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Use of drones in offshore wind farm inspections

Abstract: With the increase in global investments in offshore wind energy and the rapid implementation of wind technologies in hazardous deep water environments, operational inspection of wind turbines and related infrastructure plays an important role in the safe and efficient operation of offshore wind farms.
In recent years, much attention has been paid to the use of unmanned aerial vehicles (UAVs) and remotely piloted unmanned aerial vehicles (RPAs) commonly referred to as "drones" for remote inspection of renewable energy infrastructure, i.e. photovoltaic farms and onshore wind farms. Drones have significant potential also in in offshore wind energy. Inspection with drones allows for to reduce not only the number of flight operations (involvement of aircraft and flight crews) and the transport of personnel carrying out the maintenance and repair of offshore wind turbines. With drones is possible carry the equipment transported for hazardous inspection work.
The involvement of UAVs also reduces the plant downtime needed to detect faults and collect diagnostic information from the entire wind farm. The benefits of inspection technology in the offshore wind energy industry based on drones are confirmed by the previous tests, and the prospect of offshore energy development encourages further work with the use of UAVs. At the same time, it should be borne in mind that any unexpected failure of the drone system during its mission may interrupt control works (during inspections), and thus reduce the electricity generated by wind turbines.
The article presents the potential of drones in the process of inspecting wind farms, including offshore wind farms, presents examples of UAV models used for inspections, indicates methods of conducting inspections with the use of drones and highlights a significant reduction in the costs of the operation of offshore wind farms as a result of limiting the use of manned aviation (helicopters and flight crews) and the elimination of the risk associated with the involvement of personnel to perform inspections of wind farms at sea. The potential of unmanned floating platforms as part of cooperation with UAV in the process of inspecting offshore wind farms was also indicated.

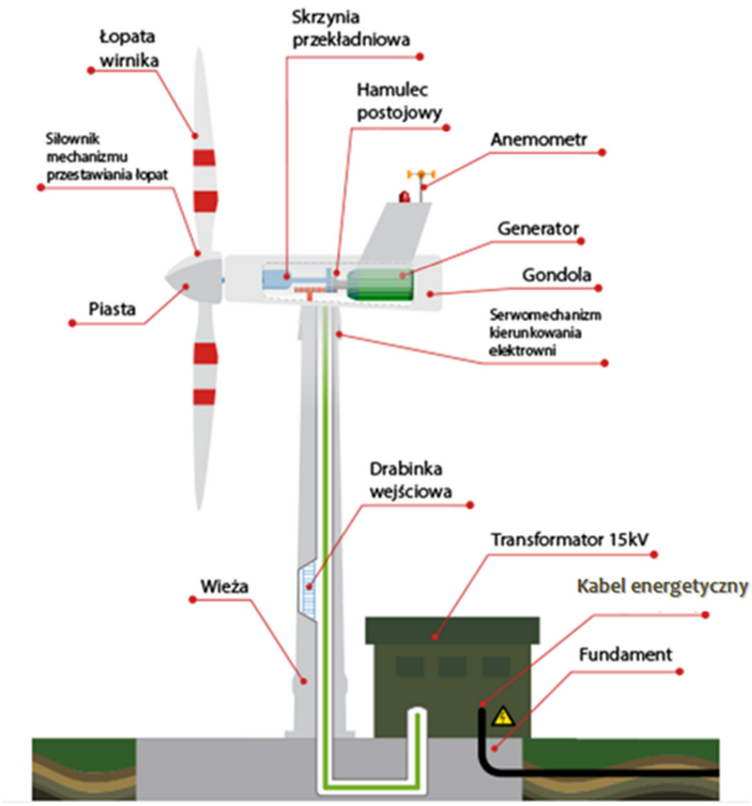
Keywords: wind energy, offshore, drones, wind farms, drone inspections, maritime inspections, marine aviation, offshore, offshore wind energy, safety air operations, risk analysis

Introduction

In recent years, offshore wind energy technologies have gained widespread attention and experienced rapid development due to the many advantages they offer. The geopolitical situation related to the Russian-Ukrainian conflict and the decisions of the international community in the context of diversification of energy sources (reducing the level of dependence on the level of gas supplies from the Russian Federation) has become an additional stimulus for the development of offshore wind farms.

