Base Load Power Hub (BLPH)

FMECA Terms of Reference

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1 INTRODUCTION

1.1 PROJECT OVERVIEW

Crosswind, a Shell and Eneco joint venture, was awarded the tender to develop the offshore Hollandse Kust Noord (HKN) wind farm, located 18.5km off the coast of Netherlands near the town of Egmond aan Zee. The consortium plans to have HKN operational in 2023 with an installed capacity of 759MW generating at least 3.3TWh per year. This is sufficient renewable power to supply more than 1 million Dutch households with green electricity.

Offshore wind farms produce intermittent electricity and balancing these dips and peaks and integrating this electricity into the national energy system requires new technologies. For this reason, the offshore wind farm will include several new technologies that could be implemented at full-scale in the future. The new technologies being explored include a floating solar park, a short-duration battery storage as well as long-term storage via green hydrogen produced by water electrolysis and subsequently consumed in a fuel cell. The combination of these individual measures, herein referred to as the Base Load Power Hub (BLPH) will ensure a continuous power supply regardless of the wind situation.

1.1.1 Project Location

The Hollandse Kust Noord (HKN) wind farm is located 18.5km off the coast of the Netherlands near the town of Egmond aan Zee.

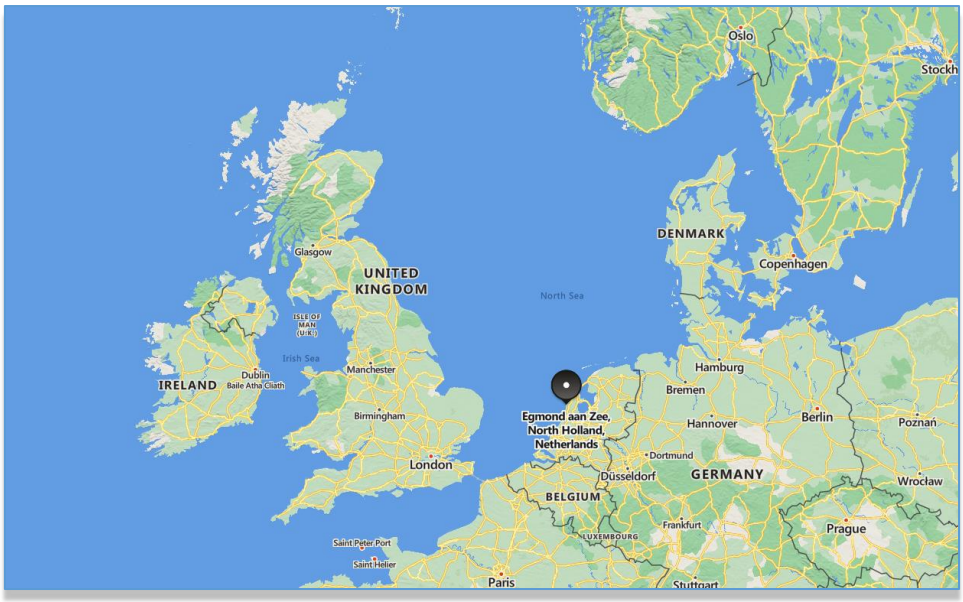


Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map

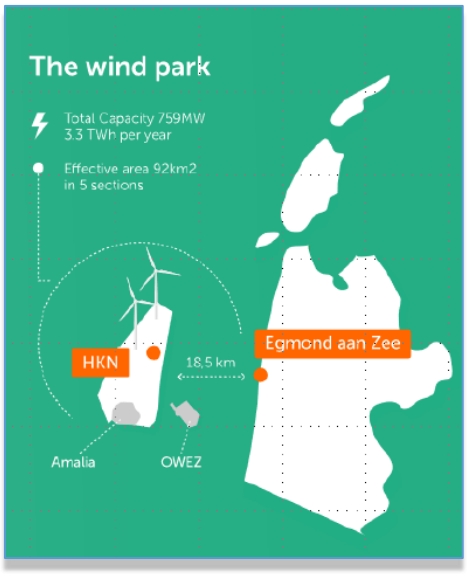


Figure 2 - Wind Park Details

The wind farm will consist of No. 69 x 11.5MW wind turbine generators each to be installed on a dedicated monopile structure. A 70th monopile located on coordinates E 590719.1, N 5841602.3 is reserved for installing the platform accommodating the BLPH. The monopile structure was designed and installed by Van Oord Offshore Wind (VooW) and therefore not part of the BLPH scope.

