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Availability Aspects in Large Offshore Wind Farms

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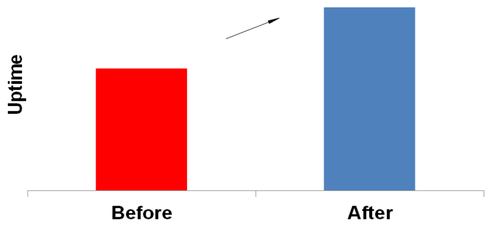
Abstract

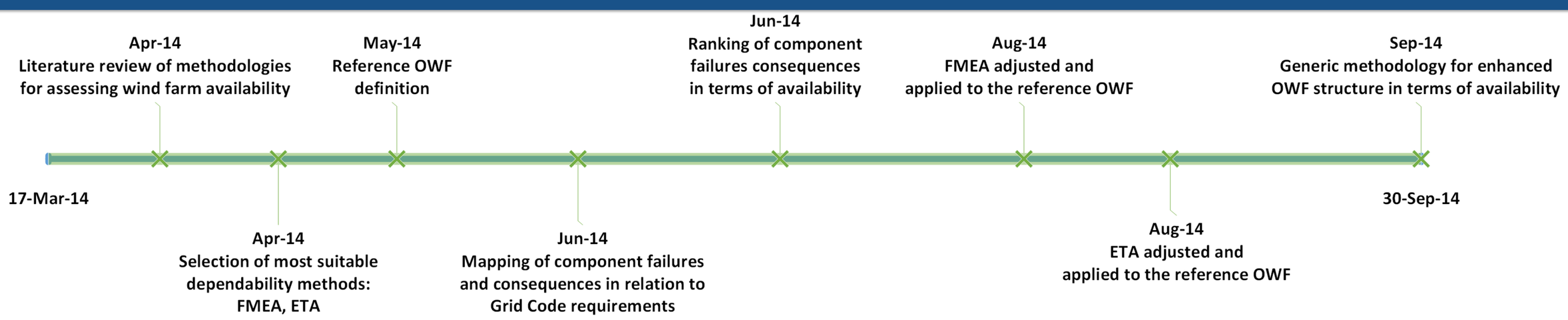
The paper presents a methodology to assess the electrical infrastructure of a large Offshore Wind Farm (OWF), in terms of availability. With this methodology, the large OWF structure can be assessed to improve the availability of the system. To achieve this, the critical components of the OWF are identified, whose failures lead to high production losses, and their effects are minimized by using dependability analysis methods and proposing new solutions. Moreover, the availability analysis is extended by mapping component failures and consequences in relation to Grid Code requirements. The methodology is based on the bottom-up dependability methods Event Tree Analysis (ETA) and Failure Modes and Effects Analysis (FMEA). These methods prove to complement each other, providing a comprehensive approach to the dependability analysis of large OWFs. FMEA provides a good summary of how single component failures affect the system availability, while ETA supplements FMEA by investigating the effects of multiple component failures along with the application of external conditions.

Objectives



- **Primary objective**: To provide a methodology to assess the electrical infrastructure of a large offshore wind farm, in terms of availability.
- Identification of critical components of the OWF, whose failures lead to high production losses.
- **Target** of the project: The electrical infrastructure of large OWFs, including the wind turbine generating units, collection grid, offshore substation, export cable, onshore substation and external grid.
- **Scope** of the project: Large OWFs located in the UK

Methods



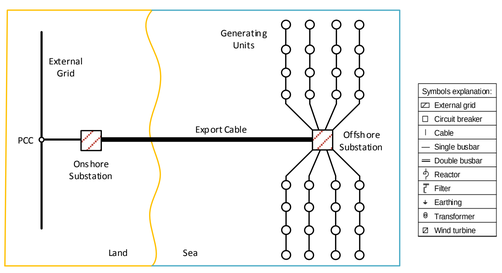
Results

Dependability methods

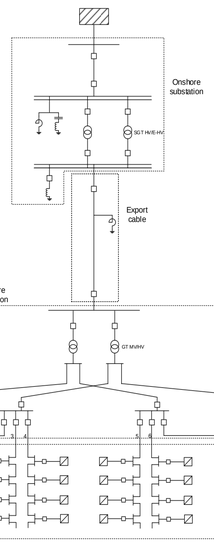
	Bottom-up	Top-down (multiple failures)
Sequence dependent	Event Tree Analysis (ETA)	Markov Analysis (MA), Bayesian Networks (BNs)
Sequence independent	Failure Modes and Effects Analysis (FMEA)	Fault Tree Analysis (FTA), Reliability Block Diagrams (RBD)

- **Chosen methods**
  - FMEA
  - ETA

Reference Offshore Wind Farm



Symbols explanation:
External grid
Circuit breaker
Cable
Single busbar
Double busbar
Reactor
Filter
Earthing
Transformer
Wind turbine



- **Reliability data provided**
  - Failure rates
  - MTTR

Input

- OWF design
- Grid Code
- Reliability data

Methodology

1. Define the OWF.
2. Obtain the necessary reliability data.
3. Identify relevant Grid Code requirements.
4. Map component failures and consequences in relation to Grid Code requirements.
5. Rank the component failures consequences in terms of availability.
6. Conduct FMEA.
7. Conduct ETA.
8. Prepare a report by summarizing the complete analysis.

