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Economic Evaluation Offshore Wind Project under Uncertainly and Risk Circumstances

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Abstract**—**Offshore wind energy as a strategic renewable energy, has been growing rapidly due to availability, abundance and clean nature of it. On the other hand, budget of this project is incredibly higher in comparison with other renewable energies and it takes more duration. Accordingly, precise estimation of time and cost is needed in order to promote awareness in the developers and society and to convince them to develop this kind of energy despite its difficulties. Occurrence risks during on project would cause its duration and cost constantly changed. Therefore, to develop offshore wind power, it is critical to consider all potential risks which impacted project and to simulate their impact. Hence, knowing about these risks could be useful for the selection of most influencing strategies such as avoidance, transition, and act in order to decrease their probability and impact. This paper presents an evaluation of the feasibility of 500 MV offshore wind project in the Persian Gulf and compares its situation with uncertainty resources and risk. The purpose of this study is to evaluate time and cost of offshore wind project under risk circumstances and uncertain resources by using Monte Carlo simulation. We analyzed each risk and activity along with their distribution function and their effect on the project.

Keywords**—**Wind energy project; uncertain resources; risks; Monte Carlo simulation.

I. Introduction

In recent years, the study of wind energy and wind development has been a topic of great interest for developers and researchers in developing countries [1].

Around the world, the potential of offshore wind energy is enormous; it could meet the United States' energy demand four times over or Europe's energy demand seven times over [2].

The Europe Wind Energy Association (EWEA) estimates that, by 2020, 60,000 MW of offshore wind power can supply 148 TWh per year, which is enough to meet more than 4% of the total electricity demand in Europe and which can reduce 87 million metric tons of carbon dioxide emissions [3]. Furthermore, there are great expectations for major extension elsewhere. Governments and companies in developed countries such as Korea, Japan, the United States, Canada and even India have shown tendency for developing offshore in their waters. Regarding to the more ambitious projections, installation of offshore wind capacity could reach to 80 GW by 2020 worldwide, with three-quarters of this in Europe [4].

Offshore wind has a number of advantages [4]: (a) Higher wind speeds and less turbulence than on land and fewer environmental constraints; (b) Specially, large-scale development near the considerable demand centers represented by the main port cities of the world, avoiding the requirement for long transmission lines to get power to demand centers, which is often the case onshore; and (c) Sensibility of building wind farms offshore in very densely populated coastal regions with high property values because high property values make onshore development expensive, sometimes leading to public opposition.

The main contributions of this paper are as follows: The economic aspect of onshore wind project in comparison with offshore is more favorable.

As of 2011, offshore wind projects were at least three times more expensive than onshore wind projects of the same nominal power [5].

Uraz and Emre [6] have identified the factors which are related to transportation and installation process of offshore wind turbines, in order to figure out how different parameters could affect the overall duration.

Huang et al. [7] analyzed the installation cost of offshore wind turbine and the transportation duration for each vessel, considered four options for wind turbine installation, and presented the best option which had minimum cost and took less time.

As stated previously, the logistics operations within the installation phase of a wind farm contain pre-assembly activities, transportation to the site, and installation components at sea. At sea, the installation is divided to installation of the foundation and the turbines. The construction of foundation and its transition pieces are completed at first. After this, the installation of foundation and turbin's component can be completed. We will be considering the activities involved in the surveying, designing, engineering, installation and conditioning process, which impact on the overall project performance. In this study, we evaluate construction of offshore wind power plant with domestic resources and time and without considering risks, then we provide an evaluation with considering uncertainty and under risk situation by using Monte Carlo simulation.

II. Offshore Wind Project Characteristics

This section will specify an analysis in order to reveal the problems and the characteristics of this project.

One of the most important problems is the components of offshore wind project are large, heavy, and fragile. Storing these enormous structures such as turbine, foundation, structure of offshore substation, etc. requires a large area. The required facilities such as the lifting equipment must be available because they were used constantly.

