Operations and maintenance of different configurations and scenarios regarding an offshore hydrogen wind turbine farm

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Abstract

With the expected growth of the Hydrogen market in the coming years, developing a low priced green hydrogen is key to ensure the transition to a sustainable energy system. The Offshore Hydrogen Wind Turbine (OHWT) project investigates the concept of possibly integrating an electrolyser with an offshore wind turbine. This report has a purpose of studying several different scenarios and configurations presented by Siemens during the meeting and in the project documentation, and determining how the scheduling of maintenance, that varies in frequency, failure rate (probability) and downtime, of those scenarios impacts yearly production of hydrogen. Overview of selected configurations with detailed descriptions and backgrounds is presented and followed up by the simulations to quantify presumptions and provide a clearer picture of the configuration's operational period. Lastly, these ideas and developments are summed up in the conclusion chapter with reflections and suggestions being proposed for future work.

Keywords: hydrogen, turbine, electrolyser, OHWT, compressor

1 General Introduction

The main idea behind the project was to establish service scheduling of the OHWT project to maximize hydrogen production while minimising downtime due to system maintenance. This was done firstly by introducing the system components, describing them and defining the pros and cons. From the list of components, the operational system for offshore hydrogen production was specified and several configurations, differing in the type of components they contain, were defined. After initial set up of the configurations, several sub scenarios of the configurations were made. These sub scenarios were then simulated in 'Enterprise Dynamics' with varying values, types and frequencies of maintenance, as well as different types of failure probabilities. As an end result, efficiency ratio and profit loss of each sub scenario were obtained and utilised in the next step. Acquired profit losses and service costs allowed decision making and possibility to choose adequate option for each presented configuration. Lastly, all the thoughts and decisions were collected and were followed up by the directions for possible improvements.

2 Parts and Components

This chapter will mention all the systems that make the OHWT operate.

Wind Turbine

This project defines a wind farm of 1000MW consisting of the wind turbine model SG14-236 by SGRE. The SG14-236 is a 14MW turbine, so to reach the wind farms output, 71 wind turbines are required. The following list presents the sub-components of the wind turbine.

Electrolyser

The collaboration partners define the electrolyser for the OHWT as the X-series Alkaline electrolyser from Green Hydrogen Systems. The X-series is a containerized electrolyser with an output of 6 MW, and a weight of around 60 tons. Currently, the X-series

electrolyser is in the development phase, and most of the specifications are not available or specified yet. Likewise, GHS indicated the possibility of enhancing the outlet pressure from 35 bar to 80 bar, in a later version. The idea of using a high pressure electrolyser comes from the fact that hydrogen is a very light gas and needs to be pressurized to be usable in practice. To avoid the additional energy consumption and overall system complexity due to the use of a compressor, the use of a pressurized electrolyser can be advantageous for several reasons.

Water Treatment

The desalination process focused more on capabilities and plausibility. The components picked were not designed for hydrogen production or maritime operation. Therefore, a new study was conducted looking into the supplier capabilities of offshore water treatment for hydrogen production.

Two technologies could be used to accomplish the water treatment process: reverse osmosis and vacuum desalination.

Backup Power

In the case of the OHWT where the power grid is disconnected from the site, a backup power is needed. There will be periods when there may be insufficient power to operate the electrolysers, and in those cases, the electrolyser will go into a standby mode to protect the internal chemistry balance. The same thing happens whenever a component of the wind turbine requires a service and a system shutdown is required. In those cases, power to restart itself will be necessary and a backup power source will be used.

To combat the high cost, a proposed solution would be to combine the fuel cell and battery storage into a backup power system.

Hydrogen Export Systems

A pipeline system is used to export the hydrogen from the farm to the shore, where the pipeline system will consist of two pipeline sections. The first section, called the backbone pipeline, transports the hydrogen from the hub station to the shore and the second section is the grid pipeline exporting the hydrogen from the OHWT to the hub station.

