also represents a vertical depth datum point from which variations in wave crests or troughs can be measured.

Aspects, features, and advantages of this disclosure will become apparent from the following detailed description when taken in conjunction with the accompanying drawings, which are a part of this disclosure and which illustrate, by way of example, principles of any inventions disclosed.

Description of the Figures

The accompanying drawings facilitate an understanding of the various embodiments which will be described:

Figure 1 is a side, cross-sectional view of an apparatus for extracting energy from an oscillating fluid, such as a wave from a body of water, in accordance with a first embodiment of the present disclosure, showing that as the profile of the local waves rise, the OWC level rises within a duct located in a housing;

Figure 2 is the same view as Figure 1, being a side, cross-sectional view of an apparatus for extracting energy from an oscillating fluid, such as a wave from a body of water, in accordance with the first embodiment of the present disclosure, showing that a falling profile of the local waves draws the oscillating water column outward from the duct within the housing;

Figure 3 is a dotted-outline cross-sectional side view of the apparatus shown in Figure 1 and in Figure 2, with part of the housing shown arranged in use substantially submerged below the mean surface level (MSL) of a body of water in which it is located, and having a sloping exterior surface at the base of the housing, for resting on the sand and rock base at a shoreline, with an elongate axis of the apparatus being oriented generally orthogonal to that shoreline,

Figure 4A to 4E are views of the exterior of the apparatus shown in Figure 1 and in Figure 2, where Figure 4A is a plan elevation view; Figure 4B is a left hand side

elevation view; Figure 4C is an end elevation view showing the entry and exit opening for the waves to enter and leave the housing, and form an OWC therein, in use; Figure 4D is an end elevation, underside perspective view; and Figure 4E is an end elevation, topside perspective view,

Figure 5A to 5G are views of the exterior of the apparatus shown in Figure 1 and in Figure 2, but in this example, the housing is fitted with flotation aids in the form of twin elongate tanks 70 which in use are filled with air and sealed, to provide sufficient buoyance to transport the assembled apparatus by acting as flotation aids, secured by releasable coupling onto both of the opposing, elongate exterior side walls of the housing; Figure 5A is a plan elevation view; Figure 5B is a left hand side elevation view; Figure 5C is an end elevation view showing the entry and exit opening for the waves to enter and leave the housing, and form an OWC therein, in use; Figure 5D is an end elevation, underside perspective view; and Figure 5E is an end elevation, topside perspective view; Figure 5F is an end elevation, underside perspective view in which the entry and exit opening for the waves to enter and leave the housing is closed by a removable door; and Figure 5G is an end elevation, topside perspective view, in which the entry and exit opening is closed by a removable door;

Figure 6A to 6C are views of two guide vanes in the form of curved planar fins which bridge the interior side walls of a curved end region of a turbine housing which is located adjacent to the upper entry of the duct located in the housing, the vanes positioned mid-stream in the axial direction of flow of air exiting the turbine in use; Figure 6A is a side, partially cross-sectioned view of the vanes in the curved end region; Figure 6B is an end side, partially cross-sectioned view of the curved end region; and Figure 6C shows an upper, perspective view of the two guide vanes in position, with the curved end region shown in phantom outline;

Figure 7A and 7D are more detailed views of the two guide vanes shown in Figure 6A to Figure 6C, but drawn as if the vanes are transparent; Figure 7A is a top plan view of the two vanes; Figure 7B is a side elevation view of the two vanes; Figure 7C shows a top, perspective view of the two guide vanes; and Figure 7D is an end elevation view of the two vanes when looking in a direction toward the air turbine;

Figure 8 is a view of the exterior of the apparatus shown in Figure 4E which is an end elevation, topside perspective view of an apparatus for extracting energy from an oscillating fluid, in accordance with an embodiment of the present disclosure, showing that the duct can become partially submerged by flooding the two side buoyancy tanks by pumping water via various flexible conduits which are shown located on the OWC housing;

Figure 9 is a view of the exterior of the apparatus shown in Figure 5E which is an end elevation, topside perspective view of an apparatus for extracting energy from an oscillating fluid, in accordance with an embodiment of the present disclosure, showing that the duct can become partially submerged by flooding the two side buoyance tanks by pumping water into various fixed conduits which are located within each tank interior.

