Hydro-Piezoelectricity: A Renewable Energy Source For Autonomous Underwater Vehicles

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LONG-TERM GOALS

There is an ever-growing military, scientific and commercial need to establish Autonomous Distributed Systems (ADS) for studying and measuring oceanographic, atmospheric and other data in the littoral regions of the world. The long-term goal of this program is to develop an electrical power supply for these applications, that is reliable and easy to operate, has a long maintenance-free operating life, and is as low cost as possible. An ideal system for meeting these goals is to have a power generation system that directly converts the mechanical energy in waves and currents into electricity. This electrical energy, scavenged from the ocean environment, can then be used to directly power or to recharge the batteries of the components in the ADS.

The successful completion of the program will provide remote electric power generating equipment for water based military and civilian applications having capacities of a few watts to hundreds of kW. Based on a unique Wave Energy Converter (WEC) buoy and intelligent power take-off algorithms, the generators require no fuel and produce no emissions. Battery recharging stations for autonomous underwater vehicles and undersea sensor networks will have their mission duration capability extended for years. Long lived oceanographic data collection systems will be possible for weather prediction and environmental monitoring. In addition, there will be significant dual use in the commercial sector for power generation in remote locations where the wave climates are favorable and power generated by conventional means(imported diesel fuel) is extremely expensive.

OBJECTIVES

The major objective of this SBIR Phase II Option program is to improve upon the power generating performance of the OPT system that was achieved in the main Phase II effort. Highlights of the Phase II program, completed in August, 1998 were:

a. Ocean deployment and operation from December, 1997 through most of 1998 of a 2.5 meter by 6.5 meter long WEC at the LEO 15 site of Rutgers University.
b. Multiple sensor outputs and performance data were reliably communicated to OPT via an OPT developed RF data link from 3.5 miles off shore.
c. The peak power achieved was 1.6 kW but the average power was under 200 watts. This was lower than predicted by OPT's model for the prevailing wave conditions.

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Item c. above then provides the rationale for this Phase II Option program. The major reason for the power shortfall is that the deployed WEC was narrowly tuned to a specific wave period of 7 seconds which was the expected dominant period. This is illustrated in Figure 1 below.

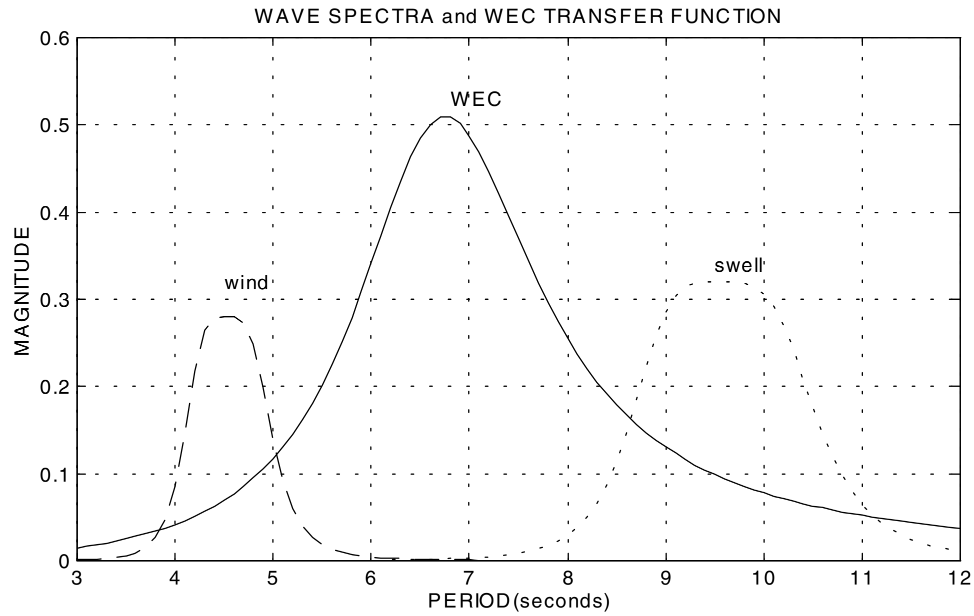

Figure 1

Note that the fixed frequency response of the mechanically resonant WEC does not coincide with the power spectrum of either the wind waves or swells. This results in less than optimal continuous overall efficiency in the expected highly variable conditions of the ocean. Accordingly, OPT has conceived a new WEC called the "Stationary WEC" which has a significantly broader response and has the large additional benefit that it can be "electronically tuned" to respond in real time to the expected but uncertain changes in wave conditions.

