Reliability assessment of offshore floating renewable structures by AHP methodology

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Abstract

The aims in selection the power generation system at offshore renewable energy production structures are the sustainability and the reduction of risk in order to achieve efficient operation, to enhance environmental friendly behaviors, to increase the safety and positively contribute to the overall operability management of the systems. In this article the use of multi criteria decision method on offshore energy structures is presented in order to provide, through the application of analytic hierarchy process (AHP) method, a model for assessing reliability based on qualitative (historical data) and quantitative (experts opinion) characteristics. According to the above method, data are evaluated and compared in pairs and the results may provide information on the improvements that will be included in the development of offshore structures in order to increase the probability of success, the structure reliability in energy production and its sustainability, depending on the choice of technology which will be installed. A field study for a floating desalination unit working with wind and waves installed in an isolated Greek island is presented to verify the proposed methodology. The results will assist the development of similar designs of large scale floating offshore installations which are essential in fighting water scarcity and electrification of isolated insular areas.

Keywords: Renewable Energy assessment; AHP; Multi-Criteria Decision Making

1. Introduction

The challenge to found clean, sustainable alternatives to fossil fuels has increased rapidly in recent decades. Furthermore energy efficiency is among the main factors for ensuring sustainable development and the entire energy generation industry must change from fossil fuels to renewable energy sources – the sun, wind, waves and tides. Hence, the vast energy reserves of renewable energy sources can help to ensure that future adequacy with low cost and to provide independence from fossil energy sources. Immense challenges and opportunities lies ahead as the global energy industry makes this change to the inbred energy production.

The construction of offshore wind farms has been extended in many European countries, but off-shore wind energy will soon need to address areas beyond the shallow, congested southern North Sea if the goals set by policy makers and industry are to be reached. Most other seas with good wind are much deeper, making fixed foundations uneconomic.

This sector is quite underdeveloped in Greece. Up until now, there isn't any offshore wind farm under operation, while 37 studies are waiting for approval, three are in the stage of early planning and five have already been rejected [1]. On these sectors should be added the offshore desalination unit that works autonomous in pilot operation at Aegean Sea with power from a wind turbine [2].

The offshore systems are very large and complex and they include technical, economical, environmental and social components [3]. So the key factors that should be taken into account for the viability of renewable energy power systems are environment adaptation technology advances, economic feasibility and social acceptance. Nowdays offshore renewable energies installations show a great potential for further exploitations in this framework [4]. Thus exploitation aim of the abundant energy resources, either from the wind or from sea waves should be investigated and ensure that in the long term, the supply of energy will come from reliable, safe, efficient and economical accessible natural sources.

The aim of this article is to provide through an integrated implementation of analytic hierarchy process (AHP) multicriteria analysis a tool in order to select the most appropriate power generation installation in offshore structure. This method can be used for evaluation of an offshore system either for the provision of electricity to the mainland or for the consumption expected in an integrated production system for drinking water as this research. Accordingly, the first part introduces the aspects related the power production from wind, wave and the combination of wind-wave technologies, and an introduction of AHP method, while the second illustrates the application of the method for evaluate each technology, followed by a discussion of the results obtained from this analysis.

2. Renewable power production technologies

The main factors that affect the selection of a technology for offshore structures have to satisfy the friendly to the environment and the autonomous operation. Environment friendly means that it does not have any side effects and autonomous means that the floating structure operates unmanned and that energy became from renewable source. The selected evaluation systems are the following:

2.1. Wind turbine system

The main application of offshore wind turbines is the production of electricity and its channeling into the mainland electrical grid or into a local grid. The coupling of wind turbines with desalination systems now is technically feasible, and the desalination systems driven by wind power could be a common renewable energy desalination plant.

The investigated pilot wind turbine model has the following features: (a) It has 30 kW in power, (b) Variable pitch of blades and (c) Variable speed. The role of the wind turbine is to provide energy for the desalination of sea water. During the system operation resulting that when the wind speed is high increased the available energy and the system produces more water. When the wind speed is low, energy production decreases and resulting less water production with a lower operational limit the 5KW. The mean water production in this case to the system installation area was 2,49 m^3/h. This is the result based on the recorded data of the pilot system.

