a generally horizontal plane such that it tends to remain in the path of prevailing wind current. The turbine has a rotor **38** with variable pitch blades **10**, which rotate in response to wind current. Each of the blades has a main blade base section **20** referred to as a main or root blade which is attached to a rotor hub **40** and a blade tip extension **22** that is chosen from a number of such blade tips that vary in length to provide a rotor of a chosen diameter.

[0034] The wind power-generating device is held by the tower structure **36** in the path of the wind current such that the power-generating device is held in place horizontally in alignment with the wind current. An electric generator is driven by the turbine to produce electricity and is connected to power carrying cables inter-connecting the generator to other units and/or to a power grid.

[0035] Power capture from wind and ocean current turbines is directly proportional to the cross-sectional area swept by the turbine's rotor blades. So, the length of the extender blade (length a, length b or length c) determines a respectively greater power capture. Conventional rotors utilize blades manufacture to a fixed length, joined at a rotating hub. These blades may be of variable pitch (selectively rotatable about their longitudinal axes) in order to alter the angle of attack relative to the incoming fluid flow, principally for power shedding in high-flow velocities. Alternatively, these blades may be fixed pitch or stall-regulated, wherein blade lift and therefore power capture falls off dramatically as wind speeds exceed some nominal value. Both variable pitch and stall regulated rotor blades with fixed diameters are well known in the art. U.S. Pat. No. 6,726,439 B2, describes a wind or water flow energy converter comprising a wind or water flow actuated rotor assembly. The rotor of U.S. Pat. No. 6,726,439 B2 comprises a plurality of blades, wherein the blades are variable in length to provide a variable diameter rotor. The rotor diameter is controlled to fully extend the rotor at low flow velocity and to retract the rotor, as flow velocities increases such that the loads delivered by or exerted upon the rotor do not exceed set limits.

[0036] The blade tip portions **22** and **22'** are designed to be attached or detached from the base blade **20** for servicing or replacement with the same blade size or with a different blade size, such as sizes a, b, or c, as shown in FIG. **1**. A cable **42** is attached to the extender blade **22'** by a connector. The cable passes up through the rotor hub **40** to a hoist in the nacelle **32**. The hoist in the nacelle pulls the cable up until the extender blade can be secured in place on the main blade **20**.

[0037] To secure the blade tip **22'** to the main blade **22**, fasteners can be threaded through aligned apertures. For servicing, the fasteners are removed. With reference again to FIG. **5**, the tower **36** can be provided with an access door **50** and fold-down latch **52**, which when opened extends a ramp for servicing and blade tip replacements. The cable **42** can be unwound to lower the extender blade tip **22'** down to ground level.

[0038] With reference now to FIG. **6**, one embodiment of a quick-release attachment mechanism for the extender blade **22** is there shown. A modular rotor blade assembly includes a main blade **60** that can have selectively secured to it a blade tip **62** via fasteners **64**. More particularly, at least one connecting part **66** extends from the blade tip **62**. The connecting part **66** is adapted to connect to a similar connecting part **68** in the main blade **60**. Each of these can have a conical opening so that the conical openings of the connecting parts are aligned with each other to form a continuous conical opening. This embodiment is described in greater detail in International Application Publication No. WO 2009/090537 that was published on 23 Jul. 2009. That document is incorporated hereinto in its entirety.

[0039] The rotor diameter is selected depending upon the characteristics of the site upon which the wind turbine is to be situated. The wind power-generating device is held by the tower structure in the path of the wind current such that the power-generating device is held in place horizontally in alignment with the wind current. An electric generator is driven by the turbine to produce electricity and is connected to power carrying cables inter-connecting the generator to other units and/or to a power grid.

[0040] A calculation methodology is used to establish what increase in rotor diameter is possible on a site specific, or pad specific location within a site, while still staying within the design envelope for the wind turbine machine. If the site characteristics change, perhaps by wind turbines being added or subtracted to an array of turbines in a wind farm, a more appropriate blade tip can be designed and manufactured to replace an existing blade tip. Since the blade tip can be removed and fitted with a different blade tip, the changed site characteristics can be accommodated.

