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Application of Drones in Electrical Power Engineering

Drones, also known as unmanned eVTOL aircraft, have undergone significant development in recent years and are finding more widespread application in various industries. The electricity sector is no exception, where drones offer innovative solutions compared to traditional methods. The introduction of drone technology into the electricity industry has radically transformed operating methods, significantly reducing the high costs and risks associated with traditional control techniques. Drones have become an essential tool for regular monitoring of critical energy infrastructure elements such as power lines, wind farms and solar farms.

Keywords: *eVTOL, drone, power line, solar park, wind turbine, electrical energy*

1. Introduction

Equipping drones with various sensors allows you to perform complex surveillance tasks that exceed the capabilities of traditional visual inspection. For example, thermal imagers can detect overheating problems, multispectral sensors can assess vegetation around solar panels, and LiDAR systems can be used to create detailed maps. This advanced sensor technology allows for a deeper and more accurate assessment of the state of the energy infrastructure, revealing hidden flaws and problems that were previously invisible.

2. Network monitoring and maintenance

Drones are powerful tools for remote monitoring and maintenance of power grids. With their help, sources of defects such as insulation defects, contact with tree branches or other foreign objects and damage to support pillars can be quickly and accurately identified. Especially after storms, foreign objects often get on the power lines that make up the power grid, or trees grow near it and affect the power line can cause a short circuit [24]. Detecting them can be done quickly and safely with the help of drones. Drones equipped with thermal imaging cameras can be used to easily identify overheated or damaged insulations that could pose a fire hazard. Some drones are able to travel long distances over wires, thus detecting network failures, corrosion, or other damage. Another advantage is minimising trampling damage [17]. Using traditional technology, vehicles must be pulled out to the supports involved in the inspection, sometimes causing serious damage to agricultural crops or valuable vegetation. Drones can be used to conduct inspections and surveys faster and more cost-effectively.

Drones can conduct hazardous tasks, significantly reducing safety risks for workers and maintenance costs. Since potential problems can be detected earlier, major breakdowns can be avoided. Drone operations provide the collection of high-precision data based on which more accurate decisions can be made. Operations can even be tracked online, processes can be digitally recorded and evaluated later. Last but not least, thanks to the mostly electric drive, their ecological footprint is quite small [9], [11].

Figure 1.
Vegetation near the wires [23]

Figure 2.
Detection of insulation defects [6]

3. Health check of solar parks

Drones can quickly cover large areas, making them ideal tools for assessing the condition of solar parks. With the help of cameras and sensors installed on drones, detailed data can be obtained on the state of the infrastructure, which allows necessary repairs and maintenance to be carried out in a timely manner [7]. In order to meet today's growing energy demands [19], service providers need to install thousands of solar panels covering ever larger areas [15]. In traditional solar panel health assessment, handheld thermal imagers are used to inspect panels to check the condition of cells and cables. However, this method is not efficient enough, as maintainers must manually locate faulty cells, which can be extremely time-consuming and sometimes dangerous, and places considerable strain on maintenance and operation units. The integration of drone technology into the inspection processes of solar farms has resulted in significant efficiency gains and increased accuracy. Drones can be used to identify contaminated or shaded solar panels that reduce the park's performance. Drones equipped with thermal imaging systems are capable of mapping large solar farms in a single flight, capturing high-resolution RGB and thermal imaging images or videos [21]. Based on the heat maps made with the infrared camera, faulty modules or overheated connections can be identified. Inspection operations from the air are ongoing, especially in heated problem areas heavily exposed to the sun's rays, where technical teams face significant challenges. The use of drones allows operators to reduce inspection time by up to 70%, which is a significant time saving compared to traditional methods [12], [18].

Figure 3.
Checking a solar park using a drone [1]

3.1. Thermal (infrared) inspections

This is one of the most widespread and important inspections conducted by drones. Thermal cameras (infrared thermal imaging) analyse surface temperature distribution and are capable of detecting numerous issues, including the following:

- identification of hotspots;
- shade problems;
- inverter and system failures.

