A RENEWABLE ENERGY SOURCE FOR POWERING OFFSHORE OIL AND GAS APPLICATIONS

MIKE M. MEKHICHE
VP, ENGINEERING, OCEAN POWER TECHNOLOGIES

KATHLEEN A. EDWARDS
MANAGER, ADVANCED TECHNOLOGY GROPUP, OCEAN POWER TECHNOLOGIES

ABSTRACT

A challenge in offshore Oil and Gas operations is how to obtain a cost effective, reliable and steady power supply at a remote ocean location. Diesel generators are costly and require frequent service. A lower-cost, reliable alternative is proposed here, namely the harvesting of power from ocean waves via the PowerBuoy® from Ocean Power Technologies. Two PowerBuoy products are described: the APB-350, suited to low-power applications such as MetOcean monitoring or AUV recharging stations, and the PB40, suited to moderate-power applications such as powering satellite fields. These and other applications for Oil and Gas operators are reviewed and the potential for lower-cost, more reliable operations is highlighted. The design history and testing of the PB40 and APB-350 are described. Both are designed to operate in autonomous mode requiring little monitoring are capable of supplying power to a wide range of applications.

Keywords: Offshore logistics cost reduction, Wave Energy, WEC, PowerBuoy®, APB-350, PB40, Renewable energy

INTRODUCTION

A key challenge to offshore Oil and Gas operations is how to supply power to devices used in operations and monitoring. This is a challenge even for devices with low to moderate-power loads, which will be the focus of this paper. In remote ocean locations, the power grid is inaccessible due to the high cost and challenge of extending power cables into the ocean environment over hundreds of km. Mounting diesel generators on platforms or barges, a typical solution, introduces its own issues. Diesel generators are difficult to maintain and operate at sea. They must be refueled frequently, requiring costly logistics such as ship trips. The cost of the fuel itself is extravagant especially for longer-term operations. Further, diesel generators emit CO_2 which can affect operations via environmental regulations.

A more innovative power source for low to moderate offshore loads is renewable energy based technologies such as solar panels or small wind turbines. However solar and wind power bring their own issues such as intermittent availability and damage in harsh ocean environment. The advantages of another renewable option, power from ocean waves, will be explored in this paper. When provided by a rugged, ocean-ready structure such as the PowerBuoy from Ocean Power Technologies (OPT), wave power can offer a reliable power source at lower operating costs. Due to careful marine engineering and a power conversion system design that includes energy storage capability (battery), the PowerBuoy can deliver a steady and sustainable power supply which is suited to a number of Oil and Gas applications which will be identified and detailed here.

DESCRIPTION OF THE POWERBUOY TECHNOLOGY

OPT has been developing wave energy converters since 1994. Its PowerBuoy product is a moored floating system that converts the motions of ocean waves into useful electrical power. The up-and-down or heaving motion of the waves moves a buoyant component or 'float' vertically along a relatively stationary spar (Figure 1). The float's motion drives a thrust rod system which is connected to a generator located inside the spar. As it turns, the generator applies a back force and generates electricity. The systems which convert the mechanical to electrical power are known as the Power Takeoff.

The present PowerBuoy design is a result of extensive numerical modeling and wave tank testing. Its field trials including a long-term deployment while connected to the power grid in Hawaii; shorter deployments in Scotland and Spain, and a 3-month deployment off New Jersey which survived Hurricane Irene.

OPT offers several versions of the PowerBuoy; here the focus will be the PB40, suitable to supplying moderate power demands, and the APB-350, suitable to supplying low power demands.