2.2. Wave exploitation system

The other under consideration system of energy production is an exploitation system of wave energy. The global distribution of wave power resource is expressed in the Figure 1.In this figure the wide range of wave energy statistics for the offshore data points distributed along the Atlantic and Mediterranean European coasts is illustrated and the largest potential are in east Mediterranean Sea. On the other hand a large number of concepts (over 1000 techniques) are available for wave energy conversion (WEC) [5], which have been patented in Japan, North America, and Europe. Despite this large variation in design, WEC generally can be classified by their positions (on-shore, near-shore or offshore), by their size (point absorbers, versus large absorbers) or by their operating principle.

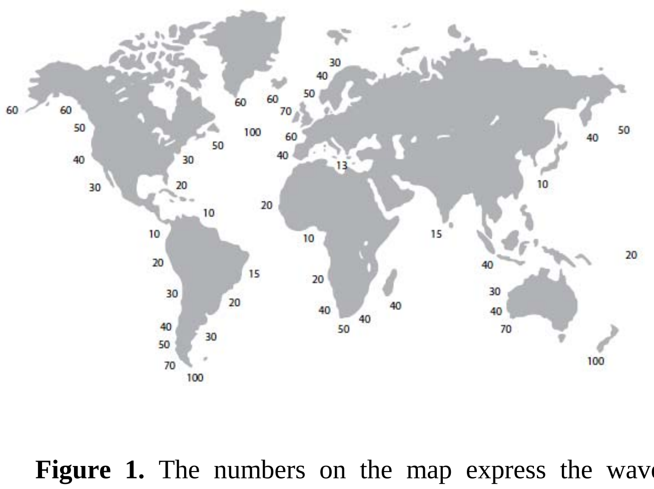

Figure 1. The numbers on the map express the wave energy potential at the specific site – the higher the number, the greater the potential (kW/m) source: www.ecowavepower.com T.W. Thorpe.

Shoreline systems have advantages like their position which being close to the utility network, can easy overhauled, and as waves reach the coast attenuated as they travel through shallow water they have a reduced likelihood to be exposed in extreme weather conditions [6]. But this is one of the disadvantages because the waves due to the shallow waters loose some of their energy. The devices are installed in relatively shallow waters and attached to the seabed, which provides an appropriate stable base on which the oscillating body can operate, but like the shoreline devices drawback as shallow water causes a decrease in potential energy of the wave. Finally offshore devices are generally installed in deep waters. The advantage of installation a WEC in deep water is that it can obtain the exploitation of greater amounts of energy because of the higher energy content in deep water waves. In this paper regarding the needs of the under consideration desalination system the model studied was designed and constructed for the exploitation of wave energy. The data used in this article was exported of the research and implementation of this wave energy system which was put into autonomous operation as a trial. The specific wave devise has the following characteristics a) Wave front of 8 meters, b) Hydraulic power 25 kW, even if the waves have more power and c) It utilizes 11% of the available wave energy. Also, it is worth mentioning that while wind varies significantly even at five minutes intervals, waves remain stable enough for long periods [7]. The results obtained from the trial operation of this system on producing water from desalination system in the investigated period of five years in weather conditions of the area that was installed was 2,14 m^3/h.

2.3. Wind and wave combination system

The combination of a wind turbine in a platform with a wave exploitation device becomes an important contributor to energy production as in this case of desalination system. The advantages of combining offshore wind and wave energy into a single power production system include reduced hours of zero power output and reduced interhour variability. Both advantages facilitate the integration of variable renewable energy production to power grid [8]. The different power output profile of combined systems allows for a reduction in the required capacity of an offshore batteries storage system which allows the safe system operation. The design of a system which could anchor in deep water in areas where wave and wind conditions are ideal ensures a high level of predictable and almost constant energy production.

