Reliability of Marine Energy Converters

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Editorial

Reliability of Marine Energy Converters

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1. Introduction

The oceans cover 71% of Earth's surface and are an enormous source of renewable energy which comes from tides, waves, ocean currents, and salinity and temperature differences. For example, the theoretical potential of wave energy is 29,000 TWh/year, and although for tides this value is much smaller—1200 TWh/year—it is still very large [1]; for comparison, the global electricity consumption in 2019 was about 23,900 TWh/year [2]. Despite this huge potential, the current contribution of ocean energy to global electricity production is insignificant: in 2020, its installed capacity was 524 MW and it produced 957 GWh, with most of which coming from tidal barrages; for comparison, in the same year, the global installed capacity of all renewable sources of energy was 2808 GW and they produced 7468 TWh [3].

To ensure the further development of ocean energy, and in particular of tidal and wave energy, large investments in these technologies are required, and for this a number of barriers need to be overcome. One of the major barriers is uncertainty associated with the installation and operation of marine energy converters (MECs), i.e., devices used for energy extraction from tides (tidal stream turbines) and waves (wave energy converters) [4]. This uncertainty is mainly due to the fact that these devices are new and have been barely tested; so, data on their failures are practically non-existent. As a result of this, there are serious challenges involved in establishing the failure mechanisms for MECs and their components, in characterising the damage/deterioration processes which can affect MECs and contribute to their failures, and in assessing the reliability of these devices. The latter is of high importance since MECs operate in harsh offshore environments and therefore may be inaccessible over long periods of time, and their maintenance and repair are usually costly. Thus, poor reliability of MECs will inevitably lead to their high OPEX and significant losses in energy production.

The reliability and availability of MECs strongly depends on environmental loads acting upon them, or more precisely upon the uncertainties associated with these loads. There is a substantial amount of work into the probabilistic modelling of environmental loads on marine structures from the offshore oil and gas and wind turbine sectors, e.g., Ref. [5]. However, these works are not fully transferable/applicable to MECs because of the specifics of the design and size of such devices, and also because they are intentionally placed in locations with strong currents and high waves.

This Special Issue aimed to address the gaps in the knowledge identified above and to contribute to the further development of the ocean/marine energy sector. The topics of interest for the issue included the following:

- Failure modes/mechanisms of MECs and their components and related damage/deterioration processes;
- Reliability assessment of MECs and their components;
- Reliability-based maintenance and inspection of MECs and their arrays;
- Probabilistic modelling of environmental loads acting on MECs.

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2. Special Issue Articles and Other Relevant Developments

Four papers were submitted to this Special Issue. The paper by O'Donnell et al. [6] investigated the dynamic responses of a catenary moored spar platform with various levels of damage. Such platforms are usually used for floating wind turbines but can also support wave energy converters attached to such turbines [7]. The paper aimed to examine different approaches toward damage identification in such platforms and their mooring systems. The investigation combined the testing of a scaled catenary moored spar platform, both undamaged and with various simulated damage conditions, in an ocean wave tank with a subsequent statistical analysis of the collected data. Two types of tests were conducted—free decay tests in still water and wave tests. Data obtained in the free decay tests were analysed to determine the natural frequency and damping ratio of the platform, while the acceleration time series recorded during the wave tests were used to derive the probability distributions of the acceleration responses. It was shown that the point characteristics of the platform response, such as the natural frequency and damping ratio, were not useful for the identification of the damage suffered by the platform. However, parameters of the probability distributions were sensitive to the different levels of damage and, therefore, were more suitable for the damage identification. The results of the paper may also be relevant to other types of floating catenary moored platforms carrying MECs.

Schoefs and Tran [8] considered how the deterioration process associated with marine growth (i.e., biofouling) might affect the reliability of a monopile subjected to wave loading. A monopile can serve as a supporting structure for tidal stream or offshore wind turbines. A stochastic model of marine growth thickness was presented. The model can be useful for assessing the long-term performance of various WECs, which are affected by biofouling. It was then shown how the model predictions can be updated using on-site inspection data and how this updating can be taken into account in the reliability assessment of the monopile based on a dynamic Bayesian network (DBN). The proposed DBN-based approach was then applied to compare different inspection schedules (i.e., times of inspection) over the service life of the monopile in terms of their effect on the reliability estimates of the latter. The approach can also be used for the time-dependent reliability assessment of MECs (in particular, in the context of optimising inspection schedules), whereby responses to environmental loads change over time due to various damage/deterioration processes.

