DESIGN AND BENEFIT POTENTIALS OF SYNERGISTIC CURRENT AND OFFSHORE WIND (SCOW) SYSTEMS

Dr. Mithra Sankrithi
RIC Enterprises
P.O. Box 248
Mountlake Terrace, WA 98043
email: drsankrithi@gmail.com

Siva Sankrithi
RIC Enterprises
P.O. Box 248
Mountlake Terrace, WA 98043
email: sivas108@gmail.com

ABSTRACT

Offshore wind, ocean current, and tidal current renewable energy systems, taken together, have global terawatt-scale power potential with zero carbon emissions. "Synergistic Current and Offshore Wind (SCOW) Systems" constitute a paradigm-shifting new class of renewable energy harvesting inventions that simultaneously capture ocean / tidal current energy below the water surface *and* offshore wind energy above the water surface. Many offshore deployment sites exist worldwide with high power densities below and above the water surface. Optimal implementation of production SCOW Systems could occur at such high-potential locations including the Gulf Stream Current off the Eastern Seaboard of the U.S.A.; the Alaska Current; the Kuroshio Current off the coast of Japan; the Brazil, Agulhas and East Australian Currents; the Antarctic Circumpolar Current; and also at locations with strong tidal currents plus high winds such as sites offshore from Maine, Alaska, Canada, Russia, the United Kingdom and the Philippines amongst others.

1. <u>POTENTIAL SCOW DEPLOYMENT REGIONS</u>

Fig. 1 maps areas of strong offshore winds and Fig. 2 maps areas of primary ocean currents. Fig. 3 illustrates the Gulf Stream Current in particular, as a likely candidate for the first application of SCOW systems.

