Abstract

The electrical generator illustrated with the present invention basically comprises the following parts:

1. a buoyant unit positioned at the top of the frame, of such a size to keep the entire device afloat and of such a shape as to minimise its hydrodynamic resistance;
2. a metal frame, composed mainly of struts having an aerofoil section;
3. two contra-rotating turbines, with three or more blades, attached to two electrical generators, symmetrically positioned on the two sides of the frame;
4. two diffusers, mounted around the two turbines, shaped so as to increase the active flow of water against the blades;
5. a container, barrel-shaped to minimise hydrodynamic resistance, placed at the foot of the frame, and containing a windlass;
6. a mooring block, laid on the sea bed, of such a shape and of sufficient weight to hold the electrical generator complying to the present invention when it is completely immersed below the water surface and when it is subject to the maximum strength of the current at the mooring site;
7. a mooring line, with one end wrapped around the windlass and the other attached to the mooring block;
8. an electric cable to connect the electrical generators to the grid; the electric cable running along the mooring line;
9. aerofoil profiles, rudder and tailplanes that, in the presence of strong currents, create an upwards force; this added to the lifting force of the buoyant unit prevents the electrical generator complying to the present invention from being dragged on the sea bed; the tailplanes are of such a shape and section as to counteract any misalignment of the electrical generator complying to the present invention with respect to the direction of the water current caused by unexpected roll, pitch and yaw.
10. bow thruster illustrated in figure 25. This element, fixed to the tail of the device, is necessary to control the orientation of the whole system during the change of current direction. In this way the whole system will be driven to rotate always in the same direction of roughly 180 degree maximum. Furthermore it will be no necessary to have a rotary device (such as brushes) to transfer electrical power.

Claims

1. Electrical generator, driven by slow moving currents of water namely tidal currents, marine currents in general, or currents in large rivers comprising a frame characterised by the fact that the structure can be built from struts possibly having an aerofoil profile section, which has a propeller under the tail to steer the device and align it in the desired direction, which on its sides has two contra-rotating turbines, with three or more blades, attached to two electrical generators, which at the top has a buoyant unit of such a size as to maintain the entire device afloat and of such a shape as to minimise its own hydrodynamic resistance, which at the foot holds a watertight barrel-shaped container in which is housed a windlass around which is wrapped a mooring line with the other end fixed to a mooring block laid on the sea bed of a sufficient weight to keep the structure and the buoyant unit completely immersed when subjected to the maximum strength of marine current at the mooring site, which to the generators is connected an electrical cable that runs along the mooring line to a transformer unit located onshore.
2. Electrical generator as defined in claim 1, characterised by the fact that to the structure is attached a diffuser having the shape of a solid of rotation in which the generator section has the shape of an aerofoil profile so as to convey the flow of water towards the turbine blades in order to enhance the efficiency of energy conversion;
3. Electrical generator as defined in claim 2, characterised by the fact that at the diffuser inlet, in a precisely determined position, is fitted a second diffuser or slat of smaller size, so as to convey the flow of water towards the two turbines further enhancing the efficiency of energy conversion of the entire apparatus;
4. Electrical generator as defined in claim 1, characterised by the fact that, in place of the dead weight mooring, the mooring line is attached to an eye swivel to a pile driven into the sea bed or drilled into a rocky bottom.
5. Electrical generator driven by marine currents as defined in claim 1 characterised by the fact that one or more wings are fitted that can contribute added buoyancy due to their lifting force.
6. Electrical generator driven by marine currents as defined in claim 1 characterised by the fact that there is a tail rudder or two V-shaped tailplanes.
7. Electrical generator driven by marine currents as defined in claim 1 characterised by the fact that the steering system consists of two rudders fitted on V-shaped tailplanes.
8. Electrical generator driven by marine currents as defined in claim 1 characterised by the fact that the steering system consists of one or more steering propellers.
9. Electrical generator driven by marine currents as defined in claim 1 characterised by the fact that the frame is comprised of struts having a circular, square or any other shape of section;
10. Electrical generator as defined in claim 1, characterised by the fact that to the frame are assembled more than two turbines with diffusers and slats.

Electrical generator driven by marine currents, equipped with diffuser and steering system

Field of the invention

The present invention refers to an electrical generator designed to be driven by slow-moving flows of water, namely tidal currents, marine currents in general, or currents in large rivers.

