

1 Tidal power generation system and methods

2

3 The present invention relates to a system for power generation and methods of use, and in
4 particular to a power generation system for conversion of tidal kinetic energy into electricity
5 or other forms of energy or energy storage. The invention has particular, although not
6 exclusive, application to low velocity tidal streams.

7

8 Background to the invention

9

10 Renewable energy sources are predicted to play an ever increasing role in the future due
11 to the need to cut down greenhouse gas emissions and reduce the current high
12 dependency on fossil fuels, which are unevenly distributed around the world.

13

14 Among the different sources of renewable energy, solar and eolic energy are currently
15 widely exploited in countries such as Spain, US or Germany. However, tidal energy is

perhaps one of the most underexploited forms and, although there is currently some commercial exploitation of tidal energy, most of the related technology is still in its development phase, with new improvements continuously seeing their way to practical application. Many countries have coastlines which are rich in low velocity tidal stream locations, giving potential to increase tidal energy utilisation and alleviating dependency on fossil fuels.

US 7,902,687 B2 describes a power generation system based on a plurality of horizontal axis turbines. Each turbine is supported in a structural frame which can rest on the seafloor or moored beneath the surface by tether on the seafloor. The system of US 7,902,687 is highly directional, and slight deviation of the stream from an essentially frontal direction would result in a considerable reduction of the energy output in the system.

US 7,470,086 B2 describes a subsea power generation system comprising several horizontal turbines arranged in a common structural support. The whole assembly is positively buoyant and is located at an intermediate distance between the ocean floor and the surface. The system is held in place by mooring lines attached to the corners of the assembly. An associated problem with the system of US 7,470,086 B2 is that the mooring lines can be easily entangled with equipment used by many ships such as fishing trawlers.

In US 2011/0084490 there is proposed a vertical turbine system for generating electricity from the force of deep ocean currents. This turbine system can be supported on abandoned oilwell structural foundations, after suitable modifications, thus reducing some of the cost of deploying subsea turbines on the seabed. However, the system of US 2011/0084490 can only be utilised in locations of existing oilfields, or requires the instatement of an oilwell style foundation reducing the economical and logistical benefits of the system.

US 8,222,761 B2 describes a subsea power generating system which can be located on the seafloor and comprises a linear array of vertical turbines aligned and supported in a frame which protects the turbines against debris in the tidal flowstream. The system of US 8,222,761 is relatively difficult to deploy and install due to the structure of the support frame. Furthermore, maintenance or repair of the turbines would be a complicated operation.

1 WO 00/28210 describes a tidal or hydraulic power generation system consisting of one or
2 more turbines located in a shroud which defines a constriction. The turbines are located at
3 the constriction where the transversal area is at its minimum and the fluid flow reaches
4 maximum speed. Whereas this concept allows a suitable protection of the turbines against
5 floating objects or fishing equipment and an improved energy output can be achieved, the
6 maintenance, repair or replacement of these turbines difficult as the shroud does not
7 facilitate easy access to the turbine unit.

8
9 There is generally a need for a tidal power generation apparatus and method of use which
10 addresses one or more of the problems associated with conventional systems, including
11 those identified above.

12
13 It is amongst the aims and objects of the invention to provide a method and/or apparatus
14 for tidal power generation that allows easy deployment and maintenance, that is suitably
15 protected against matter entrained by the tidal streams or against fishing equipment, that
16 can economically generate energy in low speed tidal streams locations, where stream
17 direction experiments continuous shifts and/or which obviates or mitigates one or more
18 drawbacks or disadvantages of the prior art.

19
20 In particular, one aim of an aspect of the invention is to provide a method and/or apparatus
21 which may be configured or optimised to generate a high energy output in low tidal stream
22 speed locations, so that tidal energy can be generated closer to the points of final use and
23 thus reducing capital and operational expenditure.

24 25 Summary of the invention

26
27 According to a first aspect of the invention, there is provided a system for the extraction of
28 energy from an underwater flow stream in a body of water, the system comprising:
29 a support frame comprising a plurality of receptacles for mounting functional modules on
30 the support frame, the plurality of receptacles arranged to form a horizontally-distributed
31 two-dimensional array on the support frame; and
32 a plurality of vertical axis turbine units configured to be interchangeably mounted in the
33 receptacles.

34

1 Preferably the system may comprise at least one functional module configured to be
2 interchangeably mounted in the receptacles.

3
4 Preferably the plurality of vertical axis turbine units may be arranged substantially in a
5 horizontal plane.

6
7 The plurality of vertical axis turbines may be arranged with a subset of the vertical axis
8 turbines vertically offset with respect to others of the plurality of vertical axis turbines.

9
10 The one or more receptacles may comprise functional modules selected from the group of
11 an energy storage module, an accumulator cell module, a hydrogen fuel cell module or a
12 control module.

13
14 The support frame and plurality of vertical axis turbines units may form an integrated
15 assembly configured to be towed to an installation and/or lowered to the bed of the body of
16 water.

17
18 Preferably, each of the turbine unit may comprise a turbine shaft. More preferably each of
19 the turbine unit may comprise a pressurised compartment located at a lower end of the
20 turbine shaft.

21
22 Preferably the pressurised compartment may be fluidly sealed and/or house a generator
23 unit. The pressurised compartment may house a gear box.