The paper by Val et al. [9] addressed the problem of the reliability assessment of the mechanical components of power take-off systems of tidal stream turbines. Since this is a new technology, there are no historical data on their failures, which could be used for the estimation of their failure rates. To resolve this problem, the paper proposes a method based on the method of the influence factors, in which generic (or base) failure rates for components are adjusted to their actual operating and environmental conditions with the help of so-called influence factors. In the proposed method, base failure rates, influence factors, and resulting failure rates are treated as random variables. This enables one to account for various uncertainties associated with the method itself and also with the actual operating and environmental conditions of the components. Moreover, this allows one to take into account new information about the failures of the components in operating turbines via Bayesian inference. The method can be applied to determine and then update the failure rates of the various mechanical components of tidal stream turbines and other MECs.

In their paper [10], Yang and Sørensen presented a novel approach for estimating the probabilities of the availability states of an energy transfer network of an array of MECs. The approach was based on DBM and proposed as an alternative to traditional fault tree (FT) analysis. This allowed the authors to account for new information about the state of the network components and to calculate the time-dependent probabilities. The approach was applied to a simple energy transfer network, which included only cables and connectors, to illustrate how it could be employed to optimise the maintenance strategy with the objective of achieving the highest availability of the network. The approach can be extended by taking into account other components of MECs and costs, and can then be used to develop optimal maintenance strategies for MEC arrays/farms in terms of cost–benefit analysis.

It has been noted previously that MECs are a new technology, which have just entered the pre-commercial stage, and so data on their performance/failures are very scarce. Still, they have been around for more than 20 years, which means that some relevant information should exist. A recently published paper [11] presented data on the failures of 58 tidal stream turbines, which had accumulated about 1.4 million hours of operating time between 2003 and 2020. No such data have yet been published on wave energy converters (WECs); however, some useful information on their failure modes, the loads acting upon them, and their responses can be found in [12]. Regarding the reliability of WECs, the fatigue failure mechanism has attracted most of the attention; there have been a number of publications on this topic, e.g., Ref. [13], and more recently [14]. Various aspects related to the topics of interest of this Special Issue are also covered in the following recently updated design standards: IEC TS 62600-2 [15] and DNV-ST-0164 [16].

3. Further Research and Conclusions

Recent developments, including this Special Issue, have contributed to a better understanding of various aspects related to the reliability of MECs. However, there are still many challenges which need to be addressed. For example, [6] investigated damage identification in a catenary moored spar platform. However, this was achieved using scaled tests in a wave tank, and so the following question arises: how accurately do the results of [6] reflect the behaviour of such a full-scale platform under real conditions? There are also many other types of MEC floaters. Thus, much more work needs to be conducted for a better understanding of the impact of possible damages on the performance of MECs, in particular on their reliability, and of how these damages can be identified. This includes both scaled testing and data collection under real conditions. Marine growth (or biofouling) may have a major effect on the performance of MECs, both those with a fixed foundation and floaters. The model in [8] was developed for a static component—a monopile. Will it be applicable to moving components such as mooring lines and the electrical cables of floating devices, or floaters themselves? How will marine growth affect the performance of various MECs, including their reliability? Research on this important topic has just started and plenty is yet to be carried out.

The reliability assessment of the mechanical and electrical components of MECs is another major problem requiring more attention. The method presented in [9] may lead to large uncertainties in failure rate estimates, at least until sufficient new data about the actual performance of the components are collected. Moreover, for some components, information about their generic/base failure rates may be unavailable or it may not be possible to properly identify all of the relevant influence factors. In such cases, the method is inapplicable. A possible solution for this is to apply methods of structural reliability to the reliability assessment of such components, as was the case in [17].

The reliability-based maintenance planning of the arrays/farms of MECs is a relatively new topic of research. The methodology proposed in [10] is promising, but much further work is required to account for all of the relevant factors affecting the maintenance of MEC farms. In particular, the reliability of all devices and their components should be taken into account. Relevant costs and benefits should be included. Such farms are not always accessible for maintenance/repair due to environmental conditions (i.e., weather, tidal current speeds) and this also needs to be taken into consideration. Other factors, e.g., the availability of vessels for transporting maintenance crews, may be important as well. Another issue related to the reliability assessment of MEC farms is the probabilistic modelling of environmental loads. Available models do not take into account the interaction between MECs on a farm, which may have a major effect on the loads acting upon individual devices. The list of topics which require further attention can be continued.

Conflicts of Interest: The author declares no conflict of interest.

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