

Research on Collection System Optimal Design of Wind Farm with Obstacles

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Abstract. To the collection system optimal design of offshore wind farm, the factors considered are not only the reasonable configuration of the cable and switch, but also the influence of the obstacles on the topology design of the offshore wind farm. This paper presents a concrete topology optimization algorithm with obstacles. The minimal area rectangle encasing box of the obstacle is obtained by using the method of minimal area encasing box. Then the optimization algorithm combining the advantages of Dijkstra algorithm and Prim algorithm is used to gain the scheme of avoidance obstacle path planning. Finally a fuzzy comprehensive evaluation model based on the analytic hierarchy process is constructed to compare the performance of the different topologies. Case studies demonstrate the feasibility of the proposed algorithm and model.

1. Introduction

As a clean and renewable energy, Wind power has been developed and applied widely under the background of increasingly environment problem and climate change. Offshore wind power will become the trend of wind power in the future [1]. Therefore, as an important component of the offshore wind farm, the topological optimization design of current collection is important for its development [2].

The study on the topological design of the offshore wind farm with obstacles is not perfect at present [3,4], so whether there are other ways available to use in addition to Voronoi diagram approach and Delaunay approach is a direction that deserves more research. Literature [5] uses the Dijkstra algorithm for the shortest path search in solving the problem of obstacle avoidance, but the problem of low search efficiency will appear in the practical application because of too many vertices [6]. In the research of radial and ring topology optimization algorithm, the Prim algorithm (minimum spanning tree algorithm) is adopted in literature [7] and literature [8] because of the fast execution speed, but the algorithm does not consider the obstacle avoidance problem. Moreover, the topology schemes coming from same algorithm are not the only one, it also should select the best one according to the indicators of economic and reliability. The current collection reliability of the offshore wind farm power system is computed and evaluated in literature [9] by using the main bus-bar method in the traditional coal-fired power plant. The factors influencing the economy of offshore wind farm power system is analyzed and the economic evaluation model is established based on quantitative factors in literature



[10]. The optimal topology design is obtained in literature [11] respectively according to the three dimensions of economic priority, reliability priority, comprehensive economy and reliability.

Based on this background, this paper focuses on the study of processing of the obstacles, optimization of the algorithm and evaluation of topology model. After layer and geometry processing of obstacles, topology design can be implemented by using the improved algorithm combining the advantages of the Dijkstra algorithm and Prim algorithm, and the optimal scheme can be selected finally based on the fuzzy comprehensive evaluation model.

2. Current collection of offshore wind power plant

The main part of offshore wind farm mainly includes wind-driven generating unit, marine booster station, current collection and transmission system, and the system structure diagram is shown in figure 1. Among them, as the key part of connection between wind turbines and grid, the current collection system which collects power from wind turbines to the booster station bus through a medium voltage undersea cable is composed of cable line, switch and bus bar [7].

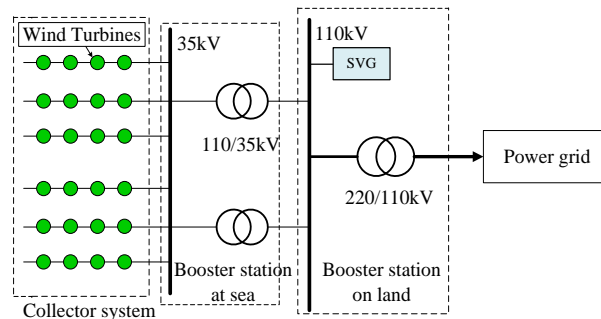


Figure 1. System structure diagram of offshore wind farm system.

Generally, the topology of current collection can be divided into three types, namely radiate, ring, star. These three types of topology are compared in the literature [11], and the results shows that the radial topology has lower cost and simple control. As a result, it is used generally in topology design of offshore wind farm, while star and ring actually use less due to the reasons such as complex structure and expensive costs. Therefore, this article adopts the radiate topology design.