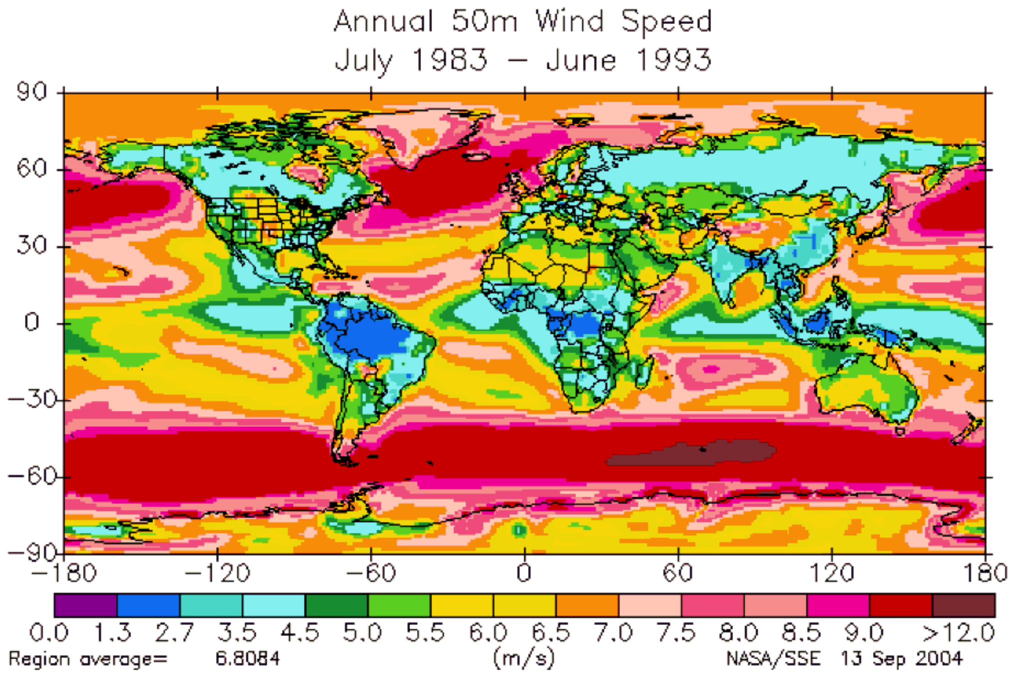

Fig. 1 (Ref. 1): Regions of strong wind worldwide

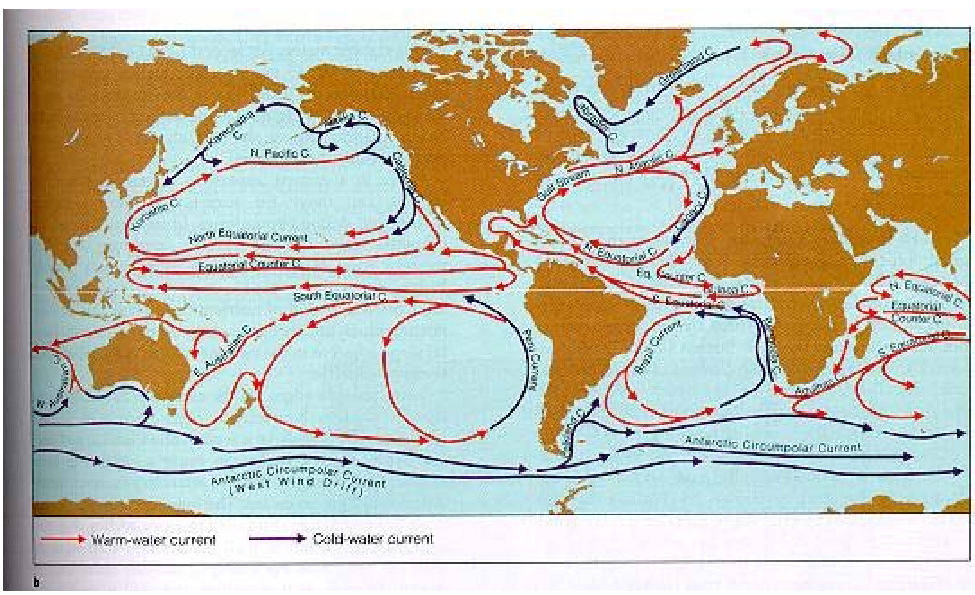

Fig. 2 (Ref. 2): Flows of wordwide ocean currents

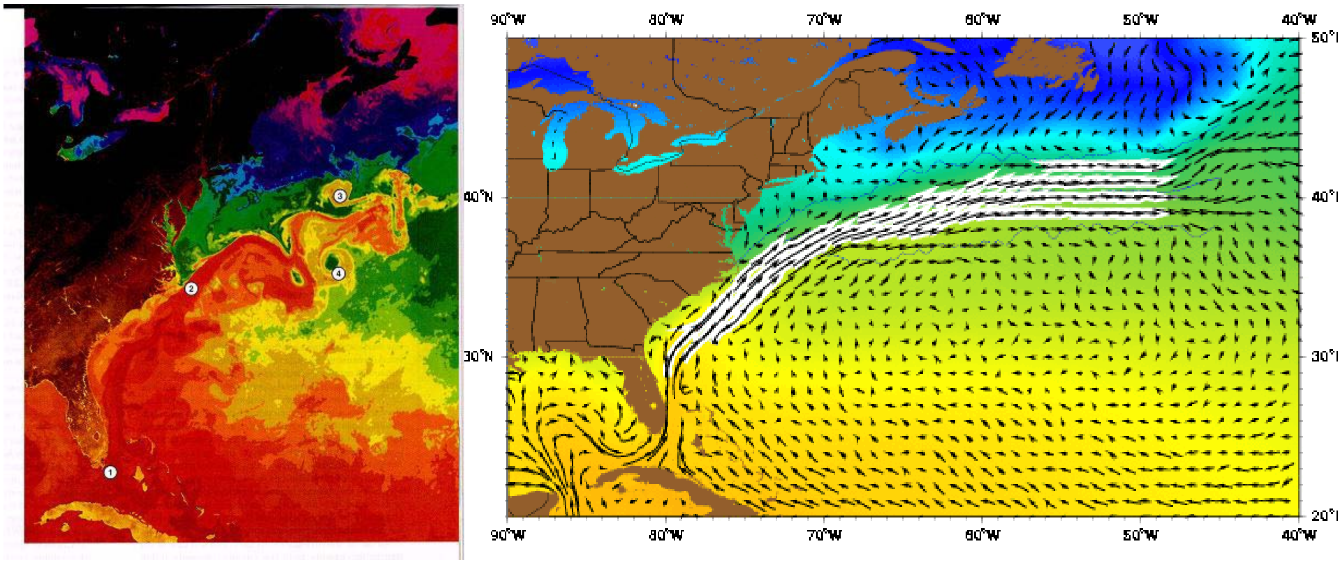

Fig. 3 (Refs. 3, 4): The Gulf Stream, flowing North along the Eastern Seaboard of the United States of America. Note that the Gulf Stream flows very fast, at up to 2 meters/second off the coast of Florida, and that it carries the volumetric flow equivalent to a hundred times the flow of all the rivers of the world (Ref. 5).

2. DESIGN AND OPERATION

The basic principles of SCOW Systems, which synergistically harvest both water current energy and offshore wind energy, are described in foundational U.S. patent 7,750,491 (Ref. 6). The patent describes SCOW Systems and the use of integrated vertical axis wind and water turbine subsystems, with many alternative embodiments described. A preferred embodiment, with circular symmetry that allows independent rotational speeds for the wind and water subsystems to optimize power harvest under varying wind and water current speed and direction conditions, is shown in Fig. 4 on the following page.

