



A fuzzy analytic network process model to mitigate the risks associated with offshore wind farms



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ABSTRACT

In the offshore renewable energy industry, it is extremely important to reduce the likelihood as well as the magnitude of potential risk events during system's actual operation. Operational risks (either risk of system failures or environmental risks) may cause catastrophic damages to personnel or infrastructure and result in substantial costs in terms of lost production and emergency maintenance operations. Selection of a suitable strategy for mitigation of the risks associated with offshore renewable energy projects is a very complex and critical task. The aim of this paper is to propose a fuzzy analytic network process (FANP) approach, based on Chang's extent analysis, in order to select the "most appropriate risk mitigation strategy" for offshore wind farms. Our proposed model consists of four possible alternatives (variation of offshore site layout, improvement of maintenance services, upgrading the monitoring systems, and modification in design of wind turbines) among which the decision maker has to select the best strategy according to four comparison criteria: safety, added value, cost and feasibility. The model is then applied to determine a suitable risk mitigation strategy for an offshore wind farm consisting of 30 wind turbines of 2 MW. Finally, the results are compared with those obtained using the crisp AHP and ANP models.

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1. Introduction

Offshore wind energy has grown very rapidly in recent years. The cumulative installed capacity of offshore wind power in the European Union (EU) has increased from 532 megawatts (MW) in the year 2003 to 6,562 MW in the end of 2013, which represents an annual growth of about 29% (EWEA, 2014). Along with the growth of the market for offshore wind energy, a particular attention should be paid to operation and maintenance (O&M) as well as reliability and availability of the installed wind power systems.

Analysis of field failure data collected from various databases like Elforsk in Sweden (<http://www.elforsk.se>) show that the availability of onshore wind farms is typically between 95% to 99%, while it is evaluated to be in the range of 60–70% for offshore wind farms. Moreover, offshore wind turbines suffer from a higher failure rate compared to their equivalent wind turbines located onshore (Tavner, 2012). The main reason is that offshore wind farms are generally exposed to a wider range of risk events, hazards or damages rather than onshore wind farms.

Basically, the risks associated with offshore wind farms can be categorized into two major groups: (i) the risks of system failures (e.g. power outage) and (ii) the environmental risks (natural catastrophes, ship collisions, etc.) (Leung & Yang, 2012). The former is caused by system/component degradation (deterioration) while the latter results from harsh surrounding environments (e.g. extreme weather, wind, wave). Any of these hazards can potentially have a negative impact on wind farm performance if it is not avoided (prevented) in an efficient way. Degradation failures result in substantial costs of repair or replacement and significant losses of power production, and nature events lead to catastrophic safety hazards to personnel and infrastructure. Therefore, there is a critical need to reduce the likelihood as well as the magnitude of potential risk events during system's actual operation. For this purpose, a *risk management plan* must be developed and applied to the existing or future offshore wind farms.

Risk management is a process focusing on identification and elimination of the hazards that could affect asset performance. This process normally includes several stages like identification, assessment, evaluation, control and monitoring, and mitigation of the risks resulting from a certain hazard (Aven & Vinnem, 2007). Among these stages, the risk identification and assessment area has received a reasonable attention within the wind energy industry. To this end, the following studies should be mentioned.

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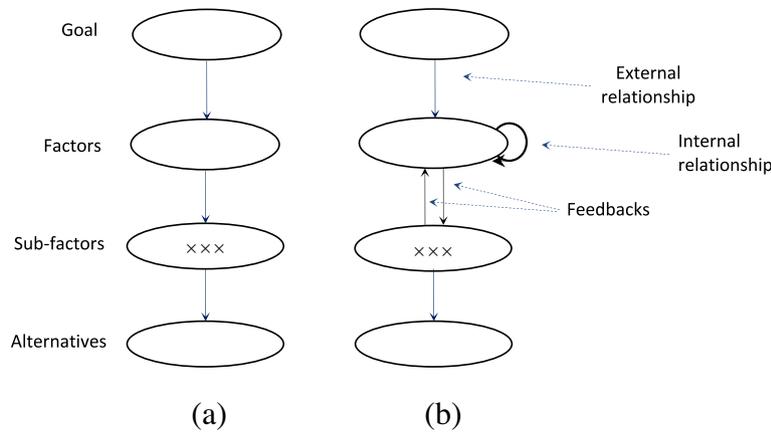


Fig. 1. (a) AHP structure (b) ANP structure (adapted from Sevkli et al., 2012).

