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Comparative evaluation of different offshore wind turbine installation vessels for Korean west—south wind farm

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Abstract

The purpose of this study is to evaluate various means of wind power turbines installation in the Korean west—south wind farm (Test bed 100 MW, Demonstrate site 400 MW). We presented the marine environment of the southwest offshore wind farm in order to decide the appropriate installation vessel to be used in this site. The various vessels would be WTIV (Wind turbine installation vessel), jack-up barge, or floating crane … etc. We analyzed the installation cost of offshore wind turbine and the transportation duration for each vessel. The analysis results showed the most suitable installation means for offshore wind turbine in the Korean west—south wind farm.

Keywords: Offshore wind turbine installation; West—south wind farm; Installation cost; WTIV; Jack-up barge

1. Introduction

Various natural disasters caused by global warming and lack of energy due to the depletion of fossil fuels are accelerating deep-sea oil exploration and development of shale gas which emerges from concerns of the environmental problem. In addition, the nuclear accident in Japan amplified anxiety about the nuclear energy. The world is putting multilateral efforts to secure renewable energy industry, and to move away from carbon-dependent economy paradigm by developing green energy technologies.

The wind power industry, the best economical option among the renewable industries, is growing 30% annually. However, onshore wind power is already reached saturation and the development is only rising moderately. As an alternative, development of offshore wind power farm has led to a lot of attention and investment.

Recently, on 24th March 2014, KEPCO (Korea Electric Power Corporation) and Six power generation companies announced a long-term plan to increase renewable energy capacity to 61.2%. In order to achieve the national goal of renewable energy, they will invest 42.5 trillion won (by 2020) on developing 11.5 GW (72% of national newly developed renewable energy capacity) which the current capacity being at 19%.

According to the plan, complete the construction of test bed and demonstration site by 2020 for development of 2.5 GW on west—south offshore wind farm, which would build a track-record for overseas expansion of offshore wind turbine generator market. The turbine manufacturer involved herein is Doosan Heavy Industries & Construction (3 MW) (Fig. 1). The offshore wind power is more efficient than the onshore wind power in terms of farm size, the turbine capacity and the development cost which leads to the lower power cost. Fig. 2 depict the capital cost breakdown of offshore wind farm.

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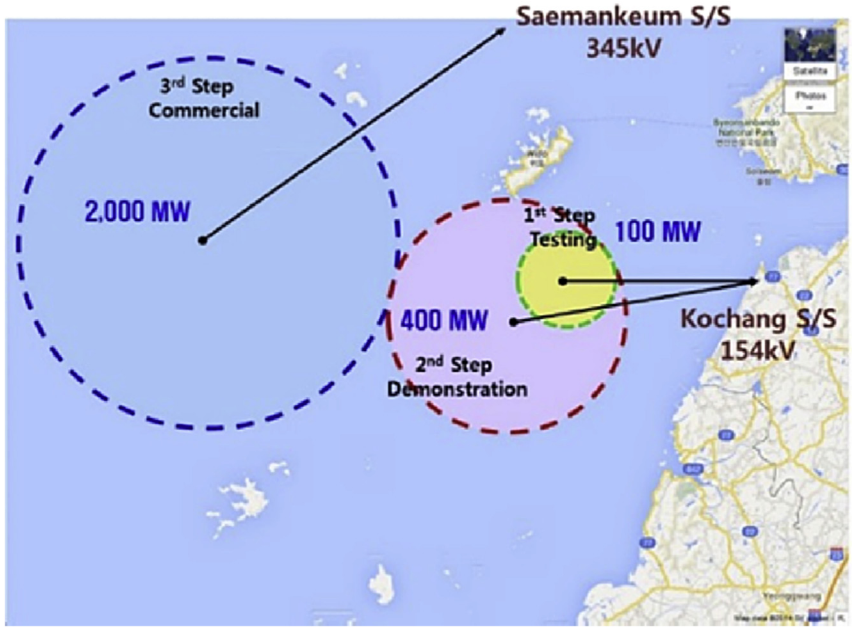

Fig. 1. West—south wind farm layout.

Logistics and installation cost takes 19% of total construction cost meaning.

In Korea, there is no domestic experience of installing offshore wind turbine generator more than 2 set (2 MW and 3 MW). Because of that, it is difficult to assume the proper installation time. The offshore wind turbine generators installed in Jeju island are pilot model. Those generators are installed above the substructure of a jacket which is placed on the sand type seabed. Because of lack of installation experience of offshore wind turbine, difficulties are expected during the installation of west—south wind farm. In addition, the environment of west—south sea is totally different compared to the that of Jeju island.

This study suggests appropriate installation means and methods for successful construction of west—south wind farm. To achieve this, case studies on installation of major offshore wind farm in Europe and studies on types and features of installation vessels have been carried out. In addition, we identify the offshore environment and the delay factor for installation of wind power farm. Installation time and costs have been selected as a factor to find appropriate installation means. We suggest the optimal installation means according to the analysis of the factors for installation of wind farm.

Therefore, this study reviews and compares the 3 types of construction methods on test bed site and demonstration site. And propose the appropriate means and methods to install offshore wind farm on the west—south Sea.