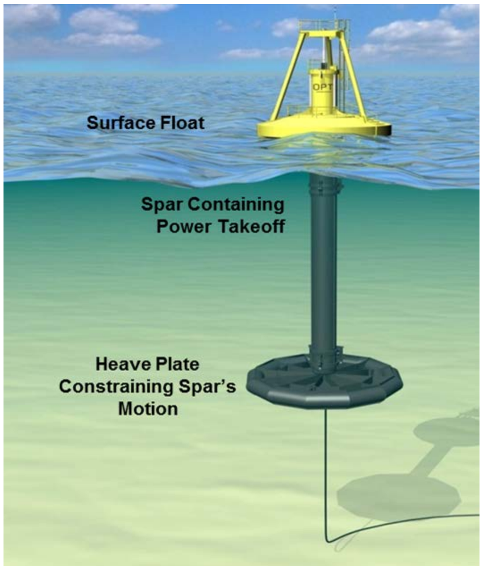

Figure 1: PowerBuoy schematic

PB40

The PB40 is part of a family of larger PowerBuoy systems targeted at the utility industry, though they can also supply power directly to moderate-load payloads as is proposed here. The PB40 is based on a 150kW-rated system that was deployed in Scotland (Figure 2) and is scheduled to be deployed in an ocean test in Spain for a utility customer. The PB40 is rated for a 40kW average power output though the actual power output depends on the wave climate at the deployment site. Figure 2 shows the device during its Scotland ocean test in 2011. After several weeks of testing, a great deal of performance data was collected and analyzed, and many areas for efficiency improvement and cost reduction were identified for subsequent design projects.

The Power Takeoff of these larger systems has been the focus of a targeted redesign effort. OPT has completed the construction of the next generation modular Power Takeoff which reduced the development and assembly cost by an order of magnitude for future systems. After extensive redesign and testing, the PB40's Power Takeoff has been significantly improved in order to increase the reliably delivered electrical power at a lower cost.

Figure 2: 150kW rated PowerBuoy deployed off Scotland

APB-350

Smaller 'autonomous' systems are targeted at a 24/7 supply of power to a lower-power payload unconnected to the power grid. The lead product, which will be the focus here, is the APB-350 which is rated for a continuous average power output of 350W to 500W, with the actual power output varying with the site's wave climate. The internal battery is sized so that payload power is uninterrupted in low waves. In high seas when the battery is fully charged, excess power is dissipated via a dump resistor. Power allocation is automated by the system's internal controller, permitting long term operation without on-site monitoring or user oversight. However, a Human Machine Interface (HMI) also allows operators to view and control the system's performance remotely from shore, as needed. An example HMI screen is shown in Figure . The system is instrumented and supports communications which allow for near real-time transmission of data to the shore. Figure 5 shows examples of transmitted data from a customer sonar payload as well as from the APB-350's internal measurements. Key characteristics of the APB-350 are presented in Table 1.

In 2011, OPT completed sea trials of an APB-350 which was designed to power a radar system under the U.S. Navy LEAP program (Figure 3). The system powered its radar payload throughout the deployment. Through the use of a buffering battery, the APB-350 was successful in providing continuous power to its payload even when wave activity was too low to actively generate power. A key focus of the project design was maximizing efficiency and minimizing standby power loads. OPT was able to achieve a 90%+ reduction in control power overhead and standby loads compared to previous designs, and identified areas for future efficiency improvement. A subsequent APB-350 deployment for the U.S. Department of Homeland Security confirmed the system's ability to support multiple payloads, namely a subsurface acoustic package and an above-water radar package. The deployment highlighted several design targets for improved marine ruggedness. Example applications for the APB-350 are maritime security, monitoring decommissioned oil platforms, and oceanographic research, as well as the Oil and Gas applications that will be highlighted here.

The commercial version of the APB-350 is suitable to the O&G applications described in the following sections.

Figure 3: APB-350 deployed off New Jersey. The U.S. Coast Guard cutter that deployed the system is in the background.

Table 1: APB-350 features.

