Feasibility study of a Semi-submersible floating Vertical Axis Wind Turbine system in the offshore Greece

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ABSTRACT

INTRODUCTION

Wind power generation is one of the most promising renewable energy solutions against the global environmental problems. Especially offshore wind industry, gaining particular interest in recent years, has experienced significant growth. A withdraw though comes from harvesting the richer wind potential further off the coasts in deep waters. Deployment of wind turbines in increased water depths has raised the issue of the appropriate selection of the most suitable wind turbines' designs and support structures' options. The possibility of mounting wind turbines on floating support structures offers the most feasible solution for installations at these depths.

When it comes to deep offshore development choosing a Vertical Axis Wind Turbine over the dominant Horizontal Axis Wind Turbine is described by research as having great potential, due to specific advantages that a VAWT can offer and make significant difference in the offshore environment. Insensitivity to wind direction, which results in a simpler design and no response delay due to the absence of yaw control, small gyro effect from the slow rotational speed of the rotor, a lower center of gravity of the structure, possibility of placing the electrical and mechanical components almost at sea level, and overall a lighter, less costly, easily accessed and maintained system summarize the main advantages of these systems. Adding to that, in the case of a straight wing vertical axis wind turbine, the total length of each blade is exploited efficiently for the power generation.

OBJECTIVES

In order to analyze the behavior of the complex floating wind turbine systems and add to the limited past research on analysis of vertical axis wind turbines as well as investigate the viability of such a system, this study sets the following targets:

1. Develop an appropriate code to model and analyze the motions of the combined system of a semi-submersible floating Vertical Axis Wind Turbine.

2. Perform a first evaluation and process statistically the environmental data of the offshore wind and wave environment of the Aegean case study area.
3. Study the behavior of the system and identify the effects of the combined parts on the system`s motions.
4. Test the system in terms of safety and energy efficiency.

METHODOLOGY

1. Concept design

The design consists of a 4 column semi-submersible platform and a straight wing vertical axis wind turbine (SWVAWT) mounted at the central column as shown in Fig.1.

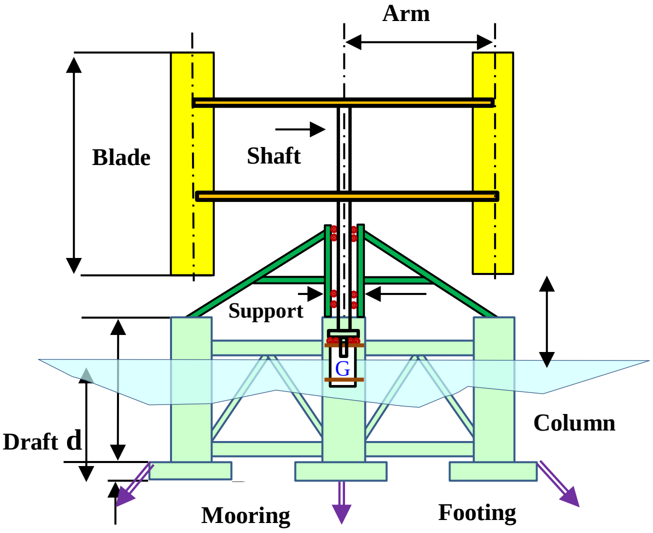

Fig.1 The floating SWVAWT and its characteristics

(Provided by: Ocean Engineering Research Inc.)

Power output	2MW
No of blades	3
Blade length	63.5m
Tower height	33.6m
Blade length	8m
Rotor diameter	95.3m
n	9.02rpm
Cp	0.461
C_E	0.3118
V rated	12m/s
λ	3.75
Draft	18.5m

2. Numerical analysis

The numerical analysis of the system`s motions is conducted based on the Singularity Distribution Method and the time histories of the six modes of motions, the translational surge, sway and heave along x, y and z axes and the rotational roll, pitch and yaw about x, y and z axes, are obtained in time domain. The governing equation is:

$$(\mathrm{M}+\mathrm{A})\{\ddot{x}\}+N\{\dot{x}\}+K\{x\}=\{F_{Wave}\}+\{F_D\}+\{D\}+\{F_M\}+\{F_{Wind}\} \quad (1)$$

Where M, A, N, K the mass, added mass, damping and stiffness matrixes of structure, X and its derivatives unknown vectors of 6 modes of motions, $\{F_{Wave}\}$, $\{F_D\}$, $\{D\}$, $\{F_M\}$ and $\{F_{Wind}\}$ the wave, drift, viscous drag, mooring aerodynamic forces. The gyro effect of the rotation of the turbine about z axis is added through the angular momentum $I\omega$ (2) and the inertia forces and moments induced about x and y axes. Under the floater`s response pitch angle, the system will now operate under a relative wind speed that equals: $V_{rel} = U - v$ (3) where U the inflow and v the induced wind speeds. The structural properties of the floater and the SWVAWT as well as the sea state conditions (wave significant height, direction, period, etc.) are inputs to the program. JONSWAP wave spectrum is selected and head waves, progressing along the x axis are assumed. The hydrodynamic coefficients (added mass, damping coefficient) are calculated and the motion responses for the six modes of motions of the combined system of the floating SWVAWT are obtained.