Figure 10 is a side, cross-sectional view of the apparatus shown in Figure 1 and Figure 2, and in Figure 5F in an end elevation, underside perspective view, showing further detail of a sloping exterior surface of the base of the apparatus;

Figures 11A and 11B each show a side elevation view of a rectangular metal frame which supports spaced apart metal bars inset into a rectangular opening in the exterior wall of the second conduit to provide a supporting structure for a deformable flap in accordance with the embodiment the apparatus shown in Figure 5C.

Figures 12A and 12B each show a perspective view of a rectangular metal frame which supports spaced apart metal bars inset into a rectangular opening in the exterior wall of the housing, used to provide a supporting structure for a deformable flap in accordance with the embodiment the apparatus shown in Figure 5C.

Figure 13 is a schematic flow diagram, showing the details of a power generation and power offtake system which is used with the apparatus of Figure 1 and Figure 2, along with some written description of the steps for use of the apparatus which is shown in the flow diagram.

the efficiency and maximize the energy conversion of the turbine blades by minimising turbulence or drag forces at the tip of the turbine blades so as to maximise the effect of airflow rate on blade surfaces.

As is typical in turbines of this type, an electric generator is configured for rotation by the turbine to generate electrical energy, and is connected to the drive shaft of the turbine 44, via an inverter 84 and this has been explained in detail later in this specification.

In addition to that, as shown in Figure 6, guide vanes have been introduced to the interior centre of the passage which is located between the turbine housing 54 and the flow passage 40. Figures 6A, 6B and 6C show different view of two guide vanes 60 which are shown in the form of curved planar fins which bridge the interior side walls 62, 64 of the curved end region 66 of the turbine housing 54 which is adjacent to the upper end of the flow passage 40. The guide vanes 60 are arranged to be positioned mid-stream in the axial direction of flow of the working fluid (air).

These guide vanes 60 function to reduce the turbulence of air flowing into the flow passage 40 during the downstroke interval (as the wave moves out of the OWC duct). During the downstroke interval, there is a rapid increase in the flowrate of air which is drawn into the flow passage 40 via the turbine 44, under that suction pressure. The aim of the guide vanes 60 is to streamline the flow of air as it turns and flows through a 90 angle degree change of direction, and as a result maximize the thrust energy being transferred onto the turbine 44 as the air is drawn past it, as well as to reduce frictional losses arising from turbulence.

As is shown in Figures 4C and 10, the uppermost region 36 of the second conduit 14 of the duct has fifteen rectangular openings 41 arranged in a grid, onto each of which is fitted a deformable flaps 38 are fitted in use as a closure. In other embodiments, more or less than this number of deformable flaps 38 can be installed at the time of the initial construction of the duct 10, depending on the location and expected ocean wave severity that will be encountered, being a design feature which can change the possible maximum venting ratio of the particular duct. In other embodiments, the type of one-way valve, closure or flap can also be varied, and also combinations of different types of one-way valves, closures or flaps are possible to be fitted onto each opening.

Once the repeated steps of opening the deformable flaps 38 as the wave enters the duct 10, followed by their closing and air being drawn into the second conduit 14 via the turbine 44 as the wave leaves the duct 10, have reached a stable pattern, the

While this is not a major issue when delivering energy into large mainland power grids, it can be an issue for microgrids (usually powered by clean and renewable energy), and for small and/or remote grids, such as those on islands and developing nations, where such an output is not a stable electrical power resource. Power quality problems have more impact on users who are linked to small, local or isolated power grids, and fluctuations in the electricity supply can cause equipment failures. Sensitive industrial loads and critical commercial operations can suffer greatly from outages and service interruptions, resulting in financial losses to both utility and consumers. In densely populated countries, depending on events which involve a mass of the population, there can be sudden swings in the grid load demand, and the gap between supply and demand have made the reliability and power quality a critical issue. Where power grids now have a greater reliance on some forms of alternative energy, and less base load sources, a grid can even become unstable.