Therefore, the specific objectives of the Option program are to:

1. Design a "broad band" WEC which will produce in excess of 1 kW average power at the LEO 15 site off Tuckerton, N.J.
2. Verify the design's validity via wave tank tests at the David Taylor Research Center.
3. Deploy, operate, and monitor performance at LEO 15 for a minimum of 30 days.

APPROACH

OPT's technical approach is to perform initial designs of systems of various geometries using OPT proprietary modeling and simulation software. The initial efforts will concentrate on an appropriately scaled wave tank unit which will be fabricated and then tested. Upon a successful wave tank test (i.e., good agreement between experimental and predicted performance), OPT will concentrate on the design and subsequent fabrication of an ocean deployable system. Care will be taken in the design to ensure that the response is flat over the expected wave period distribution of 4 to 10 seconds. The system will then be deployed at the LEO 15 site and its power generating capacity will be monitored for 30 days minimum. OPT plans to perform a complete end-to-end test of the ocean system before deployment using its newly installed Ocean Wave Simulator as the system driver.

WORK COMPLETED

OPT has designed, fabricated, and wave tank tested (twice) a 1.5 meter diameter by 3.5 meter long WEC. Extensive experimental data was obtained on power output vs. wave height and period.
OPT has completed the design and fabrication cycle of a 3.5 meter diameter by 8 meter long buoy which will house OPT's ocean deployable WEC. In house testing of critical components will begin mid-November, 1999 with ocean deployment scheduled for early December 1999.

RESULTS

The wave tank test results were highly encouraging. The example in the table below shows the experimental results of power out vs. wave period with a constant wave height of 0.5 meters and a constant generator load of 25 Ω. (Data taken October 13, 1999)

T(seconds)	P(watts)
2.0	94.8
2.5	195.3
3.0	181.0
3.5	45.8

The predicted values from the simulations are within 5 % of the experimental. Scaling these results up to the larger ocean system gives a projected average power output in excess of 1kW which is the goal of the Option program.

IMPACT/APPLICATIONS

Upon successful completion of this program, OPT will be positioned to sell its electric power generating equipment for water-based government and private sector applications having capacities of a few watts to many kilowatts. That breadth of power capacity, coupled with the following key advantages of OPT’s power system, presents a significant opportunity:

- The generators require no fuel and produce no emissions.
- Significantly higher duty cycle than wind and solar (photovoltaic).
- OPT’s systems will operate at high efficiency, with small size, and are efficient at low and variable speed.
- If the technical goals of the Program are achieved, OPT estimates that electrical power for small, secondary power applications (1 watt to 1 kilowatt) will be in the range of 7¢ - 10¢ per kilowatt hour, including capital and operating and maintenance costs. This compares very favorably to diesel power (25¢ - 100¢ per kWh, depending on location), solar/photovoltaic power (25¢ - 75¢ per kWh), and wind power (10¢ - 30¢ per kWh).

The successful development of generators utilizing electric field induced piezoelectric polymers has important applications including the following:

(a) For overt surface deployed and covert sub-surface deployed power generation:

- Tether points for local recharging of underwater equipment such as AUV's for application within the Autonomous Oceanographic Sampling Network.
- Visual, radio, radar interactive channel markers for follow-up landings where harborinfrastructure facilities are unavailable or destroyed.
- Long-live hydrophone arrays or other data acquisition sensors, including undersea sensor networks, sonar buoys and weather reporting buoys.
- Power for coastal defense networks, islands or remote coastal locations.

(b) For high current flow situations, the generator can be re-configured to generate power under the surface for similar functions as above.

(c) 10 to 200 watt generators for powering lights and horns for aids to navigation for the U.S. Coast Guard.

(d) Power for oceanographic research sensor and data communication.

(e) Power for aquaculture (fish farming) installations.

TRANSITIONS

Successful deployment of a 1 kW system will potentially lead to high volume applications in the commercial sector, e.g., supply of hybrid power generators to remote island nations.

RELATED PROJECTS

Under its current development program, OPT has worked on the construction of prototype power generating systems based on both electromagnetic technology and the piezoelectric polymer PVDF. OPT has also had (i) a Phase I SBIR Contract from Office of Naval Research to investigate the feasibility of an OPT Generator located either at or below the surface to provide up to 1 kW of power to recharge the batteries of Autonomous Underwater Vehicles; (ii) OPT has received the Phase II contract for the AUV program to deploy and test a 1 kW surface system in the ocean; (iii) OPT, with Princeton University, Pennsylvania State University and Autonomous Underwater Systems, Inc., is working on a contract for the generation of electrical power from the flow energy of water (rather than ocean waves), using eel-like generating system structures made from piezoelectric polymers.