Feature	APB-350 Capability
Construction	Welded steel/stainless/aluminium materials
Coatings/Protection	High performance marine grade paint -Marine grade epoxy above waterline -Anti-foul coatings below waterline
Interior Payload Accommodations	Two bays Water-tight, humidity controlled
Exterior Payload Accommodations	Five water-tight flanges Ruggedized antenna RADAR covers available
Power and Energy Management	Battery charge and discharge control for safety and battery longevity Multi-level load control for energy management
Navigational Aids	Configurable per requirements Beacon, GPS, etc., as required
Remote Control and Monitoring	Satellite or line-of-sight communications options Real-time remote control and monitoring Performance and diagnostic functions
Inspection Interval	1 year
Marine Growth De-fouling Interval	3 years
Refurbishment / Maintenance Interval	3 years
Untended Storage Time	6 months

A suite of measurement sensors can be installed on the APB-350 and measurements transmitted to shore, if so desired by the customer. Figure 5 plots example measurements that were transmitted from the APB-350 to shore in near real-time in a recent ocean deployment.

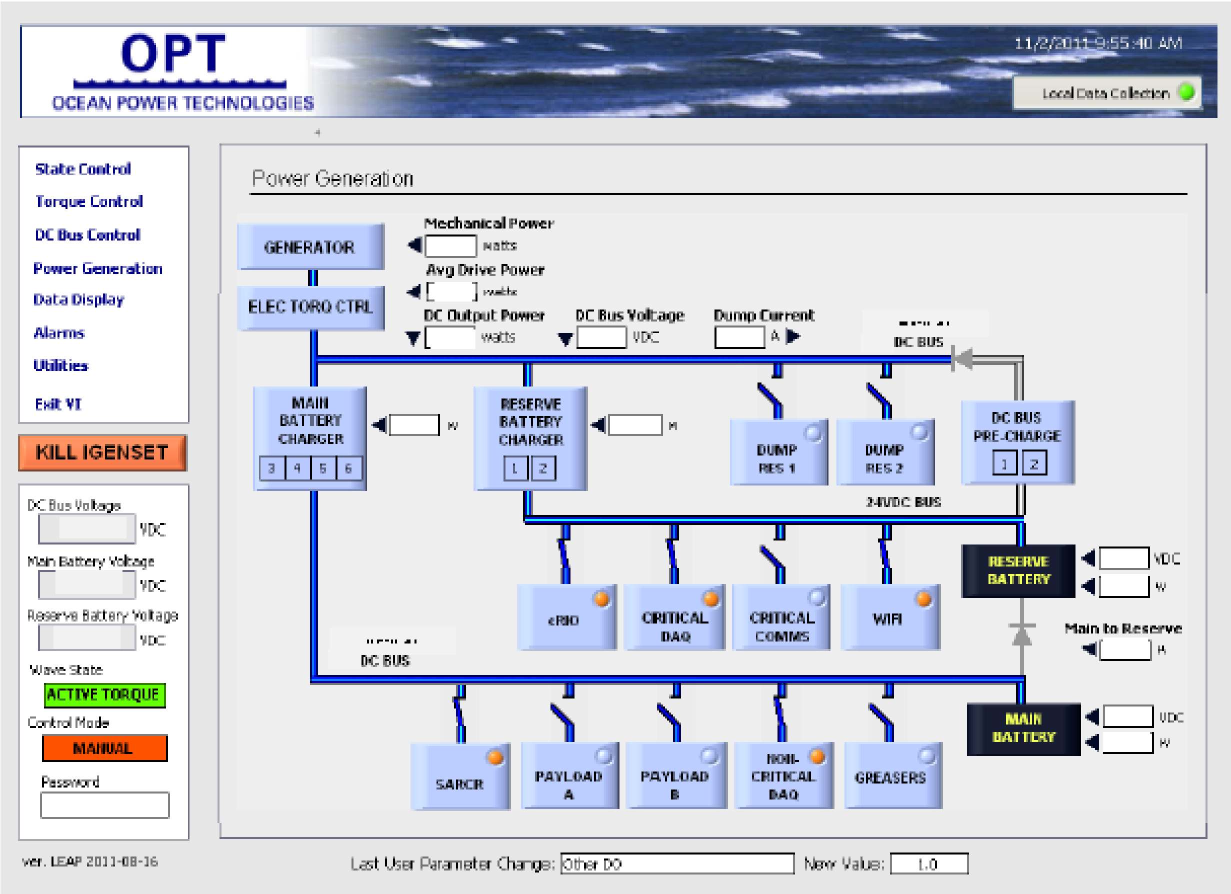

Figure 4: Operator interface for on-land control and monitoring of the APB-350. However, fully autonomous operation is the default.