Arabian-Hoseynabadi, Oraee, and Tavner (2010) proposed a failure mode and effects analysis (FMEA) methodology for prioritization of the failure modes in a 2 MW wind turbine system. Kahrobaee and Asgarpoor (2011) developed a risk-based FMEA approach for wind turbines in which the risk priorities of failure modes are determined based on failure probability and the incurred costs. Dinmohammadi and Shafiee (2013) developed a fuzzy-FMEA approach for risk and failure mode analysis of offshore wind turbines when field data is missing or is censored. Sunder and Kesavan (2013) studied the implementation of an FMEA methodology for wind turbines that operate in uncertain wind environments. Shafiee and Dinmohammadi (2014) proposed a mathematical tool for risk and failure mode analysis of wind turbine (both onshore and offshore) taking into account the key economic issues for maintenance (e.g. loss of power production, costs of logistics and transport).

In spite of the vast research on risk identification and assessment, only a few methods have been developed for mitigating the risks associated with offshore wind farms. A recently published report by the U.S. Department of Energy (DOE, 2008, Chapter 2) recommends enhancing the wind turbine reliability (through prototype testing of components before deployment) to mitigate the failure risks within offshore wind farms. Sjodin, Gayme, and Topcu (2012) and Griffin (2014) introduce the variation of offshore site placement/layout as a way of reducing the weather-related risks. Even though this solution may seem to be infeasible for many renewable energy systems, it can be considered as a practical alternative for small offshore wind projects.

The selection of a suitable risk mitigation strategy for offshore wind farms is a very complex and critical task. An appropriate risk mitigation strategy not only avoids the negative consequences of natural events but also results in increased power production and less operation and maintenance (O&M) cost. On the other side, an improper selection of strategies may adversely affect the operating budget and thereby reducing productivity as well as profitability. Risk mitigation strategy selection is considered as a typical multiple-criteria decision analysis (MCDA) problem. In this analysis approach, the decision-makers (i.e., system owners or stakeholders) must decide on the most appropriate strategy among a set of possible alternatives to mitigate the system risks. Moreover, many different goals or comparing criteria (economic, social, environmental, etc.) must be taken into account in evaluating the alternatives. These criteria are often *conflicting*, i.e., according to a criterion, a given alternative is the best one, while according to another criterion, other alternatives score higher. Thus, each alternative is evaluated with respect to each criterion and then, the evaluation ratings are aggregated to obtain a global evaluation.

Finally, the alternatives are prioritized from the best (optimal) to the worst.

In recent years, the MCDA approach has been applied to solution of a wide range of decision-making problems within offshore wind energy, including the selection of wind farm location, wind turbine technologies, the most resilient materials to be used, and decommissioning decisions. For a thorough review on the use of MCDA approach in the renewable energy industry, the readers can refer to San Cristóbal, 2012. Some recent publications in the area are briefly reviewed below:

Lee, Chen, and Kang (2009) developed an MCDA model based on the analytic hierarchy process (AHP) and the benefits, opportunities, costs and risks (BOCR) methods in order to select a suitable wind farm project. Kang, Hung, Pearn, Lee, and Kang (2011) proposed a comprehensive evaluation model on the basis of interpretive structural modeling (ISM), BOCR and fuzzy analytic network process (FANP) to select a suitable location for wind farms. Al-Yahyai, Charabi, Gastli, and Al-Badi (2012) applied the AHP method to derive wind farm land suitability index and classification under Geographical Information System (GIS) environment. Maity and Chakraborty (2012) applied the FANP approach to select the most appropriate materials for wind turbine blades. Lee, Hung, Kang, and Pearn (2012) proposed a comprehensive evaluation model based on ISM and FANP to select the most suitable wind turbines in a wind farm. In another work, Lee, Hung, Pearn, and Kang (2014) developed an evaluation model incorporating DEMATEL¹ and FANP techniques to select the most suitable wind turbines for installation in a wind farm. Yeh and Huang (2014) presented a DEMATEL-ANP based approach to prioritize the key six factors considered in determining the location of wind farms. Sánchez-Lozano, García-Cascales, and Lamata (2014) proposed an MCDA approach based on the ELECTRE-TRI method for selection of wind farm sites in the southeast of Spain. Wu, Geng, Xu, and Zhang (2014) utilized a fuzzy MCDA approach to select the best plan for wind projects.

When looking at the literature, no research is found on the *risk mitigation strategy selection* for offshore wind projects utilizing the MCDA approach to find out solution. In order to address this issue, we propose an FANP methodology on the basis of Chang's extent analysis to select the most appropriate risk mitigation strategy for offshore wind farms. The proposed model consists of four possible alternatives (variation of offshore site layout, improvement of maintenance services, upgrading the control and monitoring systems, and modification in design of wind turbine assemblies) among which the decision maker has to select the best strategy

¹ Decision MAKing Trial and Evaluation Laboratory.

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