1.1.2 Project Concept

All components included in the BLPH will be integrated onshore on a topside and installed in an offshore location within the boundaries of the HKN wind farm. At its simplest, the BLPH will store energy during periods of high electricity generation from renewable sources (a wind turbine generator and the floating solar PV farm) and release it during periods of low generation. In practice. It is expected that the energy stored will supplement generation from renewable sources to ensure that at least 1.0MW of power is exported to the electrical grid regardless of wind/solar availability.

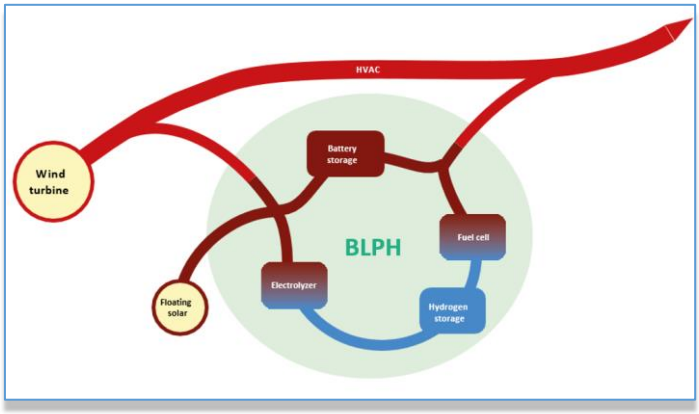


Figure 3 – BLPH Concept

Electricity in the BLPH will be stored in the form of electrons in a battery energy storage system (BESS) as well as converted into green hydrogen via water electrolysis. When the power output from the connecting wind turbine drops to below 1 MWe, the BLPH will return its stored energy to supplement the remaining power output. This will be by discharging the BESS, while stored hydrogen will be converted back into electricity using a fuel cell to extend the discharge duration.

The purpose of the BLPH s to function as a testbed for the integration of energy storage technologies with renewable generation. It is expected that equipment installed on the BLPH will operate as Normally Unmanned Installation for at least two (2) years with no or minimal maintenance and it will have its own independent control room with the ability to communicate with Crosswind's control room.

1.2 DOCUMENT SCOPE

The scope of the present document is to define the details of the work session, which must contain at least the following information:

- Description of the PROJECT and the Battery Limits of the FMECA study.
- Project documents with all the information required to develop the FMECA study:
- Procedure and methodology of the FMECA study, based on this document.
- Objectives and expected results of the FMECA study.

The study focuses on identifying potential failure modes that may occur during operation, specifically including scenarios involving the release of hydrogen due to equipment failure (e.g., valve or pipe rupture) or incorrect actions by operators.

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2 MAIN REFERENCES

Ref.	Description
[1]	ISO 17776 - Petroleum and natural gas industries – Offshore production installations – Major accident hazard management during the design of new installations
[2]	IEC 60812 "Analysis technique for system reliability – Procedure for failure mode and effects analysis"
[3]	123A90-DDL-PR-PID-80009-80027 – BLPH Piping and Instrumentation Diagrams
[4]	1724000437-PR-PID-00018 – Nitrogen Generation Package Piping and Instrumentation Diagram
[5]	1724000437-PR-PID-00018 – Instrument air Package Piping and Instrumentation Diagram
[6]	123A90-DDL-PP-DL-70070-70072 – BLPH Plot plans
[7]	123A90-DDL-SAF-RE-30006 – HAZOP Report
[8]	123A90-DDL-SAF-RE-30009 – HAZID Report
[9]	123A90-DDL-SAF-DL-30028 – F&G Detectors lay out
[10]	BLPH 3D Model – 22-05-2024
[11]	1723001756-MAC-MAN-00019 – Instruction and operating manual H2 Storage vessel V-25001 A-F
[12]	123A90-DDL-SAF-DL-30022 - Hazardous Area Classification Layout - lower deck
[13]	123A90-DDL-SAF-DL-30023 - Hazardous Area Classification Layout - upper deck
[14]	123A90-DDL-SAF-DL-30024 - Hazardous Area Classification Layout - section
[15]	123A90-DDL-SAF-RE-30003 - Safety Critical Elements (SCE) and Performance Standard
[16]	123A90-DDL-EL-RE-20178 - SAFOP Report
[17]	123A90-DDL-IN-CE-40000 - Process Safety Cause & Effect Matrix