With regard to the water production, the combination of wind and wave device [9] can give greater water production, as we can observe from the following Figure 2. As it becomes easily understandable in the case in which only the wind turbine operates, much less water is produced compared with the case in which both wind turbine and wave device operate together. The reason is that waves remain stable enough for long periods compared with the wind, which can vary significantly [10].

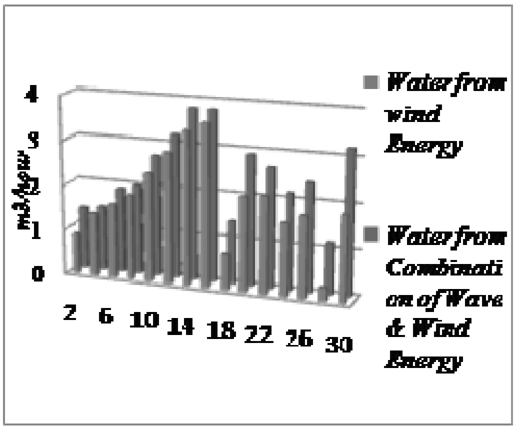

Figure 2. Every 3 hours mean water production in a month.

The most indicative finding of the combined power output is the smoother operation which provides higher availability than the individual productions systems. Both the peaks and the fast changes found in the individual productions are reduced when these are combined, and the percentage of time with null production reduces to a minimum. Variability reduces up to 31% and the percentage of time with zero production decreases to 6% [11]. The quantity of the produced water when a combination of wave and wind energy system that powering the desalination system is used, is increased compared to the previous systems, and can give a mean water production of 3,26 m^3/h.

3. AHP Methodology

The AHP is a methodology consisting of structuring, measurement and synthesis, contributing to help decision makers to cope with complex situations proposed by Saaty in 1980 [12][13]. Use of pairwise comparisons has inspired the creation of many other decision-making methods. Besides its wide acceptance, it also created some considerable criticism; both for theoretical and for practical reasons [14].

Step-by-step procedure in using AHP is the following: First define decision criteria in the form of a hierarchy of objectives. The hierarchy is structured on different levels from the top (the goal) through intermediate levels (criteria and sub-criteria on which subsequent levels depend) to the lowest level (the alternatives).

Then the criteria, sub-criteria and alternatives are evaluated according to their influence and their importance for the corresponding element of the higher level. For this purpose, AHP uses simple pairwise comparisons to determine weights and ratings so that the analyst can concentrate on just two factors at one time. One of the questions which might arise when using a pairwise comparison is: how important is the "economic feasibility" factor with respect to the "Social acceptance" attribute, in terms of the "Reliability of offshore floating" (i.e. the problem or goal)? The answer may be "equally important", "weakly more important", etc. The verbal responses are then quantified and translated into a score via the use of discrete 9-point scales Table I.

Table I: Scale used for pairwise comparisons.

Intensity of importance	Value description	Explanation
1	Equal importance.	i and j are equally important
3	Weak importance	i is slightly more important than j
5	Strong importance	i is strongly more important than j
7	Very strong importance.	i is very strongly more important than j
9	Extreme importance	i is absolutely more important than j
2,4,6,8	Intermediate values	When a compromise in judgment is needed.

After a judgment matrix has been developed, a priority vector to weigh the elements of the matrix is calculated. Then Consistency Index *(CI)* and consistency ratio *(CR)* calculated to ensure the consistency of Criteria and Alternatives with respect to the Goal and finally the final priorities are calculated. If the matrix is inconsistent, evaluating must be made until a consistency is achieved. The calculation of inconsistency index as a ratio of the decision maker's inconsistency and randomly generated index is one of AHP major advantages. Because through this index the decision maker assures him that his judgments were consistent and that the final decision is made well. The inconsistency index should be lower than 0.10. Otherwise, a higher value of the inconsistency index requires reassessment of pairwise comparisons, decisions obtained in certain cases could also be taken as the best alternative [15]. This matter of multiplying and adding carried out over the whole of the hierarchy and the results give to us the overall priorities and the solution for making the decisions.

