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A REVIEW ON THE REUSE POSSIBILITIES OF DECOMMISSIONED OFFSHORE FIXED PLATFORMS FOR MARINE RENEWABLE ENERGY APPLICATIONS

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Abstract:

There are ever-increasing efforts on utilizing non-conventional energy resources so as to reduce the global carbon footprint and reduce pollution caused by extensive use of energy from conventional sources. At the same time, the energy extraction from the abundant marine renewable energy resources which is available offshore need more development due to difference in the levelized cost of energy (LCOE) compared to energy extracted onshore, though the difference in the cost of energy is getting reduced faster than expected. Meanwhile hundreds of already existing offshore platforms in oil and gas industry will undergo decommissioning at the end of its life; which will require the platform to be removed or reused. In this context, the reuse possibility of such decommissioned offshore platforms to be used as support structures for marine renewable energy applications is examined. This paper presents a review on the research efforts on this topic and a discussion on the various aspects involved in the possible reuse of decommissioned offshore fixed platforms for marine renewable energy applications.

Keywords: Marine renewable energy, offshore fixed platforms, reuse, decommissioning.

NOMENCLATURE

CW	Capture width	J	Wave resource in kW/m
CWR	Capture width ratio	B	Principal dimension of WEC in m
P	Absorbed wave power in kW	η_1	Capture width ratio

1. Introduction

A significant share of global oil and gas resources are extracted from offshore locations. Thousands of fixed offshore platforms are installed in relatively shallow water areas globally, for the extraction of these resources. These platforms need to be decommissioned once the feasible production using the platforms is over. The design life of offshore oil and gas platforms is typically about 25 years or above. Once the design life is reached, the platforms are either considered for life extension or decommissioning based on economic feasibility, regulatory aspects etc.

Decommissioning of offshore platforms at end of its life, is a complex task involving huge costs and efforts. Many times, the decommissioning decision depends on the economic viability of the original design purpose while the structure may be still good for possible life extension or reuse. “Reuse” is one of the primary options when considering the decommissioning possibilities of a fixed offshore platforms in oil and gas industry. The possible reuse scenarios available for the earlier decommissioned platforms were limited and were seldom economical. Hence the most common decommissioning option selected is complete removal and disposal of the platform. However, as the global energy transition has been accelerated and the cost of energy from marine renewable energy sources is significantly getting reduced. This is particularly observed in offshore wind sector where due to continued research and development the wind farms are getting larger, with bigger turbines and resources at deeper water being utilised (Windeurope.org, 2020). More development and investment in offshore renewable energy sector is already visible. These developments again require offshore infrastructure similar to the offshore oil and

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gas platforms. The removal of the offshore platform, when there is a possibility for reuse is considered as a gap and economic loss for the stakeholders involved.

At the same time more and more efforts are expended on exploitation of renewable energy from marine resources which is abundant and reduces the global carbon footprint considerably. The marine energy devices used at offshore locations usually require foundations and offshore structures as support systems. This is again a significant capex which contributes to a major part of the cost of energy produced. A possible bridging of these gaps is the reuse of such old platforms as infrastructure for generation of power from marine renewable energy sources like wave, current, tide, wind, substations etc.

2. Discussions

2.1 Marine renewable energy sources at offshore locations with fixed support systems

Offshore marine environment is source of abundant renewable energy. Energy extraction from renewable sources is seeing continuous developments and, the world energy production from renewable sources has almost doubled from 2009 till 2018 (IRENA, 2019). It is also reported that (World Energy Council, 2016) more than 33% of world energy production is from oil resources. Energy production in marine renewable energy is primarily from offshore wind and tidal devices. Global offshore wind generation capacity was reported to be in the range of 28 GW in 2019 (IRENA, 2020b) which was roughly only 3% of onshore wind generation. Commercial scale development for extracting energy from other sources like wave energy, tidal energy and other sources are still in developing stage only even though some studies show the theoretical wave energy potential distributed globally is about 32 PW.h/year (Petawatt hour per year) (World Energy Council, 2016). The cost of energy from renewable energy extracted from offshore locations is very high compared to other sources and has been the main factor affecting the development and growth.

Wind energy is the most utilised form of energy at offshore locations. Wind technology is rapidly evolving and more and more commercial scale offshore wind farms being commissioned. Offshore wind sector had an approximate growth of 11% from 2017 in one year (Häfele, Gebhardt and Rolfes, 2019). Most common type of offshore wind units uses fixed bottom supports however floating type support systems are also in use and more under development which helps in energy extraction from deeper waters.