3. Obstacles geometric processing of offshore wind power plant

In the design process of collecting system path, the influence of obstacles among wind turbines should be considered. Before the topology design of obstacle avoidance path using optimization algorithm, it also needs to geometric processing for the obstacles by using the method of smallest rectangle encasing box.

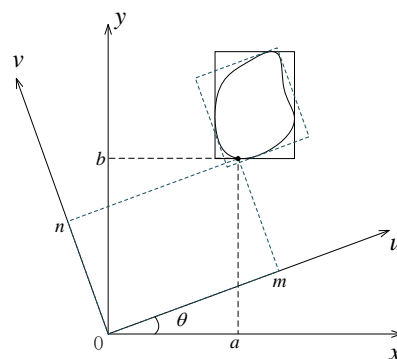


Figure 2. Diagram of rectangle encasing box of the obstacle.

As shown in Figure 2, any point at closed obstacle profile in the coordinates of the x-y coordinates can be expressed as (a,b) , but it should be rotated θ degree in order to obtain the minimum circumscribed rectangle of obstacle. The point after rotating in the u-v coordinates can be expressed as (m,n) , and the conversion relations as shown in Eq.(1):

$$\begin{cases} m = a \cos \theta + b \sin \theta \\ n = b \cos \theta - a \sin \theta \end{cases} \quad (1)$$

The circumscribed rectangular area S can be expressed as the following function:

$$\begin{aligned} S &= \max(m) \times \max(n) \\ &= \max(a \cos \theta + b \sin \theta) \times \max(b \cos \theta - a \sin \theta) \end{aligned} \quad (2)$$

When the area S is minimum, the circumscribed rectangle is the minimum one of obstacle.

4. Topological optimization design of offshore wind power plant

Based on the advantages of the Dijkstra algorithm and Prim algorithm, this section presents a optimization algorithm of collector system design considering the influences of obstacle, namely a algorithm of obstacle avoidance path on minimum spanning tree. The specific steps are as follows.

(1) Determining the initial collection, including booster station set S_1 , wind turbines set F , rectangular vertices of each obstacle R , the set L of all edges in the topology optimization:

$$S_1 = \{s\}; F = \{f_i | i=1,2,K n-1\}; R = \{r_j^k | j=1,2,3,4,k=1,2,K n\}; L=\{\} \quad (3)$$

Where the element s is the initial point of minimum spanning tree, the element f_i represents wind turbines and n is the number of wind turbine, the element r_j^k represents the four vertices of minimum circumscribed rectangle.

(2) Starting from the vertex s of the set S_1 and judging whether the line connected s and f_i intersects the line of the circumscribed rectangle. If they do not intersect, it shows that no obstacles between the two points. So the lowest weight line (s, f) associated s should be put in the set L and f should be removed from the set F to the set S_1 . If they do intersect, it shows that the obstacle exists between the two points and it should move on to the next step.

(3) The two points s and f_i in step 2 can be set to p and q , the former as a starting point, the latter as an end point, and $S_2 = \{p\}$.

(4) Pick the nearest vertex m to the point p from the set R . If no obstacle between m and q , the point p , m and q should be put in the set S_2 . Joining the three points in sequence to form the shortest path, and putting the path into the set L . If there are obstacles, the next nearest vertex m_2 to the end point q should be picked from the corresponding rectangle vertices.

(5) If there is an obstacle between m_2 and q , the point m_2 will be taken as the new starting point and repeats steps 4. If there is not, the point p , m , m_2 , q should be linked and put into the set S_2 . In the same way, putting the find shortest path into the set L .

(6) If the line connecting f and f_i (where $f \in S_1$ and $f_i \in F$) do not intersects the line of the circumscribed rectangle of obstacles, the lowest weight line (f, f_i) should be put in the set L and the point f_i should be removed from the set F to the set S_1 . If they do intersect, then repeat steps 3, 4, 5.

(7) Repeat step 6 until the set $F = \emptyset$, and the lines in the set L compose a minimum spanning tree of the graph consist.