In 2020, further investments in offshore wind energy were made in Europe - 356 new offshore wind turbines were connected to the grid in nine wind farms, which brought an additional 2.9 GW of power. Thus, Europe's total installed offshore wind capacity now stands at 25 GW, corresponding to 5,402 wind turbines connected to the grid in 12 countries [7]. Looking geographically, the North Sea remains the most established sea basin in Europe in terms of cumulative offshore wind turbine installations with almost 20 GW (79%) of all offshore wind capacity. The rest is the Irish Sea (12%), the Baltic Sea (9%), and the Atlantic Ocean (<1%). The World Wind Energy Council (GWEC) estimates that by the end of 2030, the total global offshore wind capacity will increase to over 234 gigawatts (GW) [3].

Compared to onshore winds, offshore wind resources are more abundant, stronger, and blow more consistently. In addition, offshore wind turbines, due to the environment in which they operate, are relatively less noisy and thus more environmentally friendly than their onshore counterparts. Offshore wind turbines do not pollute the natural environment, and energy generation does not emit any harmful compounds or waste into the atmosphere. Energy from wind farms is characterized by a fixed cost, which increases economic competitiveness concerning conventional energy sources.



1. Main components of a wind farm
Source: https://zielonestrefy.pl/zielone-strefy/odnawialne-zrodla-energii/energia-wiatru/

During the operation of a wind power plant, moving parts are subject to abrasion and various failures. The O&M (operation and maintenance) costs of both onshore and offshore wind farms account for a large proportion of the total life cycle cost of these projects. It is estimated that for new devices this share in the total cost of maintenance is 10 to 15 percent and increases with the wear of the turbine, even up to 35 percent [5]. In the case of offshore wind farms, additional factors are sea waves and salt. In addition, both structural elements above the water level, as well as submerged elements and marine power stations, require appropriate supervision and ongoing monitoring of their functioning [6].

The most frequently used solution in the process of inspection and repair of offshore wind farms is the involvement of HHO (Helicopter Hoist Operation) helicopters transporting technical personnel.

HHO (Helicopter Hoist Operation) helicopters are used in helicopter operations with a load on an external hitch as a part of commercial air transport. HHO flight means a helicopter flight performed following the HHO approval, to facilitate the transport of persons and/or cargo using helicopter lifting devices (definitions under Commission Regulation (EU) No. 965/2012 of October 5, 2012, laying down technical requirements and administrative procedures relating to for air operations)

Visual inspection of some components such as the tower, rotor blades, hub, and frames is very resource-intensive and often time-consuming. This operation also poses a serious risk to the health and safety of the personnel performing it, particularly in the event of severe weather conditions (e.g. strong winds or high waves). To carry out some inspection work on the internal parts of the nacelle, which extends to a height of approximately 80 - 120 m above sea level, personnel has to climb the tower of the wind turbine. To check the rotor components (blades and hub), it is necessary to use ropes hanging from the top of the wind turbines. Personnel work for several hours at high altitudes (often over 100 m) in sea conditions, which significantly increases the risk to safety and even life.

Across the world, great strides have been made in automating the servicing of wind farms. With the current nature and scale of development, and thus the scope of wind farm inspections, it is obvious that methods of operation and maintenance with the direct participation of people will be increasingly replaced by robots and drones. The involvement of unmanned aerial vehicles (UAVs) to carry out inspections of offshore wind farms is a rational and justified solution for diversifying the risk of manned aerial operations and reducing costs. The cost-effectiveness of using a BSP for inspection will vary depending on the number of turbine inspections per day, the number of personnel required for each inspection, and the time between inspections. Inspections carried out so far have shown that semi-automated drones can inspect around 12 - 15 wind turbines per day, while conventional methods can inspect up to 2 - 3 turbines per day. If the process is fully automated, the potential of drone inspections increases to 20 turbines per day.

Inspection work on offshore wind farms is carried out during periods of good weather and calm sea conditions. Industry practice shows that inspections are often carried out at two intervals, either once a year (usually in July) or twice a year (usually in May and October) [4]. The frequency of inspections of offshore wind farms depends on many factors, such as:

- types of systems or components used in power plants,
- potential failure modes and the probability of their occurrence,
- impact of the failure on the functionality of the system, availability of service vessels, accessibility to the offshore location,
- weather conditions, etc.