2. Means and methods to install offshore wind turbine

2.1. Offshore wind turbine installation vessel

Vessels used in offshore wind farm construction are as shown on Fig. 3 and Table 2. The characteristics of these vessels are as shown on Table 2. Table 3 shows the installation vessels used in the construction of offshore wind farms in Europe (Table 1).

Herman (2002) developed a computer model that calculates the transport and installation costs of a wind farm, it has been composed and implemented in the OWECOP (Offshore Wind Energy Cost and Potential) II model. Transportation and installation costs have been derived from known offshore techniques and they are structured according to the possible wind turbine assembly procedures. Besides the cost of offshore equipment, an estimation of delays due to bad weather and the simultaneous use of several vessels have been included. Alexander (2011) investigated the reliability, availability and maintenance of offshore wind farms while considering various maintenance strategies, and helps understand which is fundamental in light of the technical and economic viability of existing and future offshore wind farms.

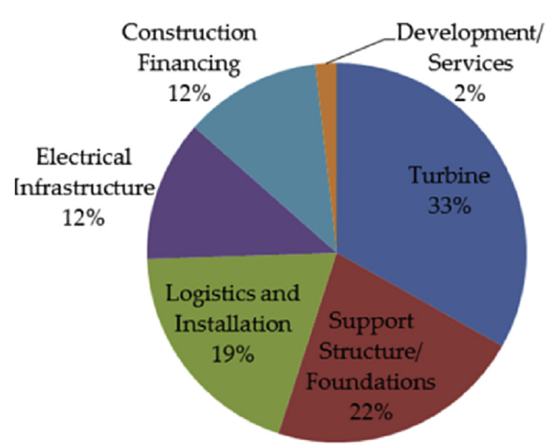

Fig. 2. Offshore wind farm plant capital cost breakdown.

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Fig. 3. Offshore wind farm construction vessel.

Emre (2011) studied the main operation parameters in an offshore wind turbine installation context: the benefits and drawbacks of different pre-assembly methods were studied and evaluated, it results in a new knowledge and a productive contribution to the optimization of "the offshore turbine transportation and installation process" based on actual time usage.

2.2. *Offshore wind turbine installation methods*

There are six installation method can be defined for installation of offshore wind turbine (Fig. 4). In the past, due to the small generating capacity, pre-onshore assembly method was mainly adopted. As shown in Table 4, the method 3 and 4

Table 1
2.5 GW west–south wind farm project.

Item	Test bed (Stage 1)	Demonstration (Stage 2)	Expansion (Stage 3)
Objective	Establish Test bed	Track record experience	Wind farm development
Size	100 MW	400 MW	2000 MW
Terms	′15~′18	′18~′20	′20~
Cost	0.43 trillion	2.0 trillion	10 trillion

Table 2
Turbine installation vessel specifications and day rates.

Type	Specifications	Remarks
WTIV	. Jacking system & DP (dynamic positioning) system . Large capacity Crane (800–1500 ton) . Loading capacity: 1500–8000 ton . Large deck area	. Day rate: 150,000–250,000 \$. Proportional to CAPEX . Deck load = 2.0 ton/m^2
Jack-up barge	. Non-self propelled . Jack-up system (Hydraulic) . Medium/Large capacity crane (200–1000 ton) . DP system or mooring	. Day rate: 100,000–180,000 \$. Proportional to CAPEX . Fleet consist of tug boat, cargo barge
Crane barge	. Large barge with crane . All in one installation method . Construction for sub-support structure, substation . Dominant factor is wave height, wind speed	. Day rate: 80,000–100,000 \$. Proportional to Crane capacity
Cargo barge	. Cargo only (Tug towing) . Relatively spacious deck area.	. Day rate: 30,000–50,000 \$. Proportional to deck area
Tug boat	. Jack-up barge, tow of crane barge. . Lowest significant wave height spec. in the fleet	. Day rate: 1000–5000 \$. Proportional to towing power

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Table 3
Vessels used in offshore wind farm construction in Europe.

Vessel name	Type	Water depth (m)	Crane capacity (ton)	Wind farms
Sea Power	WTIV	24	100	Horns Rev 1, Lillgrund, Horns Rev 2
Sea Energy	WTIV	24	100	Kentish Flats, Scorby Sans, Nysted, Princess Amalia
Rambiz	Shearleg crane	>100	3,300	Beatrices, Thornton Bank, Nysted
Sea Jack	Jack-up barge	35	1,300	Princess Amalia, Arklow, Scroby Sands
Titan2	Jack-up barge	60	400	Rhyl Flats
Buzzard	Jack-up barge	45	750	Alpha Ventus, Thornton Bank
JB114 & 116	Jack-up barge	50	280	Alpha Ventus
Eide Barge 5	Shearleg crane	>100	2,000	Middelgrunden, Bysted, Lillgrund, Sprogo
Taklift4	Shearleg crane	>100	1,600	Alpha Ventus
Kraken & Leviathan	WTIV	40	300	Walney, Greater Gabbard
Resolution	WTIV	35	300	Robin Rigg, Barrow, Kentish Flats, North Hoyle
Excalibur	Jack-up barge	30	220	North Hoyle
Lisa A	Jack-up barge	50	600	Rhyl Flats
MEB JB1	Jack-up barge	40	270	Middelgrunden, North Hoyle, Yttre Stegrund
Goliath	Jack-up barge	50	1,200	
Sea Worker	Jack-up barge	40	400	Robin Rigg, Gunfleet Sands

