Farm-Level Risk Prioritization of Structural and Substructural Failure Modes in Floating Offshore Wind Arrays

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Introduction

With the growing size and efficiency of floating wind turbines (FWTs) and the rapid expansion of FWT projects, identifying and prioritizing failure modes with potential farm-level impacts is essential. This ensures operational reliability and safety, preventing catastrophic financial, safety, and environmental consequences. As part of the IEA-Wind Task-49 study on "integrated design on floating offshore wind arrays (IDeA)," this work catalogs failure risks at the array level to suggest mitigation measures in the next phase.

Method

This study uses Failure Modes, Effects, and Criticality Analysis (FMECA) [2] to assess farm-level impacts, integrating failure data from literature and expert input from two workshops. The analysis covers all failure modes of structural and substructural components of a hypothetical floating offshore wind array with 15 MW semi-submersible turbines [3], catenary mooring systems, and dynamic lazy wave cables. Seven experts from industry, insurance, and academia ranked 118 failure modes across five FMECA survey tables to determine those with farm-level effects. The criticality of each failure mode and cause was evaluated using the mean Risk Priority Number (RPN), considering occurrence, severity, and detectability.

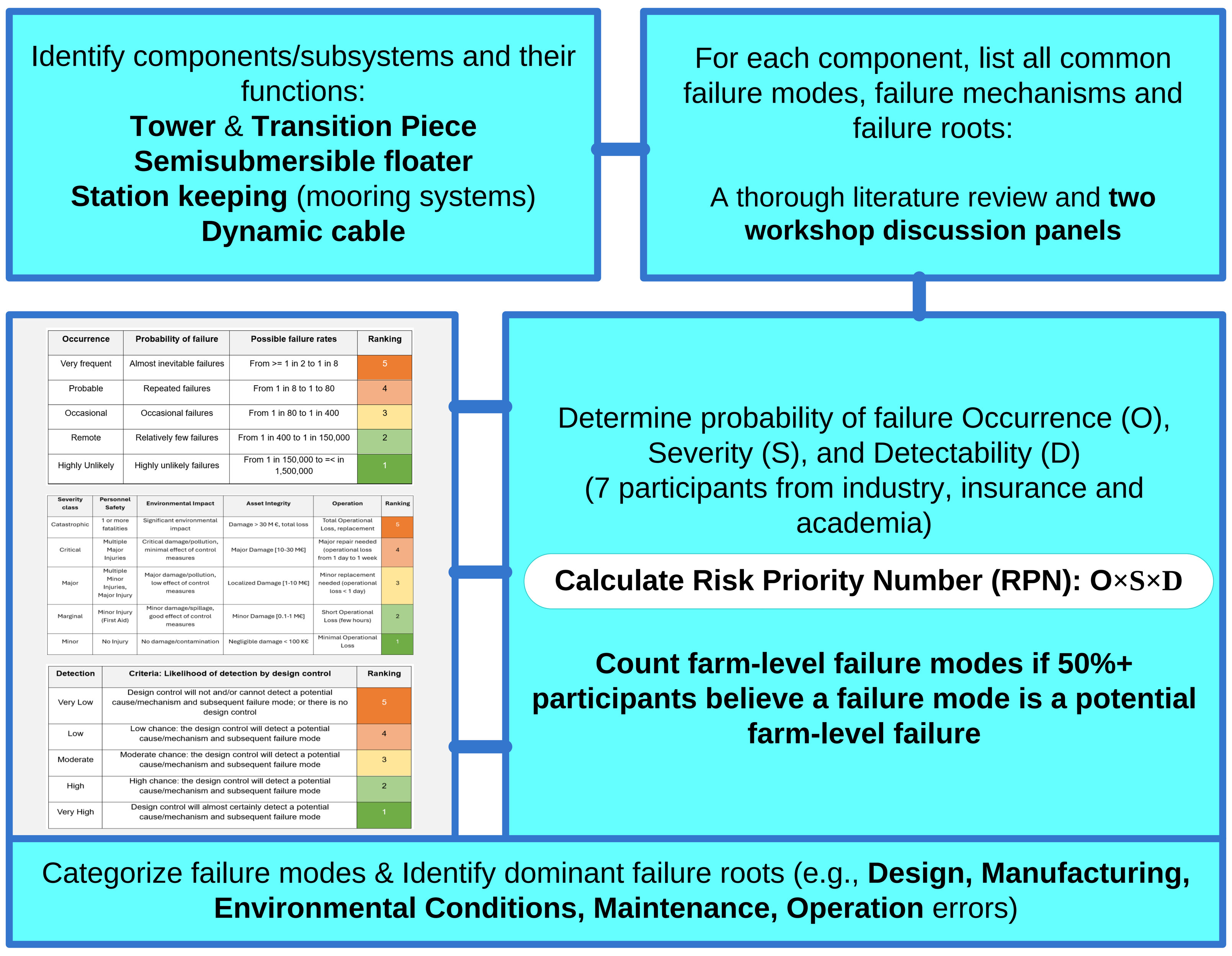

Figure 1: *Failure mode assessment*

Results