24
25 Preferably the pressurised compartment may fit within the receptacle of the support frame.

26
27 Preferably each turbine unit may be mounted into a receptacle by a quick connector. The
28 quick connector may be operable by fluid pressure.

29
30 The system may comprise at least one flow deflector assembly operable to controllably
31 adjust the flow into or out of the array of vertical axis turbines. Preferably the at least one
32 flow deflector assembly may be operable to direct the fluid flow to a desired area in the
33 turbine array.

34

1 The at least one flow deflector assembly may be operable to shut off the flow entering or
2 leaving the array in response to a control signal from a control module.

3
4 The at least one flow deflector assembly may comprise a failsafe close mechanism, which
5 may be operable to be actuated if the flow stream exceeds a velocity threshold.

6
7 Preferably the at least one flow deflector assembly may be a horizontally oriented flow
8 deflector assembly. More preferably the at least one flow deflector assembly may be a
9 vertically oriented flow deflector assembly.

10
11 The at least one flow deflector assembly may be configured to be operated in dependence
12 on a control signal from a control module of the apparatus.

13
14 Preferably the control module may be configured to generate the control signal in
15 dependence on acquired flow condition and/or operational data. The acquired flow
16 condition and/or operational data may comprise data selected from one or more of: flow
17 velocity; rotational speed; torque; vibration data; and energy output.

18
19 Preferably the acquired flow condition and/or operational data may comprise temperature
20 data.

21
22 According to a second aspect of the invention, there is provided a method of assembling a
23 system for the extraction of energy from an underwater flow stream in a body of water, the
24 method comprising:

25 providing a support frame comprising a plurality of receptacles for mounting functional
26 modules on the support frame, the plurality of receptacles arranged to form a horizontally-
27 distributed two-dimensional array on the support frame;

28 mounting a plurality of vertical axis turbine units or a plurality of vertical axis turbine units
29 and one or more functional modules in the receptacles;

30 wherein the plurality of vertical axis turbine units and/or plurality of functional modules is
31 interchangeably mountable in the receptacles.

32
33 Embodiments of the second aspect of the invention may include one or more features of
34 the first aspect of the invention or its embodiments, or vice versa.

1 According to a third aspect of the invention, there is provided a method of extracting
2 energy from an underwater flow stream in a body of water, using the system according to
3 the first aspect of the invention.

4
5 Embodiments of the third aspect of the invention may include one or more features of the
6 first or second aspects of the invention or their embodiments, or vice versa.

7
8 According to a fourth aspect of the invention, there is provided a method of servicing an
9 energy extraction system for an underwater flow stream in a body of water comprising:
10 providing the system according to the first aspect of the invention on the bed of a body of
11 water;
12 accessing a receptacle on the support frame; and
13 releasing a vertical axis turbine unit or a functional module from the receptacle.

14
15 The method may comprise accessing the receptacle through a hatch positioned above the
16 receptacles.

17
18 The method may comprise releasing a vertical axis turbine unit or a functional module from
19 the receptacle manually or via a control module.

20
21 The method may comprise installing a vertical axis turbine unit or a functional module in
22 the receptacle.

23
24 Embodiments of the fourth aspect of the invention may include one or more features of the
25 first to third aspects of the invention or their embodiments, or vice versa.

26
27 According to a fifth aspect of the invention, there is provided a modular system for the
28 extraction of energy from an underwater flow stream in a body of water, the system
29 comprising:

30 a support frame comprising a plurality of receptacles for mounting functional modules on
31 the support frame, the plurality of receptacles arranged to form a horizontally-distributed
32 two-dimensional array on the support frame;

33 a plurality of vertical axis turbine units; and

34 a plurality of functional modules;

1 wherein the plurality of vertical axis turbine units and the plurality of functional modules are
2 interchangeably mountable in the receptacles.

3
4 Embodiments of the fifth aspect of the invention may include one or more features of the
5 first to fourth aspects of the invention or their embodiments, or vice versa.

6
7 According to a sixth aspect of the invention, there is provided apparatus for the extraction
8 of energy from an underwater flow stream in a body of water, the apparatus comprising:

9 a support frame;

10 a plurality of vertical axis turbines mounted on the support frame;

11 and wherein the support frame and plurality of vertical axis turbines form an integrated
12 assembly configured to be towed to an installation and/or lowered to the bed of the body of
13 water;

14 and wherein the plurality of vertical axis turbines forms a horizontally distributed two-
15 dimensional array on the support frame.

16
17 The plurality of vertical axis turbines may be arranged substantially in a horizontal plane.

18 Alternatively, the plurality of vertical axis turbines may be arranged with a subset of the
19 vertical axis turbines vertically offset with respect to others of the plurality of vertical axis
20 turbines. A first subset of the plurality of vertical axis turbines may be arranged

21 substantially in a first horizontal plane, a second subset of the plurality of vertical axis
22 turbines may be arranged substantially in a second horizontal plane, offset from the first
23 horizontal plane. The axial dimensions of the subset of vertically offset vertical axis

24 turbines may be arranged to overlap with the axial dimensions of others of the vertical axis
25 turbines; in other words, two offset subsets may intersect the same horizontal plane.