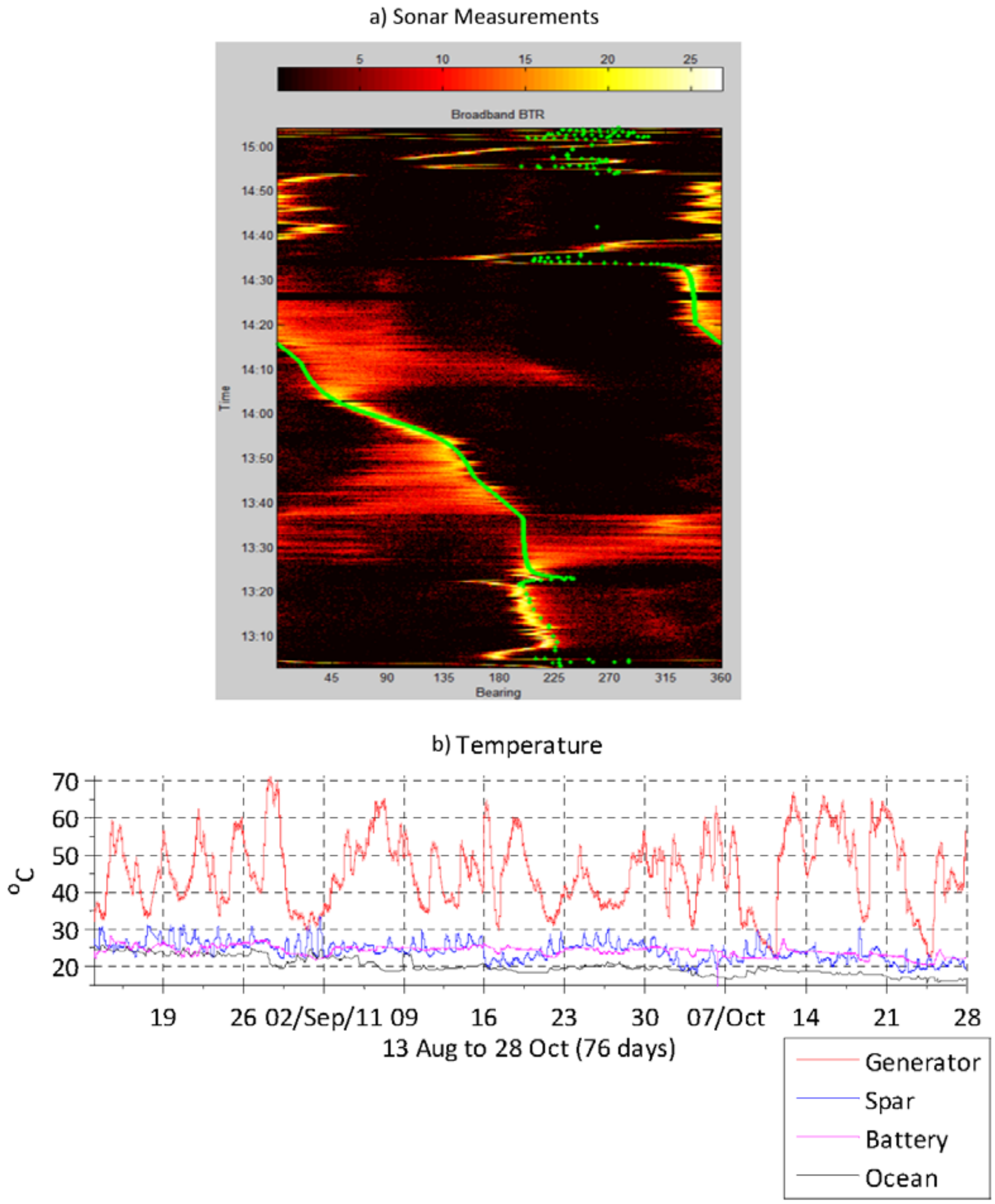

Figure 5: Example of reported information from sensors on the APB-350, using information that was transmitted to shore in near real-time: (a) sonar data, (b) system health and MetOcean information.