The operating principles of the vertical-axis wind turbine and water turbine subsystems are illustrated in Fig. 4. A plurality of vertically oriented buoyant waterfoils are connected by a toroidal waterfoil support ring, which the waterfoils drive around by cyclic control of each waterfoil's angle of attack as it revolves around the circuit.

Independently, a plurality of upwardly oriented windfoils are arranged in a circle and supported by a toroidal windfoil support ring, which the windfoils drive around by cyclic control of each windfoil's angle of attack as it revolves around the circuit. The overall system design allows the angle of attack of the waterfoils and the windfoils to be independently optimized as a function of water current and wind velocity vectors and location along their respective closed circuits of cyclic travel. Thus the baseline SCOW System will effectively harvest both water current and wind energy even in the extreme case of the wind blowing in the opposite direction as the water current.

In representative conditions in the Gulf Stream near Florida (wind 5.5 m/s, water 2 m/s) a mega-size SCOW system would produce 425 MWe; off North Carolina (wind 7 m/s, water 1.5 m/s) it would produce 220 MWe; off Maine (wind 8 m/s, tidal stream 2 m/s) it would produce 475 MWe; off Alaska (wind 15 m/s, water 0.8 m/s) it would produce 500 MWe, and off Japan (wind 8 m/s, water 1.4 m/s) it would produce 210 MWe.