The energy capture and conversion system (both hardware and software which controls it) is used to control the electrical energy output from the OWC unit. This is fundamental to the integration of the OWC with a customer power grid via a control system. Typically, the OWC turbine 44 will be connected to a motor 80 and drive 82, an electrical power generator 84 and various types of transformer 88, as shown in more detail in Figure 13 and described shortly. In the OWC of the present disclosure, the volume of working fluid (air) able to be drawn through the gas turbine will determine its rotational speed. The power output of a gas turbine is related to its rotational speed. A graph of the power output of the gas turbine over time during the downstroke interval (when a wave moves out of the interior of the OWC, in the second configuration) initially has a sinusoidal shaped form, reflecting an increase followed by a decrease in rotational speed of the turbine. The gas turbine is rotating in what is called the operating (or "running") mode. Subsequently, a graph of the power output of the turbine over time during the consecutive upstroke interval (when a wave passes into the interior of the OWC, in the first configuration) is flatline in its form, and reflects the constant, low, inertial rotational speed of the turbine, yielding a relatively low rate of power generation. The turbine is rotating in what is called the standby (or "coasting") mode of operation.

In a repetitive cycle, this type of power generation is known as "burst mode" power delivery. Power is the rate at which an amount of energy is delivered, and in the case of wave energy capture via a unidirectional turbine, the power output comes in

periodic, repeated bursts, with gaps in between of an equivalent period. Such variation in power output would not be suitable for the operation of most common electrical devices, and lighting etc., so an energy storage device can be implemented to buffer the gaps between the bursts in power output.

Improving the quality of power produced can be done with the help of energy storage devices such as supercapacitors 94 or other reactive power injection systems. Supercapacitors can be used to buffer those gaps in power output. These devices can be charged during those intervals when the turbine is operating at higher rotational speeds, when air is being drawn therethrough on the downstroke and excess power is being generated so that, during the upstroke interval which follows, when the turbine is only operating at its inertial speed of rotation and generating a low amount of power, these devices can then be discharged to deliver a burst of energy, to thereby elevate the output power level of the system, thus making the output power level more consistent over consecutive intervals (or first/second operating configurations).

Supercapacitors have the ability to store a large amount of energy, and to be recharged quite rapidly. Supercapacitors are useful through thousands of charge and discharge cycles. There are many types of supercapacitor becoming available with different materials to enhance the storage of energy, such as graphene, and cobalt-manganese oxide, and there are also possibilities to combine the storage capacity of batteries with that of supercapacitors.

Now with reference to the embodiment shown in Figure 1 and Figure 2, in use there is an OWC which moves in and out of the duct 10 which is located in the housing 15, and the oscillating working fluid which moves in and out of the flow passage 40, as the profile of the local waves rises, the OWC level rises within the duct 10 of the housing 15 to create a positive air pressure in the flow passage 40, which is located above the OWC. In the first operational configuration of the apparatus, this pressure is relieved via one-way flap valves 38 which are located int an upper, rear exterior wall of the housing 15. This manner of exhausting the positive pressure from the flow passage 40 has the consequence that it allows the gas turbine 44 to be of a design which can be operated unidirectionally. In the first operational configuration, the air turbine is rotating in the standby (or “coasting”) mode.

As the falling profile of the local waves leaves the shore, it draws the oscillating water column outward from the duct 10 within the housing 15, and an air pressure drop is created in the flow passage 40. To equalise the pressure with the atmospheric

pressure, the apparatus operates in the second configuration during which a differential pressure is present across the air-driven gas turbine 44. The gas turbine 44 is located in a turbine housing 54 which is connected to the flow passage 40. The differential pressure draws air through the gas turbine 44, resulting in its rotation, and air passes into the flow passage 40. The air turbine 44 is in the operating (or running) mode during the period when the OWC is drawn outward from the duct 10 within the housing 15, and retreats from the flow passage 40.