OIL AND GAS APPLICATIONS SUITED TO POWERBUOY INTEGRATION

Leveraging the inherent technology's ability to be tailored, OPT has reviewed a range of potential applications for the Oil and Gas industry:

- AUV garages for in permanent infield monitoring/inspection of assets
- The control of electric trees for CO_2/water field injection
- Diesel replacement
- Environmental monitoring for pre-post deployment

- Real-time on site field monitoring/sensing systems for 4D reservoir analysis and pre/post deployment surveys
- Security Cordons for offshore developments
- Temporary navigational markers for surface & submerged structures

Targeted Oil and Gas Applications

Three of these applications are of particular prevalence in line with current market trends: AUV garages, the control of electric trees and diesel replacement.

Prepositioned AUV Operational Networks

Applying the technology as a persistent power source alongside prepositioned Autonomous Undersea Vehicle (AUV) garages offers operators a fast, persistent and cost-effective investigative solution (Figure 6). OPT's APB-350 offers many advantages over existing ship-centric AUV systems, especially as most Oil and Gas fields are spread over a wide area (km^2) and are increasingly being developed in remote areas. Employing a AUV garage enables persistent and longer operating ranges AUVs as it eliminates the need to recover the vehicle for recharging and data download and by providing a two-way communication capability that removes the otherwise required vehicle resurfacing. The PowerBuoy system solution provides ample power to recharge/power most AUVS and could be scaled up to support larger workhorse vehicles. The system is equipped with a number of different on-board communication capabilities including satellite (Iridium), High Frequency (HF) and WiFi. Further, specialized antennas such as the VSAT type currently used in the Gulf of Mexico can also be implemented on the PowerBuoy considering it offers more than adequate stability and room.

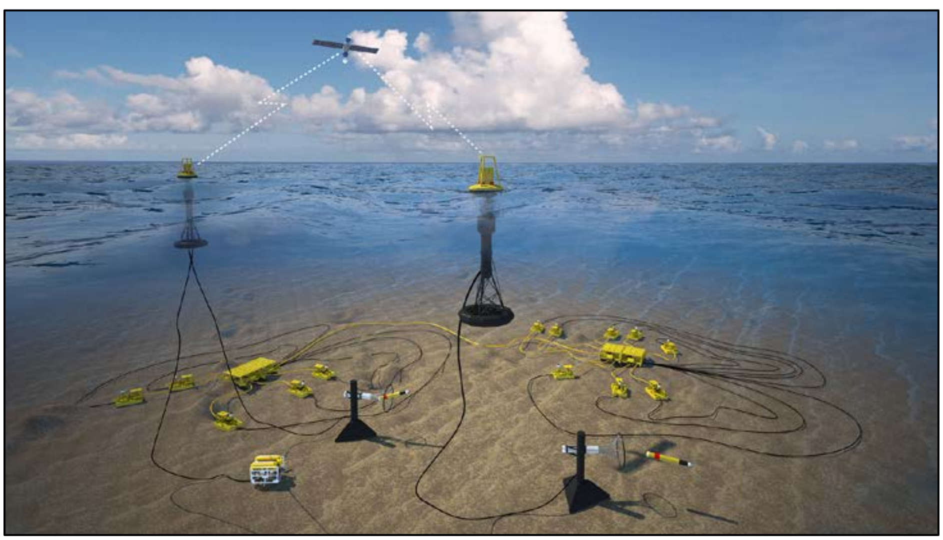

Figure 6: APB-350 as a sustainable power source and communication platform for prepositioned AUVs. Concept of operation.