3. The environmental data

Environmental data were necessary to be gathered for the input data. Thus Greece as a country of great offshore wind potential was a good candidate. The case study of the Aegean Sea, due to excellent wind conditions, was selected. Data over a period of 11 years, from 2001-2012, were collected, as provided by POSEIDON system-Hellenic Center for Marine Research, processed and analyzed statistically for describing the sea state of the area and acquiring the needed information; significant wave heights, average wave periods, wind speeds, etc. for medium, maximum and survival conditions. The survival state is considered the maximum expected wave height in the life time of the system (20 years) and resulted from the statistical analysis.

	Significant Wave Height (m)	Wave period (s)	Wind speed (m/s)
Medium state	2.75	5.57	13.5
MAX measured	5.76	7.64	18.52
MAX expected	9.82	13.91	-

Table 1. The selected three conditions

RESULTS

The time histories of motions were calculated and the results were compared with the motion of the system without accounting for gyroscopic effect and the wind force in order to recognize the effects of each component. For the survival state the significant as well as maximum values of surge, sway, heave, roll, pitch and yaw were also calculated through the power spectrum analysis of each mode. Under that severe state the system was tested for safety and energy performance factors for its life time. The stress forces exciting the system and the reduction of energy output due to the motions were also calculated. The results of the motions are given in Table 2. The maximum values of stress were found to be under the limits of the system`s structural stress but one (axial stress 2-on the outer edge in y axis). The reduction of the energy efficiency was calculated as 0.7%, while the pitch angles did not exceed over 3 degrees.

<table>
<tr><th></th><th></th><th>Surge
(m)</th><th>Sway
(m)</th><th>Heave
(m)</th><th>Roll
(deg)</th><th>Pitch
(deg)</th><th>Yaw
(deg)</th></tr>
<tr><td rowspan="2"><u>Medium</u></td><td>w/o</td><td>0.2</td><td rowspan="2">0.0045</td><td rowspan="2">0.15</td><td rowspan="2">7×10^{-4}</td><td>0.2</td><td rowspan="2">0.0028</td></tr>
<tr><td>VAWT</td><td>0.68</td><td>0.6</td></tr>
<tr><td rowspan="2"><u>Maximum</u></td><td>w/o</td><td>0.8</td><td rowspan="2">0.0017</td><td rowspan="2">0.64</td><td rowspan="2">2.7×10^{-3}</td><td>0.8</td><td rowspan="2">0.0015</td></tr>
<tr><td>VAWT</td><td>1.3</td><td>1.2</td></tr>
<tr><td rowspan="2"><u>Survival</u></td><td>w/o</td><td>4.3</td><td>0.05</td><td rowspan="2">1.8</td><td>0.04</td><td>2.5</td><td>0.10</td></tr>
<tr><td>VAWT</td><td>4.5</td><td>0.2</td><td>0.2</td><td>2.7</td><td>0.06</td></tr>
</table>

Table 2. Amplitudes of motions

Limit Shear	*Limit Axial*	*Shear* τ1	*Shear* τ2	*Axial 1*	*Axial 2*
22.09×10^7	33.33×10^7	1.28×10^7	24.9	1.39×10^7	33.6×10^7

Table 3. Stresses in (Pa)

DISCUSSION

The evaluation of the comparative results makes clear that the factors that play greater role in the progress of the response are the wave forces exciting the floater and the acting wind force, while the gyroscopic effect shares a small part on the output motion. The system under the wind force will be shifted and tilted while the amplitudes of the motions will be also enhanced. In the case of the survival condition it is noticeable that the magnitude of shift and tilt of the axis of oscillation is small. It was also found that in the survival state the gyroscopic effect was the main factor influencing the sway, roll and yaw responses. Especially the yaw motion was mitigated by the effect of the gyro moment.

CONCLUSION

From the numerical computation conducted on the present study, the motion responses of the combined system were obtained and analyzed in terms of separation of gyro and wind force effects. A statistical analysis was completed for the sea state conditions of Aegean Sea. The structure in terms of safety and power production was proven viable and efficient under the maximum expected sea state for its life time. It would be recommended the analysis to be conducted for multi directional waves and for more severe conditions. Validation of the new code is also needed.

References *Newman, J. N. 1977. Marine hydrodynamics. Cambridge: The MIT press.; Wayman, E. N., Sclavounos, P. D. et al. 2006. Coupled dynamic modeling of floating wind turbine systems; Akimoto, H., Tanaka, K., Uzawa, K. 2011. Floating axis wind turbines for offshore power generation: A conceptual study.; Katsoulis, B. D. 1993. A survey on the assessment of wind energy potential in Greece.*