Compressor

The idea of using a compressor to compensate for the loss of pressure was introduced on a previous whitepaper \cite{Workpackage5.1}. The reasoning behind this narrative is the missing presence of hydrogen compression system that can handle the immense amount of hydrogen that the OHWT farm can potentially produce. Further boundaries for the compression system include: redundancy, offshore capabilities, low power consumption, hydrogen compatibility and low service requirements. \cite{Workpackage5.2}

OHWTs will be connected with smaller array cables to the compressor, adding more complexity and cost to this solution configuration. The possibility of utilizing fuel cells to provide power for the compression system has also been investigated but was ruled out because of the high energy loss and the number of fuel cells needed to provide the needed power. There are two different configuration options presented in the next chapter as to where to situate the compressor.

3 Scenarios

It is important to understand the intricacies of managing the operational and maintenance logistics for offshore wind turbines. This includes the careful planning and coordination necessary to ensure the continuous functionality of these immense structures amidst the challenges posed by harsh marine environments and remote locations. From mobilizing personnel and equipment to optimizing maintenance strategies and supply chain operations, this chapter examines the essential components for the smooth operation of offshore hydrogen wind farms.

To be able to cover all the bases of this complex process, an overview can be created to look into how all of the different process setups are influencing to each other. The key drivers for the operation and maintenance are the logistics of the operation, the chosen strategy and the available safety features of the different scenario’s as mentioned in figure:

3.1 Operations and Maintenance costs

Reducing the expenses that come with operations and maintenance (O\&M) can be achieved by categorizing costs into three main areas: operations, planned maintenance, and unplanned maintenance. Operations engulfs the day-to-day tasks necessary to ensure seamless turbine operation, such as monitoring performance. The frequency of these tasks varies, with basic service visits typically occurring every six months, as specified in the turbine manufacturer's maintenance manuals.

Unplanned maintenance constitutes the majority, about two-thirds, of direct O&M costs. Reactive maintenance expenses include spare parts, technicians, and vessels. For major component failures, larger and more expensive vessels like crane ships or jack-up vessels may be required and can be significantly more expensive. These failures often force turbines to shut down until repairs are completed, resulting in additional indirect costs due to loss of production. Wind farms situated in remote and challenging environments face even higher costs as accessing and repairing turbines depends on relatively calm weather conditions. Waiting for appropriate weather windows can cause substantial delays.

To reduce these costs, several parameters can be optimized. Enhancing maintainability involves making it easier to maintain components, allowing for the replacement of sub components rather than the entire unit. This streamlines repairs, reduces vessel sizes, and minimizes production losses. Moreover, improving accessibility through the use of sophisticated vessels facilitates more efficient maintenance operations.

Increasing reliability is key to reducing the number of failures. Achieving this can involve employing more reliable (albeit more expensive) designs, utilizing superior design methodologies, incorporating redundancy in critical components, or implementing condition-based maintenance.

3.3 Strategy

Maintenance strategies are vital in industrial operations, enabling organizations to optimize productivity and equipment lifespan. Approaches like preventive maintenance, condition-based monitoring, and predictive maintenance's that is supported by data analysis can ensure proactive interventions, minimize downtime, reduce costs, and enhance overall efficiency.

Reactive Maintenance

This is a maintenance strategy that involves performing maintenance tasks in direct response to equipment failures or malfunctions. In the context of offshore wind turbines, this means maintenance actions are executed exclusively when problems occur, such as equipment breakdowns. Responsive maintenance is generally considered to be a less efficient maintenance strategy compared to proactive maintenance, which focuses on regularly scheduled inspections and maintenance activities to prevent equipment failures from happening in the first place. While responsive maintenance may be employed in certain scenarios, a proactive maintenance approach is preferred as it aids in minimizing downtime and reducing the likelihood of equipment failures.

Preventive Maintenance

Is an approach to maintenance that focuses on performing planned activities to safeguard against potential issues, regardless of the equipment's current state. In the case of offshore wind turbines, this entails adhering to a predetermined schedule of maintenance tasks, irrespective of whether the equipment is functioning correctly. The objective of preventative maintenance is to forestall equipment failures by proactively identifying and resolving potential concerns. By taking this proactive approach, costs associated with maintenance can be minimized, and the amount of time that equipment remains out of service can be reduced. Preventative maintenance is generally regarded as a more effective strategy than reactive maintenance, which involves addressing maintenance needs only when problems arise.

