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Assessment of Floating Offshore Wind Farm in Korea

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***Abstract*:** *Wind farm is the preferred renewable energy option in the Korean peninsula as the mountainous geography covered by three water bodies provides ample wind power. As such, wind farm is considered as a promising technology that supports the Korean green growth endeavors. This paper assesses and verifies the economic feasibility of the cutting-edge technology for the newly emerging float-type offshore wind turbine which has a competitive advantage against conventional land-based and fixed-type offshore wind turbines. The paper will comprehensively evaluate offshore floating wind turbine capacity and its economic feasibility for use in large scale wind farms.*

Keywords: *Floating wind turbine, Vertical-type, Horizontal-type, Korea*

1. Introduction

1.1. Necessity of floating wind turbine in Korea

The Korean Green Growth Initiative calls for greenhouse-gas emission reduction in the electricity generation sector. Government endeavours and general interest in climate change mitigation is propelled by the establishment of the International Emissions Trading (IET), Joint Implementation (JI), and Clean Development Mechanism (CDM) [3]. Wind energy, a zero-carbon electricity generation source, is an essential element in meeting Korea's ambitious greenhouse gas reduction goals along with securing energy resources.

Korea's renewable agenda for 2020 aims to generate 11% of total electricity from renewable resources. Among them, 9.6% will come from wind energy supported by the 270GW installed offshore capacity [2]. However, while wind energy will play a crucial role in the near future, a thorough technological and economic assessment of the competitiveness of this technology must be taken into account, considering the issues of supply volatility, sustainability, and political and regulatory measures.

1.2. Potential of floating wind power

According to the Energy Information Administration (EIA), the 2015 global wind market will grow up to $200 trillion. Because wind energy has a high technology completion rate and is economically feasible in many parts around the world, the share of wind energy in electricity production is expected to grow. In Europe, for instance, wind power generation consist of almost 80% of total electricity production from renewable energies.

Onshore wind power, in general, faces two challenges: high wind speed volatility and limited availability of land. These problems pose difficulties constructing onshore wind farms as can be easily dealt. Offshore wind farm solves both problems. Surrounded by three bodies of water, Korean offshore wind capacity is deemed stronger than that onshore. With abundant wind resources, it is expected that offshore wind power can be harvested to generate a bulk of Korean electricity.

1.3. Advantages of floating offshore wind power

Advantages of floating offshore wind are numerous. One, wind energy is the most developed renewable energy technology in operation. Two, access to inaccessible water, higher and steadier wind resources, and less sea life disturbances provides higher efficiency. For instance, energy can be harvested for an average of 4,000 full load hours. Three, the lifetime of lower offshore wind farm project is about 20~30 years [13]. Four, unlike onshore and offshore wind technologies, floating offshore wind technology has growth potential. Continued R&D development in offshore wind turbines are expected bring the cost of electricity generation down, comparable to fossil-fuel level [2]. Due to numerous advantages, there is possibility of wind power becoming a major source in the Korean electricity generation.

1.4. Objectives of the research

In this paper, economic analysis is conducted on the construction of large-scale offshore floating wind farms, taking into consideration initial investment costs and other factors such as geography, finance, and economics. Specifically, the economics of the horizontal and vertical offshore floating wind technology concepts, proposed by KAIST’s Department of Ocean Engineering and Department of Aerospace Engineering, is evaluated.

Globally, there are a number of economic analyses regarding the life cycle cost of floating offshore wind power. However, research in Korea in this field is limited and structural data for reference is scare. Industries related to renewable energy projects are evaluated using the concept of levelized cost of energy (LCOE) which calculates the unit production cost of electricity [10]. Geographical, financial, and economic factors are taken into account as to facilitate market penetration of offshore wind farm projects. This research aims to provide valuable information as to facilitate market penetration of Korean offshore floating wind industries

2. Approach

The economic analysis of horizontal and vertical types will be conducted in the following fashion. Literature review on existing wind power technologies will be assessed to clarify all technical components in developing wind projects. In the analysis of the horizontal-type, the turbine, blade, and tower specifications are fixed to match the NREL 5MW Reference model [6]. Given the NREL model, buoyancy platforms costs will be measured again. In the analysis of the vertical-type, the cost analysis method applied in the Guyed concept [5] is benchmarked. Unlike the horizontal-type, adjusted turbine, blade, and tower specifications are re-considered.

Costs concerning both the horizontal and vertical types are extracted from “Levelised cost of energy for offshore floating wind turbines in a life cycle perspective” [10]. Each items’ costs are analysed according to its weight in tons. For instance, the horizontal-type takes into account the costs related to the Windfloat project. Meanwhile, the vertical-type analysis, the TLB B project is referenced for the buoyancy platform costs and the Hywind project for mooring costs. The net present values (NPV) and internal rate of return (IRR) are calculated considering the location, country, and environmental factors.

