Maintenance philosophy for an unmanned platform: A case study for an Offshore wind substation

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Abstract. Unmanned installations introduce new challenges for the operations and maintenance. In many offshore windfarms there is a need for offshore substations and these substations can be designed as unmanned installations. Thus, the purpose of this paper is to review and discuss the available maintenance philosophies for unmanned substation platforms and as a result, propose a suitable maintenance philosophy for this type of installations with regards to key performance indicators such as high availability, low maintenance man-hours and minimal fixed maintenance campaigns. It is concluded that maintenance philosophy for unmanned substation shall consider the DIP (Design out and Intelligent preventive maintenance) concept, where the potential benefits of risk-based maintenance, design-out, predictive, and prescriptive maintenance are unlocked. To illustrate the utilization of proposed philosophy, a case study related to cooling system of a substation is presented

1. Introduction

Digitalization, automation and autonomation have provided enormous opportunities for the energy industry to increase productivity and reduce costs related to operation and maintenance of assets. (The) Offshore wind energy industry is very cost sensitive, as the margins are low and competition is tight. Thus, it is crucial to reduce the levelized cost of energy, by reducing the capital, operations, and maintenance expenditures, and increase the generated electrical energy. A substation is a part of the entire wind farm that collects and exports power generated by the wind turbines. It significantly contributes to the wind farm capital (7.5-9 % [1]) and operations and maintenance expenditures. Substations are intended to operate unmanned at only a few visits. However, these installations shall have lifts, cranes, boat landings, helicopter deck and accommodations which makes the sheer size of the structure as the main maneuvering and cost challenging. Self-installing and lifting concepts are developed and deployed to eliminate the need for expensive and risky lifting vessels. However, the configuration of the substation is highly dependent on the maintenance philosophy and how the substation is served, how frequent and how fast it shall be served. These maintenance issues are directly related to the operations and maintenance expenditures, i.e. manning and equipment cost, but they also influence the substation's configuration where redundancy of equipment (maintenance work can be done while the system is uptime), storage areas for spare parts, equipment to enable repair or replace work (fast replacement like plug and play modules) and accommodation or shelter are allocated.
Maintenance events are typically a guess or a multi sourced guess based on manufacturer experiences (planned maintenance), and operator historical data. Planning for maintenance in the case of offshore context is even harder. Substations that operate in harsh environments, like offshore, have accessibility limitation due to weather conditions, excessive and fluctuating loading profiles, as well as shallow water might complicate the cooling process. Therefore, we are looking for a maintenance philosophy that can be more cost effective, to determine the maintenance needs and satisfy the desired operating profile (Production uptime). In fact, industrial practitioners are looking forward to utilizing the maintenance notes to design out failures (e.g. gas-insulated transformers instead of oil-insulated ones), condition monitoring systems to detect potential failures, predictive analytics to predict remaining useful lifetime, and prescriptive analytics to tolerate the health until intended maintenance visit. So, if the wind energy practitioners decided to build a maintenance philosophy out from the classical maintenance philosophies (corrective, preventive, design-out) and emerging maintenance philosophies (condition, predictive, and prescriptive), the main question is “how will that work?”.

The purpose of this paper is to review and discuss the available maintenance philosophies for unmanned substation platforms and as a result, propose a suitable maintenance philosophy for this type of installations with regards to high availability, low maintenance man-hours and minimal fixed maintenance campaigns. Therefore, in the following section, three issues are provided: (1) the state of the art in unmanned installations (2) a discussion of the most common maintenance philosophies that are used for offshore substations and (3) a proposed maintenance philosophy for an unmanned installation. In the third section, a case system (cooling system) is used to demonstrate how to implement the proposed maintenance philosophy, where several maintenance philosophies are studied through a high-level failure mode analysis. In the fourth section, the discussion continues further to explore the technological and operational dependences and negative effects of implementing such multiple maintenance philosophies. Therefore, the innovation big picture matrix is filled to illustrate the potential of the proposed maintenance philosophy in short-, medium-, and long-term perspectives.