Table 1 - Reference Documents

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3 DEFINITIONS AND ABBREVIATIONS

3.1.1 Definitions

COMPANY or Client (CPY)	Crosswind.
EFFECTS ANALYSIS	The outcome of an identified failure mode. For the purpose of this project, the outcome is identified in terms capability to harm people or environment and to impact on the asset.
EPC CONTRACTOR (CTR)	ROSETTI MARINO S.p.A.
EVENT	Occurrence or change of a particular set of circumstances.
FAILURE MODE	Refers to any specific ways in which a system, component, or process can fail to perform its intended function. For example, in a mechanical system, a failure mode could be something like a component breaking, seizing, or leaking
FMECA	Acronym of "Failure Mode and Effects Criticality Analysis". It's a structured process aimed at identification of potential failure modes of a system, evaluate the consequences or effects of those failures, and assess their criticality or impact on the system's performance.
FREQUENCY	The estimated number of events per defined unit of time (normally refereed to one-year time).
PROJECT	HOLLANDSE KUST NOORD WIND PARK Project

Table 2 - Definitions

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3.1.2 Abbreviations

BESS	Battery Energy Storage System
BLPH	Base Load Power Hub
CPI	Company Provided Items
DNV	Det Norske Veritas
F&G	Fire and Gas
FMECA	Failure Mode and Effects Criticality Analysis
H&MB	Heat and Material Balance
HAZOP	Hazard and Operability
HAZID	Hazard identification
HKN	Hollandse Kust Noord
HSE	Health, Safety and Environment
PSV	Pressure Safety Valve
PV	Photovoltaic
RM	Rosetti Marino
SCE	Safety Critical Element
TOR	Terms of Reference
VooW	Van Oord Offshore Wind

Table 3 - Abbreviations

4 METHODOLOGY

4.1 GENERAL PRINCIPLE

FMECA (Failure Mode and Effect Critical Analysis) is "a systematic procedure, applied to a specific system, aimed at identifying potential failure modes, their causes, and their criticality or impact on the system's performance.

FMECA is applied to industrial processes in order to identify:

- the effects resulting from the systematic identification of possible different failure modes of each subsystem/component, which could impact the operability and safety of the overall unit;
- the criticalities and weaknesses of the process as results of possible failure modes of components, establishing a priority scale for potential improvement actions.

FMECA study is developed by using a specific worksheet which is prepopulated by expert analyst and then reviewed and completed by support of a multidisciplinary team represented the project functions (safety, technology, operations, maintenance), ensuring the analysis is comprehensive and effective.

4.2 METHODOLOGY

FMECA study on the BLPH facility will be performed according to following main steps:

1. Identification of the elements to be subjected to FMECA study.
2. Analysis of the main failure modes of each selected element and identification of main causes.
3. Evaluation of potential likelihood of the analyzed failure mode.
4. Evaluation of the potential effects of the selected failure on the single element and on the entire system.
5. Identification of the mitigating measures installed in the system to reduce the extent of the effects of the failure.
6. Semi-quantitative assessment of the initial risk associated to each failure mode (not compensated by the mitigating measures) by combination of likelihood estimate and potential impact evaluation.
7. Semi-quantitative assessment of the compensated risk which includes in the evaluation the effectiveness of the available mitigating measures.
8. Identification of possible critical issues and eventual recommendation for improvement.

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4.2.1 Identification of the elements to be subjected to FMECA study

FMECA study will be carried out with reference to the systems included into Rosetti Marino's scope of delivery, which includes:

- BLPH Topside structures.
- Hydrogen production and storage circuit, including all process equipment, piping, instrumentation and control and emergency systems but excluding CPI package (electrolyzers, fuel cells, BESS system).
- Instrument air, nitrogen production circuit and water treatment package.
- Fire and gas detection system.
- Ventilation units.
- Hydrogen Vent System.
- Vent and Blowdown System.

