Modeling and Solution of Offshore Wind Farm Maintenance Scheduling
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Abstract. Wind resources are considered to be one of the most promising alternative energy sources. It is difficult to achieve the maximum utilization of wind energy by artificial maintenance scheduling, because of poor operating environment, poor site accessibility, and other objective factors such as randomness. According to health of turbines, wind power forecasting results, maintenance resource availability, weather and other factors, how to achieve the minimum maintenance cost and minimum wind power loss of offshore wind farms in the short-term maintenance task optimization scheduling is still a difficult problem facing the industry. This paper presented an optimization model for the scheduling of short term maintenance scheduling in offshore wind field, the optimization model belongs to nonlinear optimization problem with constraints, and uses the Gurobi to solve the optimization problem with the minimum wind field maintenance cost and the minimum wind power loss.

Introduction
Compared to onshore wind, operation and maintenance costs of offshore wind power are more expensive, and the wind turbine usage is relatively low. Maintenance of offshore wind power need to call ships, helicopters, marine vessels and other special equipment, the cost is more expensive and longer maintenance cycle. In the life cycle cost structure of offshore wind farms, operation and maintenance are of 20%-30% of the total cost. However, the availability of offshore wind turbines is lower than onshore wind turbine. Usually onshore wind turbine availability rate can reach 95%-99%, but the average availability rate of offshore wind turbines is less than 90%. Therefore, as the key technologies to reduce maintenance costs and improve turbine availability, the offshore wind intelligent operation and maintenance technologies have a very important significance.

Bhaba R. Sarker, put forward a kind of offshore wind unit maintenance cost model, considering the preventive component replacement and maintenance, by optimizing the maintenance age group minimize maintenance costs[1]. S’ Kova CS’ Andra comprehensive proposed a wind farm operation and maintenance scheduling system which considered the wind turbine condition monitoring, diagnosis and maintenance, and using Cplex ILOG tools to solve the best operating costs[2]. Li Hao explores the significance and feasibility of the reliability based maintenance model applied to China’s offshore wind power field, and analyses difference and advantage between based on electricity and traditional time, and evaluates the advantages based on reliability for operation and maintenance. Zheng Xiaoxia compared the advantages and disadvantages of offshore wind farm regular maintenance, troubleshooting and monitoring, analyzes the main factors affecting the cost of offshore wind farm operation and maintenance, evaluation of the initial establishment of offshore wind farm maintenance cost function. At present, the research mainly considers the preventive maintenance and regular maintenance scheduling model, and the cost of wind power prediction is not combined with wind power forecast.

This paper presents a time window for offshore wind farm maintenance evaluation model based on the solution to the decision problem short-term maintenance tasks, what time which team, which ship completed, in order to simplify the model, no maintenance team skills into consideration, the
assumption that each maintenance team has the skills to meet the requirements of all maintenance tasks.

Development for Wind Farm Maintenance Scheduling and Optimization

The operators of wind farms always divide its maintenance crews into several regions geographically. The maintenance team of each region is only responsible for the wind turbines within their jurisdiction, making the working scopes, activities and resources being generally independent of each other. Each day, the maintenance team would devise a detailed short-term schedule specifying the tasks to be accomplished for the coming 1 to 3 days, and then execute the task set for that very day. In the following day, the team would make a new short-term schedule in line with the changes in tasks and start to implement the updated schedule on the same day, and repeated this process over and over again every day.

The Cost Function of Maintenance Scheduling

The decision variables for the optimization model include:

- \( z_{w,t} = \begin{cases} 1 & \text{if wind farm } w \text{ is visited in time } t \\ 0 & \text{if wind } w \text{ farm is not visited in time } t \end{cases} \)
- \( v_{i,t} = \begin{cases} 1 & \text{if wind turbine } i \text{ is visited in time } t \\ 0 & \text{if wind turbine } i \text{ is not visited in time } t \end{cases} \)
- \( x_{ij,k,t} = \begin{cases} 1 & \text{if task } j \text{ on wind turbine } i \text{ is performed by personnel } k \text{ in time } t \\ 0 & \text{if task } j \text{ on wind turbine } i \text{ is not performed by personnel } k \text{ in time } t \end{cases} \\
- \( y_{ij,t} = \begin{cases} 1 & \text{if task } j \text{ on wind turbine } i \text{ is put off in time } t \\ 0 & \text{if task } j \text{ on wind turbine } i \text{ is not put off in time } t \end{cases} \)

Each maintenance task on each turbine can be considered as an independent event, making the optimization model simplified to be a multi-integer linear programming problem[3].

The objective of optimization can be expressed as to come up with a plan that will result in the minimum cost under certain constraints. Hence the first step will be to build a cost function for maintenance plans, which can be considered from the following aspects[4-9]: Resource and supplies costs; Transportation cost; Labor cost; Production loss due to maintenance.

