Preliminary study of the Floating Axis Wind Turbine

Hiromichi Akimoto
Division of Ocean Systems Engineering
Korea Advanced Institute of Science and Technology
Daejeon 305-701, Republic of Korea
akimoto@kaist.ac.kr

Jong-Chun Park and Se-min Jeong
Department of Naval Architecture and Ocean Engineering
Pusan National University
Busan 609-735, Republic of Korea
jcpark@pusan.ac.kr, semin.jeong@pusan.ac.kr

Kenji Tanaka
Department of Systems Innovation
Graduate School of Engineering, The University of Tokyo
Tokyo 113-8656, Japan
kenji_tanaka@sys.t.u-tokyo.ac.jp

Abstract— **Floating axis wind turbine is a new concept for reducing the cost of offshore wind energy by using the tilted cross flow wind turbine floating in water. Since construction of high tower of horizontal axis wind turbine is expensive in ocean environment, the floating axis turbine configuration will be an alternative solution for large-capacity offshore wind turbine. The paper provides the description of the concept and sample design of the design.**

Keywords-component; floating axis wind turbine, FAWT, offshore wind turbine, vertical axis wind turbine

I. INTRODUCTION

Offshore wind turbine is a hopeful renewable energy device because of the steady wind force in offshore environment. Since shallow water region suitable for constructing bottom-fixed offshore wind turbine is limited, we have to consider the further development of floating offshore wind turbines. However, the cost of floating wind turbine is considered to be more expensive than those of offshore wind turbines with foundations on sea bed in shallow water region.

At present, most of offshore wind turbine concepts are conversion of land based horizontal axis wind turbine (HAWT) because of its successful development in these days. However, their high tower for supporting the wind turbine leads to significant increase of cost in ocean environment because keeping the upright position of high tower requires large floating structure. Also, construction and maintenance of wind turbine on the top of tower require specially designed work vessels (crane ships) or calm water condition. Since offshore wind farms will be sited in windy (and rough) sea area, the probability of calm weather for such operations is not high. It leads to the increase of construction period deteriorates the total economy of the project.

There are projects of floating wind turbines those are characterized by their ways to reduce the total cost of plant. Hywind [1] is the first large-capacity floating wind turbine, in the North Sea off Norway. Its 2.3MW turbine is on a simple spar buoy moored to sea bed by catenary cables. WindFloat proposed a concept of HAWT on a tri-column floating platform [2]. The turbine tower is on one of three columns for minimizing the structural weight of the plant. Also, there are concepts of multiple rotors on a large float to reduce the cost of float per turbine. However closely located wind turbines on a float may experience aerodynamic interference among them.

To avoid the construction of high tower, there are vertical axis wind turbine (VAWT) concepts for offshore wind power. Although large-capacity VAWT is not popular in onshore applications, it has some advantages in offshore applications. Since electric generator of VAWT can be installed at the bottom of rotating axis, the height of gravity center of VAWT can be lower than that of HAWT. It also provides easy maintenance access to main mechanisms those are installed in low altitude. Blonk showed that the economic performance of offshore VAWT concepts is comparable to those of HAWT [3]. Nenuphar [4] proposed straight blade VAWT mounted on a tri-column float with direct drive electric generator.

On a floating platform, keeping upright position of the tower or vertical axis turbine is not easy. Providing sufficient stability of the turbine increases the size of float and total cost of the plant. To avoid the situation, Sway[5] proposed the inclined floating HAWT. In the concept, the turbine is on a floating tower moored to the seabed. The ballast weight and suction anchor connected to the bottom end keep the tilt angle of tower within a few degrees. Deepwind [6] proposed a Darrieus turbine mounted on a rotating spar buoy. Since the rotating axis is supported by buoyancy, it does not require the development of large-capacity mechanical bearings even in the 20MW rated power. However, the electric generator planed to be installed in the bottom end of spar buoy requires technical challenges.

In these concepts described above, significant efforts are made for keeping the turbine in upright position. Although Sway and Deepwind concept allow their turbine to tilt, the angle is in a limited range. Figure 1 shows the schematic drawings of floating wind turbine concepts. Figures 1 (a), (b), (c) and (d) show the floating concepts of HAWT, straight blade VAWT, Darrieus blade VAWT and Deepwind respectively. For further reduction of total cost of offshore wind energy,

978-1-4577-2091-8/12/$26.00 ©2011 IEEE

Akimoto et al. [7] proposed a concept of tilted floating turbine as shown in Figure 1 (d). It is floating axis wind turbine (FAWT) concept.