were adopted a lot. Recently, however, with the rapid increasing of offshore wind turbine generator capacity, it has reached the step where pre-onshore assembly concept is difficult to adopt. To adopt pre-onshore assembly concept, it requires a large workplace, a transport vessel with large deck area and a large capacity crane. Therefore, recently, the onshore assembly concept is mainly used. The reason is that it

Table 4
Offshore wind farm installation requirements (Europe).

Project	Number of vessels	Duration (months)	Number of turbines	Installation rate (days/turbine)	Installation method
Lillgrund	1	2.5	48	1.6	3
OWEZ	1	3.5	36	2.9	5
Kentish Flats	1	4.0	30	4.0	4
Scroby Sands	1	3.0	24	3.8	4
Nysted	1	3.0	72	1.3	3
Horns Rev 1	2	4.0	80	1.5 (3.0)	4
Burbo Bank	1	1.5	25	1.8	2
P. Amalia	2	11.0	60	5.5 (9.5)	5
Middelgrunden	2	1.25	20	1.9 (3.8)	3
North Hoyle	2	3.0	30	3.0 (6.0)	4
Alpha Ventus	1	1.5	6	7.5	3
Thornton Bank	2	2.5	6	12.5 (25.0)	3
Robin Rigg	2	9.0	60	4.5 (9.0)	4
Horns Rev 2	1	6.0	91	2.0	3
L/I Dowsing	1	3.5	54	1.9	1
Barrow	1	5.0	30	5.0	4
Arklow	1	2.0	7	8.6	3

Table 5
Rate of turbine installation by number of turbines.

Installation method	Number of observations	Installation rate (days/turbine)
1	1	1.9
2	1	1.8
3	7	7.1
4	6	5.1
5	2	6.2
6	0	–

is possible to suppress the use of large capacity cranes. For the partially assembled installation, a separate transport analysis must be carried out for the design and installation of wind turbine generator in accordance with its installation method (Kaiser and Snyder, 2012; Thomsen, 2012).

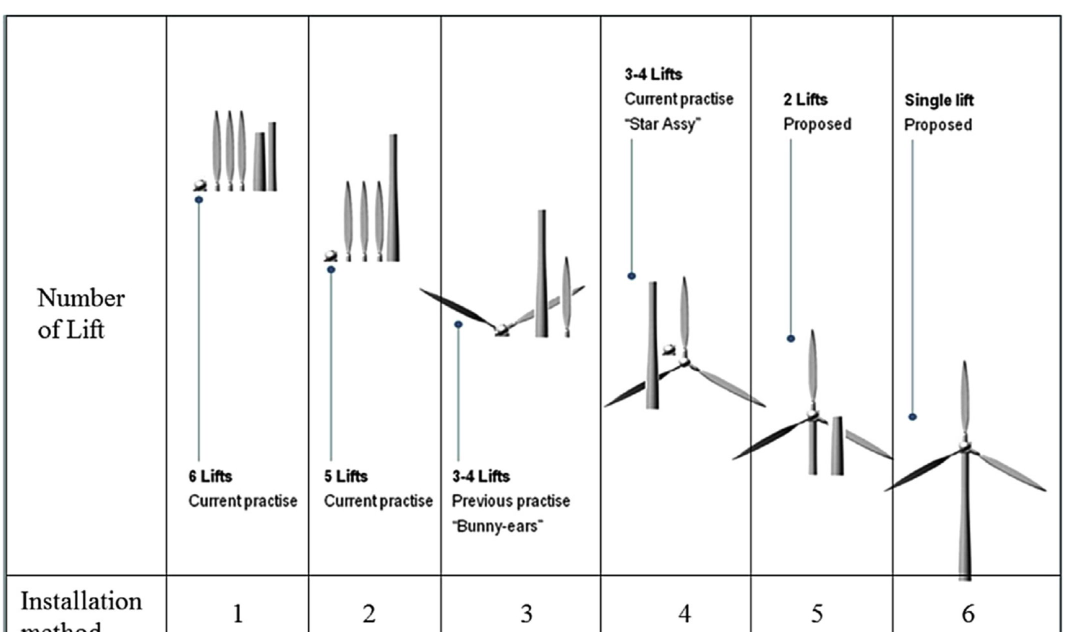

Fig. 4. Offshore wind turbine installation method.

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Table 6
Delay factors affecting duration of construction.