2. Offshore substation and maintenance philosophies

2.1 State of the art

One of the best literatures that summarised the state of the art for unmanned installations is the report by Oljedirektoratet, Ramboll [2], which provides the basic principles and main characteristics for normally unmanned installations (NUI). Although the report focuses on the wellhead platforms, used for drilling, it can be used as a reference for various offshore unmanned installations, e.g., offshore wind substations. Definitely, there are differences in terms of safety procedures, means of access and the scale of manning that they tend to require. This report guides practitioners regarding the operation and maintenance philosophies/strategies, the extent of scheduled and unscheduled maintenance actions, means of accessing the installations, the choice of materials and overnight facilities.

La Grange, et. al. [3] introduces an innovative idea related to normally unmanned installations through digitalization and a remote-control system. The key drivers of the project are the reduction of CAPEX and OPEX, maximizing reliability and availability and increasing the safety of the crew. The installation is to be placed at distant sites, in deep water and to be maintained in six-month intervals. The maintenance strategy used on the site is condition-based maintenance (CBM) as well as predictive maintenance. In addition to this, day-to-day and periodic inspections are to be carried out remotely with the help of monitoring or autonomous machines. Repair is to be performed by replacing of the components and repairing them onshore.

Tan et. al. [4] introduces a state-of-the-art solution for maintaining unmanned installations. This solution depends heavily on robotics and advanced sensors facilitating an unattended offshore site. This, together with digitalization of process control systems, and several other modifications is to reduce costs,
secure more reliability, availability and safety on offshore sites. The systems are controlled through onshore control centres. Safety procedures, for instances of the loss of contact between the control centre and the site, in the form of operating in an island mode or an automatic shutdown, are include in the planning. When it comes to the maintenance programme – predictive maintenance, supporting big data analysis is predicted (suggested? To avoid repetition) to be used on these sites. Virtualization of servers, extended levels of cybersecurity and digital twins are some of many enhancements to this concept. There are three types of human tasks predicted for the site: inspection & monitoring, routine maintenance tasks and those concerning human safety. The article mentions also four main types of tasks performed by the "dexterous robot" (inspecting of the site, simple manipulations, assisting human personnel and response to emergency situations) and a case study of an oil and gas site is being introduced. With regards to the maintenance campaigns, the estimated frequency of visiting of the site is three times per year.

Vinnem and Røed [5] put a lot of focus on the future development of unmanned installations: both from previously manned sites being transformed to unattended ones, and new sites aimed as being unmanned from the planning phase. Safety, as well as other equipment needed for manned operation, is described with regards to the frequency of personnel visits. Further predictions of this concept take into consideration the development of larger installations and floating sites in deeper waters, as compared to the current state of only bottom-fixed, unmanned installations. Autonomous, unmanned ships are also discussed where the cost reductions are expected to be substantial, with savings in CAPEX expected to reach 30% and in OPEX up to 50%. Other benefits are related to lower carbon emissions and improved safety. Contrary to the previous source, preventive maintenance is expected to be replaced by "break-down", a more outdated form of maintenance. This is supposed to reduce the need for longer manned periods, however, it might increase the cost due to possible shutdowns.

Vinnem in [6] discussed the safety and operation and maintenance aspects for oil and gas unmanned installations. It is claimed that barrier elements shall help to limit the maintenance man-hours and reduce the personnel risk. It was estimated, based on real cases and initial assumptions, that as high as 40% of the leaks is directly connected with the presence of the crew. The article also mentions the safest transportation method to the site. Besides the claim that walk to work (W2W) vessel is a safer alternative than helicopter transit.

The literature review shows an extremely limited contribution and shared experiences that is being published on the offshore unmanned installations. In fact, the authors were not able to find any literature that discusses or guides on how to maintain unmanned offshore wind substations. Several substation developers are continuously trying to cut the capital cost of substation by reducing the space related to accommodation, access points, storage, etc. Currently, 9% of CAPEX is related to the substation. On the other side, 38% of OPEX is related to maintenance and 8.3% of failures are related to electrical systems (transformers and converters). It is extremely important to find an optimal maintenance philosophy for offshore wind substations. Therefore, we are trying to answer a question "how to determine the most cost-effective maintenance philosophy or concept for unmanned substations”.