In FAWT, the turbine is on a rotating spar buoy as in the Deepwind concept. The planer motion of the turbine is restricted by the secondary float. Electric generators are installed on the secondary float above the water surface.

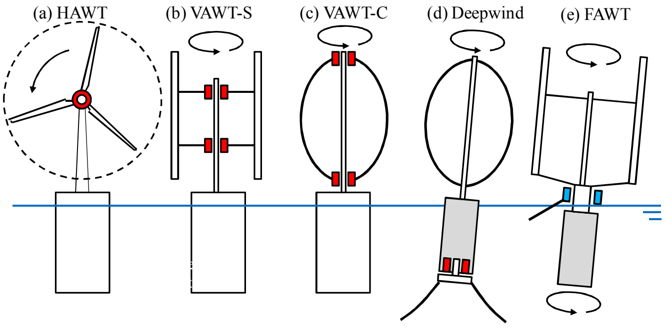

Fig. 1 Variation of floating wind turbine concepts

II. FLOATING AXIS WIND TURBINE

Although FAWT concept is based on vertical axis wind turbine, its rotating axis is inclined when it is working as shown in Fig. 2. Since righting moment of a spar buoy increases with tilt angle, we can reduce the size of spar buoy by setting the tilted position as its normal operating condition. The inclination of turbine is in the balance of wind force, gravity and buoyancy of submerged part. The turbine axis has bulged part near the water surface and ballast weight in its bottom to enhance the stability. Merits of this design are summarized as follows.

1. In strong wind, tilted position reduces the sweep area of turbine. It avoids over speed rotation.
2. It does not require large-capacity mechanical bearings since the weight of turbine is directly supported by buoyancy.
3. The load of large-capacity turbine will be shared by multiple units of contacting roller and generator installed off axis of the turbine.
4. Contacting rollers bear only the thrust of turbine (horizontal component of turbine load).

Although the concept is simple, it requires new challenges in the dynamics of large scale VAWT turbine subjected to natural fluctuating wind. It will experience Magnus force on wind turbine, wave load and ocean current on the spar buoy. The gyration moment of the turbine contributes to the stability of rotating axis and to level the power output.

The rated power of FAWT in Fig. 2 is 3MW. Table 1 shows the main particulars of the turbine and its expected cost of energy [7]. At present, the influence of tilt is included only as the change of front projection area of the turbine. Although a VAWT requires larger sweep area than HAWT, the total weight and cost of the system can be smaller than those of HAWT. The preliminary estimation showed the competitive economic performance of the present concept [7].

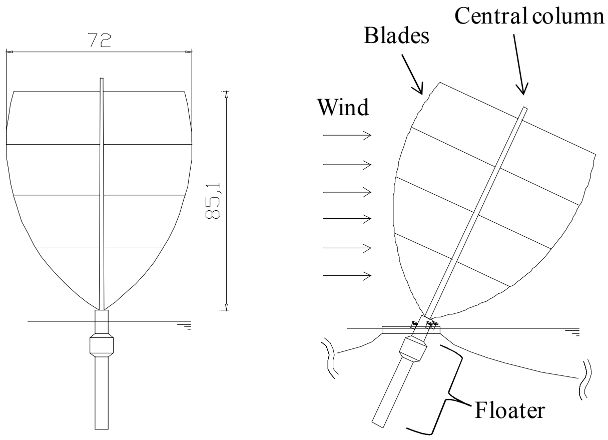

Fig. 2 Floating axis wind turbine concept

Table 1 Cost estimation of 3MW shallow-water HAWT and FAWT (1000USD)[7]

	3MW HAWT	3MW FAWT
Rotor	477	871
Drive train, nacelle	1425	659
Control, Safety Sys., Monitor	60	60
Tower/Central column	415	221
Marinization	321	244
Monopile / Float	1114	1712
Transport, Install	1835	1835
Scour Protection	204	0
Surety Bond	180	168
Offshore Warranty Premium	357	272
(Subtotal: Initial capital cost)	(6386)	(6042)
Replacement Cost (USD/yr)	55	55
O&M (USD/turbine yr)	215	145
Bottom Lease Cost (USD/yr)	12	12
(Subtotal: Annual Operating Expenses [USD/year])	(282)	(212)
Cost of Energy (USD/kWh)	0.095	0.071

III. DESIGN FOR PRACTICAL APPLICATION

For practical realization of the concepts, we have to solve some problems. Some of them are common in VAWT concepts and some are from the new feature of floating turbine configuration. They are discussed in this section.