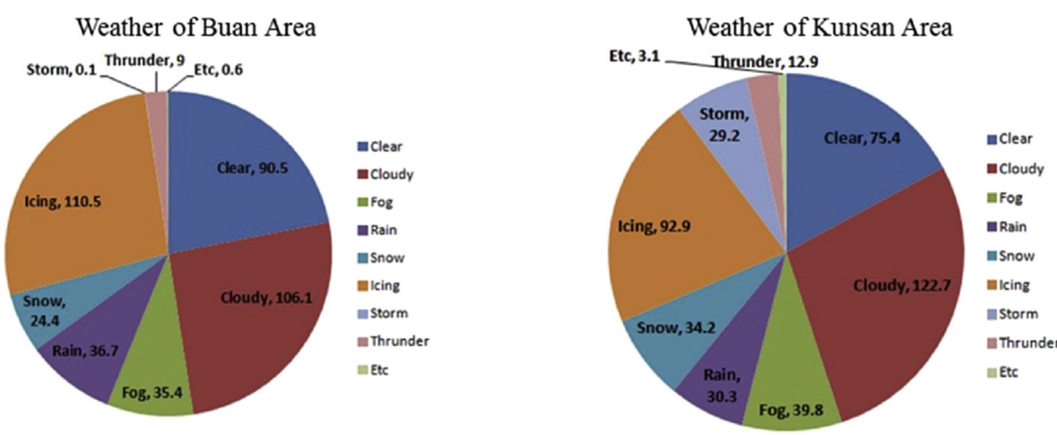
Items	Factors	Description
Delay factors	Precipitation	Daily precipitation more than 10 mm or more than 1 mm hourly
	Freezing	Temperature below −10 °C
	Light or visibility	Visibility within 100 yard caused by rain, fog, and snow
	Night work	Risk to the operation safety due to the lack or failure of light for night work
Operational constraints of vessels	Wave limitations	Significant wave height above the limit (1.5 m and more) condition of transport and operation.
	Wind limitations	Wind speed exceeding 10 m/s at 10 m above the sea surface, or exceeding 12 m/s at hub of WTG.
	Water current limitation	Not able to control due to the current above the baseline in operation of DP system or stage of pre-loading. (depends on the maritime conditions, normally applied when exceeding 1.25 m/s)
	Tidal range	Tidal range above the designed value

Obviously, the best way to reduce installation time is to reduce the number of generator parts to install.

The correlation between the offshore wind turbine generator and the installation method is; 1) the method 1,2, one by one method, take approximately less than 2 days to install, 2) the method 3,4,5 take average of more 5 days to install (Table 4).

2.3. Offshore wind turbine installation delay factors

Installation delay factors of offshore wind turbine generator, superstructure of offshore wind farm, are shown in Table 5. Delay factors presented herein, purely refers to the operation conditions not satisfying the criteria of the installation or the operation conditions affecting the safety of the installation. In particular, operational constraints of vessels are the matter of the operation of installation fleet for install height-precision tasks such as turbine installation. Most installation fleet have constraints for significant wave height. And wind speed is an important factor for determining the availability of the crane operation. Normally, wind speed exceeding 10 m/s at 10 m height of sea surface or exceeding 12 m/s at Hub height, the crane operation is restricted for safety purpose (Table 6).



*) Rain(more than 10mm), Storm(higher than wind speed 13.9m/sec), Temperature(-10°C below)

Fig. 5. General weather days (Buan & Kunsan).

Table 7
Environmental condition (wave, wind, current).

Environmental condition	Data
Maximum wave height (50 year return)	13.76 m
Significant wave height (50 year return)	7.40 m
Wave period	9.64–12.4 s
Maximum wind speed (50 year return)	41.0 m/s
Maximum current speed (at surface)	1.025 m/s
Maximum current speed (at bottom)	0.85 m/s
Tidal range	6.63 m
Air gap	12.0 m
Storm surge (at Kunsan port)	1.9 m

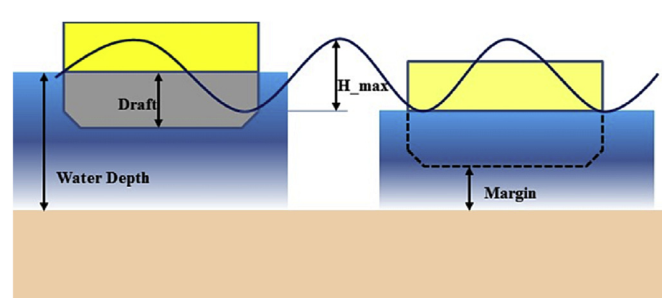


Fig. 6. Limitation of water depth.