5. Comprehensive evaluation model

Fuzzy comprehensive evaluation is that the influential factors of the evaluation objects are processed by normalisation approach based on the fuzzy linear transformation and the membership grade principle and then the weights will be assigned according to the influence degree of the index to the

evaluated object for making a reasonable comprehensive evaluation[12]. The specific steps are as follows.

(1) Determine the evaluation index set. The criterion layer of evaluation index system includes reliability factor and economy factor that $P = \{K, E\}$, and the index layer includes five factors namely $K = \{K_1, K_2\}$, $E = \{E_1, E_2, E_3\}$. K_1 is the topological equivalent outage rate, K_2 is the annual power shortage expectations, E_1 is the total investment cost, E_2 is the operation and maintenance cost, E_3 is the failure opportunity cost.

(2) Structure the judgment matrix X . In order to determine the weight of each index of all levels, the quantitative index need to be compared one with one. If x represents the quantitative index, the comparison result of the index x_i and the index x_j can be expressed in x_{ij} . The judgment matrix is shown in equation (4).

$$X = \begin{bmatrix} x_{11} & x_{12} & L & x_{1n} \\ x_{21} & x_{22} & L & x_{2n} \\ M & M & M & M \\ x_{n1} & x_{n2} & L & x_{nn} \end{bmatrix} \quad (4)$$

If x_{ij} is 1, 3, 5, 7 or 9, the results respectively indicate the equally important, the slightly important, the obvious important, the strong important and the extremely important. If x_{ij} is 2, 4, 6 or 8, the results respectively indicate the important degree between two adjacent odd judgments [13].

(3) Determine the weight coefficient set $W = \{w_1, w_2, L, w_n\}$. Based on judgment matrix X , the weights of evaluation indexes can be obtained by using normalization method, where the w_n must meet the following condition: $\sum_{i=1}^n w_i = 1, 0 \leq w_i \leq 1$

(4) Determine the evaluation set $V = \{v_1, v_2, K, v_m\}$. Each level v corresponds to a fuzzy subset and the evaluation set in general can be divided into five levels that excellent, good, fair, bad, worse, namely $m=5$.

(5) Construct the fuzzy relation matrix R .

$$R = \begin{bmatrix} r_{11} & r_{12} & L & r_{1m} \\ r_{21} & r_{22} & L & r_{2m} \\ M & M & M & M \\ r_{n1} & r_{n2} & L & r_{nm} \end{bmatrix}_{n \times m} \quad (5)$$

Where r_{ij} stands for the membership of the evaluation index set element p_i to the fuzzy subset judgment matrix element v_j .

(6) With the help of fuzzy operation and unitary processing to the fuzzy weighted vector set and the fuzzy judgment matrix, the fuzzy comprehensive evaluation result set can be obtained and the five elements represent respectively the proportions of excellent, good, fair, bad, worse.

$$S = W * R \quad (6)$$

6. Case Study

The example is constituted by 35 wind turbines and a booster station with 105MW total capacity and 20 years operating life. A layout chart can be get as shown in figure 3(a) after the layer processing. The wind turbines of offshore wind farm are marked in green and the booster station is marked in red.

6.1. Comparative analysis of different topology schemes

The shortest path optimization and the topology design of collector system obstacle avoidance can be realized by using the optimization algorithm after geometric processing. According to the three-core submarine cable parameters of 35 kV AC crosslinking polyethylene, three kinds of schemes meeting the conditions are selected from all existing topology after power flow calculation and selection of cable and switch. The three schemes are shown in figure 3(b), 3(c) and 3(d).

