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On the flexible support system of the Floating Axis Wind Turbine

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ABSTRACT

At present, most of the people expect that the Horizontal Axis Wind Turbine (HAWT) concept will be also effective in floating offshore wind turbines. However, the top-heavy configuration of HAWT is not economically reasonable in floating offshore applications because of the expensive large floats and O&M of complex high mounted mechanism.

The solution of the authors is similar to a Vertical Axis Wind Turbine (VAWT). However, the turbine shaft is a rotating cylindrical float and not fixed in the upright position. The tilt angle of the turbine is passively adjustable to the wind force. With the flexibly support of turbine, the present concept, Floating Axis Wind Turbine (FAWT), reduces the size of floats and support structures to those do not contribute to energy production.

Although the dynamics of FAWT is challenging, the proposed mechanism of the turbine is very simple. It indicates the possibility of high economic performance of the device. In this paper, the authors discuss the mechanism of FAWT and introduce the preliminary experiment of a 1.0 m blade length turbine model.

1. INTRODUCTION

The demand of offshore wind turbine is increasing due to the awareness of global warming and the expected shortage of fossil fuel in the near future. We expect that offshore sites allow larger wind turbines and provide the higher capacity factor of device than onshore sites. However, at present, most of offshore wind turbines are bottom fixed ones designed for shallow water condition. Only a few projects are testing the feasibility of floating offshore wind turbine.

The mainstream concept of floating wind turbine is Horizontal Axis Wind Turbine (HAWT) which has been quite successful in onshore and bottom-fixed offshore wind turbines. However, its top-heavy configuration (the rotor and nacelle assembly mounted on the top of high tower) has problems in floating application.

First, keeping the upright position of wind turbine requires a large float system. The expensive float increases the cost of energy produced by the wind turbine. Also, the larger floats leads to the higher wave load and mooring cost.

Second, the safety issues of construction and maintenance works are severe in floating HAWTs. Since wind farms will be constructed in the site of high wind expectation, the available days for these works in the unstable nacelle will be limited. For example, if a wind turbine is pitching in 3 degree amplitude, the swing amplitude at the 100m height nacelle is about 5m. The resultant uncertainty of project schedule also increases the charter cost of installation vessels.

2. Floating VAWT and Floating Axis Wind Turbine

2.1 Floating VAWT

As the solution to these problems discussed above, some groups are working on the reassessment of Vertical Axis Wind Turbine (VAWT) for the offshore floating application. Sandia National Laboratories (US) resumed their research of VAWT for offshore application (Sandia National Laboratories 2012). The European consortium, INFLOW, is preparing the sea trial of a floating VAWT shown in Fig. 1(a), supported by EU committee (INFLOW 2012). Since VAWT does not require yaw control, its simple mechanism contributes to the reduction of O&M cost. Also, since its main electro mechanics can be installed in a low altitude, the lowered center of gravity reduces the size of float and the risk of accidents in the maintenance work.