General description of the invention

The electrical generator illustrated with the present invention will basically comprise the following parts:

1. a buoyant unit positioned at the top of the frame, of such a size to keep the entire device afloat and of such a shape as to minimise its hydrodynamic resistance;
2. a metal frame, composed mainly of struts having an aerofoil section;
3. two contra-rotating turbines, with three or more blades, attached to two electrical generators, symmetrically positioned on the two sides of the frame;
4. two diffusers, mounted around the two turbines, shaped so as to increase the active flow of water against the blades;
5. a container, barrel-shaped to minimise hydrodynamic resistance, placed at the foot of the frame, and containing a windlass;
6. a mooring block, laid on the sea bed, of such a shape and of sufficient weight to hold the electrical generator complying to the present invention when it is completely immersed below the water surface and when it is subject to the maximum strength of the current at the mooring site;
7. a mooring line, with one end wrapped around the windlass and the other attached to the mooring block;
8. an electric cable to connect the electrical generators to the grid; the electric cable running along the mooring line;
9. aerofoil profiles, rudder and tailplanes that, in the presence of strong currents, create an upwards force; this added to the lifting force of the buoyant unit prevents the electrical generator complying to the present invention from being dragged on the sea bed; the tailplanes are of such a shape and section as to counteract any misalignment of the electrical generator complying to the present invention with respect to the direction of the water current caused by unexpected roll, pitch and yaw.
10. bow thruster illustrated in figure 25. This element, fixed to the tail of the device, is necessary to control the orientation of the whole system during the change of current direction. In this way the whole system will be driven to rotate always in the same direction of roughly 180 degree maximum. Furthermore it will be no necessary to have a rotary device (such as brushes) to transfer electrical power.

The component parts of the electrical generator complying to the present invention will be assembled at a shipyard; this will then be launched and towed to the chosen site.
Commissioning will be achieved in the following stages:

- launching of the device which will float on the sea surface due to the characteristics of the buoyant unit;
- towing the device by tug to the mooring site;
- constructing and laying the dead weight mooring on the sea bed;
- connecting the mooring cable and activating the windlass, with consequent sinking of the device;
- connection of electrical cable to a transformer unit previously constructed onshore;
- starting up electrical generator complying to the present invention and commencement of electricity production.

Initially, the device will float on the sea surface until such time as the windlass is activated when it will be dragged under the water, the shape and size of the buoyant unit being such as to ensure a perfectly horizontal position both in the presence and absence of currents; the buoyant unit, when struck by water currents, will orient itself to a position lying parallel to the current and the turbines will start to rotate, converting part of the kinetic energy of the flowing water current, into mechanical energy; the presence of the diffuser will assist the start-up of the rotation of the turbines even at very slow water current speeds (< 0.8 m/s), and will also significantly increase the coefficient of energy conversion; the movement of the turbines, which will be contra rotating to cancel out any momentum induced by the structure, will be used, after possible gearbox/rpm multiplication, to activate two electrical generators. The electrical power produced will be transferred by a specific multipolar electric cable to the transformer; the electric cable will run along the mooring line; the transformer will contain two three-phase AC/DC electronic converters (rectifiers), a DC stage for coupling and filtering and a three-phase DC/AC electronic converter (inverter) which may be grid controlled.

Background

Patents IT0001332054 and IT0001358475 describe systems for the conversion of the kinetic energy contained in water currents into mechanical energy, but conversion rates are low.
The present invention proposes to realize a system to improve the conversion rate yield of the kinetic energy in flowing water currents into mechanical energy harnessed by turbines. This system, called a “diffuser” or “shroud”, has a hollow body with custom built geometry and sections, it is attached to a frame around each turbine and is able to increase the force of the water flowing through it. More specifically, the diffuser has the form of a solid of revolution in which the generator section has the shape of an aerofoil profile. The entire solid can be described by a set of points that represent the generator section (aerofoil profile) and by the positioning of this (fixing) with respect to the turbine shaft (and of the diffuser). The project has optimized the forms by means of numerical studies and an experimental study carried out in a wind tunnel and tow-tank. In order to further enhance efficiency, it is possible to install an additional small diffuser near the point of entry to the diffuser, called a “slat”. A “slat” is the profile that is generally fitted to the wings of an aircraft: which is made to protrude from the wing on aircraft during take-off and landing because its presence increases, at the same air speed, the lifting force of the wing, i.e. it increases the lift coefficient of the wing. Therefore, when installed in a diffuser its effect is to further increase the force of the water flowing through the diffuser via an increase in the overall flow rate of the combined system comprising the diffuser+slat. The shape of its section, its setting angle with respect to the main diffuser (positioning angle with respect to the turbine shaft) and the point at which it is positioned along the turbine shaft have been studied numerically and experimentally.