2.2 Maintenance philosophies

Currently, substations are maintained based on predetermined maintenance on an annual basis (once per year, preferably during Summer, when accessibility is high, and production is low). Corrective maintenance has also some shares with a couple of maintenance visits (or maintenance transfers as (the ones) used in SPARTA database) every month [7]. For unmanned installations, there are limited and costly accessibility intervals, e.g., four weeks every three years, and two weeks every year. Therefore, such a maintenance philosophy that leads to frequent visits is not acceptable. Moreover, the availability of substations is far more important than the availability of wind turbines and therefore redundancy is applied wherever possible. However, redundancy is a costly option in terms of capital, space and maintenance expenses. Condition-based maintenance is an effective philosophy to detect failures at an early stage. However, the offshore unmanned substations require long-term early detection to gain the
(this) benefit and avoid the need for an extra maintenance visit. Furthermore, the stochastic characteristic of the wind loading and operating profile, which can vary, hour to hour, day to day and season to season, makes the failure symptoms hard to detect and tracked over time. Besides, not all failures produce measured (measurable) symptoms. Therefore, there are three more maintenance philosophies that can be utilized: (1) design out, (2) predictive and (3) prescriptive.

Design out is a great option if it is possible since you prevent the potential failure at the beginning, and forever. This option has not taken sufficient attention at the project phase due to

1. the assumption that manufacturer has provided (the) best design
2. the need for previous experience and evidence of the repetitive occurrence of a specific failure mode, and
3. not being emphasized enough by some guidelines.

It is important to note that there might be some failure modes that if they are not being designed out the unmanned philosophy with infrequent visits for an installation might be jeopardized. Predictive maintenance aims at providing a longer horizon than just detection where we hope that our model or algorithm enables us to forecast the degradation curve. Such long-term indication of the condition might help to utilize the first-coming yearly maintenance interval and fix the equipment before the failure occurs, without extra maintenance visits. However, models and algorithms might not provide such a desired long predictive horizon or might not be available for all equipment. The last philosophy is prescriptive maintenance, where one adjusts or intervenes with operating conditions (loads, conditions, process parameters) to either heal or de-accelerate (tolerate) the health degradation. Prescriptive maintenance relies on the ability to remotely intervene with the equipment by adding healing materials, filtering, reducing loads, etc. It can utilize redundancy (active or standby) to change the loads without affecting the system availability. Definitely, we are having several philosophies that might be valid and effective for some part of the system and wondering how to unlock such benefits as early as possible within the project execution model. In fact, if such philosophies are not considered and listed in the concept study phase, the engineers at FEED (Front End Engineering Design) phases or detail engineering phase, will never look into them. However, the challenge is how to adopt the benefits of different maintenance philosophies as early as possible.

It is well known that Risk-based maintenance and reliability centerd maintenance are considered and recommended by NORSOK Z-008 as the most generic maintenance programs. However, the flowchart and decision-making points to select the effective maintenance philosophy out of such many options shall be developed further. There is a need for a specific type of study that can be performed at high-level and as early as possible within the project execution model to explore and unlock any potential benefit of any maintenance philosophy. The proposed study is called "Design out and Intelligent Preventive maintenance (DIP)". The authors try to prioritize the need to study how to design out any critical failure and then explore the use of intelligent preventive technologies like detection, prediction or prescription. Moreover, the acronym "DIP" highlights the function of this study as "quick and dirty study" to dip into several maintenance philosophies at the concept study phase. Please note that the information and stakeholder involvement at the concept study phase are limited to perform comprehensive study.