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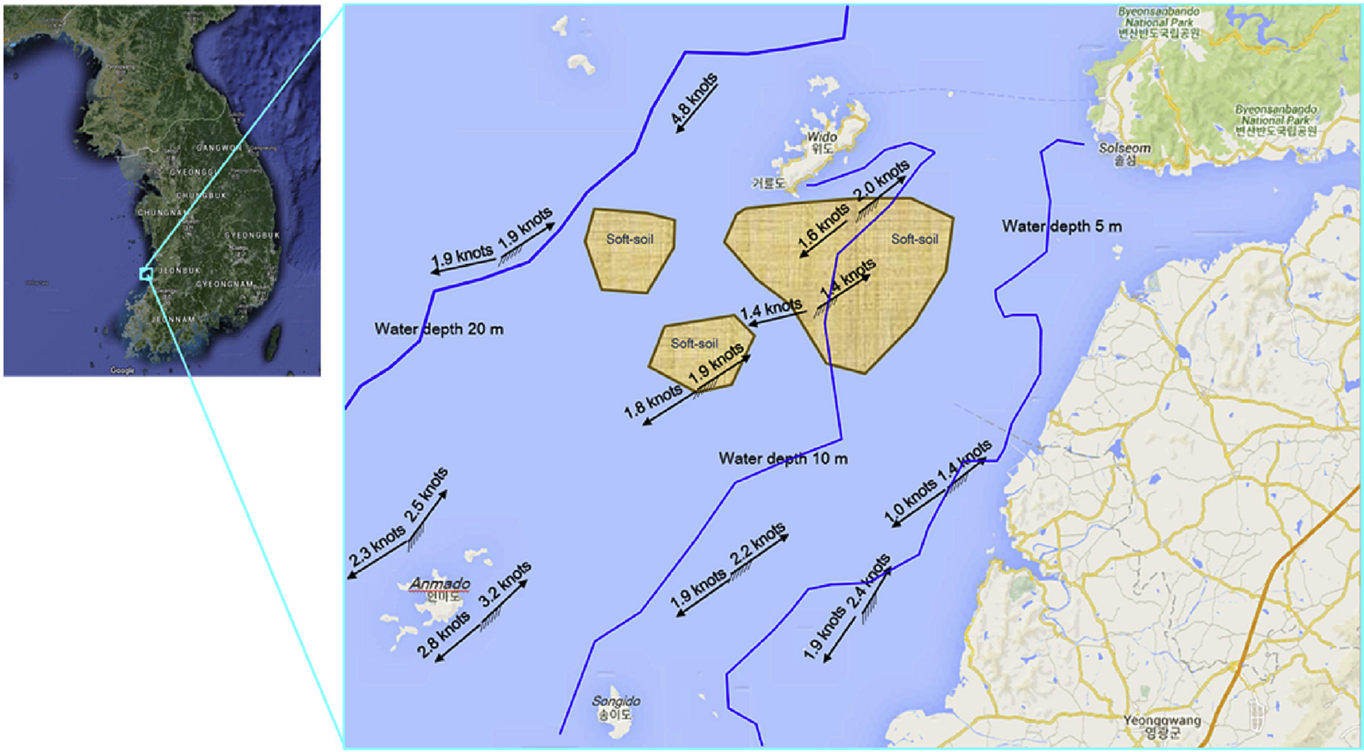

Fig. 7. Distribution of water depth and seabed with soft soil.

3. West—south offshore wind farm environment

3.1. Weather conditions

The source of symptoms days from Kunsan weather station and Buan meteorological observatory, which are placed near the west—south offshore wind farm, are show in Fig. 5. As can be seen from the table, the number of possible working days for installation is approximately 232—237days (Fig. 4).

3.2. Sea environmental conditions

Environmental conditions of offshore wind farms are shown in Table 7. Buan and Kunsan area have features of very large tidal and fast current. The direction of the current keep changing during the installation which causes the significant differences in the water depth. Because of changes in the water depth, difficulties of station keeping would possibly occur when anchor mooring method is used to keep the location.

3.3. Water depth and seabed geological conditions

Fig. 7 shows rough depth distribution of the west-south offshore wind farm. From the figure, it can be seen that the closer to the coast, water depth is near 10 m. In this case. Considering the possible operation wave height (Hs = 2.5—3.0 m) of installation vessel, it would be possible to conduct installation at a depth exceeding 9.0 m (Fig. 6). The margin was assumed to be 1.0 m (see Fig. 8).

4. Assessment of the installation means

4.1. Organization of the installation fleet

Organization of installation fleet is as follows to reflect the conditions mentioned above. First, sea transit and operating conditions of each vessel in the required fleet are shown on Table 8. WTIV has a crane of 800—1500 ton capacity, 12 knots of transit speed and 3.0 m wave height (Hs) on transit

Table 8
Transit and operating condition for construction vessels.

Vessel type	Operating equipment	Capacity	Transit condition		Operating condition	
			Speed (knots)	Wave height (Hs, m)	Wave height (Hs, m)	Wind speed (m/s)
WTIV	Jack up/down + crane	Crane capacity: 800—1500 ton	12	3.0	2.5	16
Jack-up barge	Jack up/down + crane	Crane capacity: 800 ton	4	2.5	1.65	16
Crane barge	Shear crane	3000 ton	4	1.5	1.0	10
Cargo barge	Stacking (without crane)	2000—5,000p	4	1.5	1.5	14
Tug boat	Towing	750 hp, 1000 p	13	2.5	1.0—1.65	14

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Table 9
Case study of vessel fleet for wind turbine installation.