26 Alternatively, offset turbines may be arranged with no axial overlap.

27
28 Preferably the apparatus comprises at least one flow deflector assembly operable to
29 controllably adjust the flow into or out of the array of vertical axis turbines.

30
31 Embodiments of the sixth aspect of the invention may include one or more features of the
32 first to fifth aspects of the invention or their embodiments, or vice versa.

33

1 According to a seventh aspect of the invention, there is provided a method of extracting
2 energy from an underwater flow stream in a body of water using the apparatus according
3 to the sixth aspect of the invention.

4
5 Embodiments of the seventh aspect of the invention may include one or more features of
6 the first to sixth aspects of the invention or their embodiments, or vice versa.

7
8 According to an eighth aspect of the invention, there is provided a method of installing
9 apparatus for the extraction of energy from an underwater flow stream in a body of water,
10 the method comprising:

11 providing an apparatus comprising an integrated assembly having support frame and a
12 plurality of vertical axis turbines mounted on the support frame in a two-dimensional array
13 on the support frame;
14 lowering the integrated assembly configured to the bed of the body of water and locating
15 the apparatus on the seabed such that the two dimensional array is substantially
16 horizontally distributed in an underwater flow stream.

17
18 Embodiments of the eighth aspect of the invention may include one or more features of the
19 first to seventh aspects of the invention or their embodiments, or vice versa.

20
21 According to a ninth aspect of the invention, there is provided apparatus for the extraction
22 of energy from an underwater flow stream in a body of water, the apparatus comprising:
23 a support frame;
24 a plurality of vertical axis turbines mounted on the support frame;
25 wherein the plurality of vertical axis turbines forms a horizontally distributed two-
26 dimensional array on the support frame;
27 and wherein the apparatus comprises at least one flow deflector assembly operable to
28 controllably adjust the flow into or out of the array of vertical axis turbines.

29
30 The apparatus may comprise a plurality of flow deflector assemblies oriented across a
31 plurality of sides of the support frame, and/or the at least one flow deflector assembly may
32 be oriented substantially parallel to a side of the support frame.

33 At least one flow deflector assembly may be movable between a closed position and an
34 open position, and may be movable to a number or range of intermediate positions
35 between the closed position and the open position.

1 Preferably, the at least one flow deflector assembly is operated in dependence on a
2 control signal from a control module of the apparatus. The control module may generate
3 the control signal in dependence on acquired flow condition and/or operational data. The
4 acquired flow condition and/or operational data may comprise data selected from one or
5 more of: flow velocity; rotational speed; torque; vibration data; and energy output.

6
7 Preferably, the at least one flow deflector assembly comprises a plurality of deflector
8 members. The plurality of deflector members may comprise deflector members oriented
9 substantially parallel to a side of the support frame. The plurality of deflector members
10 may comprise deflector members oriented substantially horizontally.

11
12 The plurality of deflector members may comprise deflector members operable to be moved
13 independently of one another and/or may comprise deflector members operable to be
14 moved in opposing senses.

15
16 Alternatively or in addition, the plurality of deflector members may comprise deflector
17 members operable to be moved in the same sense.

18
19 Preferably, the plurality of deflector members have movable horizontal angular positions.

20
21 Alternatively or in addition, the at least one flow deflector assembly may be operable to
22 direct the flow entering or leaving the array to a different vertical flow position.

23
24 Preferably, the at least one flow deflector assembly is operable to shut off the flow entering
25 or leaving the array, and may be operable to shut off the flow entering or leaving the array
26 in response to a control signal from the control module.

27
28 The at least one flow deflector assembly may comprise a failsafe close mechanism, which
29 may be actuated if the flow stream exceeds a velocity threshold.

30
31 Preferably, the support frame and plurality of vertical axis turbines form an integrated
32 assembly configured to be towed to an installation and/or lowered to the bed of the body of
33 water. More preferably, the plurality of vertical axis turbines is arranged substantially in a
34 horizontal plane.

1 The plurality of vertical axis turbines may be arranged with a subset of the vertical axis
2 turbines vertically offset with respect to others of the plurality of vertical axis turbines.

3
4 The support frame may comprise a plurality of receptacles for mounting functional
5 modules on the support frame, and/or the plurality of vertical axis turbine units may be
6 configured to be interchangeably mounted in the receptacles.

7
8 Embodiments of the ninth aspect of the invention may include one or more features of the
9 first to eighth aspects of the invention or their embodiments, or vice versa.

10
11 According to a tenth aspect of the invention, there is provided a method of extracting
12 energy from an underwater flow stream in a body of water, the method comprising:
13 providing an apparatus comprising a support frame and a plurality of vertical axis turbines
14 mounted on the support frame in a horizontally distributed two-dimensional array on the
15 support frame;
16 operating at least one flow deflector assembly disposed on the apparatus to controllably
17 adjust the flow into or out of the array of vertical axis turbines.

18
19 The method may comprise moving the at least one flow deflector assembly between a
20 closed position and an open position, and may comprise moving the at least one flow
21 deflector assembly to at least one of number or range of intermediate positions between
22 the closed position and the open position.

23
24 The method may comprise operating the at least one flow deflector in dependence on a
25 control signal from a control module of the apparatus, and may further comprise
26 generating the control signal in dependence on acquired flow condition and/or operational
27 data.

28
29 The acquired flow condition and/or operational data may comprise data selected from one
30 or more of: flow velocity; rotational speed; torque; vibration data; and energy output.