The DIP study starts with the high-level failure mode analysis, i.e., the main equipment and the main failure modes. After this it takes the failure mode analysis a step further to determine the potential maintenance philosophy where four categories are listed: design out, detection, prediction, and prescription. The user, e.g. the maintenance engineer, has three answer options and scores: (0) when the philosophy is not at all applicable, (1) if the philosophy is partly applicable and more exploration is required, (2) if the philosophy totally cover that specific failure mode and reduce the consequences (no production downtime, no extra maintenance visit). This three-level score (not at all, partly, totally applicable) is very simple and useful to classify and determine: what should be the focus (totally covered), what shall be explored further (partly applicable), and what shall be ignored (not at all applicable). Authors have adopted this scoring system from a diagnostic coverage study performed at Equinor and presented in [8].
Table 1. Example of the DIP study worksheet

| Element     | Failure mode                                      | Failure cause                                   | Local effect                      | Consequence (Global effect) | Redundancy | Opportunistic | Design out | Detectable | Predictable | Philosophy required |
|-------------|--------------------------------------------------|------------------------------------------------|-----------------------------------|-------------------------------|------------|---------------|------------|------------|-------------|---------------------|
| Pump        | Fails to start on demand                         | Mechanical Failure due to wear and tear,        | No cooling medium circulation    | Cooling system shutdown       | 2          | 0             | 0          | 2          | 1           | 1                   |

Redundant system equipped with CMS, prediction is possible but not recommended. For a redundant system prescription can be used to ensure no extra maintenance visit is needed. Design out at system level is not possible but can be explored at equipment level.

3. Case Study

In this section, we are going to illustrate how to implement DIP maintenance philosophy, using a simple case system. As described in the scenario above, to implement the DIP maintenance philosophy, three steps are to be performed: (1) system boundary and analysis, (2) failure mode analysis, and (3) maintenance philosophy study. The case system selected for the case study is the cooling system of a substation. The cooling system is responsible for almost 18% of total failures of a substation [9]. Furthermore, we are going to illustrate how the configuration system of cooling systems might be modified according to the DIP maintenance philosophy.

3.1 System boundary and analysis

As mentioned earlier, a normally unmanned offshore substation houses the electrical high-voltage and medium-voltage components for transforming power supplied by the wind turbines at 33 kV to 150 kV for exporting to the onshore grid. The substation system can be schematically presented as in figure 1. It is necessary to provide cooling for the substation to extend the life of the equipment and lower the losses of electrical power fed into the network, which has been proven by the industry [10]. The cooling system of our case study is also presented in a schematic way in Figure 1, with main elements of the equipment being analysed as the consumer of the cooling system, pump, heat exchanger and an expansion tank. The system boundary for this paper is limited to the cooling system where mainly three equipment are analysed further: pump, heat exchanger, expansion tank.
3.2. Failure analysis and DIP study

The proposed DIP maintenance philosophy highlights the need to perform a high-level failure analysis and criticality/consequence analysis. We emphasize the high-level analysis as not all stakeholders, e.g., vendors, operators, contractors, will be involved, and detailed information might not be obtainable at the concept study phase. This step aims at exploring the most critical failure modes, based on local and global effects/consequences of the main equipment of the selected system. To understand the criticality of these components, a Failure Mode and Effect Analysis (FMEA) has been prepared and presented in Table 1. The DIP study worksheet extends the FMEA study into maintenance philosophies and assessment of their applicability to prevent specific failure modes. For the DIP study, it is important to have a good understanding of the system and an overview of the available technologies in condition monitoring and equipment control systems to get the best outcome from this study. Therefore, a group of experts with diverse backgrounds should contribute to this study. For example, for this case study, process engineers can clarify that for pumps and heat exchangers, there is a possibility to have redundancy. Even though we cannot have redundancy option for the expansion tank, perhaps they can suggest an alternative for the atmospheric expansion tank to design out the contamination failure mode. Mechanical engineers can contribute to the evaluation of detection and prediction. In the case of the pump, due to the mechanical nature of the equipment and available condition monitoring systems, these two philosophies obtain a higher score than heat exchangers. Last but not least, the automation and maintenance engineers can provide input to determine the possibilities of using prescriptive philosophy and the availability of opportunistic maintenances. This joint effort leads to a conclusion about the strategy that is needed for each failure mode.