Electric Tree Power & Control

Electric trees offer the potential for improved control system response and increased reliability over their hydraulic counterpart. Using OPT's APB-350 PowerBuoy as a power source and control hub offer a great opportunity to avoid a complex and costly subsea umbilical (Figure 7). Considering the criticality of safety and reliability of operations and communication for this type of application, it is paramount that any solution that replaces the conventional cable based approach connecting the electric tree to a shore station, offers the same level or better performance. Based on previous deployments and testing, the APB-350 solution offers a potentially lower cost alternative with equivalent levels of reliability and safety. Other aspects of importance to the electric tree application include: - The ability to provide sufficient power at all times with margin and, - The power source must not present any risk to navigation in its immediate surroundings.

The electric tree is a low-power system requiring only a fraction of the power generated by subsea pumps with an intermittent need for bursts of power when valve operation is required. Based on test data collected from actual APB-350 ocean deployments, it is capable of delivering higher continues average power than its indicated rating. The reason being that OPT's PowerBuoy systems are designed with a peak power capacity capability that is several orders of magnitude of its continues average rating. This OPT design inherent characteristic has to do with ensuring a safe and reliable system operation even under high sea states and in conditions where steep/high waves lead to severe transient peak power generation. Further, the embedded Energy Storage System (ESS: battery system) is designed such that it can store the vast majority of the generated peak power as well as to deliver it to the loads at very high rates if required. Hence, the requirements of item 1- above are fully met and mitigated.

With regards to ensuring no safety risks to navigation are introduced by the PowerBuoys, OPT has demonstrated, as approved by the US Coast Guard, the US Navy and the US Army Corps of Engineers, that simple but effective steps can be taken that completely eliminate any such risks. Such steps include: a- Use of deployment site marker buoys, b- The identification of the deployment site on maritime navigation charts, c- The embedded GPS system that continuously provides its location, d- The continuous health and status updates broadcasted by the PowerBuoy provide real time data on its overall operation and location and hence, and e- The portion of the PowerBuoy that is above the water line is painted to meet standard maritime visibility requirements (equivalent to AtON buoys) and is sufficiently tall to be visible in most ocean conditions. Such steps have demonstrated to mitigate any risks per item 2- above.

Furthermore, there is a great deal of system configuration flexibility that is inherent in the system Human Machine Interface and associated control and communication software. Such features enable the implementation of additional capabilities that are application specific. For instance, in most military and surveillance applications, graceful degradation is a critical performance parameter whereby any system failure cannot result in an unsafe and/or damaging shutdown of the associated payloads. A relevant and similar situation in the case of the electric tree is to ensure that if the power source (PowerBuoy) shuts down for any reason, the system shuts down gracefully. This mechanism is implemented via the use of a high integrity failsafe shutdown signal that will be transmitted in the case a reset command is not received by the electric tree per a predefined schedule.

