PRELIMINARY STUDY ON AN OFFSHORE WIND ENERGY RESOURCE MONITORING SYSTEM

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ABSTRACT: The expansion of offshore wind energy is part of many national programs for the implementation of renewable energies. Recent developments focus, among others, on the exploitation of wind resources in deep water areas using floating wind turbines. The assessment of the wind resources in those areas requires versatile and cost effective monitoring systems, due to the high costs of existing technologies (such as floating lidars or meteorological masts). A preliminary design for such an alternative system has been developed in this work. Solutions to meet the diverse requirements of such a system have been proposed and evaluated. Furthermore, they were summarized in a morphological matrix and filtered with respect to operational feasibility, costs and expected R&D efforts. A final design was selected and visualized. The cost for the system are estimated to be below 180.000€, approximately a fifth of the market price of a floating lidar system. Several critical points for a possible realization were identified and discussed. Those are the survivability of the aerostat and the tether, the absence of commercial feed-tubes and the movements of the sondes. Future developments to overcome those issues at hand are proposed. Those proposals are accompanied by a general development strategy to accelerate the overall realization process.

KEYWORDS: offshore wind assessment, tethersonde, data buoy, morphological matrix, aerostat, cost analysis

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1 INTRODUCTION

Among all renewable energy source, particularly wind energy offers significant potentials for greenhouse gas emission reduction. However, the onshore expansion of onshore wind energy is limited in several ways and makes the expansion to offshore sites inevitable. To exploit wind resources in deep water areas floating wind turbines are in development. They offer access to large additional wind resource areas and could make turbine and support structure designs largely independent of water depths and seabed conditions (Edenhofer, et al. 2012).

Existing wind monitoring technologies for deep water areas, such as meteorological masts (often abbreviated as met masts) or floating lidar[1] systems, have significant cost. Therefore a need for new systems, which offer the possibilities to assess the wind resource more cost efficiently, has been identified.

A preliminary study for a new concept, based on the idea of an aerostat launched from a buoy with instrumentation along the tether, is presented in this paper. It offers a potential low-cost alternative for deep offshore wind monitoring.

2 OFFSHORE WIND MONITORING SYSTEMS

The most used methods for offshore wind resource assessment are meteorological masts, lidars and weather buoys. Weather buoys and met masts measure the wind resource using anemometers in combination with wind vanes. Sonic or cup anemometers can be used. Cup anemometer have usually lower cost, but are more susceptible to the marine environment. Sonic anemometer are characterized by a finer resolution and the capability to detect the wind direction (Deiss, et al. 2001).

Figure 1: 70m met mast in the North Sea

Figure 2: KIC InnoEnergy project **Neptune***, floating lidar during offshore trials*

Whereas weather buoys measure close above sea level, met masts have several monitoring heights (up to 100m above sea level) to obtain the wind profile. They have been the standard solution until today, but are very costly (between

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[1] Lidar abbreviates **Li**ght **d**etection **a**nd **r**anging and describes a surface-based remote sensing systems similar to a radar.

2-10Mio €), especially with increasing water depth. Floating lidars promise a more cost efficient assessment (around 1Mio €), which is independent of the water depth. The sensing system uses a laser beam to assess the wind profile up to an altitude of approx. 200m. While being a mature system onshore, floating lidar systems are still objected to ongoing development, see Figure 2, and few systems are commercially available (Brown 2012).

A cost breakdown was estimated for one of those commercialized systems (WindSentinel™ by AXYS Technologies) and is shown in Figure 3. The biggest cost driver is apparently the buoy platform, which costs more than half a million euros. The actual sensing system accounts for only 29% of the overall costs. From this numbers it can be concluded that the final concept of this work should have total costs much below half a million euros. Especially the implementation of a less expensive buoy seems to be an effective way to become economically competitive.