	Option 1			Option 2			Option 3			Option 4		
	Type	Capacity	EA	Type	Capacity	EA	Type	Capacity	EA	Type	Capacity	EA
Installation Vessel	WTIV	800 ton crane	1	Jack-up barge	800 ton crane	1	Jack-up barge	800 ton crane	1	Crane barge	3000 ton	1
				Tug boat	1500 hp	2	Cargo barge	5000 p	1	Cargo barge	5000 p	2
							Tug boat	1500 hp	2	Tug boat	1500 hp	3
							Tug boat	750 hp	2	Tug boat	750 hp	2
							AHTS	1500 hp	1	AHTS	1500 hp	1

Table 10
Time for the assembly according to the installation method.

Assembly components	One by One method				STAR method	
	3MW Installation time		7 MW Installation time		5 MW Installation time	
	Min	Max.	Min.	Max.	Min.	Max
Tower base equipment & tower 1	2	4	6	10	6	10
Tower 2 & Nacelle + rotor	3	5	8	10		
Tower 2 & Nacelle bolt 100% torque	5	10	8	14		
Blade 1	2	5	4	8		
Blade 2	2	5	4	8		
Blade 3	2	5	4	8		
Tower 2 & Nacelle					8	10
Tower 2 & Nacelle bolt 100% torque					8	14
Rotor + Blade 1 + Blade 2 + Blade 3					4	10
Total hours	16	34	34	58	26	44
Total days	0.67	1.42	1.42	2.42	1.08	1.83

Table 11
Transport unit, capacity and loading time for the economic evaluation.

Installation data	3 MW	5 MW	7 MW	Remarks
Quantity of WTG for transport	5 set	3 set	2 set	
Assembly time per 1 unit	0.67–1.42 days	1.08–1.83 days	1.42–2.42 days	
Loading capacity for installation vessel	15 MW	15 MW	14 MW	WTIV, Jack-up barge
Loading time in port	1 day	1 day	1 day	Kunsan port

condition. Operation condition on site for this vessel is wave height less than 2.5 m and velocity less than 16 m/s. Jack-up barge has a crane of 800 ton capacity, 4 knots of towing speed and 2.5 m wave height on transit condition. Operation condition on site for Jack-up barge is wave height less than 1.6 m, and wind speed less than 16 m/s.

And the vessel with such specifications have been organized as the fleet and carried out the economic and installation time assessment as shown on Table 9. Wind turbine generators for installation assumed to be transported in units of 15 MW, each assembly time per unit is shown on Table 10.

Table 12
Vessel fleet and installation time for the economic evaluation.

Vessel fleet	$Time_{load}$	$Time_{transit}/Time_{return}$	$Time_{work}$	$Time_{move}$
Option 1	1 day	0.4/0.4 day	0.67–2.42/set	0.4–0.6 day/set
Option 2		1.0/1.0 day		0.5–0.8 day/set
Option 3		1.0/1.0 day		0.5–0.8 day/set
Option 4		1.0/1.0 day		0.6–1.0 day/set

The installation time for 1 set of wind turbine generator can be derived by following Eq. (1).

$$Time_{install} = Time_{load} + Time_{transit} + Time_{work} \times Quantity_{wtg} + Time_{move}\left(1 - Quantity_{wtg}\right) \quad (1)$$

where

$Quantity_{wtg}$: quantity of WTG for transport.
$Time_{load}$: load time of WTG to the installation vessel in the port.
$Time_{transit}$: transit time from Port to wind farm.
$Time_{return}$: return time from wind farm to Port.
$Time_{work}$: working hours for installation on Site.
$Time_{move}$: moving time from one WTG to the other WTG.

The total installation time for wind farm according to Eq. (2)

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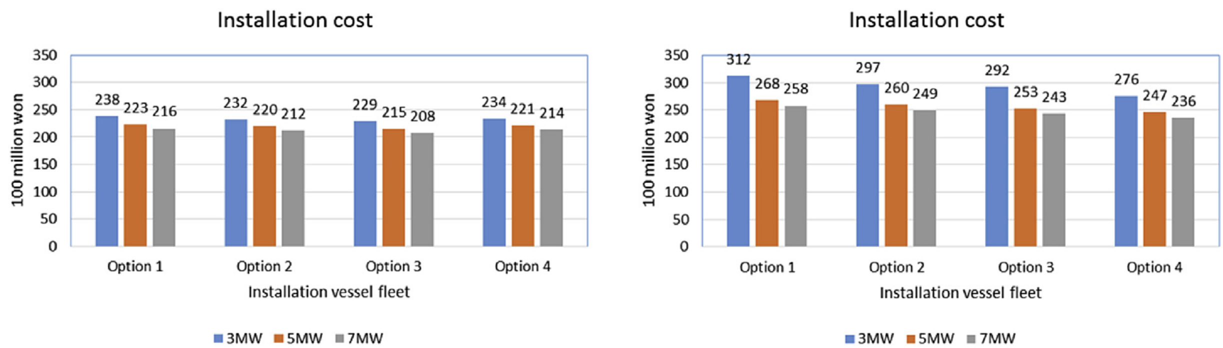
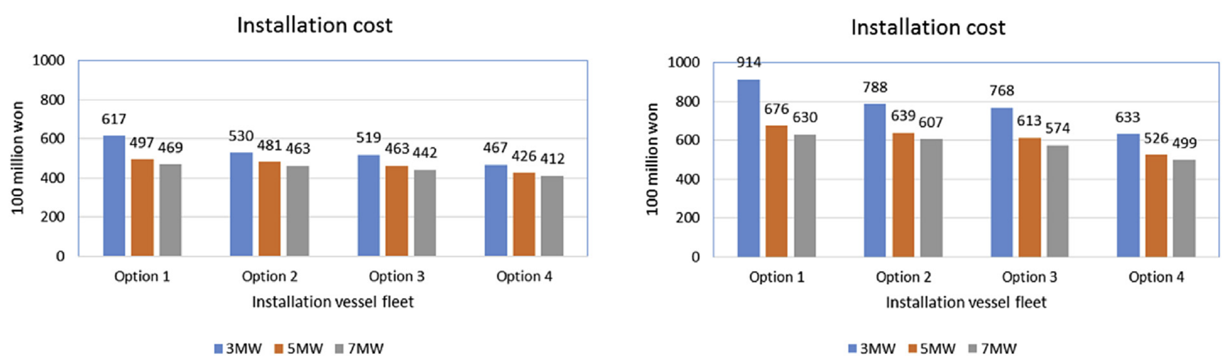