2.1. LCOE (Levelized Cost of Energy)

The Levelized Cost of Energy is a life cycle cost as it measures all costs associated with the production of electricity. Cost and revenue are measured with the time factor that comes from uncertainty in the future. LCOE is an appropriate method that compares costs among different projects. The following equation is used to calculate the LCOE and is derived from ref. [10]:

$$LCOE = \frac{\sum_t^n \frac{I_t + M_t}{(I_0 + r)^t}}{\sum_t^n \frac{E_t}{(I_0 + r)^t}} \quad (1)$$

Where I_t denotes investments at time t; M_t denotes operation and maintenance costs at time t; E_t denotes energy generation at time t; r denotes the evaluation discount rate; t denotes the time, ranging from zero to n.

2.2. NPV (Net Present Value), IRR (Internal Rate of Return)

Net present value represents the monetary value of a project. It takes into account future cash flow and applies appropriate discount rates.

$$NPV = \sum_{t}^{n} \frac{R_t}{(1+r)^t} \tag{2}$$

Where R_t denotes net cash flow at time t; r denotes the evaluation discount rate; t denotes the time, ranging from zero to n. The result of this formula is multiplied with the Annual Net cash flows and reduced by Initial Cash outlay the present value but in cases where the cash flows are not equal in amount, then the previous formula will be used to determine the present value of each cash flow separately.

The internal rate of return on an investment is the annualized effective compounded return rate or rate of return that makes the net present value of all cash flows from a particular investment equal to zero. It can also be defined as the discount rate at which the present value of all future cash flow is equal to the initial investment or in other words the rate at which an investment breaks even.

Operation cost refers to the total annual cost such as repair cost and labor cost. It has been calculated to all costs that has real cash flow. Depreciation cost is added to O&M cost and this measurement is used to predict tax costs. VAT tax costs are 13% of net profit if net profit is below 100M KRW (0.1M$) and 25% if net profit is above 100M KRW (0.1M$). 10% of the tax costs are classified as residential tax.

Net profit is measured as the difference between annual revenue and O&M and depreciation costs. Revenue equals the product of annual electricity production times the system marginal price (SMP). Jeju Island's average SMP of 0.2 USD/KWh is applied. Interest rate and discount rate are assumed to be equal at 5%. Other criteria follow that of the Energy Management Corporation.

3. Concept

The National Renewable Energy Laboratory has studied each these three designs for use in supporting a wind turbine.

The buoyancy-stabilized designs, which include the semi-submersible design and the barge, are moored with catenary mooring lines. The concept for this design is similar in principle from that of boats anchored to the seabed. The platform has a fairly significant footprint, and the slacked lines allow it to move up and down with the waves and shift slightly with changes in the wind [6].

The ballast-stabilized design is a spar-buoy also utilizing catenary or taut mooring lines. Spar technology, which consists of a hollow tube containing an extremely heavy weight at the bottom, achieves stability by placing the structure center of gravity below the center of buoyancy providing the ability to counter-act the forces the turbine encounters [6].

The mooring line stabilized design, otherwise called the tension-leg platform, uses tensioned cables to stabilize the platform. This type of design is very stable for offshore wind applications. However, this design requires the most secure mooring of all three designs and necessitates very expensive anchors [6].

Thus, in total, two different wind turbine concepts are investigated. The floating concepts consist of the TLP horizontal type and spar vertical type. In both types, displacements, mooring lines or a combination of the two serve to stabilise the floating system. Platform cost makes up a huge portion in the horizontal-type [6]. Lightening platform weight and reducing cost are imperative. The KAIST platform is 360 tons and there are no constraints regarding water depth, leaving room for cost reduction compared to the heavier and stricter NREL specifications. However, the horizontal-type may incur additional cost during the operational and repair stages.

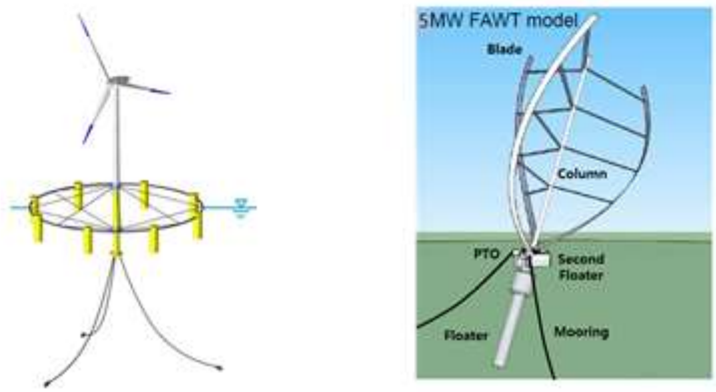

Fig. 1: KAIST's Concept (Horizontal Type, Vertical type)

As for the vertical-type, cost reduction can be attained at the manufacturing and installation stage. The generator is located at the platform, allowing cost reduction in operation and repair. Nonetheless, the vertical-type is not fully verified. Technological development is at the infant stages which may incur cost in unexpected situations [9].