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TABLE I
RISK CLASSIFICATION

Business	**Technical**	**Environmental**	**Organizational**	**Political**
Insufficient budget	Grid connection	Technology limitation	Transportation equipment	Change Rules
Supplier-contractor	Special construction vessels	Damage to environment	Damage or theft during transport or construction	Risk of war, terrorism …
Insufficient expertise	Quality of materials & spare part	Natural hazards	Lack of training	Complex approval processes
Insufficient public acceptance	Turbine performance			
	Assembling & installation			

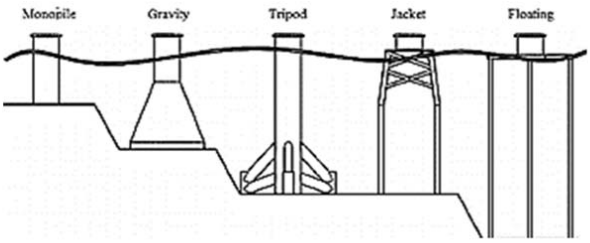

Fig. 1 Offshore wind turbines foundations [8]

A. Goal and Scope

The system boundary of this study was the whole life cycles of offshore wind project, including Planning, Engineering & Construction, Installation & Commissioning and Operation & Maintenance. The necessity of an offshore substation depends on the total installed capacity of a wind farm and its distance from the coast. Generally, when the total installed capacity is less than 30 MW, constructing an offshore substation is unnecessary. If the total installed capacity is more than 30 MW but less than 120 MW, an offshore substation should be constructed when the distance between the wind farm and the Coast is greater than 10 km. An offshore substation is generally necessary when the total installed capacity is higher than 120 MW, regardless of the distance between the wind farm and the coast [7].

In this study, offshore wind farms were assumed to include the installation of 100 wind turbines (5 MV), resulting in a total power capacity of 500 MW.

B. Assumption

The site of the offshore wind power plant is supposed to locate in Persian Gulf. The capacity of offshore wind power plant is 500 MV including 100 wind turbines with power Rated 5 MV, an offshore substation with 800 m² which transforms voltage from 33 kV to 132 kV for export to onshore substation, an onshore substation with 600 m² which transforms voltage from 132 kV to 400 kV and a met station in order to monitor and analyses all aspects of meteorological and oceanographic conditions at the site and a Construction port for pre-assembly and construction of the wind farm. The depth of the sea ranges between 30 to 45 m. Annual wind speeds at 100 m height in this area is considered between 8 to 10 m/s.

Cables must bury to 1.5-3 m below sea bed to prevent disturbance, caused by such as fishing vessels or ship anchors.

The foundation types depend on the site depth. There are five different foundations types: monopile, gravity, tripod, jacket and floating, as depicted in Fig. 1 [8]. Monopile foundations account for 96% of the commissioned offshore wind turbine foundations, followed by the jacket foundations [8], [9].

Offshore wind turbine structures are economically viable options in shallow waters no deeper than 50 m [11], [12]. For greater water depths, floating wind turbines are needed, which can be installed in the range of 100 m to 900 m depth. The foundations of these turbines are not fixed to the seabed, but they are floating structures [13].

The lifetime of wind turbines and internal submarine cables is 20 years, and the lifetime of submarine transmission cables and an offshore substation is 40 years. Only domestic transportation is considered. The distance of land transportation is assumed to be 150 km, which is approximately the average distance across three counties in Taiwan. Maritime transportation is between the offshore wind farm and Taichung Harbor, and the average distance is assumed to be 50 km.

The vessels which must be carried out during this project are geophysical survey vessel, geotechnical survey vessel, wind turbine installation vessel, Jack-up barge, Crane barge, Cargo barge, Tug boat, trenching vessel and cable-laying vessel.

For this project, about five kinds of vessel were used and rental rates for vessels are very high. The rate of loading of vessels is constrained by wave height and wind speed.

The staging port must be available 24 hours a day, 7 days a week because the storage components must be available when needed.

Offshore substation integrates AC power output from individual turbines and transforms voltage from 33 kV to 132 kV for export to onshore substation.

Onshore substation transforms power to grid voltage, 400kV. Where a high voltage DC export cable, the substation will convert the power three phase AC.

Operational support is provided 24/7, 365 days a year, including responding to unexpected events, turbine faults and weather monitoring

C. Risk Classification

Knowing all sorts of risk that faced during project, could contribute to surveying all possible responses and provide the best.

Based on surveying many project and experts' judgment, risks in this project are divided to five categories comprising Business, Technical, Environmental, Organizational and Political. All risks along with their sub has shown in Table I.

D. WBS of Offshore Wind Project

This project is composed three phases including Planning Phase, Engineering & Construction Phase and Installation & Commissioning phase. These phases along with their work packaged are shown in Fig. 2.

E. Turbine Specification

The National Renewable Energy Laboratory (NREL) has created a 5-MW offshore baseline model, whose characteristics are shown in Table I [9]. Most of the turbine designs in the offshore wind turbine industry consist of the same components. Among all, the most expensive components are the foundation, the tower, the rotor and the nacelle. Typical nacelle dimensions are 10-15 m * 4 m *4 m. Towers are generally uniformly tapered, with a top diameter of 4-5 m and a base diameter of around 6 m.