Oscillating Water Columns (OWC) and point absorber type of wave energy converters are the most common types, while numerous other types of wave energy converters are under research and development. Water movement exceeding 1 ms-1 has potential for energy extraction (Borthwick, 2016). Accordingly, there is possibility of utilizing ocean currents and tidal currents as energy sources at certain locations. These are identified as the major sources which have ‘technology ready’ energy conversion devices and a lot more types of devices are being conceptualised and under various stages of development.

There have been various studies and efforts carried out to estimate the wave energy and tidal energy potential in different parts of the world. Although the figures of potential capacities are theoretical, it gives a good indication on the quantum of unextracted energy potential and the importance of increased efforts on studies for efficiently extracting these. A study on the potential of tidal and wave energy in India (IREDA, 2014) shows the potential locations in India, stakeholders involved, barriers in development, recommendations and proposed action plan for achieving renewable energy targets as per policies of Indian government. Also there has been various studies addressing the factors affecting the development of energy from wave and tidal sources in offshore locations (Uihlein and Magagna, 2016) (IRENA, 2014a) (IRENA, 2014b) (Aderinto and Li, 2018) and identified as resource consistency and forecasting, environmental impacts, grid integration, extreme environments, capital and installation costs, operation and maintenance, social impacts, regulatory aspects, levelised cost of energy (LCOE) etc.

The wave energy at offshore oil and gas platforms is generally considered as problem (Falcão, 2010), but the same is also a chance as it is a source of energy which can be utilised. Regions with wave energy potential in the range between 20 kW/m and 70 kW/m are considered as good locations for energy extraction.

The performance or efficiency of already developed wave energy devices will assist in selecting the type of energy converting device which can be associated with fixed offshore platforms. The hydrodynamic power performance of a wave energy converter is usually expressed in terms of the parameter “capture width ratio” (CWR). Capture width (CW) is obtained by dividing the absorbed wave power P (in kW) by the wave resource J (in kW/m):

$$CW = P/J \ \text{m} \tag{1}$$

CWR (denoted by η_1) is a measure of the hydrodynamic efficiency. It is expressed as the ratio of capture width, CW to the principal dimension of the WEC, represented by B, devise width. CWR represents the fraction of wave power absorbed by the device,

$$\eta_1 = CW/B = P/(J^*B) \tag{2}$$

In some previous research (Babarit, 2015) a database of the capture width ratio of different types of wave energy converters including Oscillating Water Surge Converters (OWSCs), overtopping devices, and heaving devices was generated. The database shows that fixed OWSCs as most efficient followed by heaving devices among the technology ready types considered.

Levelized cost of electricity (LCOE) is defined as the ratio of the sum of the costs over a lifetime to the sum of electrical energy produced over a lifetime. Indicative LCOE for marine renewable energies are in the range of 120-470 $/ MW·h for wave, 130-280 $/ MW·h for tidal whereas 240 $/ MW·h for offshore wind as reported in 2015 (World Energy Council, 2015). The LCOE of offshore renewable energies are much high compared to other conventional energy systems and renewable energy extracted from onshore locations; which hinders the virtually unlimited energy potential offshore. However, the trend shows that this LCOE have been declining over time owing to the developments in technology. This LCOE of offshore wind has come down to a range of 115 $/ MW·h in 2019 (IRENA, 2020a). The advances in energy storage systems (World Energy Council, 2020) has also contributed considerably in reducing the LCOE of marine renewable energy. In different researches (Ioannou, Angus and Brennan, 2018) (Myhr et al., 2014), the various factors affecting the costs involved in an offshore wind farm development is studied.

2.2 Support structure design of marine renewable energy sources at offshore locations

Initially developed commercial scale offshore wind turbines mostly use fixed type support structures like gravity bases, monopiles, tripods and jacket structures. Tripods and jacket substructures are used in deeper waters compared to monopiles and gravity units. Jacket type foundations are similar in structural configuration to that of offshore oil and gas platforms which are designed for supporting huge topside facilities weighing several thousand tonnes. Jacket substructures are connected to the ground by piles based on the soil type which provides good support against extreme waves and harsh environments. For wind turbines, a coupled analysis with the turbine and jacket including pile-soil interaction is usually required. The jacket design normally follows typical design methodology as that of an offshore oil and gas platforms including inplace analysis, preservice analysis, fatigue analysis, ultimate strength analysis etc.