TABLE 1: Technical specification of Wind turbine

Category	Horizontal	Vertical
Capacity(MW)	5	5
Rated wind speed(m/s)	11.4	15
Rotor diameter(m)	126	91.1
Rotor height(m)	90	136.7
Total weight(ton)	1090	1284.92
Blades & Support(ton)	110	249
Generator(ton)	240	141
Central column(ton)	347	336.5
Floater(ton)	360	472.42

4. Underlying Condition

The paper builds upon a number of underlying conditions. The expected revenue is the monetary value of the benefit that comes from producing and selling electricity. The costs correspond to the construction of the turbine foundation, and the grid connection between the offshore wind farm and onshore substations. In this section, the feasibility of offshore wind power development in South Korea is reviewed by calculating the project's total revenue and total cost.

Another critical component in this section regards the selection of the optimal site for the offshore wind project. Around the Korean peninsula, wind speed is greater in the eastern and southern seas than in the western seas. It is particularly strongest in the south-eastern region, close to Jeju Island [1]. Due to the abundance in quality wind power, the Jeju Wolljeong region is chosen as the optimal site. Normal wind condition and wind rise values for the past 25 years are extracted from the ECMWF (European Centre for Medium range Weather Forecast) data.

TABLE 2: Project information for the wind turbine

Category	Value
Years of development	2013-2018
Years of commissioning	2018
Years of operation	20
Number of turbines	1
Installed capacity	5MW
Water depth	60m
Distance to port and grid connection	1km
Average wind speed	6.56m/s

5. Basis for life cycle cost analysis

In the feasibility analysis of the horizontal-type, specifications (turbine, blade, and tower) and sub-specifications (machine rating, rotor diameter, and hub height) are fixed to match the NREL 5MW Reference model. The buoyancy platform makes reference to the Windfloat concept. Assumptions include: depth of water (60 meters) and distance from coastline (1km). Additional costs include gird connection cost, mooring cost, and anchor cost. Annual electricity production, referencing the NREL Land based cost model [8], is measured using a Weibull distribution.

According to this measurement, horizontal turbine capital cost is 3.9M USD, initial investment cost is 11.22M USD, and annual electricity production is 12,358 MWh, yielding a LCOE value of 150 USD/MWh. This value is similar to the AEO2009 and NREL measurements. There is, nonetheless, more room for cost reduction in areas of buoyancy platform weight reduction and system simplification. In the analysis of the vertical-type, the cost analysis method applied in the Guyed concept [5] is benchmarked. Unlike the horizontal-type, newly adjusted turbine, blade, and tower specifications are considered.

TABLE 3: Cost Breakdown of wind turbine based on Ref. [10]

Category	Item	Horizontal(M$)	Vertical(M$)
Development	Development, Consenting	1.24	1.24
Consenting	Insurance	0.06	0.06
Production	Floating structures	1.46	0.0012
Acquisition	Anchors	0.42	0.42
	Mooring(Steel wire, Chain)	0.04	0.04
	Grid connection(Inter array, Export)	0.9	0.9
Installation	Floating structures	0.8	0.81
Commissioning	Mooring(Steel wire, Chain)	0.2	0.24
	Grid connection(Inter array, Export)	0.91	0.91
O&M	Total cost of repair per year	0.7	0.52
Decommissioning	Decommissioning	1.20	1.27
Turbine capital cost	Turbine, Generator, Tower	3.97	9.17
Total cost	Initial Investment Cost	11.22	15.07

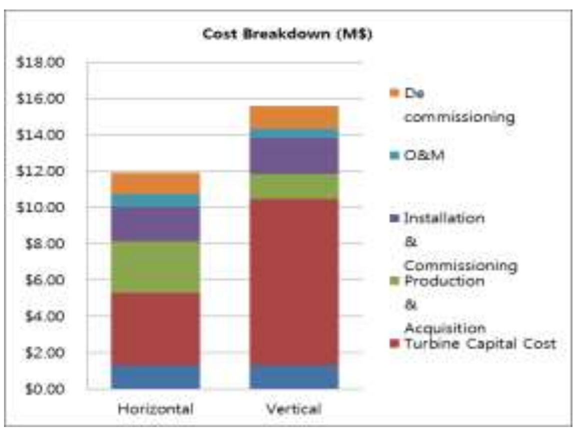

Fig. 2: Cost Breakdown of wind turbine based on Ref. [10]

6. Result

Economic analysis is conducted based on the costs associated with horizontal and vertical types and based on the revenues generated by annual electricity production. Discount rate of 5 to 15% and System marginal cost of 215 KRW (0.2$) is assumed for calculating the net present value and the internal rate of return.