31
32 The acquired flow condition and/or operational data may comprise temperature data.

33
34 Preferably, the at least one flow deflector assembly comprises a plurality of deflector
35 members, and method may comprise operating the plurality of deflector members
36 independently of one another.

1 The method may comprise moving the plurality of deflector members in opposing senses.

2
3 The method may comprise moving the horizontal angular position of the plurality of
4 deflector members.

5
6 Preferably, the method comprises directing the flow entering or leaving the array to a
7 different vertical flow position.

8
9 The method may comprise shutting off the flow entering or leaving the array, and may
10 comprise shutting off the flow entering or leaving the array in response to a control signal
11 from the control module. The method may comprise shutting off the flow entering or
12 leaving the array by actuation of a failsafe close mechanism.

13
14 Embodiments of the tenth aspect of the invention may include one or more features of the
15 first to ninth aspects of the invention or their embodiments, or vice versa.

16
17
18 Brief description of the drawings

19
20 There will now be described, by way of example only, various embodiments of the
21 invention with reference to the drawings, of which:

22
23 Figure 1A is a side view of a tidal power generation apparatus according to an
24 embodiment of the invention from a first elevation;

25
26 Figure 1B is a side view of the tidal power generation apparatus of Figure 1A from a
27 second elevation;

28
29 Figure 1C is a top view of the tidal power generation apparatus of Figures 1A and 1B;

30
31 Figure 1D is a perspective view of the tidal power generation apparatus of Figures 1A to
32 1C;

33
34 Figure 2 is a perspective view of the tidal power generation apparatus of Figure 1 with top
35 plate and flow shutters omitted for clarity;

Figure 3 is a perspective view of the base frame and protective frame of the tidal power generation apparatus of Figure 1;

Figure 4 is a perspective view of vertical axis turbine unit of the tidal power generation apparatus of Figure 1;

Figure 5 is a sectional view of an upper bearing assembly of a turbine unit in accordance with the embodiment of Figure 1; and

Figure 6 is an enlarged isometric view of the apparatus 10 showing deflector assemblies in more detail.

Detailed description of preferred embodiments

Referring firstly to Figures 1A, 1B, 1C, 1D and 2, there is represented a tidal power generation apparatus generally depicted at 10. Figures 1A to 1D show the apparatus 10 respectively from a first side elevation, a second side elevation, a plan view, and an isometric view. Figure 2 is an isometric view of the apparatus 10 having a top plate and deflector assemblies omitted to improve clarity of other components.

The apparatus 10 is anchored to the seafloor by three suction cans 11, which are designed to secure the apparatus and provide the required resistance to the loads experienced by the system in operation (such as drag forces, hydrostatic and hydrodynamic forces). It will be appreciated that other foundation systems can be used without departing from the principles of the invention (alternatively or in combination with the suction cans), including for example piles, mudmats, seabed penetrating skirts, or gravity bases as are known in the art.

The three suction cans 11 provide support for a frame 12 upon which a two-dimensional array 13 of modular vertical turbine units 20 is mounted. The frame 12, as most clearly shown in Figure 3, comprises a base frame 14 made of steel pipe segments bolted onto the suction cans 11 (although other fixing methods can also be used, such as welding or riveting). The base frame 14 has the general shape of an equilateral triangle with apexes truncated parallel to the opposing sides, and supports ten circular receptacles or hubs 16 upon which the modular vertical turbine units 20 are mounted. Adjacent to each side of

1 the triangular-shaped base are three receptacles or hubs 16, and in the centre of the
2 truncated triangular base there is one receptacle 16. The receptacles are interconnected
3 by steel pipe segments welded to the receptacles. It will be appreciated that other base
4 frame shapes, numbers or arrangements of receptacles and construction methods are
5 feasible without departing from the principles of the invention.

6
7 To improve the resistance of the apparatus 10 to trawler equipment (i.e. to facilitate
8 making the apparatus overtrawlable), the frame 12 also comprises a protective frame 18,
9 also made of welded steel pipe segments (as shown in Figure 3), and welded to the
10 perimeter of the base frame 14. The upper part 19 of the protective frame is substantially
11 the same shape as and concentric with the base frame 14, but is smaller in size. Outer
12 upright members 22 in the protective frame 18 are angled inwards in a direction upwards
13 from the base frame to the upper part 19 of the protective frame. The upper part 19 of the
14 protective frame 18 comprises a central ring 24 of steel pipe connected by steel pipe
15 segments. In use therefore, the frame 12 comprises a support structure and protective
16 surround for the two-dimensional array 13 of modular vertical turbine units 20.

17 The frame 12 also comprises support for substantially vertical planar flow deflectors 34
18 extending outwardly from each truncated corner and attached directly to the frame 12.
19 The flow deflectors 34 serve to direct the incoming tidal flow towards the turbine array 13.
20 The deflectors 34 have one spiked end pointing towards the seafloor, which penetrates the
21 seafloor when the apparatus 10 is anchored to the seafloor. The upper edges of the
22 deflectors 34 provide a surface over which trawling fishing gear can easily slide up and
23 pass over the tidal power generation system 10 without damaging the turbines or
24 becoming entangled with the system. Therefore, the tidal power generation system 10 can
25 be located in fishing sea areas too and is compatible with the fishing industry. One of the
26 deflectors 34 comprises a tow hole or tow point 24 in its reinforced portion 22.