Output

- Critical components causing loss of availability
- Energy production losses because of component failures
- Mishap outcomes
- Probabilities of outcomes
- Risks of outcomes
- Most suitable actions for redundancy of the OWF

- **Examples of how OWF availability can be improved**

1	Double busbars for redundancy
2	Cold standby redundant cable with CBs
3	Transformers: 100% rating of total power.
4	Cold standby redundant export cable
5	Ring connection of WT arrays with CB
6	Cold standby redundant branch of CB, reactor and filter

- **Proposed FMEA report**

			Existing conditions				
				Consequences			
Component	Number of stopped WTs	Occurrence - Frequency (failure rate λ)	MTTR	Expected Losses per failure per year [MWh/yr]	Severity - % of losses to total possible wind farm production per year	Risk	
WT (any)	1	1,5 failure/yr comp.	336 hrs	1198,6	0,120%	10	High
CB 1	1	0,002 failure/yr comp.	2160 hrs	7705,5	0,771%	4	Moderate
CB 2	1	0,002 failure/yr comp.	2160 hrs	7705,5	0,771%	4	Moderate
CB 3	1	0,002 failure/yr comp.	2160 hrs	7705,5	0,771%	4	Moderate
CB 4	1	0,002 failure/yr comp.	2160 hrs	7705,5	0,771%	4	Moderate
CB 5	4	0,002 failure/yr comp.	2160 hrs	30822	3,082%	6	Moderate
CB 6	4	0,002 failure/yr comp.	2160 hrs	30822	3,082%	6	Moderate

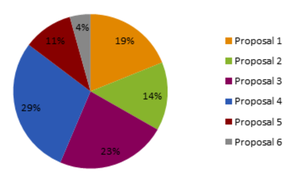
Action results				
Recommended actions for mitigation	Number of stopped WTs	Severity	Risk ****	MWh gained per year
- None	1	0,120%	10 High	-
- None	1	0,771%	4 Moderate	-
- None	1	0,771%	4 Moderate	-
- None	1	0,771%	4 Moderate	-
- None	1	0,771%	4 Moderate	-
- Proposal 5	0	0,000%	2 Low	308,22
- Proposal 5	0	0,000%	2 Low	308,22

- **Traditional FMEA report**

System											FMEA No.			
Subsystem											Page			
Component											Prepared by			
Core team											FMEA Date (org.)			
				Existing conditions						Action results				
Component/ process	Potential failure mode	Potential effects of mode	Potential causes of mode	Present control mechanisms	Severity	Occurrence	Detection	Risk Priority Number (RPN)	Recommend actions	Action taken	S	O	D	RPN

Proposal share in energy production gained annually, (1) when proposals are considered simultaneously, (2) when proposals are separately considered.

1.



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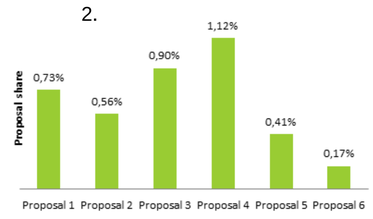

- **Example of ET diagram for the reference OWF**

Initiating Event	Pivotal Events				Outcomes			
	CB 6 fails	C 16 fails	Unavailability of maint. equipment within 1 week	Unavailability of maint. equipment within 2 weeks	Outcome probability	Number of stopped WTs	Priority ranking *	Time delay for repair **
WT 1 fails (P_1)	Yes (P_2)	Yes (P_3)	Yes (P_4)	Yes (P_5)	Outcome 1. $P_{OU1}=P_1P_2P_3P_4P_5$	13	High	T > 2 weeks
				No (1-P_5)	Outcome 2. $P_{OU2}=P_1P_2P_3P_4(1-P_5)$	13	High	1 < T < 2 weeks
			No (1-P_4)		Outcome 3. $P_{OU3}=P_1P_2P_3(1-P_4)$	13	High	T < 1 week
		No (1-P_3)	Yes (P_4)	Yes (P_5)	Outcome 4. $P_{OU4}=P_1P_2(1-P_3)P_4P_5$	5	Medium	T > 2 weeks
				No (1-P_5)	Outcome 5. $P_{OU5}=P_1P_2(1-P_3)P_4(1-P_5)$	5	Medium	1 < T < 2 weeks
			No (1-P_4)		Outcome 6. $P_{OU6}=P_1P_2(1-P_3)(1-P_4)$	5	Medium	T < 1 week
	No (1-P_2)	Yes (P_3)	Yes (P_4)	Yes (P_5)	Outcome 7. $P_{OU7}=P_1(1-P_2)P_3P_4P_5$	9	Medium	T > 2 weeks
				No (1-P_5)	Outcome 8. $P_{OU8}=P_1(1-P_2)P_3P_4(1-P_5)$	9	Medium	1 < T < 2 weeks
			No (1-P_4)		Outcome 9. $P_{OU9}=P_1(1-P_2)P_3(1-P_4)$	9	Medium	T < 1 week
		No (1-P_3)	Yes (P_4)	Yes (P_5)	Outcome 10. $P_{OU10}=P_1(1-P_2)(1-P_3)P_4P_5$	1	Low	T > 2 weeks
				No (1-P_5)	Outcome 11. $P_{OU11}=P_1(1-P_2)(1-P_3)P_4(1-P_5)$	1	Low	1 < T < 2 weeks
			No (1-P_4)		Outcome 12. $P_{OU12}=P_1(1-P_2)(1-P_3)(1-P_4)$	1	Low	T < 1 week

* Priority ranking of component failures consequences
** Time delay for repair because of equipment availability

Conclusions

- FMEA and ETA most suitable methods, which complement each other
- Conduction first of FMEA and then ETA is recommended
- FMEA and ETA steps have been modified and adjusted

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