Figs. 2 and 3 illustrate two possible configurations of the diffuser: with slat (detail A) and without slat (detail B). Fig. 3 shows in more detail how the diffuser and slat are solid figures obtained from a revolution around the turbine shaft and which have an aerofoil profile section.

Figs. 4 and 5 schematically show how the presence of the diffuser enables the active flow of water on the turbine blades to be increased: it is known that for a non shrouded turbine the streamlines tend to move away from the circle swept by the turbine; in contrast, in the presence of a diffuser, even the most peripheral streamlines become productive, i.e. those located outside the circle swept by the blades.

The added force generated by the diffuser, which could be called a flow conveyor, thereby increases the fluid flowing through the rotor disc. Therefore, for the same given area, it handles a larger mass of fluid (water or air) within a unit of time and also slightly increases the flow speed compared to the speed of undisturbed fluid found upstream. The increase in efficiency is proportional to the thrust/force generated by the diffuser itself. Thus, all the "tricks" that are able to increase the lift (or the circulation) of the diffuser (with or without the slat) and that also manage to possibly lower the pressure downstream of the diffuser, enhance its efficiency. Since the lift is also proportional to the surface of the wing involved, the chord of the diffuser is another element that determines the capacity of the diffuser (and of the slat) to increase the lift, then flow rate and finally the power. Thus, the efficiency of the diffuser is also directly proportional to the chord of the main diffuser and that of the secondary diffuser (slat).

US 2007/0241566 A1 describes a system in which the turbines are made up of watertight rotating units which on the outside have the shape of a cylinder or a cone and on the inside have custom shaped blades; according to the inventor, when these huge units are hit by water currents they begin to rotate around a fixed horizontal axle, which is integral with the frame of the apparatus: this same movement generating electrical energy.
The opposite occurs in the case of the present invention: the diffuser is fixed and integral with the frame of the apparatus; while the turbine, composed of three blades attached to a shaft, turns and activates the shaft of an electrical generator with a fixed casing that is an integral part of the frame.

In the case of the present invention, the blades of the two turbines have been designed in terms of shape, chord distribution and twist with appropriate numerical codes in order to maximise efficiency of conversion and to minimise weight as far as possible. At the same time, the geometry of the blade profile has been designed so as to preclude cavitation phenomena: this turbine is able to convert around 50% of the kinetic energy of flowing water. The added presence of the diffuser, with optionally mounted slat, allows the efficiency of conversion to be doubled; moreover, and even more importantly, due to the profile of the blades, diffuser and slat, the turbine is able to start moving and to produce electrical energy in the presence of water currents moving at speeds as low as 0.8 m/s (1.6 Knots).

In contrast, for the invention described in US 2007/0241566 A1, the flowing water current would have to be able to activate a rotating unit which, for the same overall dimension, has a much higher inertia to that of the blades of the present invention. Moreover, the movement of the unit will cause all the water in proximity to its peripheral surfaces to rotate with the surface itself.

A brief overview of Power

The same laws that govern windmill functioning also apply to the operation of the present invention; in particular to determine the power obtainable from a fluid in movement the following formula can be applied:

$$P = 1/2\, \rho\, A\, v^3\, C_p\, C_d\, K_{Betz}$$

where :

- P is the obtainable power;
- ρ is the fluid density;
- A is the surface swept by the turbine blades;
- v is the velocity of the current;

- Cp is a coefficient between 0 and 1, indicating the efficiency of the turbine (based on the number of blades, shape of blades, smoothness of blade surface, effects of sea bed etc.);
- Cd is a coefficient of more than 1 indicating the increase due to the presence of the diffuser;
- KBetz is the dimensionless coefficient determined in 1919 by the German physicist Albert Betz, equal to 16/27, and defines the maximum theoretical value of energy obtainable from a windmill.