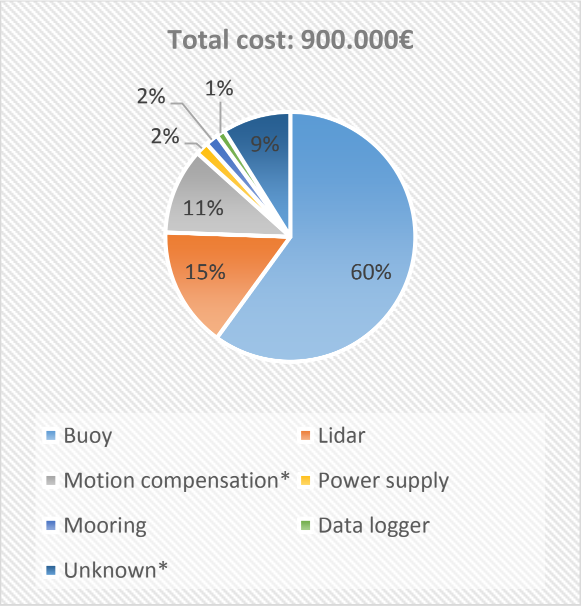

*Figure 3: Cost Breakdown for the AXYS WindSentinel™, (*assumptions)*

3 WIND INDUCED OSCILLATIONS IN CABLES AND AEROSTATS

The wind flowing around the tether and the aerostat of the possible monitoring system can theoretically induce vibrations or motions in the aerostat and the tether. This could disturb the wind resource assessment and affect its quality.

For cables four different types of wind induced vibrations have been found: Vortex-induced vibrations, galloping, flutter and buffeting (Kumar, Sohn und Gowda 2008). The last three will most likely not occur, but the tether will probably experience vortex-induced vibrations. Yet their magnitude seems to be negligible for this application with amplitude/diameter ratios of less than 1.5 (Williamson und Govardhan 2007).

The behavior of tethered aerostats has been subjected to research for many decades; see (DeLaurier 1972) and (Coulombe-Pontbriand and Nahon 2009) performing stability analyses of tethered aerostats or (Sakamoto und Hanui 1989) and (Govardhan und Williamson 1997) investigating vortex-induced vibrations of tethered spheres. Nevertheless, no reliable findings to predict the behavior of a tethered aerostat could be found.

4 BALLOON-BOURNE MONITORING SYSTEMS

The application of balloons or aerostats for monitoring purposes has a long history dating back to the 18th century, whereas the use of instrumentation along the tether started in the last decades. In 2003 Vaisala launched the *Tethersonde* product line, see Figure 4.

Today only one system is commercially available, the *SmartTether* by Anasphere. Their tethersonde can measure the wind speed and direction, pressure and relative humidity for up to 10h. The operation time is limited by the energy supply from the battery pack onboard. Similar to the tethersonde by Vaisala it is intended for onshore boundary layer profiling at moderate wind speeds of less than 50km/h (Anasphere 2014).

Also initiatives for the transition of tethersonde systems to an offshore operation were found. At the Universitat de Barcelona a first prototype was developed and tested successfully onshore (Lyasota 2013). A second development was identified at the company Allsopp Helikites, a manufacturer of resistant aerostats, trying to develop a similar system for offshore wind resource assessment (Sandy Allsopp, personal communication, 11.3.2014).

Figure 4: Tethersonde system by Vaisala carried by a blimp

5 DEVELOPMENT PROCESS

To develop the new concept in this work a certain process was established, which is depicted in Figure 5.

First, the fixed points, which were set at the beginning of the process, and the necessary operational main and sub functions are identified. Main functions are e.g. energy supply, data acquisition and data transmission. Then possible partial solutions for the sub-functions are derived to fulfil them, constrained by the fixed points. All the possible partial solutions are then summarized in a morphological matrix to get a comprehensive overview of the system. In a next step the matrix is filtered with respect to operational feasibility, expected costs and expected research and development efforts. Finally, a reasonable concept is selected and visualized.