3.1.1. Identification of hotspots

Hotspots are areas on solar panels where the temperature is higher compared to the rest of the panel. In these areas, the cell temperature can reach up to 150 °C, which can lead to permanent and irreversible damages, such as glass cracking or cell degradation. The formation of hotspots is common, but predicting their exact location is extremely difficult. In many cases, the failure of solar panels occurs due to overheating caused by hotspots, which reduces energy performance and can damage the devices in the long run. The emergence of hotspots can be clearly observed in thermal images captured by drones (Figure 4). Sometimes, hotspots appear as brown marks or other visible damage on the surface of the panel, but in most cases, these hot spots are invisible to the naked eye. A study conducted in the United States analysed photovoltaic modules operating over a 1–3-year period to investigate the causes of module failures and malfunctions. Among the 115 modules examined, 22% had lost their energy-producing capability due to hot spot effects [3].

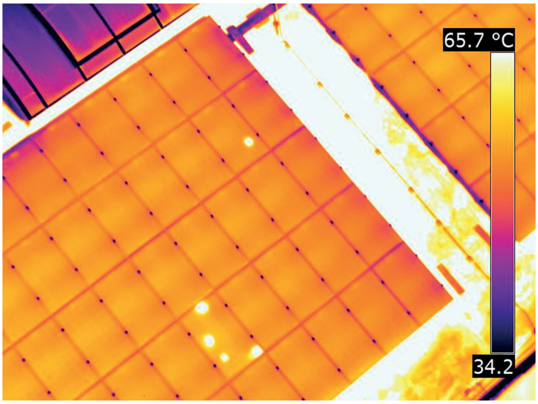

Figure 4.
Hotspots on solar cells [2]

3.1.2. Detection of microcracks

During the manufacturing of solar panels, various materials and technologies are present that can contribute to the formation of microcracks in the manufacturing process. The quality of the materials used in the production of solar panels (e.g. silicon, glass) is of fundamental importance. Contaminants or defects in the materials, such as the use of improper types of silicon during manufacturing, can lead to the appearance of cracks. The production of silicon cells is based on thermal treatment processes, and improper execution of these processes can generate stresses, thereby increasing the risk of microcracks. Temperature fluctuations can also cause additional problems. Solar panels are exposed to various temperature conditions, which can significantly affect their performance and lifespan. The constant expansion and contraction caused by sunlight put serious stress on the solar panels.

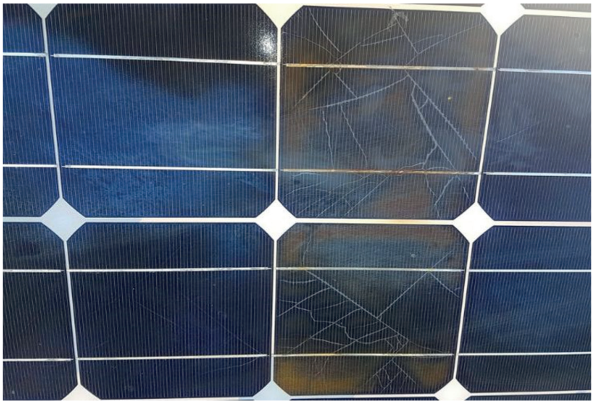

Figure 5.
Tiny cracks on the surfaces [22]

For example, thermal stress can lead to the formation of tiny cracks on the surfaces of the cells (see Figure 5). Different thermal expansion coefficients, such as those of glass and silicon, can create tensions due to their varying rates and degrees of expansion. Mechanical stresses can also cause additional microcracks. Since solar panels can be affected by various mechanical impacts, such as hail, the weight of snow, and wind load, these not only influence the physical integrity of the solar panels but can also lead to the occurrence of microcracks. Intense wind gusts and the weight of snow or ice present particularly critical problems, causing the panel structure to undergo flexible deformation, which contributes to the formation of cracks. Over time, the materials of solar panels age, leading to a decrease in light absorption capacity and deterioration of mechanical properties. Aging processes also affect the performance of the cells, especially due to long-term environmental impacts that induce material fatigue, such as ultraviolet (UV) radiation or the combined effects of heat and moisture, which can contribute to the spread of microcracks.

3.1.3. Shade problems

If a panel is in shadow (due to, for example, dirt, plants, or surface defects; Figure 6.), its performance changes, which is also reflected in the heat distribution. Localising such defects is critical for increasing efficiency. Shading, whether natural (such as trees or buildings) or artificial (such as dust or pollution), can reduce the performance of solar panels.

The variations in performance between the cells due to different shading levels can cause significant losses in energy production, reducing the overall energy output.

Figure 6.
Shaded cells [10]

3.1.4. Identification of inverter and system faults

Due to improper functioning, the panels can overheat at the system level. Drones can be used to examine temperature variations in the panels associated with different inverters.