Several studies had been carried out on alternate and simplified methods of analysis which can be used in preliminary assessment however will not exclude the requirement of full structural analysis. Some research studies includes a simplified method by checking the most stressed pile of an offshore platform against ultimate and dynamic loads (Alessi, Correia and Fantuzzi, 2019) and optimisation study of jacket type substructures for offshore wind turbines (Häfele, Gebhardt and Rolfes, 2019). For fixed wave and tidal energy devices, an open-source tool “DTOcean” (Weller et al., 2018) was developed which can assist in selection of foundation configuration. These can be used for comparison of the support systems based on aspects such as reliability, economics, and environmental impact.

There are several industry standards and guidelines available for the design of support structures of fixed offshore renewable energy converters. The International Electrotechnical Commission (IEC) has developed design guidelines for renewable energy converters. IEC 62600-2 (IEC, 2016) provides guidelines for design of marine energy converters (MECs), for a specified life. It details provisions to assess the structural integrity of the support structure, foundations, piles etc. to resist global loads. The design guidelines mention that due consideration shall be given to aspects related to the relevant limit states including ultimate limit state (ULS), serviceability limit state (SLS), fatigue limit state (FLS) and accidental limit state (ALS). This specification gives guidance based on Load and Resistance Factor Design (LRFD) methodology.

DNVGL ST-0126 (DNVGL, 2016) standard specifies guidelines for the design, material selection, loads to be considered, geotechnical aspects and structural analysis of support structures of wind turbines including towers, jackets and foundations. API RP 2A (API, 2000) is widely used code for the design and analysis of jacket structures in offshore oil and gas industry. It gives extensive guidance in the analysis of jacket structures covering all aspects including all structural components, anticipated loadings, and various limit states. However, for the static and dynamic analysis of a wind turbine substructures, the procedure followed includes modelling the combined effects of wind and wave loadings (Ashish and Panneer Selvam, 2013).

Offshore structures are exposed to cyclic loads due to hydrodynamic loadings and hence fatigue is an important criterion in design of such structures. This is further more important if the structures are dynamically sensitive. When jacket structures are used as supports for wind turbines the dynamic response and resonance with the combined action of aerodynamics and hydrodynamics will be more significant due to the added effects of dynamic wind loading. Accordingly, fatigue loading can be much more than a traditional offshore oil and gas platform and fatigue limit state is often governing condition for wind turbine support structures (Gao et al., 2015). This calls for the requirement of accurate modelling and analysis combining different combinations of wave and wind loadings.

Oscillating water columns (OWC) are one of the simplest and efficient type of wave energy converter. The advantage of OWC is that it does not have any moving parts and it can be integrated to fixed structures. Commercial scale OWCs are generally installed in near shore area, occasionally integrated with breakwaters. It may be possible that OWCs can be integrated with fixed platforms at offshore locations, however the loading on the offshore platform will be changed from its original design considerations. Some research works has been done on analysing the energy balance of an offshore OWC based on computational fluid dynamics (CFD) (Elhanafi et al., 2017) and physical experiments (Ashlin, Sannasiraj and Sundar, 2015) which give guidance on loads generated at OWCs.

2.3 Hybrid renewable energy converters at offshore location

The support structures of an offshore renewable energy converter can be a significant factor in the CAPEX which in turn increases the cost of the energy produced. At the same time, the same offshore location may have multiple sources of renewable energy like wind, wave, current etc. Hence it is logical to consider hybrid energy converters which houses multiple energy devices in same support structure or co-existing wind and wave energy converters in same field for increased efficiency and reduction in energy cost. Various types of hybrid converter concepts and multiuse concepts have been studied globally (Rusu and Onea, 2018) (O'Sullivan, 2014) (Zanuttigh et al., 2016) (Aryai et al., 2021). Studies on different combinations of systems shows that hybrid converters are able to maximize power output, increase predictability, share infrastructure for supports as well as power transportation, increase in capacity factors, stability of electrical power generated and transferred to grid, reduction in operating and maintenance costs potentially leading to a reduction in the levelized cost of energy (LCOE).