To calculate the overall cost function of maintenance plans, rolling horizon method is always used to combine the cost in both short and long horizons. According to the explanations of the cost decomposition described above, the mathematical expressions for cost function are as follows[4-10]:

1) Flexible cost of maintenance resource:

\[
\sum_{w} \sum_{t} \sum_{j} \sum_{k} x_{ij,k,t} \cdot C_{r_j} \tag{1}
\]

In which \( C_{r_j} \) is the hourly cost of task \( j \), \( i \) is turbine id, \( k \) is personnel id; \( t \) is time

2) Flexible cost of transportation:

\[
\sum_{i} \sum_{j} (C_{p} \cdot d_{i,i'} \cdot z_{i,i,t}) \tag{2}
\]

In which \( C_{p} \) stands for the mileage cost of ships, \( and d_{i,i'} \) is the distance between turbine \( i, i' \), and \( z_{i,i,t} \) is:

\[
z_{i,i,t} = \begin{cases} 1 & \text{if turbine } i, i' \text{ have adjacent task at time } t \\ 0 & \text{if turbine } i, i' \text{ don't have adjacent task at time } t \end{cases} \\

3) Labor cost:

\[
\sum_{t \in T_{short}} e_{t} \cdot C_{p}^{1} \tag{3}
\]

where \( e_{t} \) stands for whether overtime work happens, and \( C_{p}^{1} \) stands for penalty cost for overtime.
work.

4) Cost due to production loss:

$$\sum_{t \in T_{short}} \sum_{ij} \sum_{k} x_{i,j,k,t} * P_{i,t}^1 * C_{el} + \sum_{t \in T_{long}} \sum_{ij} \sum_{k} ((P_{i,t}^0 - P_{i,t}^1) * y_{i,j,t} + x_{i,j,k,t} * P_{i,t}^1) * C_{el}$$  \hspace{1cm} (4)

where $P_{i,t}^1$ stands for production of Turbine $i$ under degradation level $j$ at time $t$, $P_{i,t}^0$ stands for production of Turbine $i$ under baseline condition at time $t$, and $C_{el}$ stands for electricity price.

The final cost of corresponding maintenance tasks under the given plans, which will also be used as part of the system output:

$$Total \ Cost = \sum_{t \in T} \sum_{j} \sum_{i} \sum_{k} x_{i,j,k,t} * C_{r} + \sum_{t \in T} \sum_{i} (C_{v} * d_{i,t} * z_{i,t}) + \sum_{t \in T_{short}} \sum_{e_{t} \in E} C_{p} + \sum_{t \in T_{long}} \sum_{ij} \sum_{k} x_{i,j,k,t} * P_{i,t}^1 * C_{el} + \sum_{t \in T_{long}} \sum_{ij} \sum_{k} ((P_{i,t}^0 - P_{i,t}^1) * y_{i,j,t} + x_{i,j,k,t} * P_{i,t}^1) * C_{el}$$  \hspace{1cm} (5)

Constraints of Maintenance Scheduling Optimization Model

This section will describe the constraints that need to be considered in the optimization model, which includes but not limited to environment, maintenance resources, labor force, task fulfillment and work hour restrictions. Mathematical expressions of the constraints will be given in this section.

Constraint 1: A wind turbine can only be visited when the corresponding wind farm is visited.

Constraint 2: A maintenance task can only be performed when the wind turbine is visited.

Constraint 3: A maintenance task can either be performed or put off.

Constraint 4: Time interval between visiting two wind turbines shall be limited by maximum ship speed and their relative distance.

Constraint 5: Remove the maintenance tasks that don’t have required skilled engineers or required maintenance resources.

Constraint 6: Any maintenance personnel can only perform on task at the same time.

Constraint 7: Rescue two maintenance tasks that can’t be performed at the same time.

Constraint 8: Maintenance shall not be performed when weather condition doesn’t allow to.

Constraint 9: Wind farm daily production shall above lower limit.

Constraint 10: Working hours of maintenance personnel shall not exceed upper limitation.

Solution for Wind Farm Maintenance Scheduling Optimization Model

One of the offshore wind farm of The East China Sea which contains 28 wind turbines. The case contains 10 maintenance tasks in the next three days, single ship and maintenance team, we solve the problem using the second sections of the model and optimize by using Gurobi.

The output of the model $x_{i,t}$ optimal solution as shown in Figure 1, where the green represents the time to start the optimization of each maintenance task, grey representative of the time before the optimization (in accordance with the sequence of occurrence) maintenance task.

![Figure 1. Comparison of the model $x_{i,t}$ solution.](image-url)
The total cost of the optimization before and after optimization is shown in Figure 2, the other blue is the total cost of the previous task scheduling. In the case of the completion of all tasks, the total cost is 9965 RMB, the total cost is 12640 RMB, and the total cost is reduced by 26.8% after optimization.

Figure 2. Maintenance cost comparison before and after optimization.

Conclusion
This paper presents a short-term scheduling maintenance plan for offshore wind farms in the optimization model, considering the impact of power loss, personnel costs, transportation costs, resource costs and other maintenance cost factors, and the task execution time is optimized. The optimization model belongs to the category of nonlinear optimization problems with constraints, and uses the Gurobi to solve the model. This paper is used to validate the model of wind field operation of real data, results show that the optimized scheduling plan is 26.8% lower, proved that the model to reduce the offshore wind farm maintenance cost of wind field has a very significant effect.

Reference