The trials conducted to date on models of the present invention, which basically confirm the validity of the above, have provided the following indicators:

- the product "C_p x K_{Betz}" generally assumes a value of 0.5;
- the presence of a diffuser having the precise profile designed gives Cd = 2;
- doubling the speed of the water flow corresponds to an eight-fold increase in the power harnessed;
- doubling the length of the blades, corresponds to a four-fold increase in the power harnessed;
- the minimum current speed to start the turbine, with correctly shaped blades, is around 0.8 m/s (around 1.6 Knots).

Size and electric power

For all configurations blade size ranges from 2.5 m to 5.0 m and more; a blade length, "R", occupies the following amount of space:

- front 6 - 7 R
- height 3 - 4 R
- length 6 - 9 R

The present invention can operate in water currents from 0.8 m/s up to 4.0 m/s; the electrical power output ranges from 50 kW to 2 MW and more, depending on the length of the blades and the speed of the current.

Advantages of the invention

The idea of positioning two contra-rotating turbines, housed within diffusers, on the sides of a floating body, held underwater in the current by a simple mooring line yields the following advantages:

- no need to damage the sea bed with a tower, nor build tripods or towers in steel which are not only large in size but also extremely expensive;
- no necessity for divers on site (in an area affected by a strong marine current and thus difficult to manage) neither during installation nor for maintenance or in the event of a breakdown;
- the bathymetry of the site chosen for installation is of little importance: whatever the depth it is enough to lay a dead weight (mooring block) to which has already been secured one end of a mooring line of a suitable length;
- it matters not whether the direction or bearing of the water current is stable or continually changing; the device will constantly follow the direction of the current, always presenting the surface of the blades perpendicular to the direction of the water flow;

- the presence of the diffuser aids initial turbine rotation even at very low current speeds; moreover, for the same overall blade dimension, a turbine housed within a diffuser harnesses twice as much power;
- in the event that maintenance or repair work is required to any mechanical parts or electrical equipment, it is sufficient to detach the buoyant unit from the mooring cables and tow it to a shipyard where all the necessary work can be carried out onshore, considerably more easily and cheaply than doing the same work at sea;
- all the component parts of the present invention can easily be assembled at a shipyard; once complete the device will be able to float; as a result it can easily be towed to a favourable site for it to be put into operation, requiring only that the mooring line be secured to windlass drum and the electrical cable connected;
- in the event of the mooring line breaking, the device is buoyant and will thus float to the surface. Likewise, were the windlass to fail irreparably, it would be enough to explode a charge placed along the mooring line to bring the device afloat once more;
- by exploiting knowledge about variations in current movement at different depths occurring over time, the depth control system can be programmed to optimise energy generation capacity.

Brief description of the drawings

- Figure 1 shows in axonometric projection the overall device that is the subject of the present invention relating to configuration 1, which is the standard configuration, to use in sites with current speeds not exceeding 5 Knots;
- Figures 6 and 7 identify the component parts of the present invention in its standard configuration.
- Figures 8, 9 and 10 show all possible configurations of the electrical generator that is the subject of the present invention.
- Figure 11 presents an axonometric projection of the overall device that is the subject of the present invention relating to configuration 2;
- Figure 12 presents an axonometric projection of the overall device that is the subject of the present invention relating to configuration 3;
- Figures 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 and 24 present axonometric projections of the overall device that is the subject of the present invention relating to the various configurations;
- Figure 25 illustrates the steering propeller.

Description of the generator

As shown in figures 8, 9 and 10, the electrical generator driven by marine currents fitted with a diffuser and steering system can be configured in three different configurations: configuration 1 is the most complex, the other two are possible variations to this.

Description of configuration 1 (see figs. 1-8-13-16-19 and 22)
As shown in figure 1**,** Configuration 1 basically comprises the following parts:

a) A buoyant unit (1) shaped like a torpedo to minimise hydrodynamic resistance; the buoyant unit will be filled with a pressurised inert gas in order to counteract the external water pressure at the operating depth. A watertight compartment will be built into the top of the buoyant unit. The compartment will contain all instruments for acquiring data that can be accessed through a special hatch, and it will contain all instruments for data, control, remote control, electrical connections, back-up batteries, computer for steering, inertial platforms, data logger;

b) A V-shaped tailplane (9) designed to ensure longitudinal and lateral directional stability as well as longitudinal trim (with respect to pitching axis) and lateral-directional static and dynamic stability;
c) two contra-rotating turbines (3) with three or more blades connected to two electrical generators fitted in a symmetrical position to the sides of the buoyant unit;
d) two diffusers (4), with optionally mounted slats, attached to the frame and surrounding the turbines
e) a watertight barrel-shaped container (5) to house the windlass;
f) a mooring line (7), with one end attached to the mooring block;
g) a dead weight (6), moored on the sea bed, of such a shape and size as to hold the buoyant unit when it is completely immersed below the water surface and when it is subject to the maximum strength of the current at the mooring site. Where possible the dead weight may be replaced with a shackle cast to a pile driven into the sea bed or drilled into a rocky bottom.