'WindWaveFloat' (WWF) by National Renewable Energy Lab (NREL, 2012), is a concept of integrating a wave energy converter in a floating semi-submersible type wind turbine platform. Hybrid wind-wave energy system (HWWES) (Ding et al., 2015) is another concept of combining floating wind turbine and wave energy converter. Deep Ocean Wave Energy Converter (DOWEC) (Chandrasekaran, Raphel and Saishri, 2014) is a concept of integrating wave energy converters to a semi-sub floating unit. Integration concept for multiple kinds of energy into electricity is studied in the hybrid system W2P (Chen et al., 2016)

There have been some studies carried out on the integration of offshore wind turbines with fixed substructure and wave energy converters including the challenges (Boo, Kim and Choi, 2016). The main factors to be considered in feasibility of such hybrid units are identified as resource assessment, selection of wave energy converter and integration of wave energy converters to the substructure (Pérez-Collazo, Greaves and Iglesias, 2015) (Perez-collazo et al., 2013). Further, studies have been conducted on the hydrodynamic response of a hybrid wave energy converter including a jacket frame and a OWC wave energy converter as shown in Figure 1 based on physical model experiments (Perez-Collazo, Greaves and Iglesias, 2018). This has shown the modified hydrodynamic response of the system when an OWC converter is integrated with the substructure and reports the efficiency of the OWC which are based on the oscillation of free surface and changes in pressure inside the chamber. The study (Perez-Collazo and Iglesias, 2012) has also proposed some hybrid energy converter for wind energy converter monopile substructures as in Figure 2, combining with OWCs and point absorber type WECs. This also shows preliminary estimation of capture width ratios and power comparison between the wind turbines and WECs for the options considered.

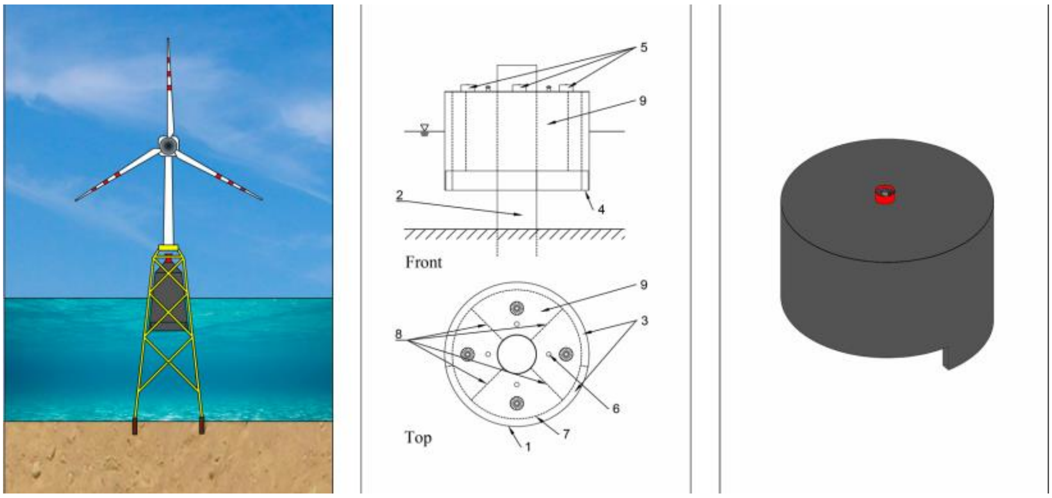

Figure 1: Hybrid wind wave system with jacket substructure proposed by Perez-Collazo et al. (Perez-Collazo, Greaves and Iglesias, 2018)

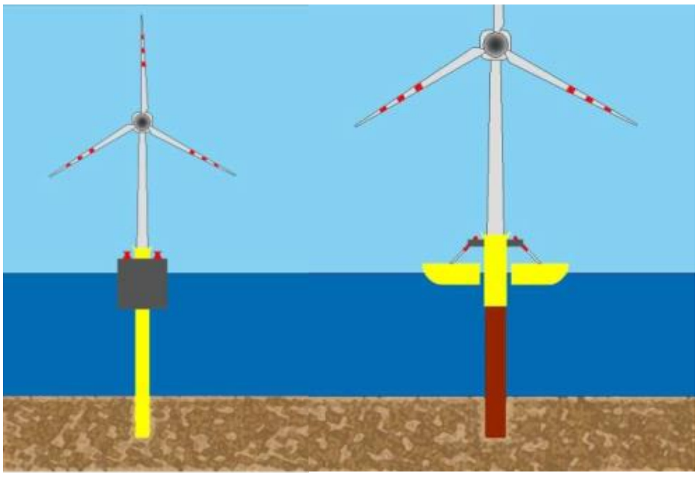

Figure 2: Hybrid wind wave system with monopile substructure proposed by Perez-Collazo and Iglesias (Perez-Collazo and Iglesias, 2012)

The mermaid project (Seventh Framework Programme, 2015) identified a new methodology developed to incorporate different types of energy converters inside multi-use offshore platforms (integration of multiple converters in single platform) or inside offshore farms (integration of multiple single devices in the available space in the offshore farms) as shown in Figure 3. It also proposes the minimum resource value required to include the studied resource in the multi-purpose offshore farm.