In Table 2, the failure modes of the three main functions (pumping, cooling, handle the thermal expansion) are being analyzed. This is an equipment level failure analysis, and failure modes of components and subfunctions are not considered at this stage. For example, the pump might fail to start or face a spurious stop caused by mechanical failure. Such failure modes will disenable the pump functionality to circulate the cooling medium and lead to cooling system shutdown. The shutdown as the primary global effect (consequence) of such failure can be avoided by redundant pumps. Opportunistic maintenance is not an option as the failure shall be fixed immediately and cannot be considered a deferred event. Therefore, the design team decided to set "0" score for opportunistic maintenance. The same concerns the design-out option. The design team believes the wear is neither a mechanism that can be designed out nor an issue to be explored further, so "0" is the score for design-out maintenance. However, the design team thinks that wear can be totally detected by sensors. This is the reason why a score of "2" is given for detection. Detection might provide an advantage to either to utilizing the last possible opportunistic maintenance event or applying prescription, e.g., loading reduction to defer the required maintenance work until the next possible maintenance event. Prediction
and prescription maintenance were both given score of "1", as the design team thinks it is partly possible to use a predictive model to estimate the remaining useful time long before the failing point and extend the useful time once prescription is applied. However, they believe it is quite challenging to depend on this, and more exploration is needed. In summary, according to this design team, the best maintenance philosophy is to have a redundant pump that is equipped with CMS to enable prescriptive maintenance to ensure no extra maintenance visit is needed. Moreover, prediction is possible but not recommended and design out at the system level is not possible but can be explored at the equipment level.

The DIP study provides almost similar recommendations for maintaining the heat exchanges as for pumps in terms of having redundant equipment and using prescriptive maintenance. However, predictive and design out maintenance are not appropriate options. Besides, detection using CMS is partially possible, and routine maintenance is required, especially for internal leakages. The DIP study presents design out maintenance as a suitable philosophy to maintain the expansion tank, especially that most of the philosophies are not applicable in this case.

### 3.3 Design modification after applying DIP maintenance philosophy

Based on the DIP study, shown in Table 2, three design requirements are recommended, and four maintenance philosophies are integrated. The study suggests redundant cooling pumps and heat exchangers and design-out the expansion tank failure. The study proposes condition-based and prescription maintenance to take advantage of redundant equipment to avoid extra maintenance events and defer the required maintenance work to the next possible maintenance event. The redundancy is represented in Figure 2. Moreover, the traditional atmospheric expansion tank is replaced by a pressurized expansion task covered with gas (nitrogen) blanket to eliminate the risk of contamination due to exposure of the cooling medium to air.

It is worth mentioning that in this case study the authors’ aim was not to design the most optimal and best solution to address each of the failure modes. The goal of this case study is to show how the DIP study is performed and how the outcomes look like. It is apparent that the outcomes of DIP study might be different for two groups of experts since the level of knowledge and experience that they possess might be different. However, as it is shown in this case study, performing a DIP study provides the opportunity to enhance the maintainability of an asset based on the available knowledge and experience within an organization.