With reference to figs. 8 and 9, the operating parts of the present invention in configuration 1, are as follows:

1. Buoyant unit
2. Wing
3. Frame (structural elements)
4. Carter (housing) for shaft, turbine and electrical generator
5. V-shaped tailplane
6. Watertight barrel-shaped container housing the windlass. N.B.: the drum is in the part exposed to the water
7. Diffuser
8. Frame (rear strut)
9. Blade (3 blades making up a turbine)
10. Sealing
11. Bearings (radial and thrustbearing)
12. Gear transmission box (optional)
13. Electrical generator (generally with permanent magnets)
14. Mooring line
15. Frame (Front strut used to support mooring line)
16. Windlass drum
17. Windlass shaft holding and bearings
18. Windlass motor
19. Division between watertight zone and waterlogged area
20. Pulley system for mooring line
21. Slide to correct horizontal trim
22. Operational details of diffuser
23. Mounting plate between wing and diffuser
24. Operational details of wing

Description of configuration 2 (see figs. 9-11-14-17-20 and 23)

As shown in figure 11**,** configuration 2, to be used in stronger currents, comprises the following parts:

h) a buoyant unit (1) shaped like a torpedo to minimise hydrodynamic resistance;

i) a V-shaped tailplane (9) designed to ensure longitudinal and lateral directional stability as well as longitudinal trim (with respect to pitching axis) and lateral-directional static and dynamic stability;
j) a wing (11) designed, in combination with the buoyancy force provided by the floating unit, to ensure the desired depth is maintained and to reduce the size of the buoyant unit as well as the mooring line and the structural supports for the diffusers;
k) two contra-rotating turbines (3) with three or more blades, connected to two electrical generators fitted in a symmetrical position to the sides of the buoyant unit with two permanent magnets positioned downstream of the turbines;
l) two diffusers (4) surrounding the contra-rotating turbines, having an aerofoil section so as to increase current flow speed; slats (12) may be fitted to the front part of the diffuser, these also having an aerofoil profile section;
m) structural supports (13) for the diffusers;
n) structural supports (2) for the turbines, which may be streamlined to contribute to the lift;
o) a mooring line (7), with one end attached to the mooring block;
p) a mooring block (6), fixed to the sea bed of such a shape and size as to hold the buoyant unit when it is completely immersed below the water surface and when it is subject to the maximum strength of the current at the mooring site.

Description of configuration 3 (see figs. 10-12-15-18-21 and 24)

As shown in figure 12**,** Configuration 3 differs from the previous because its trim is regulated mainly by the lift of the wings, structural elements and the tailplane; it can be used in areas with very strong currents. The diffuser need not be fitted in this configuration because the water current will be strong enough to drive the two turbines; thus the present invention will basically comprise the following parts:

q) a buoyant unit (1) shaped like a torpedo to minimise hydrodynamic resistance;
r) a V-shaped tailplane (9) designed to ensure longitudinal and lateral directional stability as well as longitudinal trim (with respect to pitching axis) and lateral-directional static and dynamic stability;
s) a wing (11) designed, in combination with the buoyancy force provided by the floating unit, to ensure the desired depth is maintained and to reduce the size not only of the buoyant unit but also of the mooring line and the structural supports for the diffusers;
t) two contra-rotating turbines (3) with three or more blades connected to two electrical generators fitted in a symmetrical position to the sides of the buoyant unit with two of the turbines having two direct drive permanent magnet alternators positioned downstream;
u) structural supports (2) for the turbines, which may be streamlined to contribute to the lift;
v) a mooring line (7), with the other end fixed to the mooring;
w) a mooring block (6), fixed to the sea bed of such a shape and size as to hold the buoyant unit when it is completely immersed below the water surface and when it is subject to the maximum strength of the current at the mooring site.