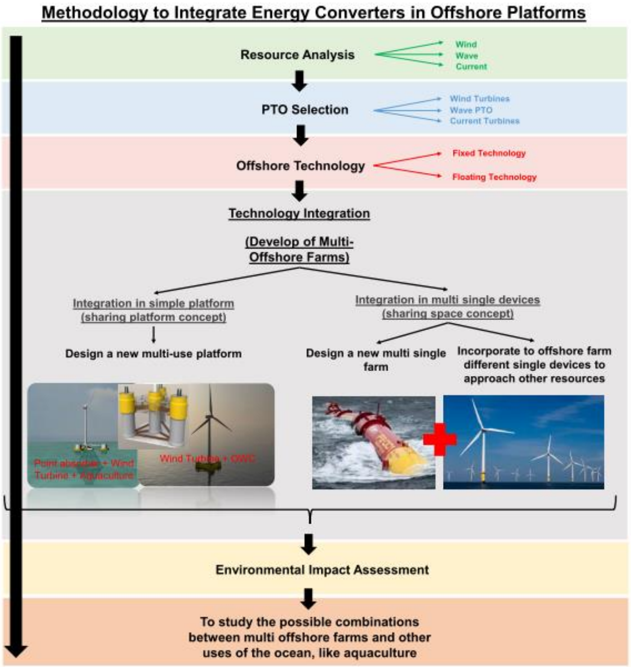

Figure 3: Proposed methodology to integrate WECs inside offshore platforms (Seventh Framework Programme, 2015)

Based on these studies it is clear that “multi-use platforms” or integration of multiple energy converters and energy storage systems in a single platform are a strong proposition to be considered. Utilising a common support structure for multiple devices can increase the efficiency of the system. Similar concepts can be a considered for reuse scenarios of decommissioned offshore oil and gas platforms.

2.4 Integration of renewable energy systems to offshore oil and gas platforms

MARINA Platform (Sojo and Auer, 2014) is a collaborative R&D project to study combined offshore renewable energy systems. This project was aimed to develop protocols for engineering and economic evaluation of hybrid renewable energy platforms. The project included selection of multiple energy converters for integration, and development of the tools for evaluation of different options considered based on criteria on the Cost of Energy (CoE), install-ability, constructability, operation and maintenance and survivability. The multiple cases considered includes various combinations of floating and fixed type supports together with integration of wave, wind and tidal energy converters attached to those.

A feasibility study was conducted in 2017 for the design of an ocean wave power generation station integrated with a decommissioned offshore oil jacket platform (Azimov and Birkett, 2017) as shown in Figure 4. This study has considered an existed decommissioned platform and integration of wave energy devices suiting the size and arrangement of the platform considered comparing efficiency and life cycle. A theoretical estimate of power generated and revenues were estimated. This shows the theoretical power generation capacity of typical oil and gas platforms considered for decommissioning. The overall costs of energy from such a station are considered to be much lower compared to a new station due to the combined effect of saving of decommissioning costs as well as reduction in new infrastructure costs.

The fixed offshore oil and gas platforms are generally jacket type structures. The structural arrangement of jacket type structures is designed primarily to support the topside weights and functional loads and at the same time aiming for minimal exposure to environment loads like wave, wind etc. Hence it is important to consider the integration of energy converters to the jacket structures for multi-use case. Offshore wind turbines generally use jacket type substructures and hence the integration of such turbines on an existing platform may require modification above water level only. However fixed wave energy converters like OWCs if added needs to be in the wave zone which not only adds the hydrodynamic loads on the platform but may also requires subsea structural modifications. Also, for older platforms there is possibility that many structural components will be corroded especially in the splash zone and accordingly there can be requirement of repairs and strengthening of certain members in case of reuse. There are different types of repair techniques used in offshore platforms including subsea welding repairs, repair by grouted clamps etc. (Harwood and P, 1988) (Nichols and Khan, 2017). The effectiveness of integration will thus depend not only on the efficiency of the energy converter, but also the capital and operational expenditure required for modifications, strengthening, operational aspects etc. required for the reuse case.