A. *Self starting capability*

Since the torque of VAWT is small at the start of rotation, self-start of the turbine is not easy. In some large scale VAWTs, the main turbine has an additional Savonius turbine for the assist of starting torque. Although Savonius turbine shows high torque at low revolution speed, it deteriorates the total performance of the system at the designed operating condition. Another solution is the use of helical blade design to reduce the pulsation of turbine torque as shown in Fig.3. Helical blade design is known to improve the self-starting characteristics. Since the curvature of the helical shape is moderate in the present design, it does not increase the cost of blades significantly.

Other treatment for self-starting is to reduce the required torque and loss of drive train at low revolution speed. Since viscous drag on the submerged part of turbine axis is proportional to rotation speed, the drag does not appear at startup. Therefore, the floating axis design highly contributes to the self-star characteristics of the system.

Although the difficulty of self-starting is considered to be one of major problems of VAWT, it does not matter in large-scale applications. Since offshore wind turbines have to be connected to onshore power grids by undersea cables, it is easy to borrow electricity from the grids for start-up and to use the generator as a starter motor.

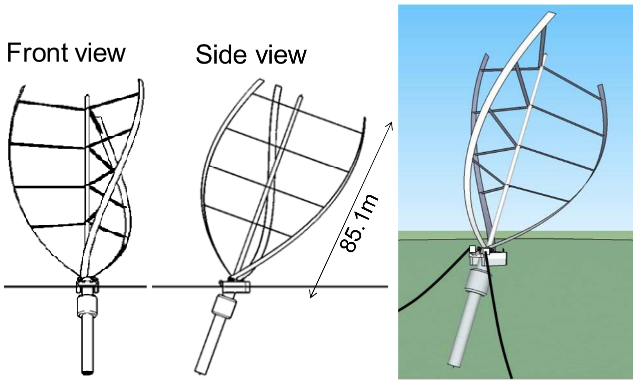

Fig. 3 Helical blade design of FAWT

B. Treatment of reaction torque

In floating wind turbine, we have to manage the reaction torque of the electric generators. A simple solution is absorbing the torque by mooring cables attached on the secondary float. However, it leads to the complexity of mooring system and needs additional consideration in the design of secondary float. Our alternative solution is twin-turbine configuration where two counter rotating turbines are connected by a bridge as shown in Fig. 4.

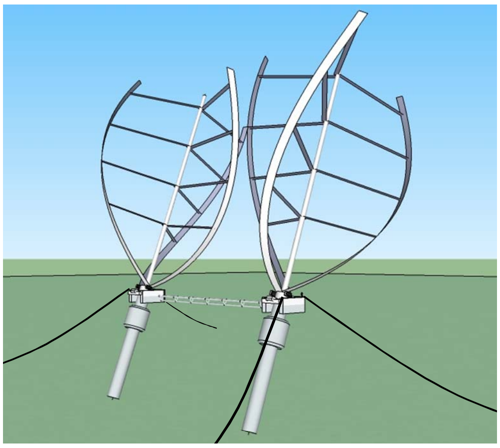

Fig. 4 Twin turbine configuration of FAWT

Since reaction torque will be cancelled between the two turbines, the mooring system can be simplified. The bridge between the two floats restricts only their yaw motions for minimizing the structure of total system. The closely positioned turbines may have interferences between them. Further investigation will be required for the selection of reaction torque treatment.

C. Structural requirement

The present design indicates that blades experience compression in span wise direction. It is needed to optimize the structure so that the centrifugal force acting on the turbine reduces the compression load and reduces the structural weight of turbine. However, the situation is not significantly severer than those in HAWT designs.

Stable offshore wind and availability of large area are benefit of offshore wind turbine concepts. However, at present, large-capacity floating wind turbine than is not easy. One reason is the difficulty of high structure on a floating platform as described above. The second reason is the difficulty of developing large capacity bearing, drive train and generators. The unstable motion of the mechanism in ocean environment makes their R&D more difficult. In this point of view, present FAWT concept is a suitable candidate of future large-scale offshore wind turbine. Since the floating turbine will be supported by multiple units of contacting roller and generators, the load of turbine can be shared by small-capacity units. It significantly reduces the difficulty of scale-up. The drive train and generator of HAWT should be compact and light weight for the requirement of installation into the small nacelle on the top of tower. In FAWT concept, the mechanisms are off axis of main rotor and not limited in installation space.