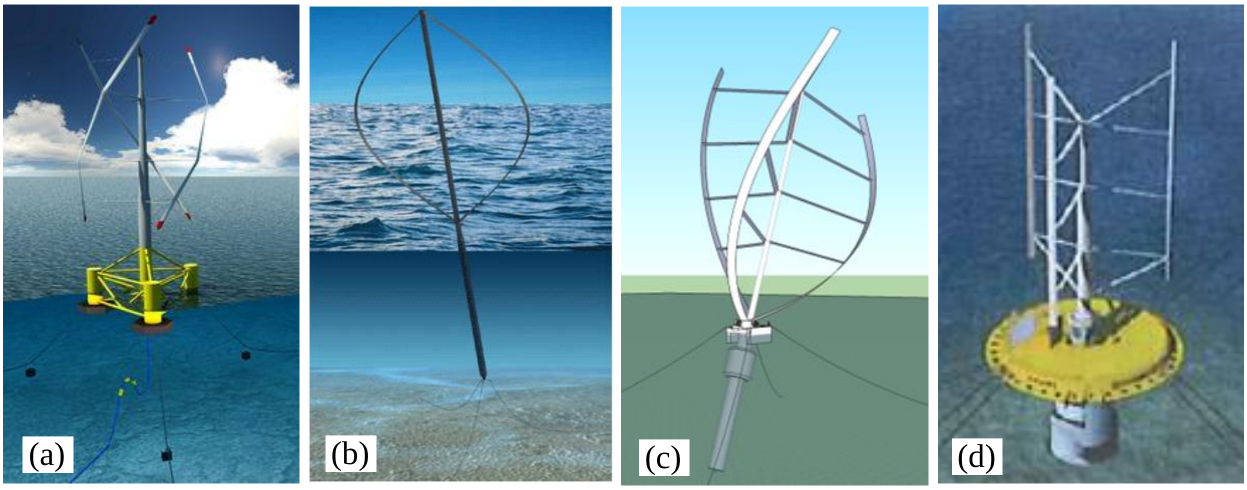

Figure 1: Floating VAWT concepts; (a) INFLOW project, (b) DeepWind, (c) Floating Axis Wind Turbine and (d) Skwid turbine

However, the floating VAWT has some problems. A VAWT requires high capacity mechanical bearings for supporting its heavy rotor assembly. The high bending moment at the root of turbine shaft also increases the difficulty of R&D.

Paulsen et al. proposed the DeepWind concept for a large floating VAWT in 2010. It is a Darrieus wind turbine mounted on a rotating spar buoy as shown in Fig. 1 (b).

Since its turbine shaft is directly supported by buoyancy, the problem of bearings will be alleviated (Paulsen et al. 2012). Although the economic performance of floating VAWT can higher than that of floating HAWT, some technical challenges are remaining.

2.2 Floating Axis Wind Turbine (*FAWT*)

Akimoto et al. (2011) proposed the Floating Axis Wind Turbine (FAWT) shown in Fig. 1(c). It allows a large tilt angle of the turbine (30 deg. at rated wind) by a floating support mechanism. By discarding the idea of fixed upright position of turbine, the concept reduces the size of floats and supporting structures. A Japanese offshore engineering company MODEC extended the FAWT concept to the hybrid turbine composed of a Darrieus wind turbine and a Savonius water turbine as shown in Fig. 1(d) for higher economic performance (Nakamura et al. 2013).

FAWT concept is very simple and its idea is mainly in the mechanism of flexible turbine support system. However, since it is a new mechanism, there are many design candidates and uncertainty of their costs. In this paper, the authors discuss the sample plan of the supporting system and show that the technical challenges for the device is moderate.

2. FLOATING SUPPORT MECHANISM OF FAWT

The main concept of FAWT is to reduce the support structures and floats by allowing the passive tilt of wind turbine. In this design, the wind turbine and submerged cylindrical float rotates as a rigid body as shown in Fig. 2(a). Since the turbine assembly is self-floatable, it does not require large-capacity bearings. The righting moment of turbine is enhanced by the additional buoyancy at the bulge of the shaft and the concentrated mass installed at the bottom end of shaft. There is no electro mechanics inside the turbine assembly (Akimoto et al. 2011).