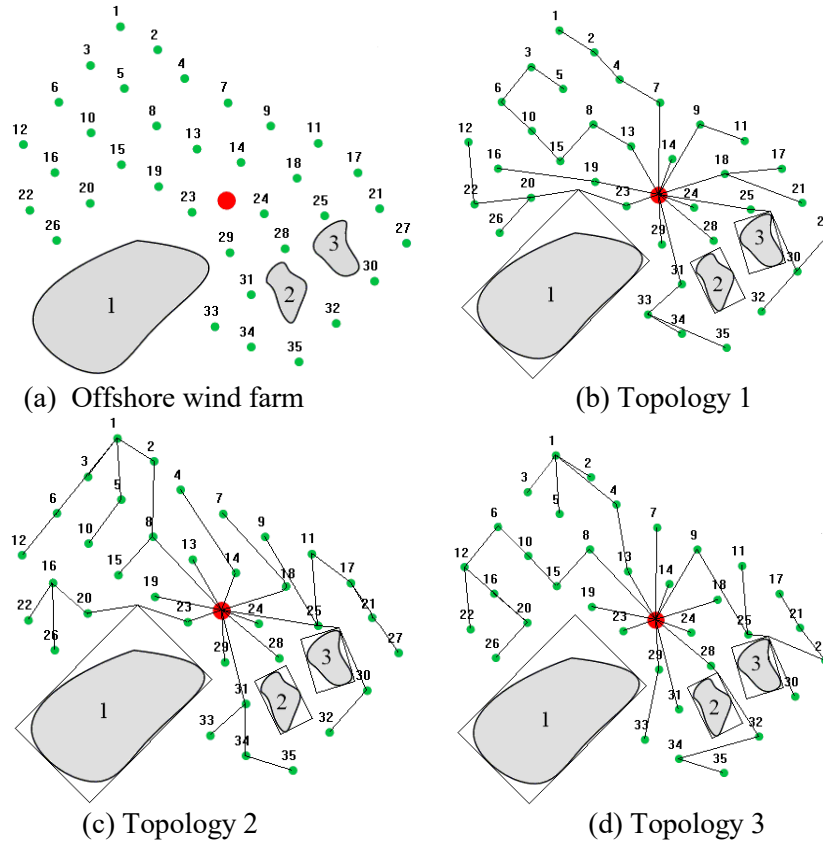


Figure 3. The offshore wind farm with obstacles and topology schemes.

6.2. Fuzzy comprehensive evaluation

Based on the investment level and operation experience of offshore wind farm, the judgment matrix of criterion layer and index layer is constructed. Then the fuzzy relationship matrixes of the three topology schemes are got by equation (5) shown in table 1.

Table 1. Fuzzy relationship matrix of three topologies.

Scheme	R_K	R_E
Topology 1	$\begin{bmatrix} 0.4 & 0.4 & 0.2 & 0 & 0 \\ 0.2 & 0.6 & 0.2 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0.6 & 0.4 & 0 & 0 & 0 \\ 0 & 0.4 & 0.6 & 0 & 0 \\ 0.6 & 0.4 & 0 & 0 & 0 \end{bmatrix}$
Topology 2	$\begin{bmatrix} 0 & 0 & 0.6 & 0.4 & 0 \\ 0 & 0 & 0.6 & 0.4 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0.6 & 0.4 & 0 & 0 \\ 0.6 & 0.4 & 0 & 0 & 0 \\ 0 & 0.2 & 0.6 & 0.2 & 0 \end{bmatrix}$
Topology 3	$\begin{bmatrix} 0 & 0.4 & 0.4 & 0.2 & 0 \\ 0 & 0.4 & 0.4 & 0.2 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0.2 & 0.6 & 0.2 \\ 0 & 0 & 0.4 & 0.6 & 0 \\ 0 & 0.4 & 0.6 & 0 & 0 \end{bmatrix}$

The obtained evaluation results by using of the fuzzy comprehensive evaluation model considering reliability and economy are as in table 2.

According to the maximum membership degree principle, the evaluation result of topology 1, topology 2 and topology 3 are excellent, fair and bad respectively. Finally the topological scheme 1 is just the optimal topology of collector system in this example.

Table 2. Fuzzy comprehensive evaluation results of three topologies.

Scheme	Excellent	Good	Fair	Bad	Worse
Topology 1	0.4919	0.4238	0.0843	0.0000	0.0000
Topology 2	0.0557	0.4132	0.4327	0.0984	0.0000
Topology 3	0.0000	0.1396	0.3296	0.4191	0.1116

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