27
28 In this example, three flow deflectors are provided but in alternative embodiments a lesser
29 or greater number of flow deflectors may be provided. Other forms of flow deflectors may
30 be used in alternative embodiments. For example, alternatives to the spikes may be used
31 depending on soil conditions, ease of penetration or potential for scouring. Further
32 alternative embodiments of the invention may comprise pivoting mounts for the planar
33 vertical flow deflectors 34, for example on the suction cans or other foundation points,
34 which enable selective channelling of the flow stream towards a particular side of the
35 array.

1 The apparatus 10 also comprises a top plate 30, which provides additional protection for
2 the array of turbines against dropped objects and fishing equipment, and additional
3 support for the turbines. The top plate 30 comprises a turbine hatch 32 located above each
4 turbine which enables access to the vertical turbine units 20. Optionally, the top of the
5 frame 18 is provided with an interface (not shown) for a tooling package to aid turbine
6 installation, retrieval and maintenance.

7
8 Mounted on the outside of the frame 12 are horizontally oriented deflector assemblies 40,
9 which comprise deflector members 42 substantially parallel to the perimeter of the base
10 frame 14. The deflector members 42 are movable between closed and open configurations
11 to enable the deflectors to modify the fluid flow entry into the apparatus as will be
12 described below.

13
14 The apparatus 10 is rendered positively buoyant during towing of the apparatus to an
15 offshore location. Buoyancy is provided by the hollow pipe segments that form the frame
16 12, and additional buoyancy is provided where required by floodable buoyancy chambers
17 (not shown). Other detachable buoyancy elements could also be provided, such as
18 syntactic foam floaters. Buoyancy of the apparatus feature permits an easier deployment
19 of the tidal power generation system 10 in a single vessel trip to the deployment location,
20 by a towing and sinking procedure, as is known in the art of subsea engineering.
21 Significantly, the installation of the apparatus 10 may be performed without requiring a
22 heavy-lift vessel.

23
24 Figure 4 is an isometric view of a modular vertical turbine unit 20 as used in the apparatus
25 of Figures 1 and 2. The turbine unit 20 of Figure 4 is of the helical Darrieus type. The
26 turbine unit of this embodiment has three vertically extending blades 52, each with an
27 asymmetric hydrofoil profile, each having a helical twist of sixty degrees. The blades 52
28 are 120 degrees from one other. This blade configuration is selected to distribute the
29 torque evenly over a whole turbine revolution, reducing the effects of pulsing. The blades
30 52 are connected to a turbine shaft 54 by three equally vertically spaced apart sets of
31 radial arms 56. It will be appreciated that this is just one example of a turbine type that
32 may be used with the invention.

33
34 At a lower end of the turbine shaft 54 is a pressurised compartment 58, fluidly sealed to
35 avoid water ingress. The compartment 58 houses a gearbox and an electrical generator

unit (not shown), coupled to the turbine shaft 54. Each turbine unit therefore comprises its own generator equipment and gearbox (where necessary).

The pressurised compartment is shaped and sized to fit within a receptacle 16 of the base frame 12 of the apparatus. Each receptacle therefore provides a turbine interface cell.

The turbine units 20 are preferably standardised modules which can be fitted into any one of the receptacles 16, and therefore the units are modules which can be positioned in the frame interchangeably and according to system requirements.

Each turbine unit is mounted into a receptacle 16 of the base frame by a suitable quick connector (not shown) which enables fast and reliable attachment/detachment of the turbine to/from the base frame receptacles 16. Although mechanical connectors may be used in alternative embodiments, the quick connectors are preferably operable by fluid pressure. The quick connector comprises upper and lower connector assemblies secured to the turbine unit and receptacle respectively. The upper and lower connector assemblies are brought together, and when coupled, the connector assemblies define a fluid chamber disposed between the upper and lower connector assemblies. A fluid conduit system connected to the suction pump 33 (Figure 1B) and valve-controlled flowline arrangement to each of the receptacles enables the controlled flow of fluid into and/or out of the fluid chamber, to reduce the pressure and load the connector system together. The suction pump 33 therefore provides a low pressure volume which secures the unit into a receptacle. Fluid can be pumped back into the fluid chamber between the upper and lower connector assemblies to release or eject the turbine unit 20 from the receptacle.

At an upper end 59 of the turbine unit 20, the shaft 54 is connected to a circular bearing assembly 60, which is configured to be mounted into the frame 12 and top plate 30 of the apparatus. Figure 5 is a sectional view through the bearing arrangement 60 in situ in the apparatus (showing elements of the upper part of the frame 18). The shaft 54 extends into a turbine top plate 62, and a bearing ring 64 is located between the shaft and the turbine top plate. The shaft 54 rotates with respect to the turbine top plate 62, which is fixed with respect to the frame 18 and top plate 30. A load ring 66 distributes the load of the turbine unit 20 through the apparatus.

With the turbine units 20 mounted in the receptacles 16, the compartments 58 are electrically connected by an electrical penetrator into a system of electrical conductors (not

shown) in the apparatus 10. The electrical conductors are configured for the transfer of electrical energy from each unit to a common wet-mate connector, shown at 35 on Figure 1A. The wet-mate connector 35 enables the apparatus to be connected to the electrical grid via a single umbilical (not shown) and an on-shore electrical sub-station.