6 MORPHOLOGICAL MATRIX

The morphological matrix of this process is shown in Table 1, containing all the identified functions with the respective partial solutions. After filtering the matrix, as described in the previous section, many solutions were removed. From the remaining solutions the final design was determined and can be seen in Table 2.

The aerostat is launched from a buoy and can carry up to six sondes along the tether. The operation time, which is expected to be around half a year, can be achieved through a constant helium replenishment. The gas is stored on the buoy and transported in a feed-tube to the aerostat to replace the leaking gas. The wind is monitored with ultrasonic anemometers carried by the tethersondes. The altitude and orientation of the sonde are detected via DGPS and a digital

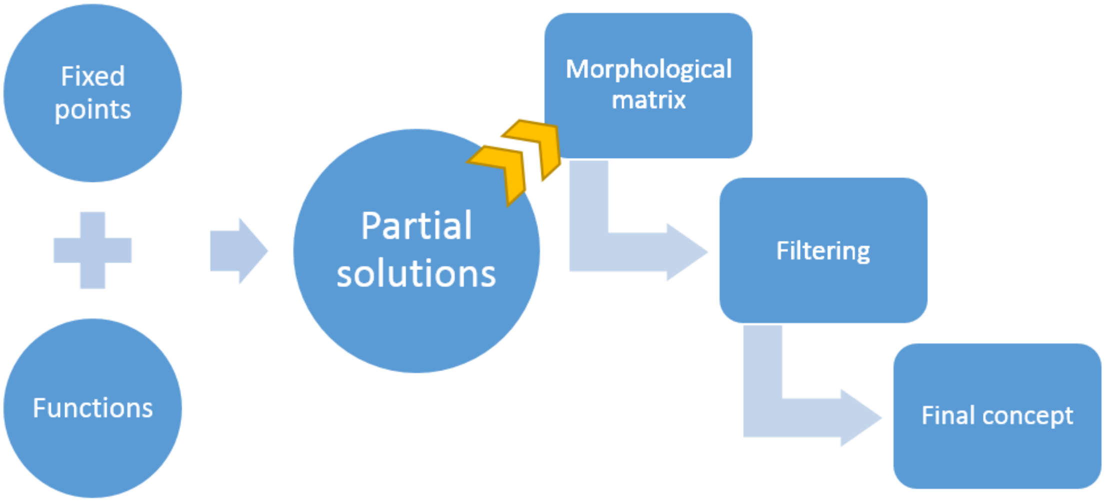

Figure 5: Diagram showing the development process

compass. For the first prototypes an Arduino based micro controller for the sondes is proposed. The sondes are supplied with energy from solar panels, same as the aerostat. The batteries of the buoy are charged from a combination of solar panels and a micro wind turbine. To transmit the meteorological data two data links are implemented. Between the aerostat, the buoy and the sondes a radio link on an ISM band is selected. A satellite connection establishes a connection from the central data logger on the buoy to shore. The buoy itself is a watertight 3m-discus buoy, made from aluminum with sufficient storage space for the gas cylinders and additional equipment. It is moored by an all-chain mooring line with a concrete sinker.

7 FINAL CONCEPT

To understand the final concept, as described in the previous section, a visualization was created. It shows all the system feature of the final concept in Figure 6.