3.2. Inspections with general and RGB camera

Drones also capture data using conventional or RGB[1] cameras, which are important for providing information during condition assessments. The images obtained from the cameras can reveal visible physical damages such as broken, cracked, or displaced panels, as well as other external anomalies. They also effectively assist in identifying contaminants or deposits like dust, bird droppings, or leaves, which can significantly reduce the efficiency of the panels. Structural element inspections are common in assessments conducted with traditional cameras; however, beyond the panel-supporting scaffolding, there is also the opportunity to assess the condition of attachments, cabling pathways, or other infrastructural elements. When installed on the ground, the extent of any undergrowth is important, as it can potentially cause dangerous shading on panels mounted on low supports (Figure 7).

Figure 7.
Solar panels installed on the ground [5]

3.3. Multispectral and hyperspectral measurements

Drones equipped with multispectral (Figure 8) or hyperspectral cameras capture images across multiple wavelengths (e.g. UV, infrared, near-infrared). These cameras can reveal issues that neither thermal cameras nor RGB cameras can detect. One such issue is the detection of panel degradation caused by the PID[2] effect which can lead to a significant decrease in energy production.

[1] RGB camera – this camera takes photos in red, green, and blue colours.
[2] PID – Potential-Induced Degradation.

Figure 8.
Multispectral drone camera [8]

4. Inspecting of wind turbines

Wind energy is one of the fastest-growing sources of renewable energy, with wind farms becoming increasingly larger and more complex. Turbines often exceed heights of one hundred meters, and blade lengths may surpass eighty meters (Figure 9).

Figure 9.
Wind farm in Mosonmagyaróvár [14]

As wind farms grow in size and scale, maintaining the infrastructure becomes increasingly challenging. Traditional inspection methods such as rope access technicians, cranes, or helicopters are time-consuming, expensive, and risky. The maintenance and inspection of wind turbines are critical for ensuring optimal performance and maximising energy output while minimising downtime and operational costs. In recent years, the use of drones, also referred to as Unmanned Aircraft Systems (UAS), has revolutionised the way wind turbines are inspected. Drones allow for faster, safer, and more cost-effective inspections compared to traditional methods such as manual climbing or ground-based imaging systems. The mechanical components of wind turbines are constantly exposed to environmental influences such as dust, rain, snow, hail, lightning strikes, or corrosion caused by salt air. These damaging factors have a significant impact on the performance or lifespan of wind turbines. But additional factors such as cracks caused by extreme load fluctuations or defects due to blade manufacturing technology, such as layer detachment, also contribute to damage to turbine blades or generator. There are generally two main methods used to check the mechanical components of wind turbines:

1. Tower and foundation inspection
2. Rotor blade condition check

The other method involves a thorough inspection of the blades, using a telephoto lens to assess the condition of the rotor blades.

4.1. Tower and foundation inspection

Inspection of the tower and foundation is usually conducted traditionally, using the rather dangerous rope technique, using platforms on platforms or visually observing them from the ground (see Figure 10).

Figure 10.
Inspection of wind turbines from the ground [25]

The advantage of ground observation is that it is generally safer and more cost-effective because there is no need to work at height, which reduces the risk of accidents and injuries and insurance costs. However, the disadvantage is that certain parts, such as the internal structure of the blades, are not always sufficiently visible or accessible from the ground, so the inspection may not be complete. Another problem is that the resolution and level of detail of the tools used in ground-based inspections may not always reach the level of direct, field inspections. During tower inspections, the structural integrity is assessed, and the condition of the welded joints is analysed. The turbine tower can be examined in detail with the assistance of drones, allowing for the detection of corrosion, dents, cracks, or other structural defects. Additionally, weak points located in the welding seams of the tower can be identified using infrared thermography, employing a non-destructive testing method.

4.2. Rotor blade condition check with rope technology

The use of rope technology or platforms usually requires the presence of more than three specialists on site, which entails significant wage costs. The use of rope technique poses a high risk [16] for technicians, as they work at height, which increases the possibility of accidents and injuries. These methods are extremely time-consuming to implement, as technicians can only inspect one or two turbines per day. Working at heights carries additional risk factors that also increase insurance costs. The use of rope technology is influenced by weather conditions, such as intense winds or precipitation, which can hinder work and increase risks (Figure 11).