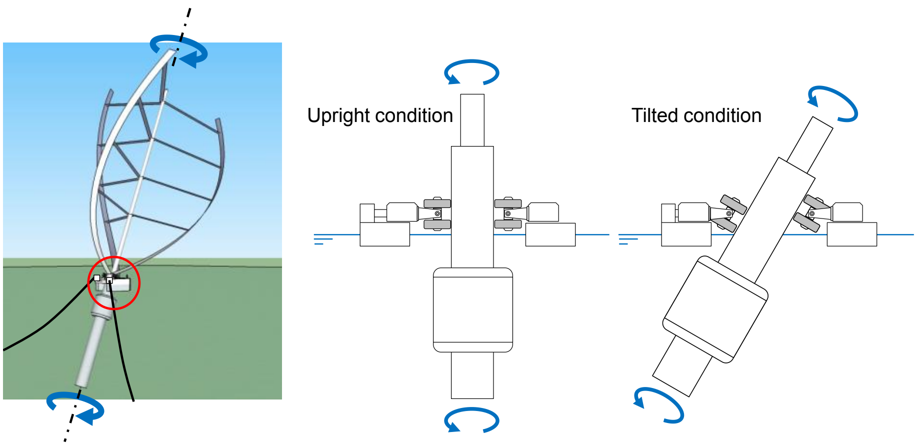

Figure 2: Floating Axis Wind Turbine concept; (a) overall view and (b) flexible turbine support

Figure 2 (b) shows an example of flexible turbine support which allows the large tilt angle of turbine shaft. The assumed tilt angle at the rated power is 30 degrees.

The performance of VAWT is less sensitive to the tilt angle than HAWT. The analyses for the roof-top mounted VAWTs show that the power coefficient of VAWT does not drop rapidly in the skewed flow which is expected on the rooftop of buildings (Mertens et al. 2003, Hara et al. 2005).

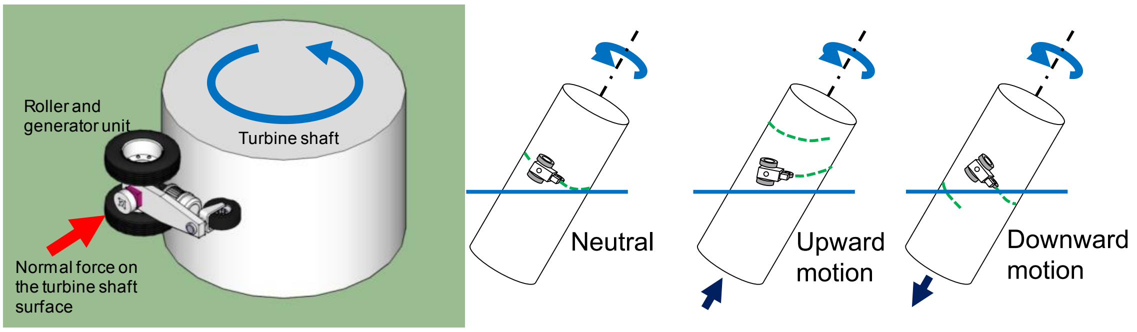

Figure 3: Flexible supporting system of the turbine shaft; (a) roller and generator unit and (b) the treatment of relative heave motion

In the previous design, the contacting rollers were mounted on multi-axis joints (Fig. 2(b)). However, the authors simplified the design for better feasibility as shown in Fig. 3 (a). The roller unit has an electric generator and three rollers and runs on the cylindrical surface of the turbine shaft. The roller-generator unit and its rear roller has swivel mechanisms for the passive steering adjustment of the unit when the shaft is in a heaving motion relative to the unit as shown in Fig. 3 (b).

The joint between the roller-generator unit and the supporting float is also flexible. An easy treatment of the flexible joint is employing a rubber mount. The technique is quite common in the handling of riser tubes in ocean plant engineering to avoid the stress when the float system is rolling on waves.