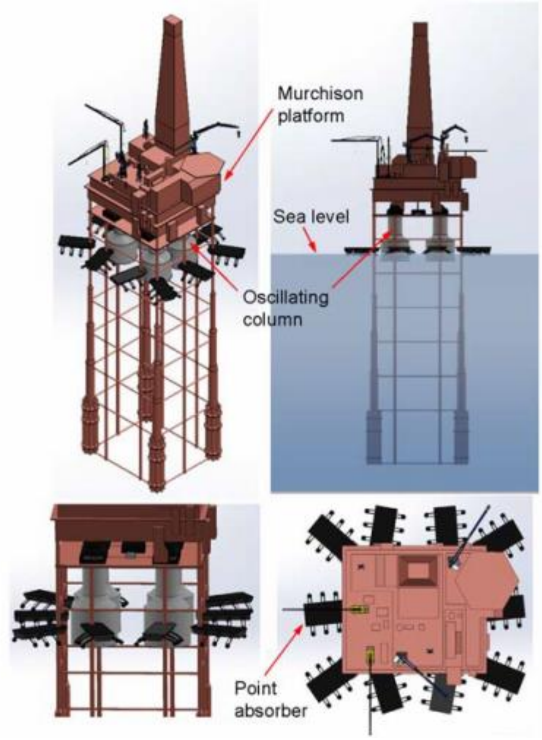

Figure 4: Concept assembly of wave power station integrated to the offshore platform proposed by Azimov and Birkett (Azimov and Birkett, 2017)

2.5 Reuse of fixed offshore platforms

Regulations stipulate that oil and gas platforms are to be decommissioned at the end of its production life. The decommissioning of offshore oil and gas platforms incurs huge costs. Majority of the cost are associated with removal and disposal of the platforms. The usual options considered in a decommissioning scenario includes complete removal, partial removal, rig-to-reef (Bull and Love, 2019) (Smyth et al., 2015) or reuse (Zawawi, Liew and Na, 2012). There are numerous platforms around the world which has to go through decommissioning now or in the near future. At the same time renewable energy sector is more and more expanding in offshore locations which brings the situation of parallel decommissioning and construction activities of two separate industries possibly in same locations. These decommissioned platforms can open potential reuse possibility for these offshore renewable energy infrastructures (Capobianco et al., 2022). Though several studies (Oudman, 2017) (Bernstein, 2015) (Alberti di Catenaja et al., 2005) and national policies (EBN, 2017) mentions the reuse option for alternate energy, there has been only limited studies on the detailed feasibility of such options.

One possibility of reuse of offshore oil and gas platforms is use for conversion and storage of energy produced from offshore wind farms. Jepma and Schot (Jepma and Schot, 2017) proposed the possibility of reusing old platforms as a base for conversion of electricity produced to hydrogen (power-to-gas) and subsequent transport of the hydrogen to shore using the existing pipeline systems. A technical feasibility of the reuse of oil platforms for wind power generation in Brazilian context has also been carried out (Barros et al., 2017) and (Quissanga, Antonio Do Nascimento and Galgoul, 2020). These studies included an analysis of wind potential, global market tendencies, structural capacity of jackets and an evaluation of LCOE for reuse of a decommissioned platform to be used as wind turbine support structure. Though the LCOE was obtained higher when compared to onshore wind energy, it shows a promising opportunity considering the costs associated with decommissioning. The project "RELife" (Leporini et al., 2019) considers the technical, environmental, and commercial aspects of decommissioned platforms to be converted to assist renewable energy generation. It has been concluded that various options for conversions represents very profitable scenarios.

The financial analysis of the reuse option involves an important role in the selection of reuse option during decommissioning. Several studies have been performed on business models (Basile and Vona, 2021) (Zagonari, 2021) (Capobianco et al., 2021) and financial analysis using Net Present Value (NPV) and considering other non-financial factors also in a reuse scenario for decommissioning (Al-Ghuribi et al., 2016)

2.6 Structural strength assessment of old fixed offshore platforms

There are several industry guidelines which address the structural strength assessment of existing aged fixed offshore platforms. API RP 2SIM (API, 2014), which is a recommended practice for the structural integrity management of fixed offshore structures and is intended is to provide guidance on structural integrity management (SIM) of existing fixed offshore platforms. The SIM process has been developed around internationally recognized industry standards including API RP2A (API, 2000) and is based on global industry best-practices.