![Figure 2. Schematic representation of the system after implementing of the new maintenance strategies.](image-url)
| Element        | Failure mode          | Failure cause                      | Local effect                  | Consequence (Global effect) | Redundancy | Opportunistic | Design out | Detectable | Predictable | Prescribable | Philosophy required |
|---------------|-----------------------|-----------------------------------|-------------------------------|----------------------------|------------|---------------|------------|------------|-------------|--------------|---------------------|
| Pumps         | Fails to start on demand | Mechanical Failure due to wear and tear, – power failure | No cooling medium circulation | Cooling system shutdown | 2          | 0             | 0          | 2          | 1           | 1            | redundant system equipped with CMS; prediction is possible but not recommended. For a redundant system prescription can be used to ensure no extra maintenance visit is needed. Design out at system level is not possible but can be explored at equipment level |
| Spurious stop during operation | Mechanical Failure due to vibration, wear and tear, operation stress – power failure | system shutdown, No production | | Cooling system shutdown | 2          | 0             | 0          | 2          | 2           | 2            | redundant system equipped with CMS, prediction is possible and can be explored, prescription can be used to ensure no extra maintenance visit is needed. Design out at system level is not possible but can be explored at equipment level |
| Heat exchanger Internal leakages | Mechanical failure, | Mixing of mediums, lack of sufficient heat transfer | | Cooling system shutdown, extensive repair campaign | 1          | 0             | 0          | 0          | 0           | 0            | detection is very hard and if detected having redundancy can be helpful if it is not too late. routine preventive maintenance is needed to inspect the equipment once a year. Design out at system level is not possible but can be explored at equipment level redundant system equipped with CMS, prescription can be used depending on the leakage, for a small leakage prescription can be used to ensure no extra maintenance visit is needed. Design out at system level is not possible but can be explored at equipment level |
| Heat exchanger External leakages | Mechanical failure, human error in maintenance | Leakages of seawater, lack of sufficient heat transfer | | Seawater leakage to the platform, Cooling system shutdown | 2          | 1             | 0          | 1          | 0           | 1            | redundant system equipped with CMS; Prediction can be used to ensure no extra maintenance visit is needed. Design out at system level might be possible |
| Insufficient heat transfer | Plugged / blocked heat exchanger due particles from seawater – fouling | Reduced cooling effect. | | Cooling system shutdown | 2          | 1             | 1          | 1          | 0           | 1            | |
| Expansion Tank Leakage | Mechanical Failure | Losing cooling medium | | System shut down if the leakage continues | 0          | 1             | 0          | 1          | 0           | 0            | Design out shall be explored, detection shall be explored, routine preventive maintenance is needed to inspect the equipment once a year |
| Contamination Degradation due to contact with air, maintenance error | Lack of sufficient cooling | | | System shut down if the degradation passes a certain point, extensive repair campaign | 0          | 0             | 2          | 0          | 0           | 0            | Design out shall be explored, |
4. The big picture analysis of the DIP maintenance philosophy

Innovation is the key for improvement; however, any innovative technology or methodology has potential negative effects. Moreover, it is crucial to evaluate and clarify all the dependencies around a new technology or new approach to maximize its potential positive outcomes. To have a holistic view of the suggested maintenance philosophy we have used in this paper the Innovation big picture matrix (as shown in Table 3), which is an effective tool for this purpose. The time frame of the matrix is defined based on the typical lifetime of a substation platform which is 25 to 30 years. The short-term aspects of the maintenance philosophy are presented for the first three years of operation, the medium-term outcomes and dependencies are evaluated for the period between the third year of operation up until 15 years, and the long-term refers to the last 10 to 15 years of the lifetime of a substation.

Table 3. Innovation big picture of the proposed maintenance philosophy

|                      | Short-term, immature, partly, 1-3 years | Medium-term, Mature, full scale, 3-15 years | Long-term, Lifetime 15-30 years |
|----------------------|-----------------------------------------|---------------------------------------------|--------------------------------|
| **Positive impacts** | Availability due to design maintenance  | Availability due to corrective maintenance  | Extend lifetime               |
|                      | Maintenance cost (low maintenance frequency) | Maintenance cost (low level of damage)     |                                |
|                      | Utilize opportunistic intervals          | Warranty utilization                        |                                |
| **Dependencies**     | Sensor sensitivity, durability           | Equipment reliability                       |                                |
|                      | Decision-making process                 | Sensor sensitivity, durability               |                                |
|                      | Diagnostic coverage                     | Diagnostic coverage                         |                                |
|                      | Clarity of the purpose                  | Clarity of the purpose                      |                                |
|                      | Fit to purpose                          | Fit to purpose                              |                                |
|                      | Change management                       | Change management                           |                                |
|                      | Data Quality                            | Data Quality                                |                                |
|                      | Training data, data Richness            | Training data, data Richness                |                                |
| **Negative impacts** | High investment                         | Cyber security                              | Obsolete technology            |
|                      | High false alarms                       | System upgrading (sensors, software)        | Inability to cope with ageing  |
|                      | High fault/error rate (Maintenance management system) | Over-maintenance                           | Hard to upgrade/update         |
|                      |                                        |                                            | due to data history            |