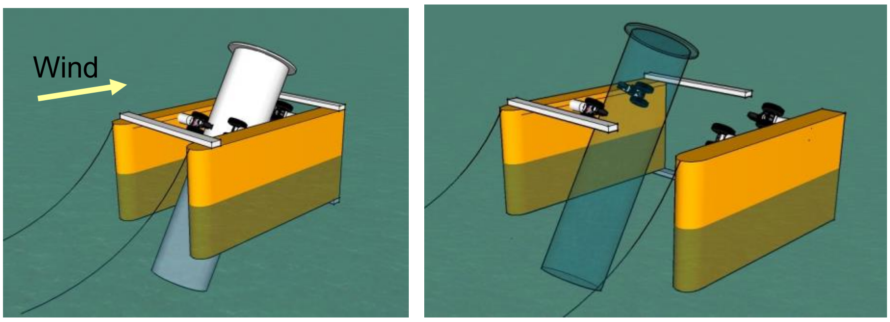

Figure 4: Flexible supporting system of the turbine shaft

Figure 4 shows the assembly of the supporting float and the turbine shaft. In the figure, the number of roller-generator units is four. In a large turbine, the number will be increased for the safety and the reduction of the load per unit. With the redundant number of units, it is possible to maintain or replacing one of the units without stopping the turbine. The maintenance cost of the device will be lower than that of floating HAWTs where we have to do the work in the high-mounted nacelle or bring the rotor-nacelle assembly down by a crane ship.

The support float in Fig. 4 is smaller than that of other floating wind turbine concept. It is because the float bears only the weight of roller-generator units and the vertical component of the mooring cable tension. Also, the rotating shaft of FAWT is more stable than the support float because of the larger mass and gyration effect of the turbine (Nakamura et al. 2013). The situation is quite different from that of other floating turbine concepts.

The flexible configuration may be quite strange for the engineers of “onshore” wind turbines those are firmly fixed on the ground. However, in ocean engineering, the flexible support is a common and reasonable solution because of the unavailability of firm basement there.

2.3 Electric generator units

Assuming the drag coefficient C_D=1, the thrust force on the 3MW rated FAWT is 20ton (Akimoto et al. 2011). It is less than 10% of the rotor weight. Since the load level is similar to the weight of a bus or a tram car, the required technology is not in a high level. Also, the load can be distributed to two or three roller units in the downwind side of the turbine. Therefore, we do not have to develop a single huge roller-generator unit for the larger FAWT.

The output power of the 3MW FAWT turbine can be also distributed to multiple roller-generator units. If the total number of roller units is five, the required capacity of a unit is 600kW (or 300kW per driven roller). The power on a roller is in the level of a high performance Electric Vehicle (EV). For example the motor of Tesla Roadster is 225kW (Tesla Motors Inc. 2011). The EV technologies of in-wheel motor and direct-drive motor also provides the simple configuration of the device. Although the available size of in-wheel motor is about 65kW (Sim-Drive Co. 2011), it can be used for a small FAWT and we can expect its scale-up.

One concern on the present power takeoff system is the slip between the roller and turbine shaft in the wet condition. Its solution is the Antilock Brake System (ABS) of modern automobiles. Actually, ABS has a longer history in the rail road system because the friction between an iron wheel and rail is small (especially in rain wet condition). The slip on the rail road is now very rare because of the quick response of electric motor/generator. The technology will be effective in the FAWT device. Also, the wet condition of shaft occurs only in heavy sea states and the probability of wet condition can be reduced by simple coverings around the roller-generator units.

2. PRELIMINARY EXPERIMENT OF SUPPORT SYSTEM

A model wind turbine was tested in a water tank. Since the purpose of the test was to check the concept and basic mechanism of the support system, we do not have quantitative measurements yet. The model is for the small mobile FAWT concept shown in Fig. 5. In the concept, the turbine can be folded like an umbrella for easy transportation. When it is deployed on the sea surface and anchored, it opens the blades for electric generation. The device can be used as an emergency power supply in large scale hazards like tsunami or a regular power supply of ocean platform (Akimoto et al. 2012).