Anodes 37 are provided on the apparatus 10 and form part of a corrosion protection system as is known in the art.

Figure 6 is an isometric view of the apparatus 10 showing the features of the deflector assemblies 40 in more detail. Each deflector assembly 40 comprises deflector members 42 substantially parallel to the perimeter of the base frame 14 which are movable between closed and open configurations to enable the deflectors to modify the fluid flow entry into the apparatus. The deflector members 42 are pivotally mounted about pivots fixed to uprights 22 of the frame 12. Deflector assemblies 40a extend across substantially the whole the long sides of the frame, and deflector assemblies 40b are disposed in the short sides of the frame 12 between the uprights 22 and the deflectors 34.

Movement of the deflector members is controlled by electric servomotors operated from a control module on the apparatus 70. The position of the deflector members is optimised by the control module 70 according to the energy generation from the system in particular flow conditions. The control module 70 receives data from each of the modular vertical turbines, such as rotational speed and/or energy output, and adjusts the angular deflection of each deflector member in order to obtain an improved energy output.

Each deflector member 42 is capable of being adjusted independently of the others, and may be rotated in the same sense or the opposite sense as other deflectors in the same assembly. Opposing rotation may tend to cause convergence of the flow in a vertical direction, whereas in other flow conditions divergence or laminar deflection may be preferred.

By adjusting the horizontal angular position of the deflector assemblies, the vertical position of the inflow and outflow of the apparatus can be adjusted to direct the flow to the appropriate vertical position of the turbines for preferred operation of the system. The fluid flow can be directed to the turbines at a particular horizontal plane of attack. While in many cases this may be for optimum energy output, this need not be optimal for all turbine

1 units in the system. The flow regime around the turbine units in the array is complex, and
2 depending on the flow conditions, it may be preferable to reduce energy output from a
3 particular turbine unit to generate more energy output from the array as a whole. There
4 may also be other considerations which require control or restriction of the flow, for
5 example, to keep the turbines operating below an upper operational threshold in high flow
6 and/or flow demand conditions.

7
8 The deflector members are automatically positioned to direct the fluid flow to the desired
9 area in the turbine array. The position of the shutters can also be controlled manually,
10 without automatic control, for example in situations when the control module 70 is not
11 operative.

12
13 The deflector member may also be closed completely to shut off flow into or out of the
14 apparatus along one or more of the sides of the apparatus. Shutting off the flow may be
15 desirable in high or turbulent flow conditions, for example to protect the apparatus.
16 Moderating or reducing the fluid flow entering the turbine space may reduce or eliminate a
17 requirement for turbine brakes. Instead of shutting of the flow completely, one or more of
18 the deflector members may be partially closed to restrict or choke the flow through the
19 apparatus. In one embodiment, the deflector assemblies are configured to have a passive
20 failsafe close feature, which is actuated if the flow stream exceeds a velocity threshold. In
21 extreme flow conditions, the flow deflectors are closed to shut-off the flow and protect the
22 turbine array from damage.

23
24 Variations to the above-described deflector assemblies are within the scope of the
25 invention. For example, although the apparatus 10 comprises horizontally oriented flow
26 deflector assemblies, in alternative embodiments the apparatus may comprise one or
27 more vertically oriented flow deflector assemblies, which operate according to the same
28 principles as the horizontal deflector assemblies to direct the fluid flow to the desired area
29 in the turbine array. Alternatively or in addition, the positioning of the deflector assemblies
30 could be controlled by hydraulic or mechanical means, rather than the electrical servo
31 motors described above. The shapes of the deflector members need not be straight and
32 need not be regular; curved or other complex shapes may be used to form the deflector
33 assemblies.

34

1 The provision of deflector assemblies enables the apparatus to be operable in a wider
2 envelope of tidal stream speeds. For example, at low tidal stream speeds the shutters can
3 be positioned so as to focus and increase the speed of tidal stream in a particular
4 horizontal plane. When high tidal stream speeds occur, the flow deflectors can distribute
5 the stream over the whole height of the apparatus and deflect some of the stream away
6 from the turbine space, so that the turbines do not rotate above their operational
7 parameters (thus eliminating the need for turbine braking). This increased operational
8 flexibility allows the apparatus 10 to be situated in a wide range of locations, for example in
9 rivers and estuaries, including those which are close to where the energy demand is
10 greatest. By placing the apparatus in offshore locations close to the energy demand, the
11 need for expensive and lengthy power umbilicals may also be reduced. The apparatus
12 may also be functional in low speed tidal areas, where its deployment is likely to be
13 operationally more straightforward (due to the favourable flow conditions) and more
14 economical. The flow deflector assemblies also provide protection against debris in the
15 flow stream when in their open condition (against objects larger than the spaces between
16 the flow deflectors) or when closed (e.g. when it is known or thought that there is a risk of
17 debris damage).