During the first few years of operation, the uncertainties are high, and the platform deals with infant mortality failures. Implementing the suggested maintenance philosophy leads to high availability in the short term due to the designing out of the major failures and implementation of sufficient redundancies. In addition to high availability, it is expected to have low maintenance costs since the maintenance philosophy is based on low frequent maintenance campaigns. However, the success of this maintenance philosophy depends on the best available technology that can be used for performing a specific function and equipment reliability. Equipment reliability cannot always be compensated for by adding redundancy since adding more equipment increases the capital cost, there is also limited space available on an offshore platform. Therefore, equipment with high failure rates is a barrier in achieving low frequent maintenance campaigns. On the other hand, utilizing the latest technology, highly reliable equipment, and advanced sensors and data analyzing systems means high investment cost, which can be categorized as one of the negative aspects of this maintenance philosophy. Furthermore, the high degree of digitalization and sensor usage increases the chance of false alarms in the short-term phase.
Therefore, a high rate of errors might be seen in a sophisticated and complex maintenance management system during the first few years of operation.

In the medium-term, the substation reaches maturity in operation, and the majority of the positive impacts of our maintenance philosophy are targeting this phase of operation. A combination of proper preventive and prescriptive maintenance and performing effective corrective maintenance makes it possible to see a continuation in the platform's high availability. In addition, this maintenance philosophy leads to a lower chance of major damage to key equipment, and the cost of major repairs should be eliminated. Following vendor preventive maintenance provides the opportunity to use the equipment warranty when needed and subsequently lower maintenance costs. Another contributor to low maintenance cost is the potential for performing opportunistic maintenance since full monitoring of the asset's health is available.

However, these benefits and the effectiveness and efficiency of our maintenance activities are dependent on the sensors' sensitivity, the durability of the condition monitoring system and diagnostic coverage. If the sensors are not suitable to identify the potential failures well ahead of functional failure, or if the sensors have high failure rates, then the unplanned maintenance increases. There will be a higher potential of major damage to the asset. Another critical factor in the success of the maintenance philosophy in the medium term is the maintenance team's decision-making process. Based on the available data from different sensors, operation conditions, fixed maintenance campaigns and potential prescriptive maintenance, the maintenance team has to decide what is the best course of action to tackle an identified failure. For example, when a sensor indicates a potential failure in equipment, if the next maintenance campaign is to take place in the nearest future and it is possible to reduce the load on the equipment, then it might be beneficial to postpone the corrective maintenance until the next campaign. Clarity of the purpose of utilizing different sensors and monitoring systems is essential for making the best possible decisions at any moment. In other words, each system and sensor shall be used to point out a specific failure that requires specific corrective actions. Otherwise, the decision-making process will be disrupted by noises from different unclarified inputs. Some parts of the decision-making process can be automated when prescriptive maintenance philosophy is implemented, but only if we have a high level of data richness. The data set covers different operational conditions, failure modes and consequences. It is impossible to have an effective algorithm when failures and their data are unique and unprecedented. Other dependencies in the medium-term have the equipment fit for purpose and, therefore, reliable and comprehensive change management and data management systems to ensure the completeness and conformity of data. Conformity of data means that the data follows a certain standard, and it conforms to the format, type and range of its definition. Changing a sensor without considering the conformity might lead to the collection of data that are not mergeable with historical data.

Making an asset highly digitalized and highly automated introduces cyber security vulnerability to the asset. In recent years there has been a significant increase in cyber-attacks and a complicated digitalized industrial asset with automated controlling systems is an attractive target for these types of attacks. We believe this is a potential negative effect of this maintenance philosophy in the medium term. To mitigate this risk, continuous updating and upgrading of the digital and automated systems are needed. This can be another challenge for maintaining the asset because any significant change in the systems might make the historical data irrelevant or at least reduce the effectiveness of prescriptive maintenance. Another negative impact of this philosophy might be the potential of over maintaining the asset. There might be overlaps between the preventive maintenance activities suggested by the vendor and maintenance activities based on the condition monitoring systems.