Tasks are traditionally performed in two ways using "rope access" or "ground camera". Rope access inspection involves two or more workers climbing to the top of the wind turbine and descending each blade using ropes or elevated platforms to identify and capture defects. The danger of using this method is the risk of falling into the sea. During the inspection, the camera stands on the boat about 70 - 80 m from the wind turbine and takes pictures of the elements. For inspection of offshore wind turbines using only a drone, UAVs are transported by ship (e.g. boat) or helicopter and then flown to the top of the wind turbines with the help of a pilot (UAV operator). Drone control operations in offshore wind farms involve at least two employees, one to control the drone (pilot/operator) and one to control the boat (ship captain).

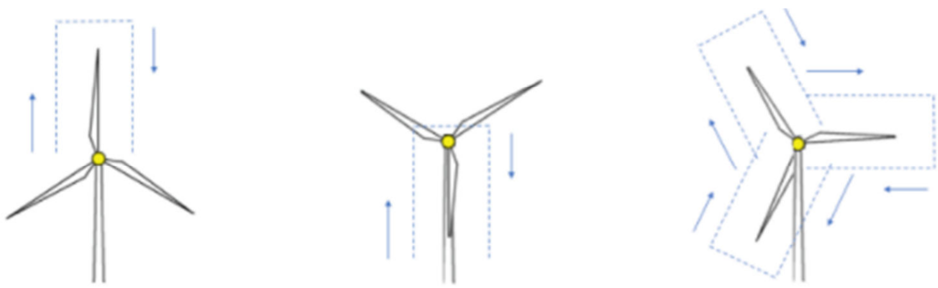
Inspection of wind turbine blades using a drone can be carried out in three ways (Figure **2**):

- blade position at 12 o'clock

  - during an inspection, each blade is manually positioned in the upward direction. The drone flies manually or automatically along the sides of the blade, covering the entire surface of the blade and keeping the camera at a 0-degree pitch, pointing vertically to the surface of the blade. The maneuver is performed in front and behind the blade
- blade position at 6 o'clock

  - during an inspection, each blade is manually positioned downwards. The drone flies manually or automatically along the sides of the blade, keeping the camera at a 0-degree pitch pointing vertically to the surface of the blade.
- fixed position

  - the wind turbine is manually stopped at a predetermined or random position (excluding the 6 o'clock and 12 o'clock positions) for inspection. The drone in auto-flight mode on a mission flies around the sides of the blade, recording data along the surface. The maneuver is performed in front and behind the shovel. The maneuver is performed in front and behind the blade.



Blade position at 12 o'clock **Blade position at 6 o'clock** **Fixed position**

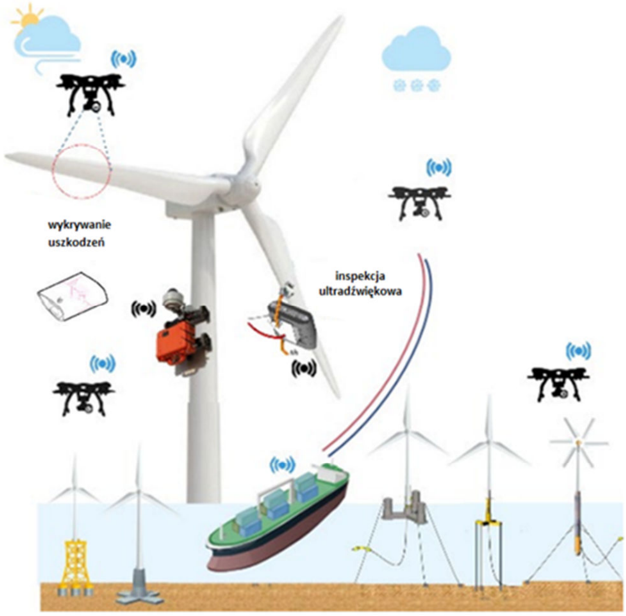
2. Inspections of a wind turbine at 12 o'clock, 6 o'clock, and in a fixed position
Source: own study

Among the damage to wind farms detected by drones, one should point out:

- fatigue cracks,
- corrosion fatigue is caused by the development of cracks with the simultaneous action of corrosion,
- corrosion (uniform, localized),
- pitting corrosion leading to the formation of small holes in the plating of the blades/turret/turbine nacelles,
- cyclic stresses,
- mechanical damage,
- extreme wind/wave loads.