Figure 11.
Application of rope technique [14]

4.3. Rotor blade inspection with drone technology

Drones, equipped with advanced imaging sensors and artificial intelligence (AI), present an innovative alternative, allowing wind farms to be inspected quickly, accurately, and efficiently [5], [20]. Drones can be used to examine the surface of the rotor blades in detail and also identify cracks, dents, or other damages [16]. With the help of drones, the condition of the tower and foundation can also be checked, so corrosion damage or structural defects can be detected in time. Drone-based technology allows technical personnel to access any part of the wind turbines, allowing them to fully assess the machine's operating condition, determine the extent of damage and what needs to be done to optimise performance. Unlike previous time-consuming and costly inspection procedures that required the use of specialised equipment and human resources, modern drone technology provides precise and up-to-date information about necessary repairs or modifications, significantly speeding up and optimising the maintenance process [13].

Figure 12.
Inspection of wind turbines by X-ray technology [4]

4.4. The advantages of drone-based investigations

Traditional inspection methods, such as rope technology, pose significant risks to personnel. The utilisation of drones eliminates direct physical interaction, thereby considerably reducing the risk of accidents. Drones are capable of inspecting an entire turbine within a matter of minutes, whereas conventional methods may take hours or even days. This presents a substantial advantage, particularly for larger wind farm installations. The elimination of rope technology, helicopters, or heavy machinery can also lead to significant cost reductions [26], [27]. Moreover, expedited inspections decrease losses associated with energy production downtime. The high-precision data captured by drones facilitate the early detection of faults that conventional methods may overlook. Regular and frequent inspections support predictive maintenance, which anticipates potential failures, thus lowering repair costs and minimising unplanned outages.

5. Economic advantages of drone applications

The principal adversary of energy facilities is unplanned downtime. Each minute of inactivity can lead to substantial revenue losses and potentially jeopardise safety under critical circumstances. Traditional inspection methods have often necessitated the cessation of operations, which can extend for prolonged periods, thereby plunging facilities into a state of uncertainty both literally and metaphorically. The integration of drones aims to enhance inspection processes and reduce downtime by eliminating the necessity for scaffolding, thereby equipping the maintenance team with comprehensive information prior to scheduled downtimes. Drones facilitate the inspection of specific assets while operations are ongoing or not entirely ceased. Furthermore, the use of drones entails fewer safety protocols compared to human personnel, as well as expedited and more adaptable deployment times, resulting in a diminished requirement for equipment mobilisation for inspections. It is essential to acknowledge that drones not only expedite the resumption of power plant operations but also contribute to the prevention of unexpected shutdowns by promoting enhanced preventive maintenance practices and transforming inspections from reactive protocols to proactive strategies.

6. Challenges and future prospects

Although drones offer many benefits in the energy sector, there are still many challenges to their application. These include, for example, legal regulations, data protection, range, and weather conditions, as well as requirements for operators that vary from continent to continent. In the future, drone technology is expected to continue to develop and become more widespread in the electricity sector.

7. Conclusion

Drones have significant potential in the energy sector. By making inspections and surveys more efficient, safe, and environmentally friendly, drones can contribute to increasing the reliability and sustainability of electricity systems. Drones are not only suitable for visual inspection, as their advanced sensors allow them to take measurements in a wide spectrum, from temperature signals to gas leak detection. This capability enables comprehensive monitoring of energy infrastructure to provide critical data to help develop maintenance and safety protocols. The collection of real-time, high-quality data reduces the need for human intervention, thereby reducing the risk of workers working in hazardous conditions.

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Drónok alkalmazása a villamos energetikában

A drónok vagy más néven személyzet nélküli eVTOL légi járművek, az elmúlt években jelentős fejlődésen mentek keresztül, és egyre szélesebb körben találnak alkalmazást a különböző iparágakban. Ez alól a villamos energetikai szektor sem kivétel, ahol a drónok innovatív megoldásokat kínálnak a hagyományos módszerekhez képest. A dróntechnológia bevezetése a villamosenergia-iparba radikálisan átalakította az üzemeltetési módszereket, jelentősen csökkentve a hagyományos ellenőrzési technikákhoz köthető magas költségeket és kockázatokat. A drónok mára elengedhetetlen eszközökké váltak az olyan kritikus energia-infrastruktúra elemeinek, mint például a távvezetékek, szélerőművek és napelemparkok rendszeres ellenőrzésének.

Kulcsszavak: *eVTOL, drón, villamos hálózat, naperőmű, szélturbina, elektromos energia*

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