[0041] It is entirely conceivable that different blade tips will be necessary for different wind turbine machines located at a wind farm, depending upon the exact location of a given wind turbine in the wind farm. Equipped with different tips, each wind turbine may have different aerodynamic properties in order to customize the wind turbine for that specific site, including a given location in the array of wind turbines at a wind turbine site.

[0042] In order to determine what site specific parameters may need to be accommodated at a specific wind turbine site, an anemometer may be positioned at the site in order to obtain, for example, one year's worth of data. That data can be entered into a suitable computer and a suitable software program can be run in order to determine the meteorological characteristics for that specific site. Then, a blade can be tailored for both energy capture and noise reduction with the tip design of the blade giving the wind farm operator different aerodynamic properties. In this way, the wind farm operator can optimize the core structure design for the majority of the blade and have a modular tip with which the length, aerodynamic performance, load and noise characteristics of the wind turbine can be optimized. In this way, manufacturing consistency is enhanced. The following chart illustrates the known maximum lengths of blade lengths and rotor diameters:

Ave. Wind Speed	Class	Blade Length	Rotor Diameter
8.5-10 m/s	1	75 m	150 m
7-8.5 m/s	2	71 m	162 m
>7	3	87.5 m	175 m

[0043] In another embodiment, the baseline blade length can be on the order of 42.5 m, 44 m or 47.5 m and a tip can be added thereto to optimize the overall length of the blade for the sites specific conditions.

[0044] The site suitability assessment process is well known to those skilled in the art. In the instant disclosure, the output of the site suitability assessment process is employed to modify the blade drawings, as well as the manufacturing process. The conventional state of the art is to use a fixed type of blade for a given wind regime and to curtail the operation of the turbine via controls based on site suitability assessments. The instant disclosure is advantageous in that it optimizes the wind turbine machine for energy capture while maintaining the loads envelope of the specifically tailored blades for the specific site.

[0045] With reference to FIG. **7**, an exemplary method for constructing a rotor blade according to measured characteristics of a wind turbine site is illustrated. It is to be appreciated that the exemplary methods presented herein may include fewer, more, or different steps from those shown and need not necessarily proceed in the order illustrated. The illustrated methods may be entirely automated or may include some user input, as noted herein. The method starts at step **100**.

[0046] At step **105**, a suitable computer and/or site operator determines load, noise and performance characteristics of the wind turbine site. This may include obtaining meteorological data of the type discussed previously for an extended period of time. The extended period can be one or more months, one season of a year or more than one season. An entire year's worth of data (12 contiguous months or four seasons) can be gathered, if so desired.

[0047] At step **110**, an optimum energy capture blade design is determined based on the characteristics developed in step **105** above. The design can be determined by a computer, an engineer, or by both acting together.

[0048] At step **115**, the site operator assesses a need for blade design modifications based at least in part on the determined load, noise and performance characteristics of the blade.

[0049] At step **120**, an engineer creates and/or updates blade drawings for blade production corresponding to the rotor blade of the wind turbine based at least in part on the assessed need for blade design modifications.

[0050] At step **125**, an engineer creates and/or modifies blade molds in accordance with the blade drawings of step **120**.

[0051] At step **130**, a blade is manufactured employing the blade mold designed in step **125**.

[0052] The method ends at step **135**. Subsequently, the blade so manufactured is mounted to a rotor held on a tower, such as rotor **38** supported on tower **36** shown in FIG. **5**.

[0053] In one embodiment, a wind turbine blade built on a common base structure is provided with a customizable out board section based on a wind site characteristic assessment. In another embodiment, a wind turbine blade is provided with a modular tip that can be customized based on wind site characteristic assessments and mounted to a common in board section of a wind turbine blade.