Also, since the weight of turbine is supported by the buoyancy of rotating spar buoy, the roller units have to bear only the horizontal component of turbine load. The authors think FAWT is more promising in future large-scale offshore wind turbine than HAWT and VAWT concepts.

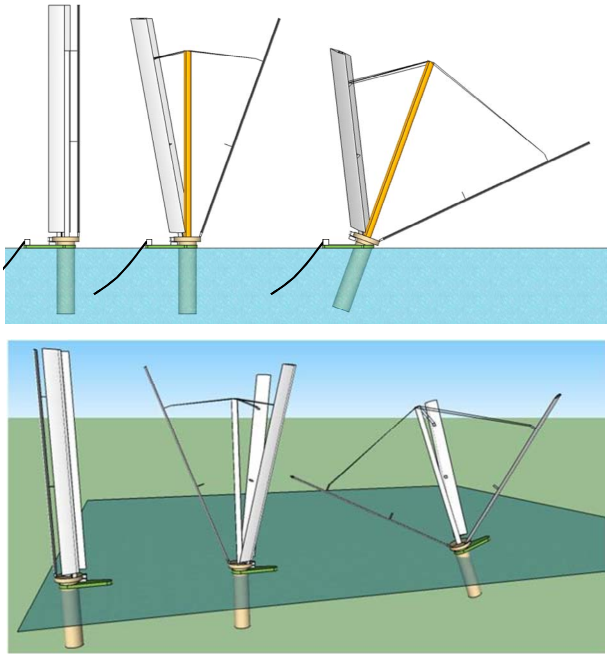

Fig. 5 Experimental small plant of FAWT

D. *Pilot plant configuration*

Since the present concept is new one, we have to start from small pilot plant and then develop scale-ups of the concept step by step. For this purpose, we provide the plan of small experimental FAWT plant as shown in Fig. 5.

Since main purpose of the plan is to understand the dynamics of floating turbine in actual offshore condition, it has simplified design of FAWT. The turbine blades can be closed for transportation and durability in high wind. The turbine can be transported and used to obtaining electric power on offshore platforms or small islands those are not connected to onshore power grids. Also, in a wide scale disaster of ocean side, i.e. earthquake and tsunami, wind turbines of this design can be deployed near the disaster area to provide electricity. If it can reduce the work of fuel transport to the disaster area, the limited transport capability to the affected area can be used for other rescue operations.

CONCLUSIONS

The floating axis wind turbine concept can provide low cost offshore wind energy. Since the idea is still in the conceptual study, there are some problems we have to solve for its commercial realizations. The some expected characteristics of the concept are suitable for large-capacity offshore wind turbine. The authors think that in deep water region where sea-bed-mounted wind turbines are not reasonable in economics, the present concept is a hopeful candidate of large-capacity offshore wind turbine design.

ACKNOWLEDGMENT

This research was supported by WCU(World Class University) program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (R31-2008-000-10045-0).

REFERENCES

[1] Statoi, “StatoilHydro inaugurates floating wind turbine,” 2009-09-08 news artcicle of the company, http://www.statoil.com/en/newsandmedia/news/2009, (retrieved 2012/04)

[2] Principle Power, “First WindFloat Successfully Deployed Offshore,” company news release, Nov. 2011, http://principlepowerinc.com/news/press_PPI_WF_deployment.html (retrieved 2012/04)

[3] D. Lindert Blonk, “Conceptual Design and Evaluation of Economic Feasibility of Floating Vertical Axis Wind Turbines -Public Version-", MSc. Thesis, Delft University of Technology, 2010

[4] “Nenuphar Technology benefits”, http://www.nenuphar-wind.com/technology, company website (accessed Apr. 2012)

[5] Sway company web site, http://www.sway.no (retrieved 2012/04)

[6] U. S. Paulsen, T. F. Pedersen, H. A. Madsen, et al., "Deepwind - an innovative wind turbine concept for offshore", Proc. EWEA Annual Event 2011, 9 pages, Brussels, Belgium, 2011

[7] H. Akimoto, K. Tanaka and K. Uzawa, “Floating axis wind turbines for offshore power generation—a conceptual study,” Environmental Research Letters, vol. 6, 2011