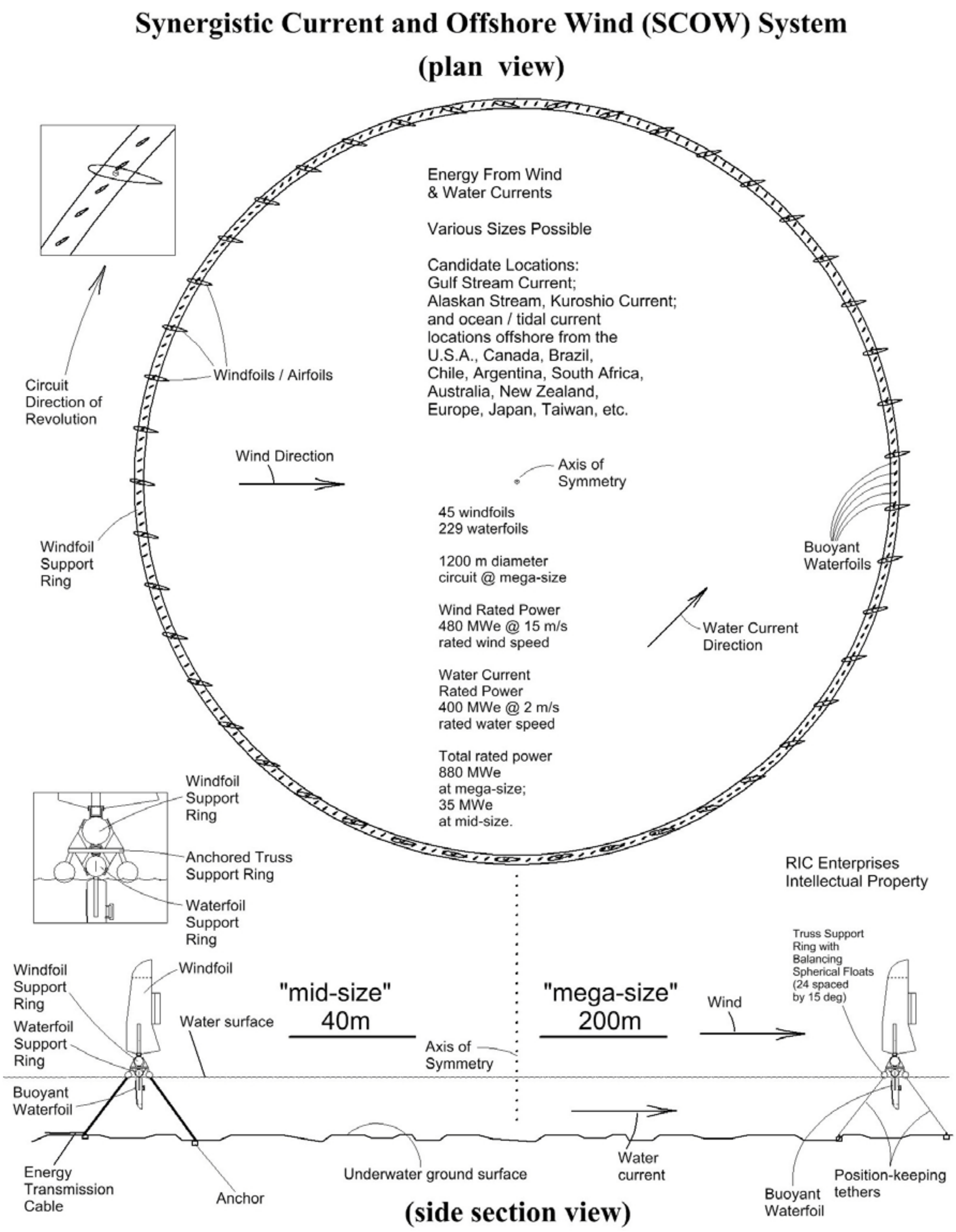
Synergistic Current and Offshore Wind (SCOW) System
(plan view)
Energy From Wind
& Water Currents
Various Sizes Possible
Candidate Locations:
Gulf Stream Current;
Alaskan Stream, Kuroshio Current;
and ocean / tidal current
locations offshore from the
U.S.A., Canada, Brazil,
Chile, Argentina, South Africa,
Australia, New Zealand,
Europe, Japan, Taiwan, etc.
Windfoils / Airfoils
Circuit
Direction of
Revolution
Wind Direction
Axis of
Symmetry
45 windfoils
229 waterfoils
1200 m diameter
circuit @ mega-size
Wind Rated Power
480 MWe @ 15 m/s
rated wind speed
Water Current
Rated Power
400 MWe @ 2 m/s
rated water speed
Total rated power
880 MWe
at mega-size;
35 MWe
at mid-size.
Windfoil
Support
Ring
Buoyant
Waterfoils
Water Current
Direction
Windfoil
Support
Ring
Anchored Truss
Support Ring
Waterfoil
Support
Ring
RIC Enterprises
Intellectual Property
Truss Support
Ring with
Balancing
Spherical Floats
(24 spaced
by 15 deg)
Windfoil
Support
Ring
Windfoil
"mid-size"
40m
"mega-size"
200m
Wind
Waterfoil
Support
Ring
Water surface
Axis of
Symmetry
Buoyant
Waterfoil
Energy
Transmission
Cable
Anchor
Underwater ground surface
Water
current
Buoyant
Waterfoil
Position-keeping
tethers
(side section view)