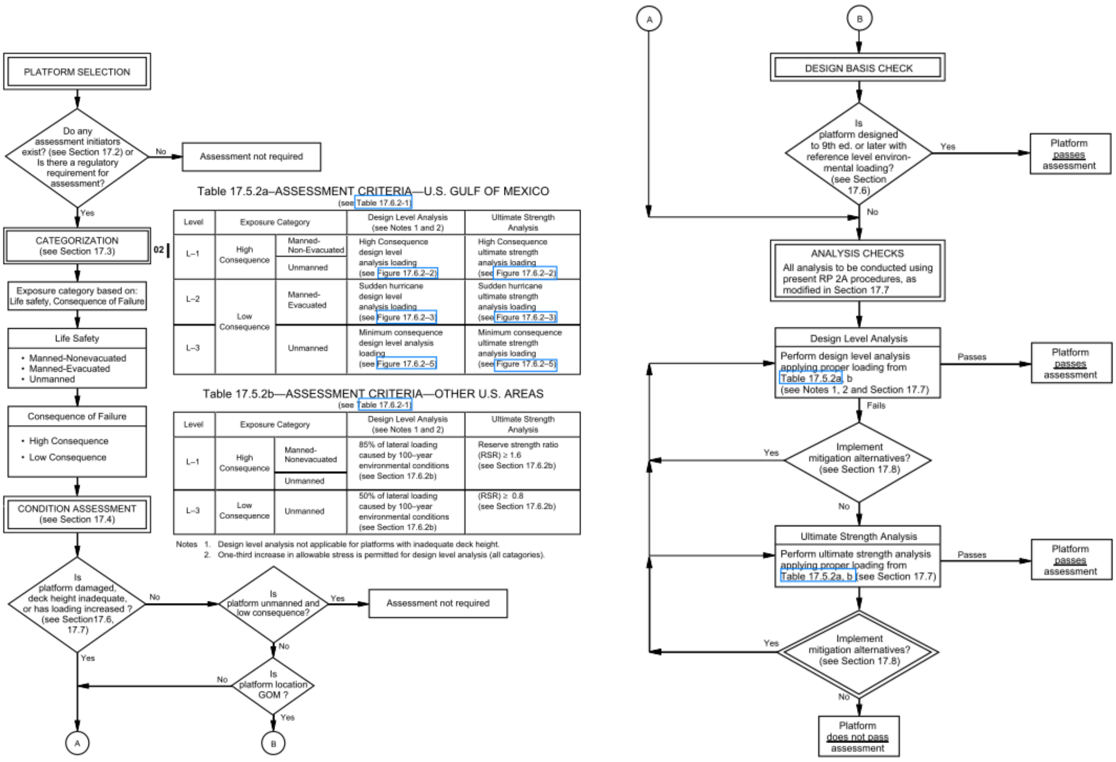

Table 17.5.2a–ASSESSMENT CRITERIA—U.S. GULF OF MEXICO
(see Table 17.6.2-1)

Level	Exposure Category		Design Level Analysis (see Notes 1 and 2)	Ultimate Strength Analysis
L–1	High Consequence	Manned-Non-Evacuated	High Consequence design level analysis loading (see Figure 17.6.2–2)	High Consequence ultimate strength analysis loading (see Figure 17.6.2–2)
		Unmanned		
L–2	Low Consequence	Manned-Evacuated	Sudden hurricane design level analysis loading (see Figure 17.6.2–3)	Sudden hurricane ultimate strength analysis loading (see Figure 17.6.2–3)
L–3		Unmanned	Minimum consequence design level analysis loading (see Figure 17.6.2–5)	Minimum consequence ultimate strength analysis loading (see Figure 17.6.2–5)

Table 17.5.2b—ASSESSMENT CRITERIA—OTHER U.S. AREAS
(see Table 17.6.2-1)

Level	Exposure Category		Design Level Analysis (see Notes 1 and 2)	Ultimate Strength Analysis
L–1	High Consequence	Manned-Nonevacuated	85% of lateral loading caused by 100–year environmental conditions (see Section 17.6.2b)	Reserve strength ratio (RSR) ≥ 1.6 (see Section 17.6.2b)
		Unmanned		
L–3	Low Consequence	Unmanned	50% of lateral loading caused by 100–year environmental conditions (see Section 17.6.2b)	(RSR) ≥ 0.8 (see Section 17.6.2b)

Notes 1. Design level analysis not applicable for platforms with inadequate deck height.
2. One-third increase in allowable stress is permitted for design level analysis (all catagories).

Figure 5: Platform assessment procedure of existing platforms as per API (API, 2000)

API RP2A WSD (API, 2000) has guidelines for strength assessment of existing platforms based on the collective industry experience which can be applied for reassessment of old platforms. These provides a guideline for factors involved in reassessment including the type of information required, the criteria to be used, design level or ultimate strength level analysis which can be employed, together with guidance on possible mitigation measures. This recommended practice is widely used to determine the "fitness for purpose" of aged platforms. The procedure for platform assessment is shown in Figure 5.