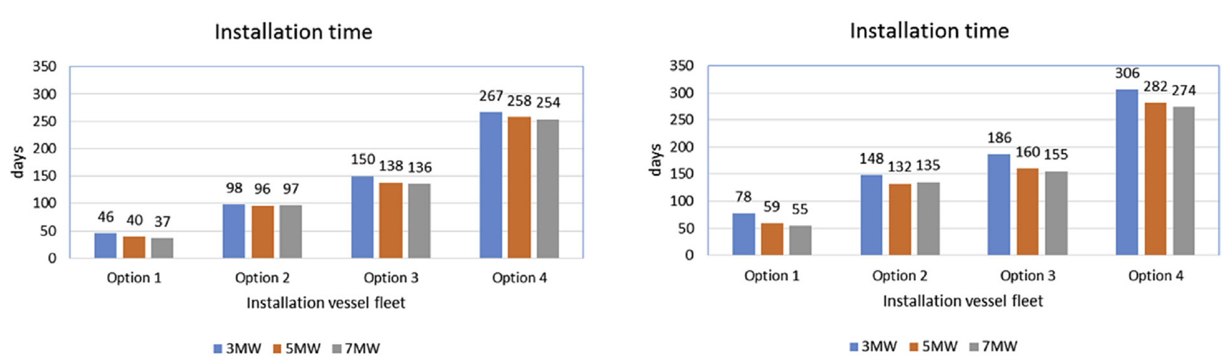
(a) Minimum installation period per unit (b) Maximum installation period per unit

Fig. 8. Installation cost of 100 MW wind farm.



(a) Minimum installation period per unit (b) Maximum installation period per unit

Fig. 9. Installation cost of 400 MW wind farm.



(a) Minimum installation period per unit (b) Maximum installation period per unit

Fig. 10. Working days of 100 MW wind farm.

$$Time_{total} = \sum_{i=1}^{n} (Time_{install})i \quad (2)$$

where n: integer number of (wind farm size/loading capacity for install vessel).

The installation cost was calculated with the day rate of each vessel. Which is, $200,000 for WTIV, $150,000 for Jack-up barge, $90,000 for crane barge, $50,000 for cargo barge and $3000 for tug boat. And the cost was calculated in a monthly basis considering the total lease period (Tables 11 and 12).

4.2. Economic evaluation

Figs. 8–9 shows the installation cost for the test bed (100 MW) and demonstrate site (400 MW).

There is a little difference in the cost of installation of 100 MW wind farm. However, the option 4 method was shown to have relatively little cost. Also, the greater the generation capacity of offshore wind turbine generator showed a relatively low cost. For the installation of 400 MW wind farm, the cost seems to reduce significantly when installed in the