F. Uncertainty Resource and Duration

Ornithological environmental survey is normally one of the first tasks to be undertaken at a potential wind farm site because at least 2 years are needed to get conclusive results about species population numbers and flying patterns at a site, and the results can have a significant effect on wind.

TABLE II
SPECIFICATIONS OF NREL OFFSHORE 5 MW WIND TURBINE

Wind turbine characteristics	Value
Rated power	5 MW
Rotor orientation	Upwind
Control	Variable speed, collective pitch
Drivetrain	High speed, multiple stage gearbox
Rotor/hub diameter	126 m/3 m
Hub height	90 m above MSL
Cut-in; rated; cut-out wind speed	3 m/s; 11.4 m/s; 25 m/s
Cut-in; rated; rotor; generator wind speed	6.9 rpm; 12.1 rpm; 670 rpm; 1173.7 rpm
Rated tip speed	80 m/s
Overhang, shaft tilt, prepone	5m;5°; 2.5°
Rotor mass	110,000 kg
Nacelle mass	240,000 kg
Tower mass	347,460 kg

Met stations are erected at a proposed wind farm site to monitor and analyze all aspects of meteorological and oceanographic conditions at the site. Met mast foundations are generally monopiles with transition pieces similar to turbine foundations but of much lighter construction.

The rotor for a 5MW turbine costs about of €1.2-€1.5 million.

The distribution of resource uncertainty as mentioned is considered triangle and by this the cost and duration.

III. METHODOLOGY

Monte Carlo simulation is a technique used to understand the impact of risk and uncertainty in cost, project management, and other forecasting models.

We cannot know with certainty what the actual value will be, but based on past experience, historical information, and expertise, we can draw an estimate.

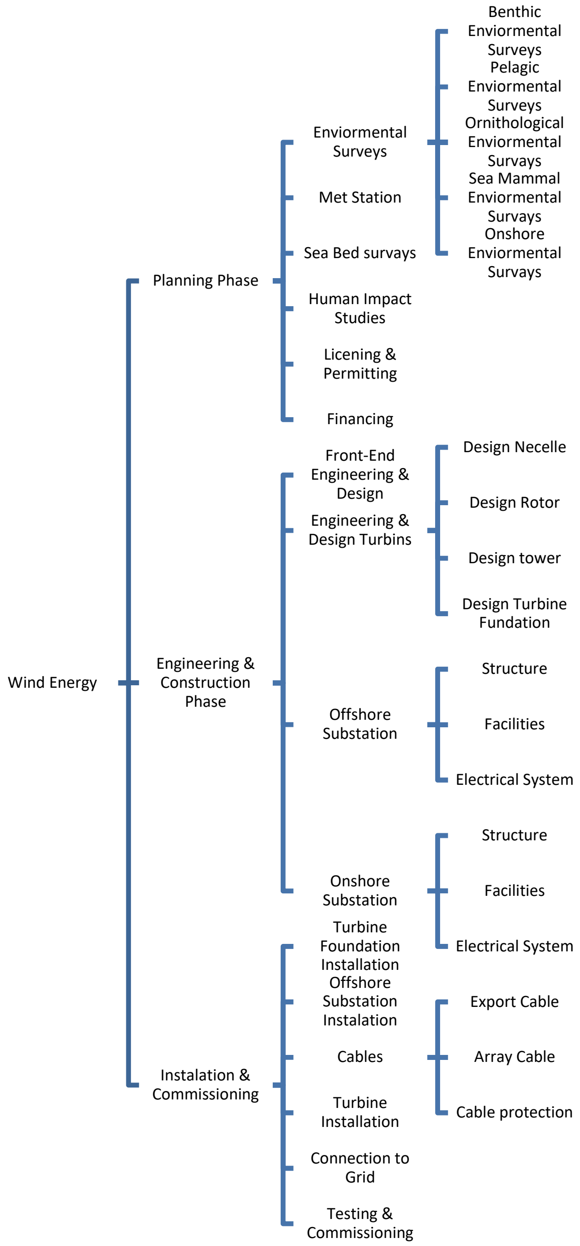

Fig. 2 WBS of offshore wind project

In this paper, discussions were on how to estimate cost and time of offshore wind project based on uncertainty and risk circumstances.