18
19 Prior to use, the apparatus will be configured onshore or at an offshore facility by
20 assembling the frame 12 with the foundation structure and the turbine units 20. The
21 apparatus will be designed and assembled according to the requirements of the specific
22 location in which it is to be deployed. Turbine units 20 will be installed in the receptacles
23 16 of the frame 12 prior to towing and deployment of the apparatus to the installation
24 location, and the electrical penetrators will be connected to couple each turbine unit into
25 the electrical transmission infrastructure of the apparatus. The turbine units 20 are
26 interchangeable in the receptacles 16, and therefore the apparatus forms a modular
27 system comprising the support structure and the turbine units.

28
29 The frame 12 of the apparatus 10 comprises ten receptacles, but it is not necessary for
30 each receptacle to have a turbine unit installed in it. In some applications, one or more
31 receptacles 16 may comprise modules which perform energy storage function or contain
32 some other type of subsea equipment. For example, an accumulator cell module may be
33 located in a receptacle of the apparatus instead of a turbine unit. The accumulator may be
34 charged by energy generated by the turbine units of the apparatus, and may be used to
35 provide a power source for nearby subsea equipment. Alternatively (or in addition) a

receptacle may provide a mounting point for a hydrogen fuel cell, which is driven by operation of the turbine units to store energy for subsequent use. Alternatively (or in addition) a receptacle may provide a mounting point for a subsea control module.

Whatever function the modules perform, they are conveniently installed as interchangeable modules in the apparatus 10.

After assembly of the apparatus in the desired configuration, the apparatus is rendered positively or neutrally buoyant to enable it to be towed to an offshore location and lowered to a seabed location on which it is installed. With the apparatus secured to the seabed, the wet-mate connection of the subsea umbilical is made up to connect the apparatus to power transmission infrastructure. Alternatively, if it did not prevent successful deployment of the apparatus, the electrical connection could be fully made up at surface. In alternative configurations, a number of apparatus 10 may be connected together to "daisy chain" the apparatus 10 into a larger array.

In use, the deflector assemblies 40 of the apparatus are opened to expose the turbine units of the apparatus to the tidal flow stream and cause rotation of the turbines and extraction of energy from the flow stream. As noted above, the energy generated by the apparatus is monitored by the control module, and the positions of the deflector assemblies are manipulated by the servo motors to optimise the flow into and out of the apparatus. The modular nature and flexible configuration of the apparatus 10 means that in different applications the two-dimensional array of the apparatus may be configured differently (i.e. with turbine modules in different locations and energy storage modules in different locations in the array). The deflector assemblies 40 enable the flow to be optimised according to the specific flow conditions, and the specific configuration of the apparatus.

After a period of use it may be necessary to remove, replace or service a module from the apparatus 10. The configuration of the above-described embodiment facilitates access to the individual modules of the apparatus 10 via the hatches 32 positioned above the receptacles 16. A hatch 32 is opened by a diver or remotely operated vehicle (ROV), and the turbine unit (or other module) is released from the receptacle in which it is located manually or via the control module 70 (which may be activated by a remote signal received by the control module 70). The module to be removed can easily be extracted from the

1 apparatus via the hatch, for example by lifting it using an ROV or cable from surface, or by
2 attaching it to a controllable buoyancy apparatus to allow it to be recovered to surface. A
3 module (e.g. a new or recently serviced turbine unit) may be installed in the apparatus 10
4 via the hatch 32. Advantageously, an individual module may be removed and/or installed
5 in the apparatus without disrupting the installation or operation or other modules forming a
6 part of the apparatus. Optionally, the deflector assemblies may be closed while removal
7 and/or replacement is being completed, to isolate the operation from the surrounding tidal
8 regime, increasing the operational envelope for completing the task.

9
10 The invention provides a system for the extraction of energy from an underwater flow
11 stream in a body of water. The system comprises a support frame which comprises a
12 plurality of receptacles for mounting functional modules on the support frame. The plurality
13 of receptacles are arranged to form a horizontally-distributed two-dimensional array on the
14 support frame. The plurality of vertical axis turbine units is configured to be
15 interchangeably mounted in the receptacles.

16
17 The invention also provides apparatus for the extraction of energy from an underwater flow
18 stream in a body of water and a method of use. The apparatus comprises a support frame
19 and a plurality of vertical axis turbines mounted on the support frame. The support frame
20 and plurality of vertical axis turbines form an integrated assembly configured to be towed
21 to an installation and/or lowered to the bed of the body of water, and the plurality of vertical
22 axis turbines forms a horizontal two-dimensional array on the support frame. In a
23 preferred embodiment, the apparatus comprises at least one flow deflector assembly
24 operable to controllably adjust the flow into or out of the array of vertical axis turbines.

25
26 Various modifications to the above-described embodiments may be made within the scope
27 of the invention, and the invention extends to combinations of features other than those
28 expressly claimed herein.