In the long term, since the substation is well maintained, there is a potential for extending the lifetime of the systems and platforms. However, there might be changes in the equipment's behaviour due to ageing and its consequences, and the maintenance activities need to be updated based on these changes. In general, the quality and the quantity of the data plays a significant role in the success of this
philosophy. Here, the quality of data refers to the completeness, conformity, and timeliness of data. By timeliness, we mean the degree to which data presents the asset's current condition and, therefore, is relevant. For example, initial equipment and sensors are replaced by new equipment with new technologies, or the initial sensors are replaced with more sophisticated sensors with different ranges and measurements. In that case, this maintenance philosophy is not as effective as it is intended. Even if the hardware part of the monitoring system stays intact, a failure in software might reduce the positive impact of this philosophy. For example, due to software failure, there might be a major data censor in the system, which leads to missing the opportunity of performing proper maintenance or improving the prescriptive algorithms.

The main negative aspect of this maintenance philosophy in the long-term might be the compulsion to use obsolete technologies to avoid updating the systems and losing historical data. As discussed previously, the prescriptive and preventive maintenances are dependent on the data. If new technology is utilized for performing an operational function or collecting data, the effectiveness of the maintenances drops. As a result, there might be a need for an extensive overall upgrade of all systems, which will be a significant investment cost.

5. Conclusion
This paper discusses what is locking the benefits of modern maintenance technologies. It illustrates through a case study the importance of studying several maintenance philosophies during the concept study phase within design and development. It became clear that if a specific maintenance philosophy is not discussed and considered at the concept study phase, it will probably be impossible or costly to re-considered later at FEED or EPC phases or retrofitted at the utilization phase. Currently, the maintenance philosophy is discussed to some extend at the concept study phase. However, such study shall be widened, opening the space for the exploration of new maintenance philosophies. Therefore, it is concluded that Design out maintenance philosophy and Intelligent Preventive maintenance philosophy (DIP philosophy) like predictive and prescriptive shall be explored during the concept study phase. Predictive and prescriptive maintenance are relatively new philosophies that are being developed rapidly by several technologies like IoT, Machine learning, Big data, Digital twinning. Even though design out maintenance is a fairly old philosophy, it is often under-estimated in the concept study phase due to several reasons: (1) the existence of an industrial belief that original equipment manufacturer gives the best design and the highest reliable equipment, (2) the lack of previous and conclusive experience about several failure modes, or lack of client and vendor involvement, (3) Not being recommended or emphasized enough by some guidelines.

This paper proposes a quick and dirty worksheet to implement the DIP philosophy, which is applicable and simple for industrial purposes. The DIP study worksheet can be considered an effective communication tool between stakeholders at the concept study phase to collect inputs, brainstorm potential approaches, and guide further exploration of the technology. The DIP philosophy is implemented on offshore wind substations. The DIP study worksheet is filled, where the case study shows the apparent potential of design out and prescriptive maintenance to offer a more effective option than classical preventive philosophy. The filled DIP study worksheet for the cooling system of substation indicated the difficulty of implementing predictive maintenance philosophy, e.g., not providing the required detection earliness or predictive horizon to satisfy the desired maintenance scenario. A good aspect of the DIP study is to guide practitioners on which maintenance philosophy and technology shall be further explored and not ignore it totally at that stage. Ignoring a maintenance philosophy at the concept study phase means locking its potential benefits. Authors also recommend some updates in the NORSOK Z-008 to include the DIP philosophy and study.

The authors have also given a critical assessment of the DIP philosophy based on the big picture matrix. The big picture of DIP philosophy shows good potential over the mid-term interval, which is the useful life period. However, it also highlights the high capital investment and system complexity (level of instrumentations) during the short-term, the cyber security and over-maintenance cost as main negative issues for mid-term, and obsolete data and technology issues for the long-term (ageing). The
big picture also emphasizes that technology dependencies shall be carefully considered to keep the maintenance philosophy act in the desired positive manner and avoid falling into the negative impacts.

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