

RISK-COST ANALYSIS OF THREE MOORING SCHEMES OF FOWTS WITH ONE MOORING LINE FAILURE

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Offshore wind power has great potential for application, but its high investment cost makes cost reduction imperative. Currently, most offshore wind projects adopt nine-line mooring systems for safety, while the risks and costs of six-line and three-line mooring systems remain unclear. This study examines the failure patterns and risk-cost relationships of three-line, six-line, and nine-line mooring systems under extreme environmental conditions with the failure of a single mooring line. The study indicates that, after the mooring failure, the platform drift in the three-line mooring system is significantly greater than that in the six-line and nine-line mooring systems. Although the mooring line tension and anchoring force increase after failure in all three mooring schemes, they remain within safe limits. The six-line mooring system is proved to be a well-balanced solution that considers both risk and cost.

Keywords: Floating offshore wind turbine, mooring scheme, failure pattern, risk-cost relationship.

1 Introduction

Wind energy is a clean and reliable source of power. Compared to onshore wind power, offshore wind power offers advantages such as more stable resources and larger available areas, making it highly promising for application (Subbulakshmi et al. 2022, Fer•ák et al. 2022). However, the current investment cost of floating offshore wind turbine (FOWT) remains too high to achieve cost-competitive development (Myhr et al. 2014, Sajith et al. 2024). The cost of the mooring and anchoring system in offshore wind power projects often exceeds 20% of the total investment. Therefore, reducing its cost is of great importance. Most operational offshore wind power projects use nine-line mooring systems, which are relatively conservative. However, the risks associated with six-line and three-line mooring systems remain unclear.

This study employs numerical simulations to investigate the drift of platforms, mooring line tension, and anchoring force under the failure of a single mooring line for three different mooring schemes. The failure patterns of FOWTs with different numbers of mooring lines are analyzed, and the relationship between risk and cost is further quantified. The findings provide a reference for the design of mooring and anchoring systems for FOWTs.

2. Numerical Modeling of Floating Offshore Wind Turbines

2.1. Floating Offshore Wind Turbine and Load Conditions

The Orcaflex software was used for calculations, employing a time-domain simulation approach. The wind turbine model used in the analysis was the NREL 5MW turbine (Jonkman et al. 2009). The lower support

structure is an OC4-DeepCWind tri-column semi-submersible platform, with the wind turbine tower centrally positioned (Robertson et al. 2014). In extreme marine environments, floating wind turbine mooring systems are prone to failure under cyclic and highly nonlinear loads. Therefore, a 50-year return period environment condition is selected (Subbulakshmi et al. 2024).

2.2. Three Mooring Schemes

The mooring and anchoring layout of the floating wind turbine is shown in Figure 1. The mooring lines are made of R3 grade studless chains, with an unstretched length of 480 m per line. The mooring lines used in the three-line, six-line, and nine-line systems have diameters of 87 mm, 60 mm, and 48 mm, respectively, ensuring that the total bearing capacity of moorings in the same direction is approximately equal among different schemes.

In this study, mooring line failures are modeled by assuming the failure of lines 3-1, 6-1, and 9-2, respectively, to simulate accidental breakage events of individual mooring lines. The total simulation time for each condition is set to 3600 s, with the mooring line failure occurring at 600 s in each case. Once a mooring line fails, its tension is set to zero.

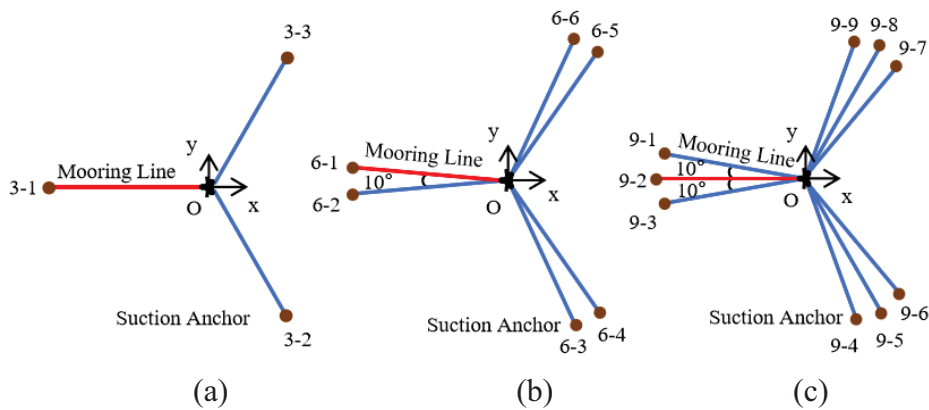


Fig. 1. Schematic representation of mooring systems. (a) Three-line mooring; (b) Six-line mooring; (c) Nine-line mooring.