According to the results, horizontal-type IRR is 8.4% and payback period is 9.55 while the vertical-type IRR is 5.2% and payback period is 12.28 years, suggesting that the horizontal-type is currently more economically feasible than the vertical-type. However, due to the different level of technical maturity and different components in the cost structure, a simple comparison is impossible.

TABLE 4: Result of economic analysis

Type	Wind Turbine Horizontal		Vertical	
Machine Rating	5,000	Kw	5,000	Kw
Capacity	28.20	%	25.8	%
Interest Rate	5 ~ 15	%	5~15	%
Investment Cost	11.2	M$	15.1	M$
Period	20	Year	20	Year
Depreciation	0.56	M$	0.75	M$
O&M	0.7	M$	0.52	M$
Tax (Year)	0.21	M$	0.16	M$
Misc. cost	0.9	M$	0.68	M$
Power sales volume	12,351	MWh	11,300	MWh
Base price	0.08	$/KWh	0.08	$/KWh
SMP	0.2	$/KWh	0.2	$/KWh
Sales revenue(yr)	2.09	M$	1.91	$
IRR	11.1%		5.2%	
NPV(M$)	6.17		0.86	
LCOE($/MWh)	150		195	
Payback period(Year)	7.90		12.28	

7. Discussion

Both globally and locally (Korea), economic analyses of horizontal and vertical type wind powers are limited. Existing literature are not suitable for application in the Korean wind power environment, which partly explains for the limited research base. As such, this research aims to contribute to the growing literature regarding the development of offshore floating wind farm projects by analysing the economics from the perspective of project life cycle cost.

As of now, data on manufacturing cost, transportation cost, and installation cost regarding buoyancy platform is scarce. A cost measurement based on weight standardization is necessary. Also, the gap between foreign and domestic (Korean) O&M cost serves as barriers for fair comparison. Standardizing O&M unit cost calculation through simulation is necessary.

Regarding annual electricity production, there are numerous optimization models for horizontal-type generation. However, the difference in mechanism for vertical-type generation calls for new optimization models that take into account the different wind direction, energy capture ratio, and various other technical specifications.

8. References

[1] Ji-Young Kim, Ki-Yong Oh, Keum-Seok Kang, Jun-Shin L , "Site selection of offshore wind farms around the Korean Peninsula through economic evaluation" Renewable Energy 54 (2013) 189-195
http://dx.doi.org/10.1016/j.renene.2012.08.026

[2] Global Wind Report Annual market update 2012 GWEC

[3] Jeong-woo Ha and Suduk Kim , "Study on the Wind Power Generation and Its Economic Feasibility at Daekwanryung", 26 April 2005

[4] Bjerkseter, C. & Ågotnes, A., “Levelised Costs of Energy for Offshore Floating Wind Turbine Concepts”, 2013

[5] D. L. Blonk , “Conceptual Design and Evaluation of Economic Feasibility of Floating Vertical Axis Wind Turbines MSc. Thesis”, May 25, 2010

[6] G.R. Fulton, D.J. Malcolm, H. Elwany, W. Stewart, E. Moroz, and H. Dempster , “Semi-Submersible Platform and Anchor Foundation Systems for Wind Turbine Support”,,August 30, 2004 – May 31, 2005,

[7] W. Musial, S. Butterfield, and A. Boone, “Feasibility of Floating Platform Systems for Wind Turbines”, January 5–8, 2004

[8] L. Fingersh, M. Hand, and A. Laxson, “Wind Turbine Design Cost and Scaling Model”, December 2006

[9] Hiromichi Akimoto, Kenji Tanaka and Kiyoshi Uzawa, “Floating axis wind turbines for offshore power generation—a conceptual study”, 4 November 2011

[10] Anders Myhr, Catho Bjerkseter, Anders Ågotnes, Tor A. Nygaard, “Levelised cost of energy for offshore floating wind turbines in a life cycle perspective”, Renewable Energy 66 (2014) 714-728
http://dx.doi.org/10.1016/j.renene.2014.01.017