The failure mode analysis will be applied to the identified SECEs, as included in:

- Document Number: 123A90-DDL-SAF-RE-30003 "Safety Critical Elements (SCE) and Performance Standard"

This selection is aimed at including the already identified critical elements for the module.

Note:

According to the HAZOP and HAZID studies, the loss of the water treatment system or a single detector does not pose a risk to equipment or personnel. In other words, failure of these utilities or detectors (considering only a single failure at a time, without double jeopardy) does not directly lead to hydrogen release or equipment failure. The platform's design includes safety measures to effectively manage such events, including automatic shutdown procedures that safely stop hydrogen production in critical situations, ensuring overall system integrity and safety. Therefore, these systems are not considered in the present study.

4.2.2 Analysis of the main failure modes of each selected element and identification of main causes

For each element a detailed analysis will be made for the definition of the possible failure modes. These typically include (among others):

- Failure modes leading to loss of capability to perform its design intent;
- Failure modes leading to degradation/loss of mechanical integrity.

4.2.3 Evaluation of potential likelihood of the analyzed failure mode

The likelihood evaluation is performed by application of a simplified approach as detailed in following table.

Likelihood Level	Likelihood Definition
High (1.0)	The threat-source is significantly capable and controls to prevent the vulnerability from being determined are ineffective.
Medium (0.5)	The threat-source is significantly capable, but controls are in place that may impede successful determination of the vulnerability.
Low (0.1)	The threat-source lacks capability, or controls are in place to prevent, or at least significantly impede, the vulnerability from being determined.

4.2.4 Evaluation of the potential effects of the selected failure on the single element and on the entire system

The evaluation of magnitude of the potential effects is performed by application of a simplified approach as detailed in following table.

Magnitude of Effects	Impact Definition
High (100)	Exercise of the vulnerability: 1) may result in the very costly loss of major tangible assets or resources; 2) may significantly violate, harm, or impede an organization's function, reputation, or interest; 3) may result in human death or serious injury.
Medium (50-90)	Exercise of the vulnerability: 1) may result in the costly loss of tangible assets or resources; 2) may violate, harm, or impede an organization's function, reputation, or interest; 3) may result in human injury.
Low (10-40)	Exercise of the vulnerability: 1) may result in the loss of some tangible assets or resources 2) may noticeably affect an organization's function, reputation, or interest.

4.2.5 Semi-quantitative assessment of the initial risk associated to each failure mode (not compensated by the mitigating measures) by combination of likelihood estimate and potential impact evaluation

Initial risk (not compensated by the mitigating measures) is performed by application of the following matrix.

Threat	Impact		
Likelihood	Low (10-40)	Medium (50-90)	High 100
High (1.0)	10 x 1.0 = 10	50 x 1.0 = 50	100 x 1.0 = 100
Medium (0.5)	10 x 0.5 = 5	50 x 0.5 = 25	100 x 0.5 = 50
Low (0.1)	10 x 0.1 = 1	50 x 0.1 = 5	100 x 0.1 = 10

Classification of the risk is as follows:

- High Risk (red region): action is required for the risk reduction;
- Medium Risk (yellow region): risk is tolerable but further mitigating measure shall be evaluated also on basis of cost-benefit analysis;
- Low Risk (green region): risk is tolerable; continuous improvement area.

4.2.6 Identification of the mitigating measures installed in the system to reduce the extent of the effects of the failure

The analysis is dedicated to identification of available mitigating measures, specifically designed to mitigate the effects previously identified as consequences of the failure mode.

Measures can be selected as indicated in following table.

Type of measure	Mitigating measure	Likelihood reduction
Mechanical/Structural	PSV / Rupture disk	0.1
	Dike for spill containment	0.1
	Passive fire protection	0.1
	Blast resistance wall	0.1
Instrumental	Safety Instrumented Function	0.1
	Alarm and operator response	0.1 – 0.5
Procedural	Periodical Inspection	0.1 – 0.5
	Periodical Maintenance	0.1 – 0.5

Notes to the table:

1) Each mitigation measure shall be designed for the effects under analysis (e.g.: to properly apply mitigation associated to a PSV in case of fire, it is required that the PSV is designed for this scenario).