3. Failure Patterns of FOWT with One Broken Mooring Line

3.1. Platform Drifts

The time history curves of platform drifts in the surge direction following mooring line failure for different mooring systems is shown in Figure 2. As observed, in the case of the three-line mooring system, the failure of mooring line 3-1 results in significant drift in the surge direction, posing considerable safety risks to nearby marine structures. In contrast, both the six-line mooring and nine-line mooring systems experience much smaller drift in the surge direction following the failure of a single mooring line.

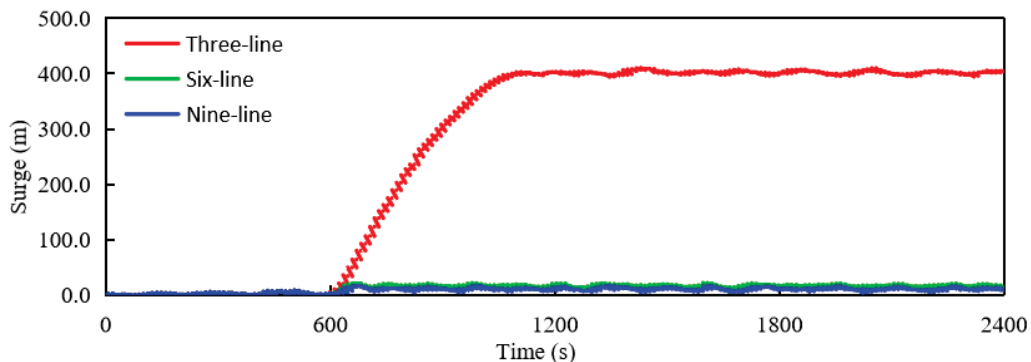


Fig. 2. Platform drifts in the surge direction

3.2. Mooring Line Tensions

The time history curves of the tension in the remaining mooring lines after mooring line failure are shown in Figure 3. For the three-line mooring system, when the upwind mooring line 3-1 fails, the tension in mooring line 3-2 continuously increases. For the six-line mooring and nine-line mooring systems, after the failure of the upwind mooring lines 6-1 and 9-2, the tension in the remaining upwind lines 6-2 and 9-1 increases. The tension in mooring line 6-2 increases more significantly. This is because the environmental load is primarily borne by the remaining upwind line 6-2.

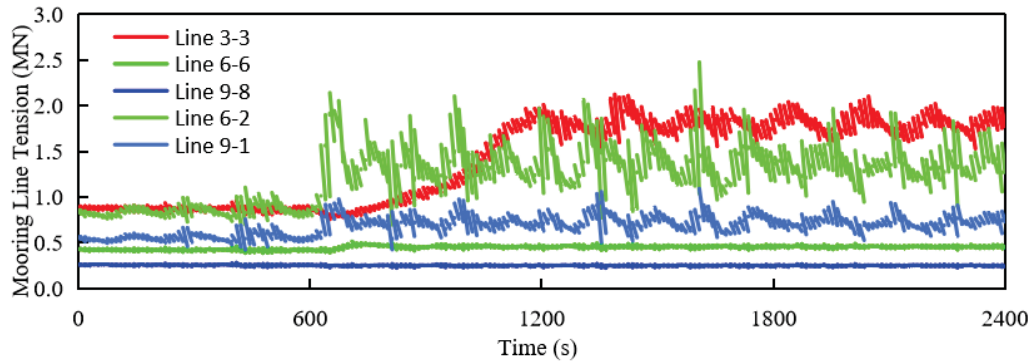


Fig. 3. Tensions of remaining mooring lines

3.3. Anchoring Loads

The time history curves of the anchoring loads after the failure of mooring lines are shown in Figure 4. After the failure of mooring line 3-1, the load on the downwind foundation 3-2 increases significantly. For the six-line mooring and nine-line mooring systems, after the failure of the upwind mooring lines 6-1 and 9-2, the load on the upwind foundations 6-2 and 9-1 increases. The load on foundation 6-2 reaches nearly 2.5 MN.