Reference is now made to Figure 13 which shows some of the power generation and power offtake details of the apparatus. The pneumatic power arising from air pressure acting on the gas turbine is capture by creating mechanical power in the form of air turbine torque. The air-driven turbine 44 is direct coupled to a 3-phase electric motor 80 that is controlled by an Active Front End (AFE) drive 82. An energy output inverter 84 which produces electrical power is connected to the rotating turbine 44 and the electric motor 80. There is an appropriate rotational speed to which the turbine 44 is driven by the electric motor 80. A typical operational rotational speed of 1000rpm is set through the power generation period at this stage.

The AFE drive 82 operates in a regenerative braking mode. The speed setpoint of the motor 80 by the AFE drive 82 is set below the value which would normally occur from the torque which drives such an air turbine in response to the air pressure differential when the OWC system is operating in the second configuration. In this way, the motor 80 and AFE drive 82 system actively opposes the mechanical power in form of the air turbine torque, which is created from the pneumatic power resulting from air pressure changes. The regenerative braking against the torque converts the mechanical energy of the gas turbine 44 into electrical energy (power) at the energy output inverter 84. A rechargeable energy storage device such as a DC Bus 86 is thus charged during rotation of the turbine 44 in the second configuration. Depending on the optimal operating band (based on sea and generation conditions) in one pilot plant example, the electric motor 80 can be driven by the AFE drive 82 to have a speed setpoint below the turbine 44 speed of between 5 RPM to 850 RPM. The AFE drive 82 will apply a constant braking force at a defined setting, and this braking force will cause a rise in the DC Bus 86 voltage.

Some suitable rechargeable energy storage devices (such as supercapacitors 94) can be charged during the intervals when the turbine 44 is operating at a higher

rotational speed, and then can be discharged to elevate the output power level of the system when the turbine 44 is operating at lower rotational speed when operating in the first configuration. As stated previously, a supercapacitor 94 is an enclosed capacitor unit that can rapidly store and discharge electrical power. A DC-DC converter 92 is used to reduce the DC Bus 86 voltage to the appropriate DC voltage for the supercapacitor 94. This module ensures that the supercapacitor 94 is charged and ready for generation.

The supercapacitor 94 Charge/Discharge flow setpoint is established during operation. A minimum starting charge must be achieved, then the supercapacitor operates between 20-80% of its State of Charge to prevent rising voltage on DC bus 86, and a shortening of the supercapacitor 94 lifespan.

The electrical discharge from this chargeable device 94 is used to maintain the export power at a desired constant value during the fluctuation of wave power coming into the system. In one example, the discharge electrical power of the supercapacitor 94 is approximately 0.76kWh which would provide export power at the average of 30kW for 90 seconds. The use of a chargeable device such as a supercapacitor 94 smooths out the surging generation which is otherwise inherent in the burst mode type of power generation system.

The Active Front End (AFE) Module 82 is designed to connect from the DC Bus 86 of the drive module to the local AC power grid 90. The role of the AFE drive 82 is to ensure power supply to the equipment connected to the DC Bus 86 and maintain their powered state, and to convert the DC Bus voltage to the AC Voltage using a transformer 88 with the desired constant power value required for export into the local grid 90. AC power is exported via a transmission link 98 to a power grid 90.

The inventor has shown that when the energy capture system is combined with a partial energy storage system, this can complement the operation of the OWC module, by eliminating the peaks and troughs in the output electrical power that is being produced and provide more of a constant output electrical power, which in turn is emitted via a control system to users connected to an electricity grid.

In further embodiments, the supercapacitors can also be used in conjunction with chemical batteries. Once the voltage is buffered, the electricity produced can be put through the inverter to supply AC power to the grid.

The apparatus disclosed herein has many advantages over convention power generation devices, as well as previous OWC technologies:

- The turbine performance/efficiency for the expected pressure/flow characteristics can also be optimised;
- The device can be mechanically isolated in storm conditions to prevent damage by shutting off the valves. Because of its robust construction, it will not become damaged in a storm;