Monte Carlo method produces artificial values of a probabilistic variable by using a random uniformly distributed number generator in the [0, 1] interval and also by using the cumulative distribution function associated with these stochastic variables. We can create a more realistic design of what would be happened in the future by applying a range of possible values.

The key feature of a Monte Carlo simulation is that it can tell us – based on how we create the ranges of estimates – how likely the resulting outcomes are.

In this sort of simulation, for each activity, a random value is considered, based on the range of estimates. Based on this random value, the model is figured out. The conclusion of the model is recorded, and the process is repeated. A Monte Carlo simulation calculates the model hundreds of times, each time using different randomly-selected values.

When the simulation is completed, we have results, based on random input values from the model. These results are used to describe the probability, or likelihood, of reaching various results in the model.

This method has seen many interpretations, received various definitions, therefore we can state that this method has come a long and process of evolution and development. Initially, an important issue of the method was to generate large series of random numbers. In the first stage, there were used pseudo-random numbers, and then, with the development of computer technology, this barrier has been removed [10].

Fig. 3 describes a process for providing schedule risk model by using Monte Carlo.

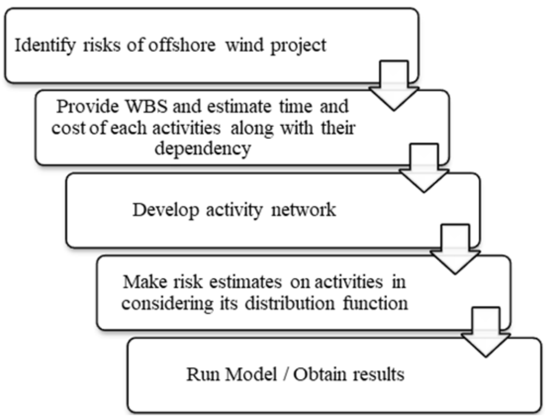

Fig. 3 Processes of Monte Carlo simulation

IV. Result and Discussion

As can be seen from Table III, risks that impacted project are shown and depict which activities affected. In order to survey risk impact on activities, uniform distribution has been mentioned for all risks based on expertise. All estimations were conducted by expert due to promotion of accuracy and perception of evaluation. For every risk that affects activities, we consider two estimations, one of them related to schedule and the other one related to cost. For each task, we estimate the minimum and maximum expected time and likewise for cost (based on expertise, experience and historical data).

Based on Monte Carlo simulation, we would estimate the absolute maximum time under worst circumstances, and the absolute minimum time under best circumstances. In order to estimate time and cost of project in considering uncertainty time and resource and risks, Monte Carlo method is exerted. In the Monte Carlo simulation, we will randomly produce values for all activities, then calculate the total time to completion according to critical path. The simulation was carried out with 1000 iterations and result contains distribution and cumulative graph have shown in Fig. 2. As the chart in the figure depicts, the project would take 1619 days with 80% and with 50% would be completed within 1577 days. Accordingly, the project would be delayed about 82 days with 50% and by 80%, it takes 124 days behind schedule. The project might be completed in as little as 1465 days, or as long as 1693 days. The original estimate for the "most likely", or expected case, was 1495 days. From the Monte Carlo simulation, the total time was 1465 days or less in only 2% of the cases.

TABLE III
Work Packaged Are Affected by Risks

Risks	Work packaged are affected by risks
Supplier-contractor	Facilities of Offshore substation
	Facilities of Onshore substation
Insufficient expertise	Front-End Engineering & Design
	Engineering & Design Turbines
	Environmental Surveys
	Connection to grid
Insufficient public acceptance	Testing & Commissioning
Grid connection	Export Cable
	Array Cable
	Connection to grid
Special construction vessels	Structure of offshore substation
	Turbine Installation
	Turbine Foundation Installation
Quality of materials & spare part	Electrical System of offshore substation
	Electrical System of onshore substation
	Facilities of Offshore substation
	Facilities of Onshore substation
Turbine performance	Testing & Commissioning
Fabrication design	Design Turbine Foundation
	Design Nacelle
	Design Rotor
	Design tower
Natural hazards	Turbine Foundation Installation
	Structure of offshore substation
	Offshore Substation Installation
	Turbine Installation
	Cable Protection
	Export Cable
	Array Cable
Technology limitation	Front-End Engineering & Design
	Engineering & Design Turbines
Transportation equipment	Turbine Installation
Damage to environment	Testing & Commissioning
Damage or theft during transport or construction	Turbine Foundation Installation
	Structure of offshore substation
	Offshore Substation Installation
	Turbine Installation
Complex approval processes	Likening & Permitting
Change Rules	Likening & Permitting

Cost estimation under uncertainty and risks circumstances was conducted by Monte Carlo simulation and there is a range of possible outcomes. The result is shown in Fig. 2, and performing the project with 1,227,100,000 € as a planning budget is impossible. This chart depicts the project would cost

1,415,069,600 by 50%, thus its expenditure will be increased about 15% likewise will have 18% in creation in cost of project with 80%.