Fig. 4

The use of integrated support, coupling, anchoring and power processing subsystems should offer large benefits towards achieving competitive levelized cost of electricity (LCOE) for offshore renewable energy. Relative to stand-alone offshore wind energy systems, the SCOW System eliminates the very expensive dedicated foundation systems (sea-floor or floating) needed by conventional offshore wind turbines, and also eliminates the heavy and expensive towers needed to elevate the hub of a conventional horizontal-axis wind turbine to 100 meters or more above the sea surface. Where current offshore wind turbine systems cost about $5.2 million per megawatt (Ref. 7), SCOW Systems could achieve target costs of less than $3 million per megawatt, assuming a combination of metallic (steel, aluminum) and composite (fiberglass, carbon fiber) construction and including the use of airship style truss framed structure for the very tall windfoils. The SCOW System has the further advantage of providing substantial base-load power using the ocean current subsystem, which wind systems cannot do because of wind variability. Taking credit for base-load is critical to enable reductions in fossil fuel powerplants and corresponding sustained reductions in carbon emissions. Finally, with lower windfoil tip speeds than conventional wind turbines, SCOW Systems will produce substantially less noise and pose substantially lower hazards to birds and bats.

3. TECHNOLOGY READINESS STATUS

While the SCOW System concept is feasible with respect to following the laws of physics, materials science and fluid dynamics, there are many practical challenges that will have to be overcome to engineer, manufacture and operate such systems reliably, especially in the face of potential hostile and stormy conditions in the open ocean. SCOW Systems utilize many components that are already in service in other applications, such as airfoils applied in aircraft, racing yachts and wind turbines; hydrofoils applied in hydrofoil ships and water turbines; and well-proven components for structures, control systems, generators and electrical subsystems. By definition these components considered by themselves are at Technology Readiness Level (TRL) 9, as they are in service. However, the integration of these components into effectively engineered and synthesized wind and water current harvesting subsystems that need to function reliably in the aforesaid hostile environment at the water surface (subject to waves, swells and spray under storm conditions), is judged to be at TRL 3, based on component and subsystem data and completed preliminary evaluations of the SCOW System baseline design to estimate performance and economic potential and to identify technical, operational and economic risks and challenges to be addressed.

4. ALTERNATIVE EMBODIMENTS

Some of the many alternative embodiments of the SCOW Systems invention, as described in foundational U.S. patent 7,750,491, use one or more of stacked independently revolving subsystems, rigid linking of modules, cable linking of modules, circular or noncircular revolving geometries or reciprocating geometries, and hybrid configurations.

In addition to the baseline embodiment shown in Fig. 4, an alternate embodiment that also uses stacked independently revolving subsystems is shown in Fig. 5 on the subsequent page. This version has independent toroidal floating support rings for the vertical-axis wind power subsystem, rather than having the water power subsystem providing the buoyant support to hold up the wind power subsystem. The version of Fig. 5 has the advantage of avoiding the truss support ring and the extensive bearing systems used in Fig. 4, but has the corresponding disadvantage of significant additional hydrodynamic drag acting on the wind power subsystem and consequently reduced net power extraction efficiency. The Fig. 5 system could optionally use steps or hydrofoils on the toroidal floating support rings to mitigate the drag to some extent under high wind, high RPM conditions.