4. Evaluation model and Results

Offshore renewable and efficient energy systems are preferred because they produce clean energy, but unfortunately none of the alternative systems can meet all the requirements solely. As pointed the three alternatives are the wind turbine system, the wave system and the combination of wind and wave system. In order to assess the reliability of the different renewable energy production systems are used and each technology is compared with the others. The criteria that are considered to assess the reliability and adequacy of selected systems in this study are:

- The adaptation flexibility in technology advances, which include the reliability of the system as result of technological maturity and the adaptation ability of each system to the technology improvements.
- Environmental impact of its installation to the surrounding ecosystems and conformability on new environmental demands are done without very costly modifications.
- The Economic Feasibility which includes the investment cost in comparison to service life, the operational and the maintenance cost and its trends on the chances for economical development to have sustainability.
- The Social Acceptance as a part of renewable energy technology implementation which can vary because renewable energy structures affect the residents' visual disturbance and the safety when they disturb the ship routes.

In the proposed model, a typical AHP hierarchy developed in order to assessing the offshore renewable technologies for reliable operation and through their pairwise comparison to propose the best one in respect of expert's judgments as it's shown in Figure 3.

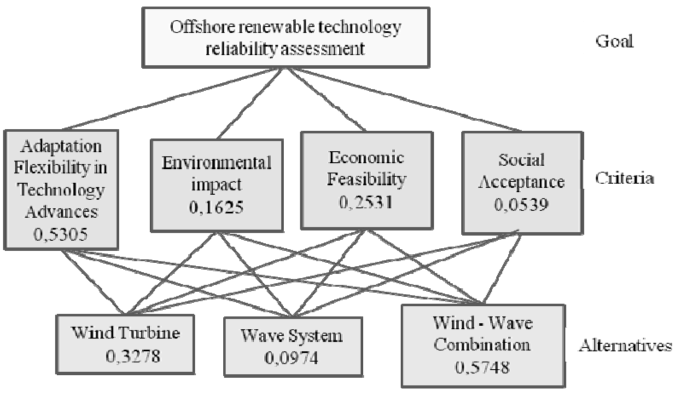

Figure 3. Hierarchical structure and weights in Reliability assessment for offshore structures.

The criteria are evaluated by five experts in areas of research and development for offshore structures, and technical departments. Also they taking into account the recorded data, compare the criteria one-to-one using the scale of Table I.With respect to weights resulting in Figure 3, adaptation flexibility in technology advances seems to be the most important criterion in determination of alternatives. The importance values are shown in figure 1 and the ranks for the alternatives dealt within the study presented in Table II where shown that from the three technology alternatives the wind and wave combination seems to be the best for sustainable and reliable choice according AHP methodology.

Table II: Ranks for the alternatives.

Power system	**Rank**
Wind Turbine	2
Wave System	3
Wind - Wave Combination	1

5. Discussion

Due to the high potential of renewable energy sources availability in various regions and the abundance of available technology the investigation that could lead to the selection of technology or the combination of technologies that will be used for harnessing this energy is essential. Also the production of energy from renewable sources would enhance the effort towards sustainable development. But the sustainability of structures using these technologies should be ensured as far as possible through research and development in order to overcome the technological and economic implications which still exist.

Especially for countries with abundant renewable energy potential the exploitation could play crucial role in enhancing their energy security and reduce their dependences from fossil fuels. Furthermore it could improve their environmental footprint by reducing greenhouse gas emissions. Also the adoption of renewable systems development will reduce the initial investment costs through economies of scale. Therefore the investigation by using multicriteria methodologies (MCDM) will encourage the development; will propose solutions to problems that may arise and will improve the efforts in setting realistic goals.

Conclusion

This paper presents a multi-criteria decision making method for assessing different technologies and determine the best alternative of renewable energy production system in offshore structure. The AHP approach is proposed as an efficient and effective methodology to be used by decision makers. The results of the decision analyses suggest that the wind and wave combination is the best renewable energy alternative in order to operates an autonomous desalination system.

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