[0054] For example, FIG. **8** illustrates a method of selecting an optimal extender blade tip for a wind turbine. The method starts at step **150**.

[0055] At step **155**, a site operator mounts a wind turbine on a structure that is held stationary with respect to a fluid flow. The wind turbine includes a rotor with a main blade portion connected to a rotor hub at a proximal end and includes provisions for attaching a modular extender blade tip to a distal end of the main blade.

[0056] At step **160**, the site operator, optionally in conjunction with a suitable computer, determines an optimum energy capture using one or more site specific conditions such as air density, wind speed, extreme wind, wind shear, noise and turbulence intensity. These conditions can be evaluated over an extended period of time as discussed previously.

[0057] At step **165**, the site operator selects from a finite number of extender blade tips an extender blade tip having a length and/or shape that is closest to providing the determined optimum energy capture calculated at step **160**.

[0058] At step **170**, the site operator attaches the selected extender blade tip to the blade main portion. This step creates the overall blade meant for use at that site.

[0059] The method ends at step **175**.

[0060] In one embodiment, the in-board section or root section **20** of the blade can be on the order of 90 to 95 percent of the overall length of the blade while the tip section can be on the order of anywhere from 5 to 10 percent of the overall length of the blade.

[0061] The disclosure has been described with reference to preferred embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the disclosure be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

1. A fluid-flow power generating method, comprising steps of:

A. mounting a turbine on a structure that is held stationary with reference to a fluid flow, said turbine including a rotor having a main blade connected to a rotor hub at a proximal end and including a distal end with provisions for attaching a modular extender blade tip to said main blade;

B. determining an optimum energy capture using site specific conditions including one or more of air density, wind speed, extreme wind, wind shear, noise and turbulence intensity;

C. choosing from a number of extender blade tips an extender blade tip whose length is the closest to said optimum energy capture of step B; and

D. attaching the extender blade tip chosen in step C to said main blade.

2. The method of claim **1** further comprising steps of:

E. maintaining said turbine in alignment with fluid-flow direction; and

F. converting an output of said turbine to electrical energy.

3. The method of claim **1** wherein the step of determining comprises accumulating data for a period of time.

4. The method of claim **3** wherein the period of time is extended.

5. The method of claim **4** wherein the period of time includes at least one season of a year.

6. The method of claim **4** wherein the period of time includes all four seasons of a year.

7. A method of selecting a turbine blade for fluid flow power generation, comprising:

forming a blade base portion;

forming a plurality of blade tip portions of varying lengths and/or shapes;

determining an optimum energy capture blade length and shape for a site at which the blade will be employed, using site specific conditions including one or more of air density, wind speed, extreme wind, wind shear, noise and turbulence intensity;

selecting a blade tip from the plurality of blade tips formed, which blade tip when mounted to the blade base portion will most closely approach the determined optimum energy capture blade length and shape; and,

securing the selected blade tip portion to the blade base portion.

8. The method of claim **7** wherein the step of determining comprises accumulating data for a period of time.

9. The method of claim **8** wherein the period of time is extended.

10. The method of claim **9** wherein the period of time includes one or more months of a calendar year.

11. The method of claim **9** wherein the period of time includes all four seasons of a year.

12. A method of selecting a turbine blade for fluid flow power generation, comprising:

A. determining a configuration of a blade base portion;

B. determining an optimum energy capture blade length and shape for a site at which the blade will be employed, using site specific conditions including one or more of air density, wind speed, extreme wind, wind shear, noise and turbulence intensity;

C. determining a configuration of a blade tip portion based on step B above;

D. configuring a blade mold based on steps A to C above; and,

E. manufacturing a blade in the blade mold configured in step D.

13. The method of claim **12** wherein the step of determining comprises accumulating data for a period of time.

14. The method of claim wherein the period of time is extended.

15. The method of claim **14** wherein the period of time includes at least one season of a calendar year.

16. The method of claim **4** wherein the period of time includes all four seasons of a year.

* * * * *