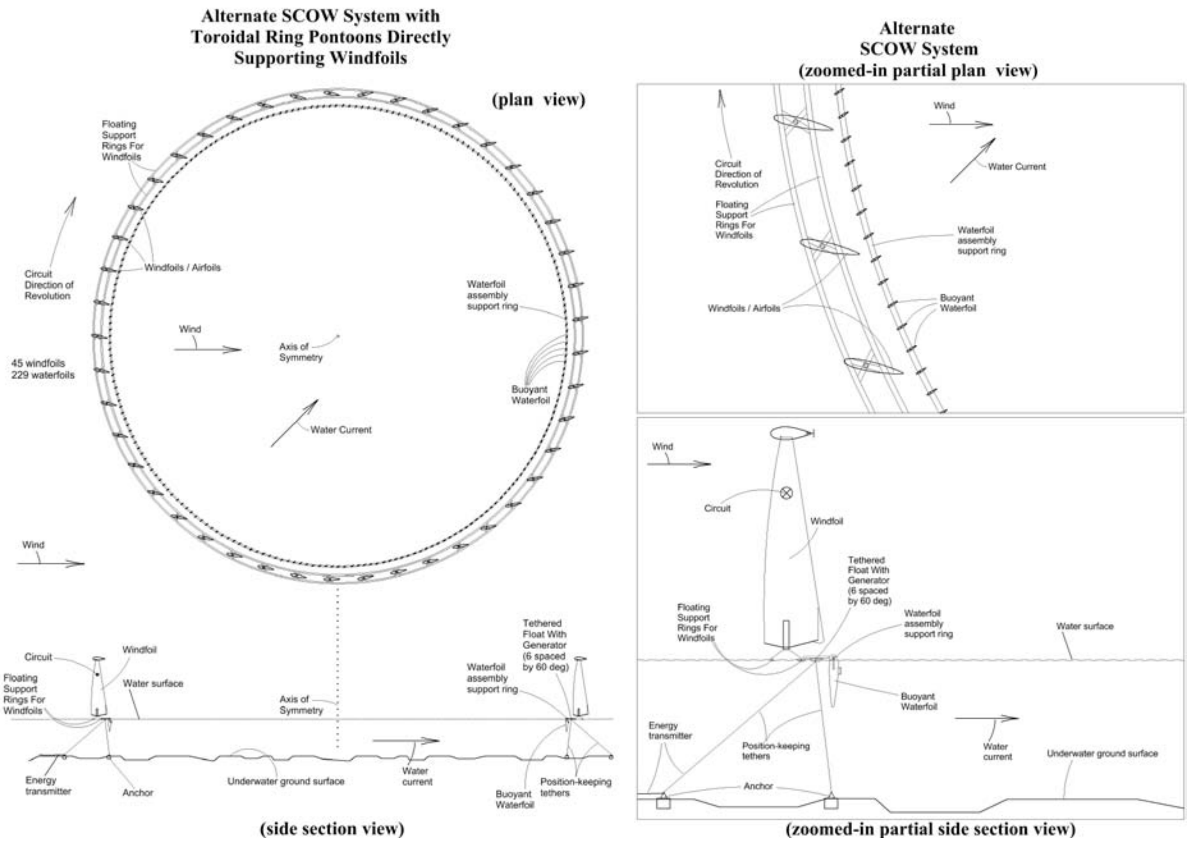

Fig. 5

An alternate cable-connected embodiment that uses cable linking of multiple floating modules, each of which is fitted with a windfoil and a set of supporting waterfoils, is shown in Fig. 6 to the right.

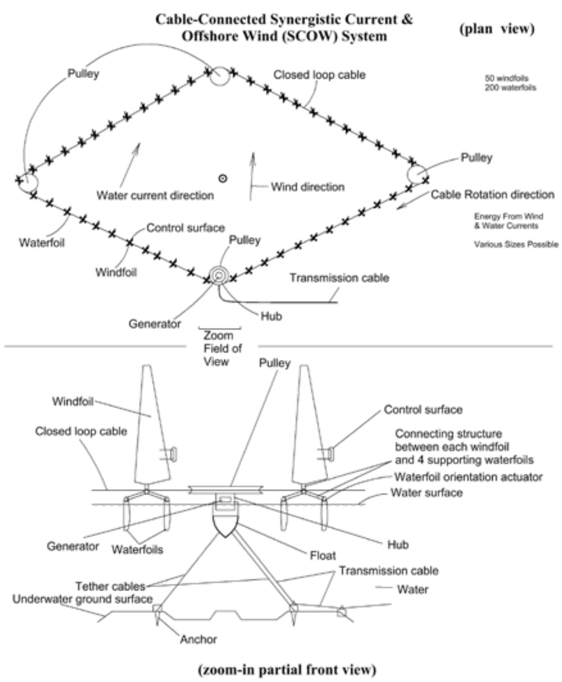

Fig. 6

The multiple cable-connected floating modules move around a circuit, in a manner analogous to a ski area chairlift. Each floating module floats due to buoyancy of vertically oriented waterfoils, which harvest energy from the ocean or tidal current. Each floating module also supports an upwardly projecting windfoil, which acts like a sail and harvests energy from the wind field above the water surface. As in the baseline of Fig. 4, the system allows the angle of attack of the waterfoils and the windfoils to be independently optimized as a function of water current and wind velocity vectors and location along the closed circuit of module travel. Thus the system will effectively harvest both water current and wind energy even in the extreme case of the wind blowing in the opposite direction as the water current.