2) It is suggested to apply a maximum number of two distinct independent mitigation measures as maximum (e.g.: one mechanical plus one procedural measure).
3) Range of variability for mitigating measures based on human intervention to be applied as follows:
   - 0.1 in presence of rigorous procedure, with evidence of training activities and signed records of each activity;
   - 0.5 in presence of less rigorous procedural system.

4.2.7 Semi-quantitative assessment of the compensated risk which includes in the evaluation the effectiveness of the available mitigating measures

After application of mitigating factors, the semi-quantitative risk evaluation is performed again in order to determine the updated risk level associated to the analysed failure mode.

Risk matrix is applied again to re-evaluate the classification of the final risk.

4.2.8 Identification of possible critical issues and eventual recommendation for improvement

The failure modes that are classified as High Risk determine a critical case and therefore it is required to determine specific recommendations aimed at risk reduction.

The additional measures shall be selected in same approach of the existing mitigating measures, taking into account following considerations:

- Select, if possible, an additional measure which is of different typology of the existing mitigating measures (if the existing measure is an alarm, it is suggested to recommend a mechanical type of measure and vice versa).
- When possible, select a measure to reduce the likelihood of the failure (thus preventing the occurrence of the scenario) rather than mitigation of the effects of the failure scenario

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5 FMECA STUDY DEVELOPMENT

FMECA development will be in accordance with following steps:

- Definition of Terms of Reference (present document).
- Preliminary analysis and pre-population of FMECA worksheet by expert analyst on the basis of project documentation.
- Joint review of the proposed results with a multidisciplinary team representing the project functions (safety, technology, operations, maintenance), ensuring the analysis is comprehensive and effective.

The joint expert responsible for worksheet preliminary population will be also the facilitator of the final meeting, guiding the team on the main evidences of prepared analysis.

The analysis of critical cases and identification of possible recommendations will be performed during the final joint meeting, in order to allow all the team members developing a comprehensive discussion on the decision regarding the additional measures to be taken.

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6 RECORDING AND REPORTING

At the end of the FMECA joint review meeting, a report will be produced with the intent of recording all the main aspects of the activity.

The FMECA study report shall clearly list all the recommendations, if any, and identify the assigned parties.

The report must contain the following key points:

- A general description of the project.
- A description of the FMECA methodology.
- Main results of the analysis in terms of calculated risks and critical cases.
- Detailed worksheet of the analysis.
- List of reference documentation.
- list of participants in the FMECA final meeting.

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ATTACHMENT 1 – FMECA Template

id	System	Element	Failure mode	Effects analysis	Original Threat Likelihood	Orignial Impact	Result	Risk Rating	Mitigating Measures	Mitigating Measures likelihood	Threat Likelihood	Impact	Mitigated Result	Mitigated Risk Rating	Recommendations	Notes
1	Pressure vessel V-25001A-F	Mechanical Integrity	Corrosion issue on the shell	Possible, in long term, loss of mechanical integrity and consequent loss of containment with release of hydrogen and fire with potential escalation and extensive damage to the structure	0,2	100	20	Medium	1. Periodic Inspection	0,2	0,04	100	4	Low		
2	Pressure vessel V-25001A-F	Mechanical Integrity	Leak from a gasket on flanged joint	Loss of containment with release of hydrogen and fire with potential escalation and extensive damage to the structure	0,2	100	20	Medium	1. Periodic Inspection	0,2	0,04	100	4	Low		
3	1"-HY-007-03HSS-N	Mechanical Integrity	Leak from a gasket on flanged joint	Loss of containment with release of hydrogen and fire with potential escalation and extensive damage to the structure	0,2	100	20	Medium	1. Periodic Inspection	0,2	0,04	100	4	Low		
4	25-SDV-001	Loss of instrument air	Spurious closure leading to production stop		0,5	10	5	Low		1	0,5	10	5	Low		