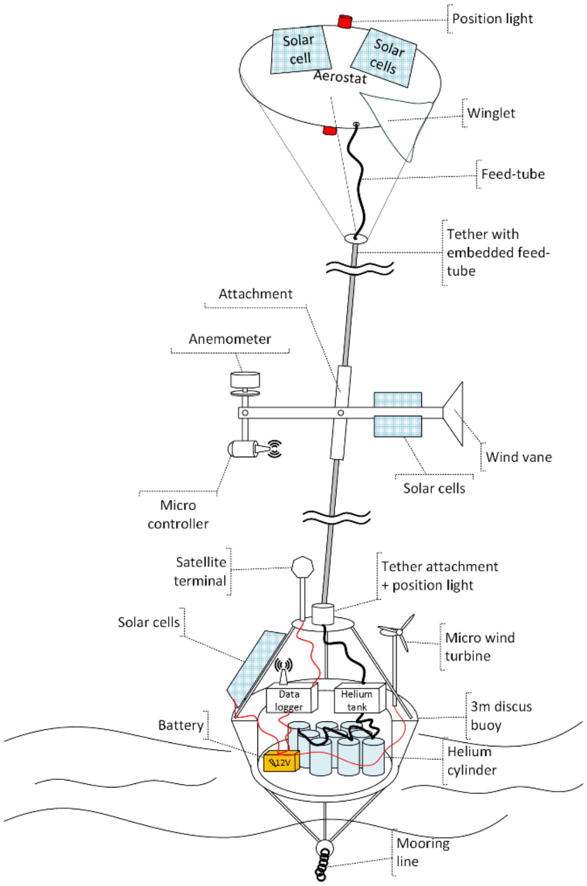

Figure 6: Visualization of the final concept

Table 1: Morphological matrix summarizing all the partial solutions sorted by the main and sub functions

MAIN FUNCTION	FUNCTION	Solution #1	Solution #2	Solution #3
OPERATION TIME	Maintain lifting force	Overloading	Take down	Feed-tube
	Provision of lifting gas	Helium cylinder	Hydrogen cylinder	Elektrolyser
	Keep altitude in strong wind	Helikite/spheroid	Winch control	
DATA ACQUISITION	Instrumentation for wind assessment	Cup anemometer	Sonic anemometer	
	Detect position and movement of instrument	DGPS (EGNOS)	Orientation sensor (barometer + accelerometer)	Optical/Ultrasonic range finder
	Detect cardinal direction of instrument	Digital compass		
	Combine the hardware	Hacking	Arduino	Custom microcontroller
ENERGY SUPPLY	Aerostat	Battery	Via tether	Solar panel
	Sonde	Battery	Via tether	Solar panel
	Buoy	Battery	Renewable source	Generator
INFORMATION TRANSPORT	Transmission Sonde/Buoy	Wi-Fi	ISM band	
	Transmission Aerostat/Buoy	Wi-Fi	ISM band	Optical cable
	Transmission Buoy/Shore	GSM/3G	Marine VHF radio	Satellite
PLATFORM	Supporting structure	Navigational buoy	3m buoy	NOMAD
	Mooring	All chain mooring		

Table 2: Morphological matrix with the partial solutions of the final concept

MAIN FUNCTION	FUNCTION	Solution #1	Solution #2	Solution #3
OPERATION TIME	Maintain lifting force	Tank on board	Take down	**Feed-tube**
	Provision of lifting gas	**Helium cylinder**	Hydrogen cylinder	Elektrolyser
	Keep altitude in strong wind	**Helikite/spheroid**	Winch control	
DATA ACQUISITION	Instrumentation for wind assessment	Cup anemometer	**Sonic anemometer**	
	Detect position and movement of instrument	**DGPS (EGNOS)**	Orientation sensor (barometer + accelerometer)	Optical/Ultrasonic range finder
	Detect cardinal direction of instrument	**Digital compass**		
	Combine the hardware	Hacking	**Arduino**	Custom microcontroller
ENERGY SUPPLY	Aerostat	Battery	Via tether	**Solar panel**
	Sonde	Battery	Via tether	**Solar panel**
	Buoy	Battery	**Renewable source**	Generator
INFORMATION TRANSPORT	Transmission Sonde/Buoy	Wi-Fi	**ISM band**	
	Transmission Aerostat/Buoy	Wi-Fi	**ISM band**	Optical cable
	Transmission Buoy/Shore	GSM/3G	Marine VHF radio	**Satellite**
PLATFORM	Supporting structure	Navigational buoy	**3m buoy**	NOMAD
	Mooring	**All chain mooring**		

8 COST ANALYSIS

The total fixed cost of the system are around 180,000€, thus making it significantly less expensive than a floating lidar system. The structure of the cost, however, is very similar, compare Figure 3 and Figure 7. Even though the 3m-discus buoy hull costs only a fifth of the buoy for a floating lidar, it is the biggest cost item. It is followed by the cost item *miscellaneous*, which comprises e.g. assembly and deployment, and the *buoy equipment*.