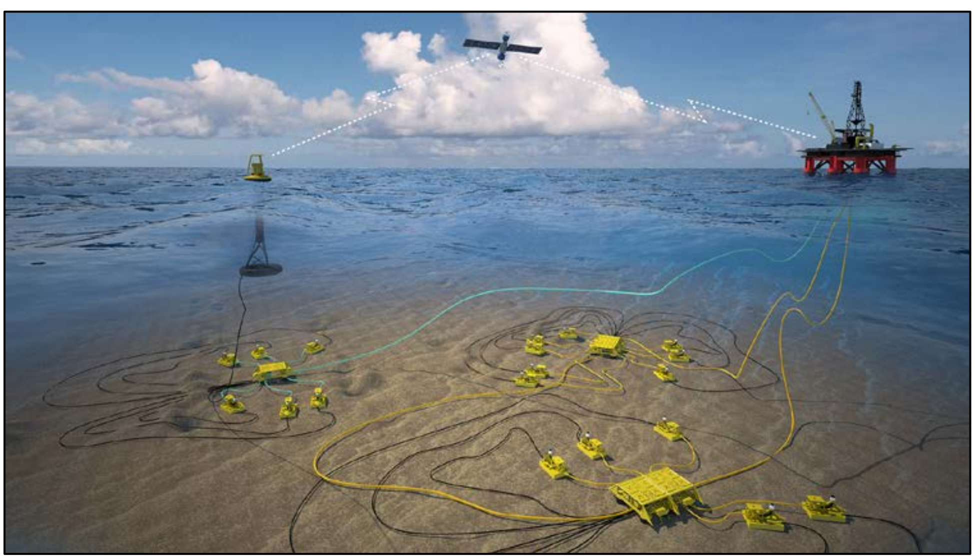

Figure 7: APB-350 as a sustainable power source and communication platform electric power trees operation and management. Concept of operation.

Diesel replacement

While diesel generators offer a conventional off-the-shelf electric power generation solution to fulfil the need for an offshore power supply for Oil and Gas operations, the diesel solution comes with a high price associated with the required fuel, the transportation needed to deliver it to site, and the frequent maintenance needs of the diesel generators themselves. An effective and cost saving approach would be to use the PB40 as an auxiliary power source where it is connected to the same loads as the diesel generators via a subsea cable (Figure 8). This dual source configuration allows for the PB40 to generate a portion (perhaps under some operating conditions all of) the required electric power, which leads to: 1- Drastically reducing the consumption of fuel, 2- off loading the diesel generators, which increases their reliability and life, 3- Reduced maintenance and fuel costs, and operational costs in general. Further, this configuration also offers a level of redundancy that mitigates the failure of one of the power sources and enables graceful degradation of the entire system, and thus significantly reducing downtime and increasing asset availability. In addition, the planned evolution of the technology means that larger PowerBuoys have the potential to redefine the way assets are managed by reducing or replacing diesel usage, making current fields that offer low commercial returns more attractive for investment.

Figure 8: PB40 as a sustainable power source for offshore platform electric power supply and/or diesel generator replacement Concept of operation.

Why the PowerBuoy is a Solution for Identified Oil and Gas Applications

Case Study

As discussed above, there are a variety of applications to which ocean wave energy can be applied to increase value and to transform operations. The increased value is not simple to quantify in terms of dollars. However, one thing is certain: systems such as OPT's PowerBuoy technology simplify greatly the logistics involved in carrying out standard Oil and Gas operations. Simplicity here is synonymous with improved reliability, reduced overall costs and enhanced capability. Further to this tremendous advantage, PowerBuoy systems can provide a catalyst for the development and implementation of innovative operations concepts that will revolutionize the implementation and management of critical assets. In turn this will open access to more remote exploration fields that were cost prohibitive and commercially unattractive until now.

Examples of such new operational concepts include intelligent AUVs that can now operate with greater persistence and considerably extended range equipped with additional sensors and equipment than is presently feasible due to the limited on-board power source (batteries). Having an on-site sustainable and persistent power source with advanced data processing and communications will enable the use of larger and more capable AUVs to carryout activities that traditionally and presently required heavy and costly human intervention and means (large and expensive ships).

One application that can be quantified perhaps in a more straight forward fashion is the use of PowerBuoy systems in support of and/or as a replacement to conventional diesel generators. Rough Order Magnitude estimates indicate that a combined cost per kW and per year of power generated by a diesel generator located 300 miles offshore is in the order of $10,000 ($10,000/kW.year). Further, published studies assess the daily emissions of CO2 by a 1MW offshore diesel generator station is in the order of 1,000kg/day.

A location in the North Sea was selected for the purpose of this study as shown in Figure 9. Figure 10 shows the ocean wave conditions to be expected at this site and associate energy.