The conceptual design of Figure 6 can be scaled to a wide range of waterfoil sizes, windfoil sizes and circuit sizing.

This cable-connected embodiment saves some weight and cost in eliminating the beefy rigid windfoil and waterfoil support rings, and also has a site-specific advantage of allowing tailoring of the cable circuit geometry in regions with a strong and consistent wind direction, such as the "roaring forties" and "screeching fifties" winds south of Australia, New Zealand, Chile, Argentina and South Africa. However, this cable linked version will yield lower wind power harvest as the windfoils are constrained to the same lower module speed relative to the water as the waterfoils. Also, the smaller size of the modules which are no longer rigidly linked, will make them more vulnerable to capsizing under severe storm and wave conditions.

5. TECHNOLOGY ADVANCEMENT PLAN

While advantages and challenges of a couple of alternate embodiments have been described above, the next steps in research, development and demonstration work will focus on increasing Technology Readiness Level (TRL) of the baseline SCOW System of Figure 2, which is currently assessed to have the best potential to deliver (i) high performance under variable wind and water current conditions, (ii) low cost of delivered electric power, and (iii) robust ability to withstand stormy conditions at sea.

To advance Technology Readiness Level from TRL 3 to TRL 6, detailed plans have been developed to design and build a subscale, fully functional prototype of a SCOW System, and to test this in a real wind and water current environment in Florida. A project team including RIC Enterprises, Florida Atlantic University and Columbia University is in the process of applying for ARPA-E grant funding for this project to advance Technology Readiness Level. In addition to prototyping work, a math model will be developed that is structured to permit multi-objective optimization on SCOW systems, with a variety of technical, performance, economic and environmental objectives and variable relative weightings. Sizing considerations will also be modeled, leading to preliminary recommendations for preferred ranges for windfoil, waterfoil, and powerplant sizing. Initial modeling, simulation and analysis will be included on impacts and potential mitigation of the effects of adverse conditions such as severe sea state and hurricane or cyclone or tsunami conditions, on the operation, safety and survivability of SCOW Systems. This project will also add details to a roadmap for technology maturation and product development leading to commercial production and deployment.

The ultimate broader impacts of this Research & Development (R&D) and TRL advancement work could include widespread worldwide deployments of SCOW Systems that serve growing global needs with near-zero carbon footprint and near-zero land use. An additional environmental benefit mechanism is that deployment of SCOW Systems will reduce Arctic Ocean sea ice melting & Kalaallit Nunaat ice cap melting & European Alpine glacier melting, consequent to reduced pole-ward heat transport by ocean currents, especially the Gulf Stream. This environmental benefit mechanism will also contribute to reduced sea level rise and reduced harm to polar bear habitats.

6. CONCLUSIONS

SCOW Systems should be able to achieve a step-change improvement in cost-effectiveness relative to current technology offshore wind power systems. Worldwide deployment of this new cost-effective renewable energy harvesting technology could potentially add trillions of dollars of economic value through direct economic as well as monetized energy and environmental benefits. Widespread deployment of SCOW Systems in the many well-suited U.S. offshore sites including the Gulf Stream, the Alaska Current, island areas such as Hawaii and Guam and Puerto Rico, and tidal stream areas such as offshore from Maine, should also enable reduced U.S. dependence on expensive and geopolitically vulnerable foreign fossil fuel sources. In addition to the many promising locations for U.S. deployments, extremely promising international locations for widespread long-term deployments of SCOW Systems include the Kuroshio Current off the coast of Japan and many locations with strong ocean or tidal currents and high winds offshore from Canada, Europe, Brazil, Chile, Australia, New Zealand and South Africa. Ultimately, SCOW Systems have high potential to cost-effectively provide a terawatt (1000 gigawatts) or more of carbon-free renewable power to meet 5% or more of anticipated global energy needs by 2035.

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