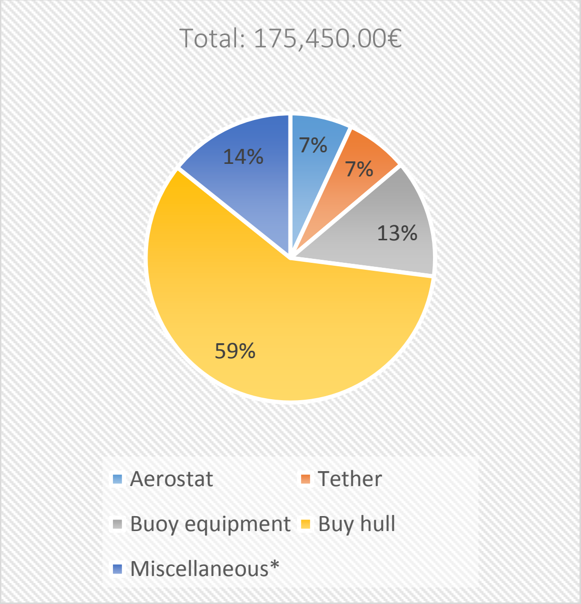

*Figure 7: Total fixed cost of the developed system (*assumptions)*

For the running cost two scenarios have been calculated. One standard scenario and a second scenario, which included a tether and aerostat replacement every 6 month due to high mechanical stress. In the first scenario the running cost for half a year are about 10,000€, in the second scenario the running cost increase significantly and sum up to 27,000€. A major cost factor, besides the possible replacing of the aerostat and the tether, is the lifting gas. The helium supply costs 5,000€ per half year.

To further reduce costs a less expensive buoy hull is necessary. Alternatives are either a combination of standard (navigational) buoys or a less expensive replica of the 3m-discus buoy. Also custom-made data logger equipment and economy-of-scale effects may contribute to cost reduction.

9 CRITICAL POINTS OF THE DESIGN

Several critical points have been identified during the development process. Those are:

- The absence of commercially available feed-tube systems.
- The uncertain survivability of the aerostat in harsh offshore winds during a long term operation.
- The uncertain survivability of the tether, which is exposed to millions of load cycles between the heaving buoy and the aerostat during a long term operation. The magnitude of the tether loads is significant with up to 10kN.
- The horizontal orientation of the sonde may be affected by the solar panels if exposed to strong wind. However, a horizontal orientation is critical for the quality of the wind resource assessment.

10 FURTHER DEVELOPMENTS

Several developments are proposed to solve the critical issues at hand and advance to a more mature concept. They are as follows:

- Fatigue testing of aerostat and tether
- Development of a steady and robust sonde design
- Development of the sonde software
- Identification of alternative feed-tube concepts
- Identification of a modularization strategy and implementation of a life cycle cost analysis

11 CONCLUSION

A preliminary concept for a versatile and cost effective system for wind resource assessment in deep water areas has been presented in this work. Solutions to fulfil the diverse functions of such a system have been identified and were evaluated. The partial solutions have been summarized in a morphological matrix and filtered with respect to operational feasibility, costs and expected R&D efforts. Eventually a final design was selected and visualized.

The cost for such a system are much below those of a floating lidar system with about 180,000€. Potentials for further cost reduction have been identified (e.g. buoy hull, economy of scale, etc.). However, further developments are still necessary to realize the presented system.

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