Condition-based Maintenance

Is a maintenance strategy that focuses on continuously monitoring the condition of equipment and performing maintenance activities only when specific conditions indicate the need for maintenance. In the offshore wind turbine context, this involves utilizing sensors to track parameters such as vibration, temperature, and oil quality to assess the equipment's condition. Maintenance tasks are then executed when predetermined thresholds are surpassed or when abnormal conditions are detected by the sensors. By adopting this approach, maintenance costs can be reduced, and equipment downtime can be minimized, as maintenance activities are carried out only when necessary. Condition-based maintenance is generally recognized as a more effective strategy than reactive maintenance, which responds to maintenance requirements solely when equipment problems occur. However, it may be considered less comprehensive compared to preventive maintenance, which involves regularly scheduled proactive maintenance tasks.

Predictive Maintenance

Is an advanced maintenance strategy that leverages data analysis and sophisticated machine learning techniques to anticipate when maintenance will be required. In the context of offshore wind turbines, this entails the collection and analysis of data from diverse sensors to forecast the likelihood of equipment failures. By scrutinizing data patterns, predictive maintenance algorithms can accurately identify potential failure points and schedule maintenance activities accordingly. This method optimizes maintenance costs and reduces equipment downtime by ensuring that maintenance tasks are performed precisely when necessary. Predictive maintenance is generally acknowledged as a superior maintenance strategy compared to reactive or preventive approaches, as it effectively minimizes downtime and mitigates the risk of equipment failures.

3.4 Sub scenarios

The five predetermined configurations will be divided into three sub scenarios. These sub scenarios will be set up so it can provide data on the operations and maintenance of each of the configurations.

Sub scenario 1: Offshore High pressure electrolyser

This sub scenario goes into the scenario where an offshore high pressure electrolyser is integrated into the system. It will go deeper into the predictive strategy as the high pressure electrolyser is a newly implemented product into the system with custom build components. As there is no data yet available for this high pressure electrolyser, a solution could be to monitor the system with a condition-based maintenance strategy so that over time enough data can be gathered to change the system into a predictive strategy into the future.

Sub scenario 2: Onshore Compressor station

The next sub scenario is an onshore compressor station which is connected to the offshore plant. For this solution it is important to look into the effect of standardization of the system. It has great potential into having a standardized system as it is placed onshore and does not require special components for an offshore environment.

Sub scenario 3: Offshore Compressor station

Sub scenario 3 dives into an offshore compressor station that is centrally connected to the grid. For this solution the investigation will be to notice a difference between having a centrally located compressor or that each turbine has a local compressor connected to the grid.

4. Simulation

The following section contains the simulation setup and explains different estimates and considerations taken into account to obtain the simulation results. The main goal of this simulations is to illustrate a general influence of different kinds of maintenance on the yearly production of hydrogen. While as a parameter, other than type of maintenance, also having failure probability and maintenance frequency over a one-year period. Simulation was done in 'Enterprise Dynamics' and the zoomed-out setup of the simulation can be seen in the picture below:

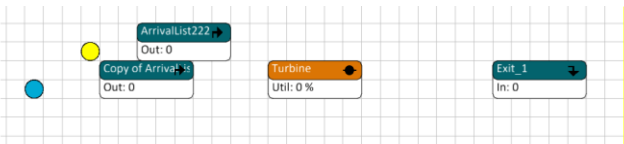

Fig.1. Simulation setup for a single turbine

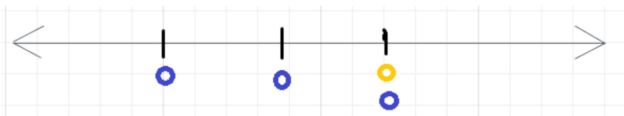

Fig.2. Line diagram with three scheduled maintenance

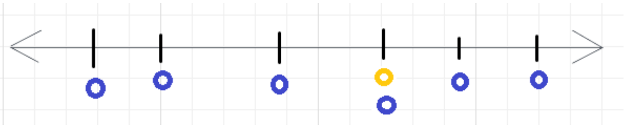

Fig.3. Line diagram with six scheduled maintenance

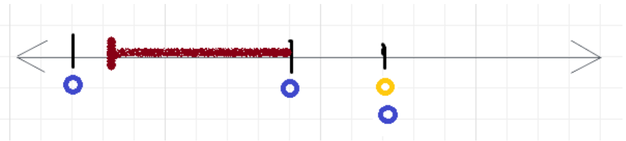

Fig.4. Line diagram with unexpected three month system failure

5. Operations and Maintenance

The different configurations face different challenges. So, to determine critical points for every configuration different decision have to be made to come to a suitable solution. This will enlighten all the strengths and critical points of the configurations.

6. Conclusion

For future design of the whole system it is important to keep the operations and maintenance in mind when designing components for the offshore hydrogen wind turbines. The configuration with a high pressure electrolyser and a condition-based strategy where the systems are constantly monitored to see when a system needs to be serviced can be interesting for different reasons. As the hydrogen market is expected to grow significantly in the for seen future to 2050 a condition-based system can help to spark new upgrades and faster implementations of higher capacity systems. This will result in a more reliable system into the future while still full filling the growing needs for the market.

For the second configuration a low pressure electrolyser will be used in combination with an onshore compressor station. This will create the opportunity to use a standardized system for the compressor as it does not need to be subjected to the offshore environment. This will significantly reduce initial investment costs and the opportunity to upgrade this system into the future with using standardized systems. This will result in a lower threshold for investors to overcome to be able to invest into the project.

For the third configuration a low pressure electrolyser will be used in combination with an offshore centrally located compressor station. The initial costs will be higher than the second configuration as the compressor station needs to be adapted to an offshore environment. But if the maintenance of the offshore compressor can be in synchronization with the maintenance schedule of the turbine and electrolyser.

Regarding the simulation results, the conclusion comes naturally. The less maintenance is performed the less money is lost due to the down time. However, there are several interesting results worth noting and first is the difference between the lost profit in scenarios with three and six maintenance. Sub scenario 1.1.3 is 'only' 700 000 €/year more profitable than sub scenario 1.1.4 even though it has two times less scheduled services. That is due to the three additional maintenance being regular 8-hour ones. One conclusion that can be drawn from this is that having larger amount of smaller maintenance spread over the year might significantly decrease likelihood of unwanted system failure while in return not costing a lot in non-produced hydrogen. Also, worth noting is the small difference in profit lost in the scenarios with failure probability of 0.1 %. Aspiring to have a high quality, reliable electrolyser can prove to be better long-term option even though it might represent higher initial cost.

Since the safety is affected by the choices of components and sub-scenarios, once the path has been chosen a more in-depth risk assessment must be done to guarantee the safety of the system as well as the safety of all the workers.

7. Future Work

Weight Reduction of electrolyser

During our visit to the Green Hydrogen System's headquarters their lack of use of lightweight materials was observed. In discussion with them and consulting their documentation, it was stated that they currently do not have weight reduction of electrolyser in mind, as the weight has not been a problem (or cost driver) up until now. Relatively large weight could potentially have a big effect on the way the electrolysers are serviced, as the number of components a vessel may be able to carry may be limited due to the weight of the electrolyser.

Therefore, this opens the idea to look more into the use of lightweight materials, such as composites, that might be suitable to operate under pressurized, maritime conditions. Several other upsides of use of composites are the prevention of hydrogen embrittlement, limitation of corrosion and prevention of ignition.

Simulation with improved scheduling

The alternative possibility for the future work comes in a way of simulating the real-life process environment with more realistic scheduling. As mentioned before, all the simulations assumed sufficient number of workers and vehicles to complete all the maintenance at the same time. Realistically, such solution would prove too costly purely from the standpoint that each wind turbine has it's assigned ship and a maintenance crew. Previously described simulation set ups could still be used for determining general values and directions in which to proceed with the project, but in case more realistic results have to be obtained, that has to be done with the simultaneous use of improved maintenance scheduler and data gathered based on

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