From the total 3700 RPNs received from the FMECA survey, 37% (1381 RPNs) have potential farm-level implications. The distribution of RPNs across 20 main failure modes is summarized in Figure 2. Higher RPNs indicate more critical failure modes requiring attention. Below is a summary for each subsystem:

Tower: Out of 23 failure modes, only 3 (13%) could impact the farm. The main failure mode (over 70% of RPNs) is tower cracks, caused by high waves, wind, or blade interactions. Plastic deformation due to design errors is another concern.

Transition Piece: Among 21 failure modes, 5 (24%) could affect the farm. The primary issue is cracking or breaking, with causes including climate change (40%), design mistakes (42%), and poor maintenance (18%).

Floating Structure: Out of 30 failure modes, 12 (40%) could impact the farm. Design errors cause 35% of failures (capsize 18%, break 9%, sinking 8%). Operational failures account for 33% (fatigue 12%, cable connector damage 9%, extreme temperatures 6%, collisions 6%). Environmental factors cause 23% (typhoons, severe wind/waves, climate change). Poor maintenance quality causes 10%, leading to structural fractures and welding damage. Key failure modes include cracks, capsize, break, and sinking.

Dynamic Cable: Half of the 32 failure modes could impact the farm. Key issues include cable positioning system (CPS) movement, cable fatigue, watertightness failures, conductor failures, hang-off damage, j-tube termination failures, reduced sediment and debris disturbance.

Mooring Systems: Of 22 failure modes, 10 (46%) could affect the farm. Mooring line (ML) breakage, due to wear, fatigue, friction, tension, and poor materials, accounts for around 50% of farm-level