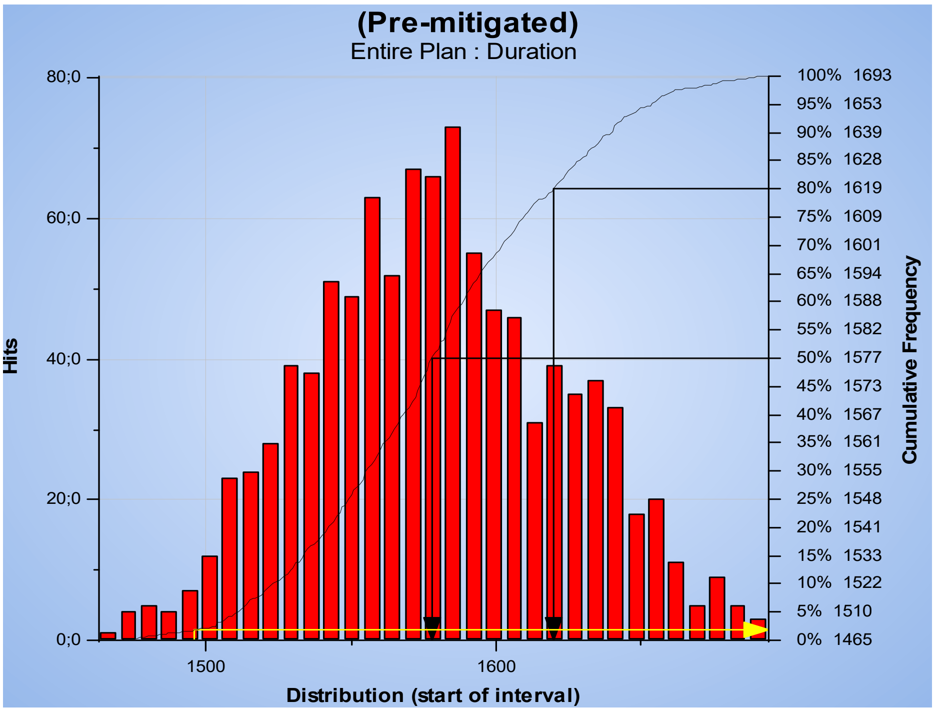

Fig. 4 Time estimation under uncertainty and risks

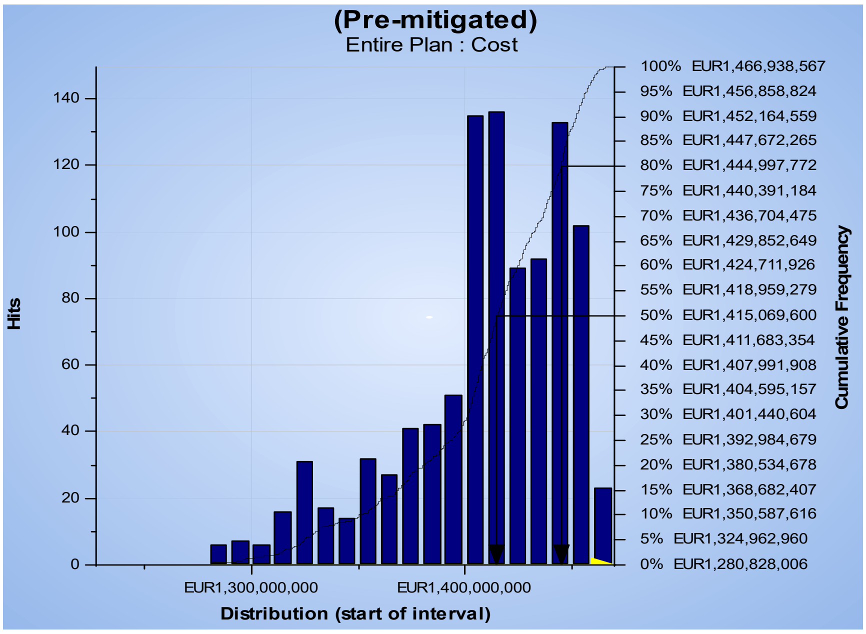

Fig. 5 Cost estimation under uncertainty and risks

The project might be completed in as min as about 1,280,828,000 EUR or as max as about 1,466,938,000 EUR.