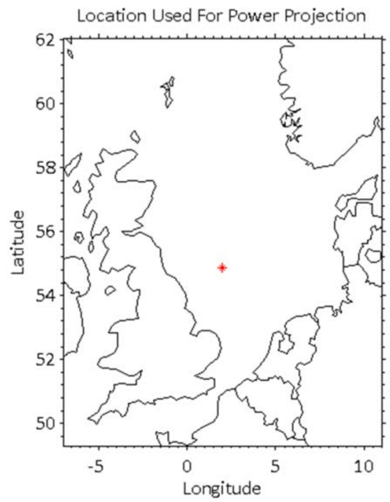

Figure 9: Notional North Sea location used for power projections. Power is highest in the open ocean and lower toward the coasts.

Wave JPD * 10^4
Lon 1.50W, Lat 54.50N
Site Power 18.0 kW/m

H_s (m) \ T_a (s)	3	4	5	6	7	8	9	10	11	12	13	14	15	16
9.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	1	-	-	-	-
8.5	-	-	-	-	-	-	-	-	-	1	-	-	-	-
8	-	-	-	-	-	-	-	-	-	1	-	-	-	-
7.5	-	-	-	-	-	-	-	-	2	1	1	-	-	-
7	-	-	-	-	-	-	-	2	5	1	-	-	-	-
6.5	-	-	-	-	-	-	1	7	6	1	-	-	-	-
6	-	-	-	-	-	1	6	9	4	1	-	-	-	-
5.5	-	-	-	-	-	4	15	11	4	1	-	-	-	-
5	-	-	-	-	-	16	31	12	4	1	-	-	-	-
4.5	-	-	-	-	6	52	42	15	5	1	-	-	-	-
4	-	-	-	-	44	91	41	20	5	1	-	-	-	-
3.5	-	-	-	3	160	99	47	20	8	1	1	-	-	-
3	-	-	-	99	295	112	52	24	9	3	-	-	-	-
2.5	-	-	4	423	310	127	62	28	9	5	1	2	-	-
2	-	-	257	695	316	163	62	28	9	2	2	-	-	-
1.5	-	52	913	608	327	156	55	26	10	2	-	-	-	-
1	5	728	890	479	239	79	41	16	7	3	-	1	-	-
0.5	181	558	379	188	79	36	18	3	2	-	-	-	-	-

Figure 10: Wave JPD for location in Figure . Annually, 18 kW/m wave power is incident at the site.

Based on a preliminary performance assessment using OPT's proprietary modeling tools, the required production of power can be replaced in total or partially with OPT PowerBuoy systems (PB40 and/or Mark 3) resulting in the following benefits:

- Elimination of CO2 emission
- Reduction of OPEX costs by 15% to 35% conservatively
- Enhanced system availability and reliability: Off-loading of diesel generators and reduced maintenance requirements.

CONCLUSIONS

This paper provided a detailed overview of an innovative approach to using ocean wave energy converters, namely OPT's PowerBuoy systems, to reduce logistics costs and enhance the effectiveness and sustainability of various critical Oil and Gas exploration applications. The emphasis is the flexibility of OPT's APB-350 and PB40 in terms of their versatile applicability to such Oil and Gas activities as: on-site generation of critical power, electric power tree control, and AUV network operations management. The use of the PowerBuoy as a power source enables the development and deployment of new concepts of operations that will redefine the way valuable Oil and Gas assets are managed at the global scale while reducing OPEX and CAPEX costs and increasing reliability and availability.

ACKNOWLEDGEMENTS

OPT is thankful for the contribution of the following contracts which helped fund projects described here: Naval Undersea Warfare Center N00253-09-D-005, U.S. Department of Energy DE-EE0003645, and European Communities Framework 7 239368.

REFERENCES

Anres, S. C. Colmard, R. Hallot, F. Firola, J. Ruer, S. A. Sapem, E. Martin, and S. A. Total, 2012: Innovative wave energy converter for oil & gas developments. Offshore Technology Conference, Houston, TX.

Watson, P., K. Edwards, M. Mekhiche, J. Rixon, C. Morris, and T. Sebire, 2013: Improving the economics of marginal fields through technology transfer from the defense and renewables industries. Submitted to SPE Journal.