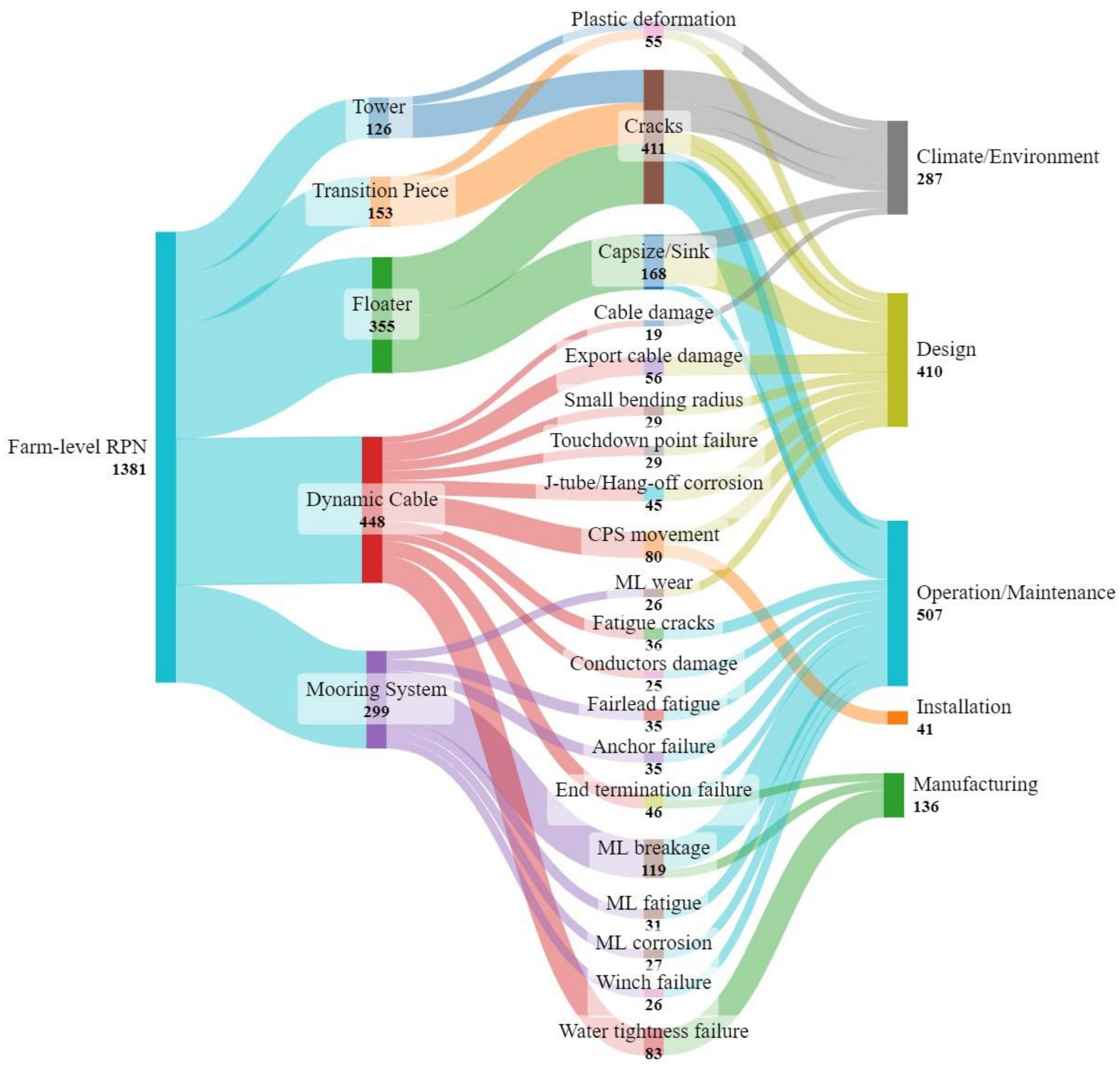

Figure 2: *FMECA farm-level RPNs flows & nodes: subsystems, failure modes, failure roots*

Conclusions

Identifying and classifying RPNs aids in recommending strategies to mitigate failure modes with high farm-level impact potential. This study highlights critical failure modes and causes, underscoring the importance of careful design, environmental considerations, operation and maintenance. Special attention is needed for dynamic cables and mooring systems, as their designs are highly site-specific.

Reference

[1] IEA Wind TCP Task 49. Integrated Design on Floating Wind Arrays (IDeA) https://iea-wind.org/task49/

[2] IEC, IEC 60812: 2018–Failure modes and effects analysis (FMEA and FMECA), International Standard, Geneva, Switzerland., 2018. doi: 10.1152/ajplegacy.1975.229.6.1510.

[3] C. Allen et al., "Definition of the UMaine VolturnUS-S Reference Platform Developed for the IEA Wind 15-Megawatt Offshore Reference Wind Turbine," NREL/TP--5000-76773, 1660012, MainId:9434, Jul. 2020. doi: 10.2172/1660012.

University College Cork's participation has been funded by the Sustainable Energy Authority of Ireland under the SEAI Research, Development & Demonstration Funding Programme 2022, Grant number 22/RDD/804.