The simulation will be run 1000 times. The original estimate for the "most likely", or expected case, was, 280,828,000 EUR. By using the Monte Carlo simulation, however, there is no chance that total cost would be 1,280,828,000 EUR.

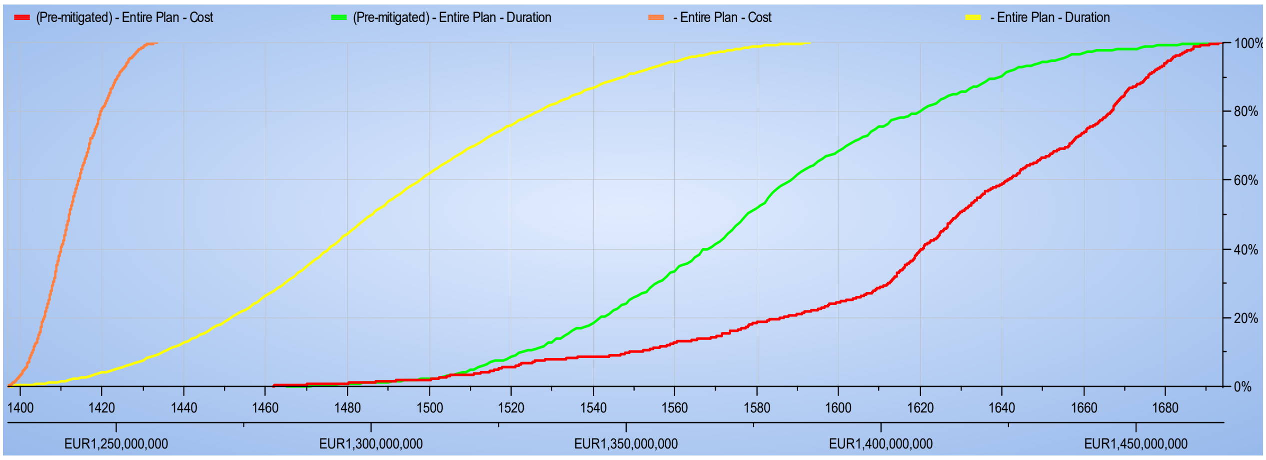

Fig. 6 Comparison of time and cost estimation in deterministic situation and under uncertainty and risk circumstances

As can be seen from Fig. 6, the project compared entire plan and when risks and uncertainty resources affected activities of project in terms of time and cost. Uncertainty resources and risks which affected activities effect on project and according to expenditures of this kind of project, would make managers and investors become reluctant to expand offshore wind power plant in developing countries.

V. Conclusions

The risk of wind farm projects is usually due to the specific circumstances of these projects (the need for specific equipment for oceanographic studies, deep sea surveys and marine species, the need for ships and special cranes to carry and install equipment and items, deployment On-site personnel to carry out periodic and emergency repairs, to consider locations along the turbines for the landing of the helicopter and the ship's side to resolve potential problems, the use of special equipment for installing cables between turbines and stations Sea and coast at depths of 2 to 3 m below sea level). In this regard, identifying the risks of these projects and knowing their prioritization can help to manage risks and identify ways to deal with them in order to reduce the impact and probability of the project risks.

In this paper, the influence of offshore wind energy risks and uncertainty resources on project activities has been assessed and quantified by using Monte Carlo simulation. First, the risks which are associated with offshore wind project identified by investigation articles and project were performed in this field and classified these potential risks into five groups. Then, we prepare a WBS for this sort of renewable energy project which comprising four phases. Then, we provide schedule plan and time and cost estimation for all activities with analog method. In the next step, activities affected with risks according to their distribution functions were determined. Finally, Monte Carlo simulation was carried out in order to estimate time and cost of project in considering risks and uncertainty resources. This study helps developers to make decision efficiency to faced risk and could inform them to adopt best strategies comprising avoidance, transition, mitigation and acceptance and determine appropriate contingency reserve. By these measurements, we can expect that the project is less exposed to unforeseen risks and can achieve its goals and meet the needs with higher probability. Therefore, having more information about risk might has an impact on our financing, insurance, permits, and hiring needs and we can make a better scheme for going forward and make decisions.

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