NORSOK standard N-006 (NORSOK, 2009) also gives guidance for re-assessment of existing offshore structures which exceeds its original design life. This gives guidance for utilising the service life, historical data and advanced analysis methods in assessing the structural integrity.

The assessment of aged platforms need not be similar to that of design and analysis of new platforms. Depending on the age, environmental conditions, and maintenance the condition of an offshore platform can vary significantly in various locations. Also, the fatigue strength can significantly vary based on the operation history, operating environment during its lifetime which could have contributed to significant fatigue damage (Heo et al., 2022). Because the structure may have significant degradation and corrosion, the structural strength assessment usually utilises advanced analysis like ultimate strength assessment. The strength assessment can identify whether the structure can maintain a satisfactory level of safety for continued operation in its as-is state or by strengthening

(Hamid et al., 2013) and the proposed modifications (Nichols and Khan, 2017) which can be minor or major based on the level or degradations (Bai et al., 2015) (Moan, 2018). Alternate risk-based structural integrity management methods based on risk assessment and accordingly develop inspection plans (Guédé, 2019) are also used in case of offshore jacket platforms.

A feasibility study done in 2013 (Alluri et al., 2013) shows an analysis carried out to find an optimum wind turbine capacity and suitable substructure configuration on fixed platforms for offshore wind turbines. Monopile and jacket were the two fixed type substructure concepts analysed for prevailing site and environmental conditions for supporting offshore wind turbine and there are several industry guidelines for the design and numerical analysis of the same (The European Marine Energy Centre Ltd, 2009) (Gao et al., 2015). Several works (Ersdal and Ho¨rnlund, 2008) (Stacey, Birkinshaw and Sharp, 2008) have been globally carried out in addressing the strength assessment of ageing offshore platforms for extended operation for units that have serviced well beyond its original design life. In several instances, it was found that the existing condition of very old units was not good for the proposed life extension but still showed satisfactory results with different retrofitting options considered for the life extension. There has also been some works which tries to develop frameworks to assess structural strength and remaining fatigue life more accurately like a proposed model (Aeran et al., 2017) to capture time-dependent structural degradation by more precise corrosion models. In order to enable overriding the platform age and other inherited characteristics of the platform, global ultimate strength assessment can be performed to evaluate the as-is condition of the platform and establish the Reserved Strength Ratio (RSR) of the system.

3. Conclusions

In the review, various renewable energy technologies applicable at offshore locations are reviewed and matured technologies using fixed supports are identified. Various ideas and research efforts on multi-use platforms around the world are studied. The existing concepts of multi-use platforms and the guidelines for design and development of such platforms are identified. Though there are some existing concepts of multi-use platforms, it is noted that there are only very few works related to reuse of fixed offshore platforms as support structures of multi-use platforms. The factors considered for the economic feasibility and LCOE of the multi-use platforms will have significant difference in the case of "reuse" rather than that of a new platform. Hence many configurations of energy converter combinations which was opted out in previous studies may be a good option for re-evaluation.

There are different possible "reuse" scenarios available for decommissioned offshore fixed platforms to be used for renewable energy applications. This includes use of these platforms as support structures for energy converters, substations, energy storage applications etc. This opens a chance of a cost-effective synergy between the ever-increasing offshore oil and gas decommissioning market and increasing offshore renewable energy market. The structural assessment of aged offshore platforms reused for renewable energy converters may require a combination of considerations and guidelines applicable for offshore oil and gas and offshore renewable energy sector which may need to include the consideration of combined loads of aerodynamic loads with modified hydrodynamic loads, various limit states including ultimate strength and fatigue etc. When an aged jacket type structure in offshore is to be reused, essentially it involves repairs, modifications, strengthening etc related to life extension and associated cost factors. Hence considering an aged offshore platform for reuse in renewable energy application shows a value proposition however at the same time the efficiency of reusability depends on the effectiveness of integration of the energy converters as well as considerations of economic implications required for conversion and management.

The review clearly shows a gap in efforts for identifying the structural adequacy of decommissioned platforms for such a reuse and any recommendations for identifying the feasibility of this concept. Considering the fast pace of energy transition focused on marine renewable energy in offshore locations and decommissioning of oil and gas fixed offshore platforms, much more research efforts is needed towards the reuse possibility of such platforms considering various aspects involved.

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