With the predicted growth of the drone inspection market in the offshore wind industry in the coming years, the technology will become more affordable, faster, and easier.
During the inspection, drones can hover in one place and take high-quality photos of wind turbine components from different positions and angles (Figure **3**). These images can then be (are) analyzed by a computer system to identify early signs of defects or damage to the turbines and to identify appropriate maintenance actions to prevent failure modes from occurring. For this purpose, high-resolution cameras installed on board the drone are used. In addition, optoelectronic (OE) Optoelectronic sensors operating in infrared (IR) and near-

infrared (NIR) as well as hyperspectral can be installed to capture various types of data, including visual and thermal imaging.



3. Robotic platforms in the process of inspection of offshore wind farms
Source: [8]

Obtaining high-quality data in inspections of wind farms using drones confirms the higher effectiveness of UAVs compared to inspections performed by technical personnel. These devices (drones) can fly 3-10 meters above the blade and circle it to cover the entire surface of the turbine and are often equipped with a digital camera, a thermal imager, or a combination of both. With thermographic inspection, you can get more accurate data on temperature over large areas, hidden defects, corrosion, and other irregularities. Tests have shown how defects in composite wind turbine blades can be detected using a drone equipped with a thermal imaging camera [2]. Photogrammetry software for detecting wind turbine blade defects based on aerial photos taken by a drone is part of building a data library, which can then be tagged with metatags and used to construct a 3D model of a blade with an accuracy that is difficult to achieve by manual methods.

The most common NDT (Non-Destructive Testing) methods that can be performed with the use of UAVs during the inspection of wind turbines, also offshore, are presented in **Table 1** [1].

Table 1. Methods of non-destructive testing (NDT) of wind turbines
Source: Own elaboration based on [1]

NDT	Advantages	Disadvantages
Ultrasonic testing UT	• high sensitivity • surface defects detection • defect depth information • repeatable defect detection • mode purity option • low signal complexity • on-demand inspection	• requires extensive technical knowledge • requires surface preparation • difficulty checking irregular shapes • high penetration • time-consuming • short-term field inspection • supervision is needed • high signal attenuation
Acoustic Emission AE	• high sensitivity • high signal-to-noise ratio (SNR) • defect location • can detect failures at an early stage • passive and operational control • portable or highly automated operation • adaptable to wireless sensor networks • no supervision needed • the frequency range is far from load disturbances • long-term field inspection • no need to disassemble and clean the sample • multiple access points are required	• a unique event • event-based • a very high sampling rate is required • no quantitative results regarding size and depth • high signal attenuation
Fiber Optics	• high sensitivity • no attenuation over long distances • small size and light weight • high multiplexing capabilities • immunity to electromagnetic interference	• impractical for large wind farms • requires special care for safe installation • susceptibility to physical damage • thermal sensitivity
Thermographic Testing TT	• large-scale control • full coverage in a short time • can be used in inaccessible places • access from one side is required • no special security required	• limited to surface or near-surface defects • manual and costly handling • difficult to use on rotating blades • interior damage difficult to detect • relies on regular inspections • short-term field inspection • supervision is needed
Radiographic Testing RT	• defect depth information • suitable for complex structures and different materials • large-scale control • full coverage in a short time • 2D and 3D images • good contrast sensitivity	• manual operation (expensive), supervision required • two-way access is required • difficult to use on rotating blades • health and safety risks • relies on regular inspections • short-term field inspection

Types of drones used in wind farm inspections

Unmanned aerial vehicles that can be used in wind farm inspection operations can be generally divided into three types: single-rotor, multi-rotor, and fixed-wing multi-rotor flying devices:

- Multirotor or multicopter
  - is a type of drone that consists of three rotors (known as a tricopter), four rotors (a quadcopter), six rotors (a hexacopter), or eight rotors (an octocopter). Quadcopters are the most popular and widely used multi-rotor drones as they offer the best balance of hover, control, maneuverability, and cost. Multirotor drones are the cheapest type of drone on the market, but they require a lot of energy to operate, and their durability and speed are limited. With current battery technology, multi-rotor drones are only able to fly for about 20 to 30 minutes at a time while carrying a light camera payload;

4. Matrice 300 RTK quadcopter drone
Source: https://enterprise.dji-ars.pl/inspektion-turbin-wiatrowych-z-wyzyskienie-dronow-zwiekszaja-wydajnosc-i-nieospodarnosc-farm-wiatrowych/

- Fixed-wing drone
  - a type of drone designed with a single rigid wing, like an airplane, to provide lift, rather than vertical lift rotors. Fixed-wing drones only need the power to move forward but not to hover, making them much more efficient than multi-rotor drones, and also capable of covering long distances and mapping large areas. Nevertheless, their main disadvantages are the high cost and the impossibility of hovering in one place.

5. Quantix fixed-wing drone
Source: https://www.komputerswiat.pl/aktualnosci/sprzet/quantix-przemyslowy-dron-od-aerovironment/g53xj9z

- Single Rotor Drone
  - having only one rotor to keep the machine aloft and a tail rotor to control the direction of flight. It can hover with a heavy payload (e.g. airborne LIDAR laser scanner) or have a mix of hovering with high endurance or fast-forward flight. Single-rotor drones are complex devices and their rotating blades can be dangerous. LIDAR (an acronym, formed from the expression: Light Detection and Ranging) is a method of measuring distance by illuminating a target with laser light and measuring the reflection with a sensor. In terms of difficulty in use, single-rotor drones fall between multi-rotor and fixed-wing drones.

6. Single Rotor Model TD112-G
Source: https://tianda.en.made-in-china.com/product/YNdxutarheVy/China-12kg-Load-Full-Autonomous-Single-Rotor-Oil-Power-Plant-Protection-Drone.html

Summary

Along with the increase in the number of installed offshore wind farms to increase the capacity of offshore wind energy in the world, research and development works are undertaken to reduce the average cost of energy to make offshore wind energy more competitive and attractive to investors. Operation and Maintenance (O&M) accounts for a large portion of the total life cycle cost and is the longest phase in the development of offshore wind projects. Therefore, reducing the time, costs of operation and maintenance is a top priority for operators, producers, and insurance companies in the offshore wind energy sector. According to some studies, the high O&M expenses of offshore wind farms are mainly due to limited access to turbine infrastructure for inspection and maintenance. To overcome accessibility barriers and reduce costs, the use of drones and remote inspection technology has received a lot of attention in the offshore wind industry in recent years. In addition to the proven cost optimization, reduction of risk to people, and manned aircraft used for missions at sea, the advantage is that drones can reduce the need for heavy lifting equipment for inspection tasks. Inspection drones equipped with a powerful digital camera capable of capturing high-resolution aerial images of the tower, nacelle, rotor blades, and bolted joints are an excellent solution for diversifying the risk of direct human inspections. The images and data collected by the BSP can be analyzed using machine learning to create algorithms to detect early signs of degradation and identify appropriate maintenance actions to prevent failure modes and downtimes in wind power plants. As a result, drones can reduce the time needed to detect faults and collect diagnostic information from all wind turbines.

At the same time, despite all the potential benefits, the technology for controlling offshore wind turbines using drones is still in the development stage and further research is needed to identify potential technological gaps, opportunities, and future technology requirements in terms of hardware, software, and data collected during the preparation and management process. inspection. The failure rate of drones is significantly lower than in manned aviation. To identify, analyze and mitigate the risk, as well as reduce the maintenance costs associated with the failure of drones dedicated to the inspection of offshore wind farms, it is necessary to develop methodologies that will be able to determine the reliability of the drone both at the level of the system and its components. Reliability, which is defined as the likelihood of the system operating without failure for a specified period in a designed environment, is a key performance indicator of drone systems. Ensuring the availability of drones in mission mode is a challenge, as any unforeseen failure of the drone system during its flight can interrupt inspection work and thus significantly reduce the electricity generated by wind turbines.

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