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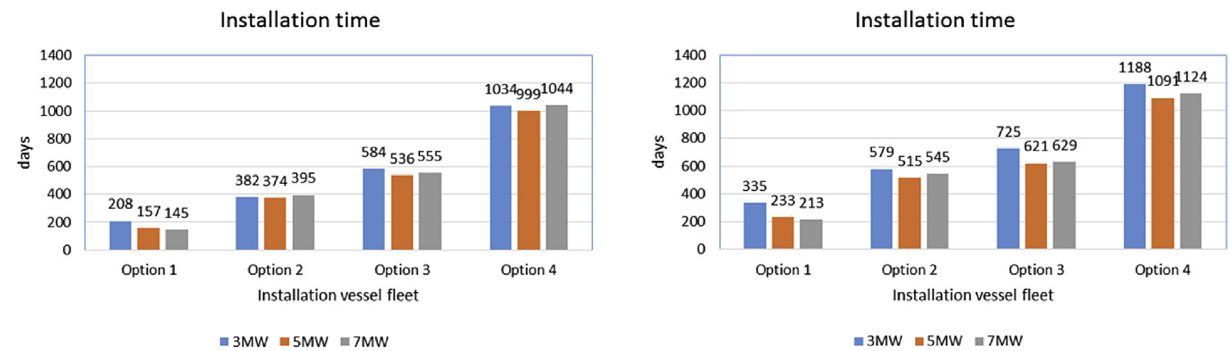
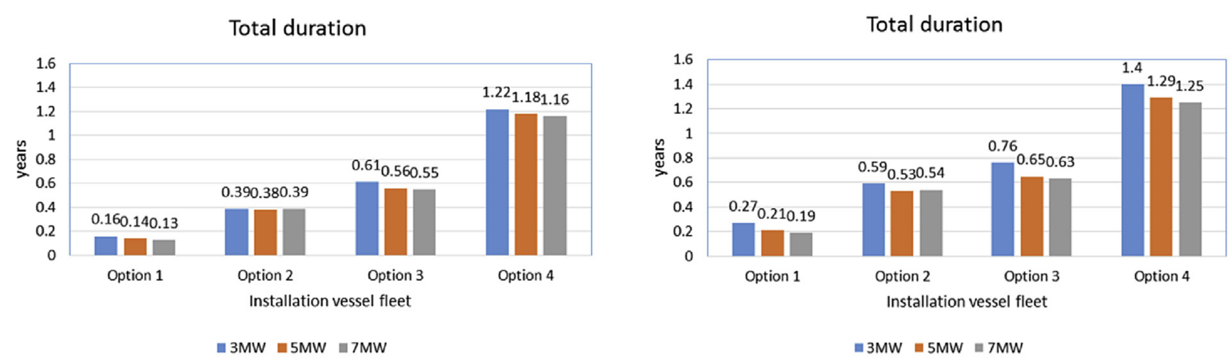


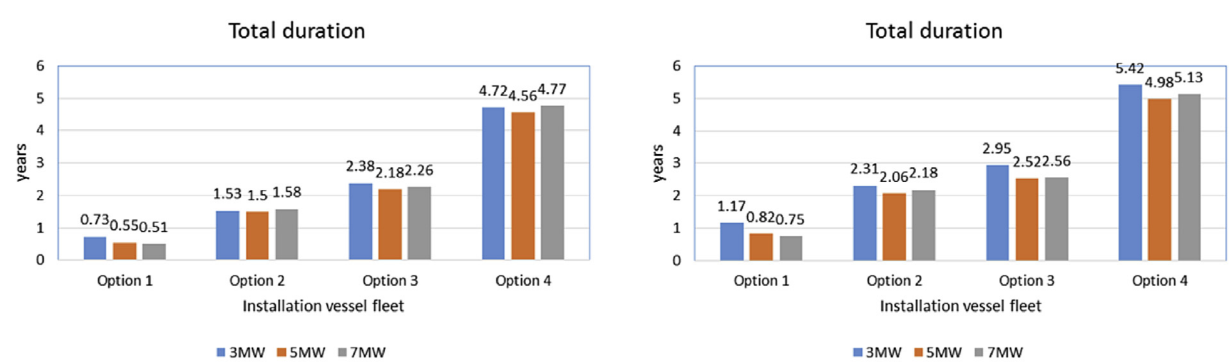
(a) Minimum installation period per unit (b) Maximum installation period per unit

Fig. 11. Working days of 400 MW wind farm.



(a) Minimum installation period per unit (b) Maximum installation period per unit

Fig. 12. Installation duration of 100 MW wind farm.



(a) Minimum installation period per unit (b) Maximum installation period per unit

Fig. 13. Installation duration of 400 MW wind farm.

manner specified in option 4. This is possible because option 4 has low daily charter rate.

4.3. Evaluation of working days and duration

Figs. 10 and 11 shows the number of working days for installing the wind turbine generator in 100 MW and 400 MW wind farm. As you can see from the figures, the data for the option 4 method is derived under the influence of the west—south offshore wind farm's conditions. With this result, it has great impact on installation period shown on Figs. 12 and 13. Construction of 100 MW wind farm using the method stated in option 4 is expected to take 1—2 years. Construction of 400 MW wind farm is expected to take 4—5 years.

5. Conclusions

This study presented a research result of the proper installation means of wind power turbines in Korean

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west−south wind farm. The following conclusions can be obtained from the results:

(1) Suggested environmental survey results for the construction of Korean west−south wind farm.
(2) The required depth to install using installation means is 9 m and more, it is judged to be inappropriate to use mooring as the installation means due to a difference in ebb and flow of the tides.
(3) Installation method using WTIV or Jack-up barge costs relatively higher than the other methods, however it is expected to reduce the installation working days and duration, which results in reducing the total installation cost.
(4) The cost or duration was found to be reduced as the capacity of offshore wind turbine generator increases.
(5) Advantage of shortening the installation period at relatively equivalent cost, when utilizing WTIV or Jack-up barge, is only be achieved with experienced installation specialists and a define schedule. If the installation delay factors such as uncertainty in installation schedule or delay in supply of turbine by the manufacturers occur the cost of installation is expected to increase sharply.

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