1 Claims:

- 2
- 3 1. A system for the extraction of energy from an underwater flow stream in a body of
4 water, the system comprising:
5 a support frame comprising a plurality of receptacles for mounting functional
6 modules on the support frame, the plurality of receptacles arranged to form a
7 horizontally-distributed two-dimensional array on the support frame; and
8 a plurality of vertical axis turbine units configured to be interchangeably mounted in
9 the receptacles.
- 10
- 11 2. The system according to claim 1, comprising at least one functional module
12 configured to be interchangeably mounted in the receptacles.
- 13
- 14 3. The system according to claim 1 or claim 2, wherein the plurality of vertical axis
15 turbine units is arranged substantially in a horizontal plane.
- 16
- 17 4. The system according to claim 1 or claim 2, wherein the plurality of vertical axis
18 turbines is arranged with a subset of the vertical axis turbines vertically offset with
19 respect to others of the plurality of vertical axis turbines.
- 20
- 21 5. The system according to any preceding claim, wherein one or more receptacles
22 comprises an energy storage module.
- 23
- 24 6. The system according to any preceding claim, wherein one or more receptacles
25 comprises an accumulator cell module.
- 26
- 27 7. The system according to any preceding claim, wherein one or more receptacles
28 comprises a hydrogen fuel cell module.
- 29
- 30 8. The system according to any preceding claim, wherein one or more receptacles
31 comprises a control module.
- 32
- 33 9. The system according to any preceding claim wherein the support frame and
34 plurality of vertical axis turbines units form an integrated assembly configured to be
35 towed to an installation and/or lowered to the bed of the body of water.

1

2 10. The system according to any preceding claim wherein each turbine unit comprises a
3 turbine shaft and wherein a pressurised compartment is located at a lower end of the
4 turbine shaft.

5

6 11. The system according to claim 10 wherein the pressurised compartment is fluidly
7 sealed and houses a generator unit.

8

9 12. The system according to claim 11 wherein the pressurised compartment houses a
10 gear box.

11

12 13. The system according to claim 11 or claim 12 wherein the pressurised compartment
13 fits within the receptacle of the support frame.

14

15 14. The system according to any preceding claim, wherein each turbine unit is mounted
16 into a receptacle by a quick connector.

17

18 15. The system according to claim 14, wherein the quick connector is operable by fluid
19 pressure.

20

21 16. The system according to any preceding claim, wherein the system comprises at least
22 one flow deflector assembly operable to controllably adjust the flow into or out of the
23 array of vertical axis turbines.

24

25 17. The system according to any preceding claim, wherein the system comprises at least
26 one flow deflector assembly operable to direct the fluid flow to a desired area in the
27 turbine array.

28

29 18. The system according to claim 16 or claim 17, wherein the at least one flow deflector
30 assembly is operable to shut off the flow entering or leaving the array in response to
31 a control signal from a control module.

32

33 19. The system according to any of claims 16 to 18, wherein the at least one flow
34 deflector assembly comprises a failsafe close mechanism, which is operable to be
35 actuated if the flow stream exceeds a velocity threshold.

- 1
- 2 20. The system according to any of claims 16 to 19, wherein the at least one flow
3 deflector assembly is a horizontally oriented flow deflector assembly.
4
- 5 21. The system according to any of claims 16 to 19, wherein the at least one flow
6 deflector assembly is a vertically oriented flow deflector assembly.
7
- 8 22. The system according to any of claims 16 to 21, wherein the at least one flow
9 deflector assembly is configured to be operated in dependence on a control signal
10 from a control module of the apparatus.
11
- 12 23. The system according to claim 22, wherein the control module is configured to
13 generate the control signal in dependence on acquired flow condition and/or
14 operational data.
15
- 16 24. The system according to claim 23, wherein the acquired flow condition and/or
17 operational data comprises data selected from one or more of: flow velocity;
18 rotational speed; torque; vibration data; and energy output.
19
- 20 25. The system according to claim 23 or claim 24, wherein the acquired flow condition
21 and/or operational data comprises temperature data.
22
- 23 26. A method of assembling a system for the extraction of energy from an underwater
24 flow stream in a body of water, the method comprising:
25 providing a support frame comprising a plurality of receptacles for mounting
26 functional modules on the support frame, the plurality of receptacles arranged to
27 form a horizontally-distributed two-dimensional array on the support frame;
28 mounting a plurality of vertical axis turbine units or a plurality of vertical axis turbine
29 units and one or more functional modules in the receptacles;
30 wherein the plurality of vertical axis turbine units and/or plurality of functional
31 modules is interchangeably mountable in the receptacles.
32
- 33 27. A method of extracting energy from an underwater flow stream in a body of water,
34 using the system according to any one of claims 1 to 25.
35

- 1 28. A method of servicing an energy extraction system for an underwater flow stream in
2 a body of water comprising:
3 providing the system of any of claims 1 to 25 on the bed of a body of water;
4 accessing a receptacle on the support frame; and
5 releasing a vertical axis turbine unit or a functional module from the receptacle.
6
- 7 29. The method according to claim 28 comprising accessing the receptacle through a
8 hatch positioned above the receptacles.
9
- 10 30. The method according to claim 28 or 29 comprising releasing a vertical axis turbine
11 unit or a functional module from the receptacle manually or via a control module.
12
- 13 31. The method according to any of claims 28 to 30 comprising installing a vertical axis
14 turbine unit or a functional module in the receptacle.
15
- 16 32. A modular system for the extraction of energy from an underwater flow stream in a
17 body of water, the system comprising:
18 a support frame comprising a plurality of receptacles for mounting functional
19 modules on the support frame, the plurality of receptacles arranged to form a
20 horizontally-distributed two-dimensional array on the support frame;
21 a plurality of vertical axis turbine units; and
22 a plurality of functional modules;
23 wherein the plurality of vertical axis turbine units and the plurality of functional
24 modules are interchangeably mountable in the receptacles.
25
26