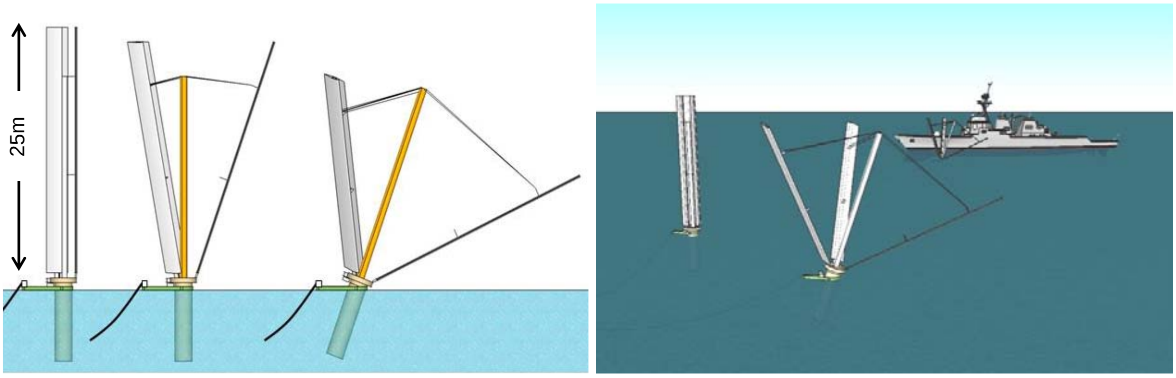

Figure 5: Mobile FAWT concept (Foldable blade, mobile floating wind turbine)

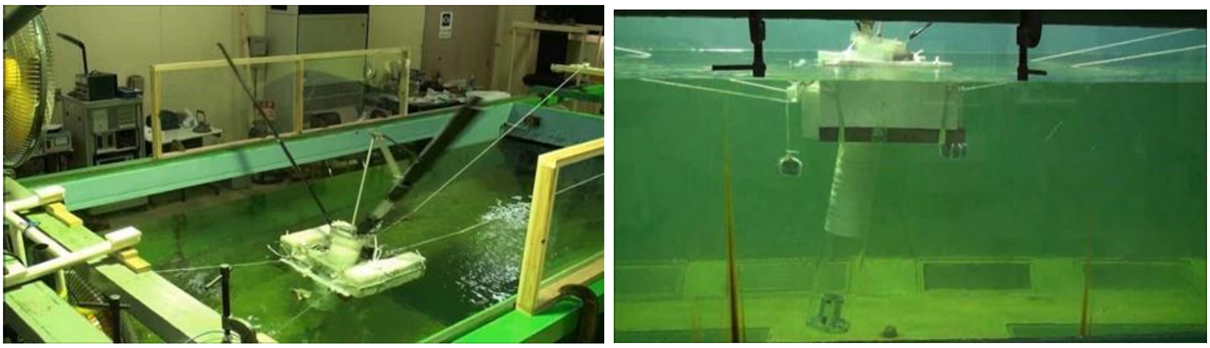
Figure 6: Snap shots of preliminary experiments; (left) rotating wind turbine part and (right) side view of the submerged part

Figure 6 shows the snap shots of the model wind turbine. It is a three-blade CFRP rotor mounted on an acrylate resin pipe. The blade was originally for radio controlled model helicopters. The blade span is 1000mm. Although the supporting float in Fig. 6 is larger than in the concept design, it will be reduced to the original size in the next experiments.

In the preliminary experiments, we had to solve several mechanical problems those came from the insufficient balance of roller units. Although quantitative measurements were not conducted in the limited schedule, the authors confirm that the turbine rotates on the flexible rollers. Self-starting of the turbine was also observed in the experiments. The static friction of the turbine is small because the hydrodynamic friction on the submerged cylinder is proportional to the rotating speed. The hydrodynamic friction is zero at starting condition without rotation.

The authors are planning the quantitative measurement of turbine output and the improvement (simplification) of the turbine support system.

3. CONCLUSIONS

The design of Floating Axis Wind Turbine is for reducing the size of support structure and float. Although it looks quite different from the conventional designs of floating HAWT and VAWT, it is based on the practical considerations of ocean environment. The present trend of floating HAWT has been supported by the significant success of onshore HAWTs. However, there may be a special design for the offshore floating environment.

The technology level required for the present concept is not in a high level. It is because the load on the drive train is moderate with the help of buoyancy and the load can be distributed to smaller units. Also, the off-turbine-axis layout of power takeoff system leads to the simple design.

At present, the research of FAWT is still in a preliminary level. Further quantitative analysis of the economic performance and detailed design of the power takeoff system have to be conducted in the future study.

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