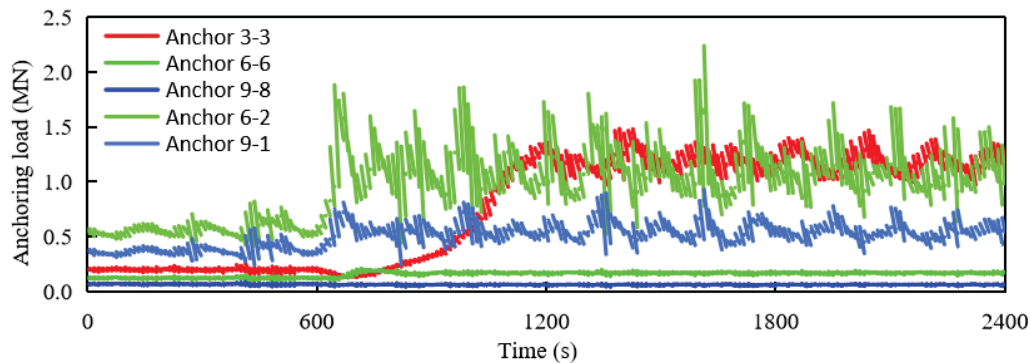


Fig. 4. Anchoring loads

4. Risk-cost Analysis

The cost estimation for the mooring system primarily considers two components: the material costs of the mooring lines and the materials for the suction anchors. The risk of a floating offshore wind turbine is evaluated using the ratio of the maximum surge drift of the platform after mooring failure to the maximum surge drift under normal operating conditions, the ratio of the maximum tension in the mooring line to its breaking strength, and the ratio of the maximum horizontal load of the suction anchor to its horizontal ultimate bearing capacity. The risk-cost relationship is shown in Figure 5. The drift of the platform in the three-line system is significantly higher than in the six-line and nine-line systems, exceeding 40 times the drift under normal conditions, which is highly dangerous. The mooring line tension and anchoring load for all three schemes are below their respective ultimate bearing capacities.

In summary, the six-line system offers a lower cost, with platform surge, mooring line tension, and holding force all within safe limits. It represents a balanced solution for both cost and safety.

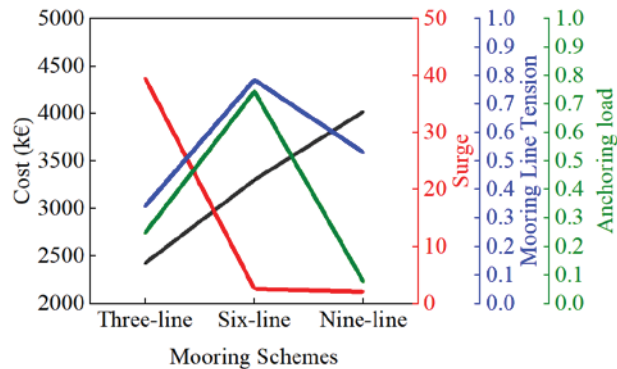


Fig. 5. The risk-cost relationship of three mooring schemes

5. Conclusions

This study investigates the displacement of the floating platform, the tension of the surviving mooring lines, the load on the anchoring foundation, and the risk-cost relationship of the floating wind turbine after the sudden failure of an upwind mooring line in three mooring schemes. The results show that after mooring failure, the platform drift in the three-line mooring system reaches 400 m. The six-line mooring system has lower costs while keeping platform drift, mooring line tension, and anchoring force within safe limits, making it a balanced solution in terms of both cost and safety.

Acknowledgements

This work was supported by the Shenzhen Science and Technology Program (grant number KQTD20210811090112003), the General Program of National Natural Science Foundation of China (Grant number 52479095), Shenzhen Steady Support Project for Universities Key program (Grant Number GXWDS20220818152909001).

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