http://www.moderntechno.de/index.php/meit/article/view/meit37-01-036
DOI: 10.30890/2567-5273.2025-37-01-036

RISK MANAGEMENT THROUGH UAV INSPECTIONS AND ARTIFICIAL INTELLIGENCE WITH AIDI SOLAR® SOLUTION

Denys Syntiuk
ORCID: https://orcid.org/0009-0003-9268-2722
CEO, Co-Founder, Drone Inspect LLC (Ukraine) Cognitivision LLC (USA)
16192 Coastal Highway, Lewes, Delaware 19958, County of Sussex, USA

Abstract. *The article explores risk management approaches in the renewable energy sector by utilizing unmanned aerial vehicles (UAVs) equipped with thermal imaging sensors and artificial intelligence for inspecting solar power plants. The study aims to assess the effectiveness of AIDI Solar® technology in solar panel monitoring, analyze the economic benefits of automated solutions, and justify the further integration of machine learning algorithms into risk management systems. The research employs general scientific methods of cognition, including analysis, synthesis, statistical methods, modeling, and comparative analysis. The findings indicate that UAVs with thermal imaging sensors and AI significantly reduce maintenance costs for solar power plants by automating inspection processes. Traditional inspection methods require substantial human and financial resources, whereas UAVs enable rapid and efficient monitoring of large solar panel areas. The use of machine learning algorithms enhances defect detection accuracy, minimizing the risks of unplanned downtime and operational losses. Statistical analysis of AIDI Solar® implementation in real projects demonstrates a significant economic impact. The use of UAVs and AI increases energy generation efficiency by 5–8% annually, generating an additional revenue of €1.9 million. Overall, the company has inspected over 360 MW of solar power plants and analyzed more than one million solar modules, confirming the technology's effectiveness in mitigating operational risks. To further optimize risk management in renewable energy, it is recommended to expand the integration of automated monitoring technologies, enhance the use of machine learning algorithms for equipment failure prediction, and improve training programs for UAV operators. The combination of these measures will improve maintenance efficiency, ensure long-term stability, and enhance the profitability of solar energy.*

Keywords: *unmanned aerial vehicles, artificial intelligence, solar power plants, risk management, machine learning.*

Introduction

The development of solar energy in the United States reached record levels in 2023, highlighting the need to improve solar power plant management methods. A total of 32.4 GW of new capacity was installed, representing a 51% increase compared to 2022. Solar energy accounted for 53% of all new capacity in the country, surpassing the 50% threshold in overall generation growth for the first time in 80 years. Given forecasts that the installed capacity of U.S. solar energy could reach 673 GW by 2034, effective management of these systems is becoming critical to ensuring their stable and uninterrupted operation [9].

Despite the rapid growth, the solar energy market faces numerous challenges, including fluctuations in solar module costs, supply chain issues, and grid connection difficulties. Additionally, political and economic factors—such as changes in tax credits, trade policies, and financing availability—can significantly impact industry development. Projections indicate a 200 GW gap between optimistic and pessimistic growth scenarios by 2034, underscoring the need for flexible and adaptive solar power plant management strategies.

A systematic approach to monitoring and maintenance is essential for ensuring the efficiency and longevity of solar power plants. The use of advanced technologies, such as UAVs for panel diagnostics and AI systems for operational analysis, enhances plant reliability and reduces operational costs.

Literature Review

The topic of risk management through UAV and AI inspections in solar energy solutions remains underexplored in scientific and industry literature. Various studies highlight the role of UAVs and AI in improving efficiency, reducing risks, and optimizing photovoltaic (PV) system performance. A significant contribution to this field was made by A. Kobaszynska-Twardowska, J. Łukasiewicz, and P. W. Sielicki [5], who proposed a risk management model for UAV flight operations, focusing on safety, regulatory requirements, and operational efficiency. Their research provides a foundation for understanding the risks associated with UAV inspections of solar power plants.

Additionally, O. Olayiwola and F. Camara [8] analyze the challenges and opportunities of autonomous UAVs in PV system inspections, emphasizing technological advancements and limitations in AI applications. D. Kiryati [4] examines the benefits and challenges of multi-drone systems for large-scale solar farm inspections, highlighting logistical and computational resource constraints. Furthermore, U. Jahn, M. Herz, M. Köntges, D. Parlevliet, M. Paggi, and I. Tsanakas [3] provide a comprehensive review of infrared and electroluminescence imaging for PV system diagnostics, which is crucial for defect detection and maintenance planning.

The role of AI in improving solar energy efficiency has been extensively studied by A. Mohammad and F. Mahjabeen [7], who explored the application of machine learning algorithms to enhance energy production and detect PV system failures. I.

Ukpanah [10] examines how AI maximizes energy efficiency through real-time data analysis and predictive maintenance.

Industry reports, particularly those from SEIA [9], document the growth of solar energy installations in 2023 and the increasing adoption of AI-based solutions. Additionally, companies such as AIDI Solar [1] and vHive [4] demonstrate the practical application of UAV inspections, confirming their benefits in risk management and efficiency improvement.

Despite the availability of extensive literature, comprehensive studies that systematically integrate AI- and UAV-based risk management strategies into a unified methodological framework are lacking. This analysis synthesizes existing knowledge, structures key aspects, and proposes an organized approach to risk management in solar power plant inspections.

The objective of this article is to develop effective risk management models for renewable energy by leveraging AIDI Solar® technology and demonstrating how artificial intelligence and machine vision improve defect detection, reduce risks, and lower maintenance costs.

Research results

Large-scale solar photovoltaic (PV) systems play a crucial role in ensuring stable electricity generation. However, their efficient management involves several risks, including panel degradation, adverse weather conditions, technical malfunctions, surface contamination, and challenges in grid integration. Advances in energy production forecasting, storage, and automated monitoring technologies significantly enhance the reliability and efficiency of these systems. To minimize risks, key measures include deploying unmanned aerial vehicles (UAVs) equipped with infrared, electroluminescent, and RGB cameras for rapid fault detection, utilizing intelligent data analysis platforms for automated defect identification, and integrating artificial intelligence for panel monitoring and predictive maintenance. A comprehensive implementation of these technologies enables effective risk management, improves operational safety, and supports climate goals by increasing the use of clean energy [8].

The advancement of UAV technology is gradually replacing traditional inspection methods for medium and large-scale PV systems, which are time-consuming and costly. One of the key advantages of UAVs is the speed of solar panel inspections. Compared to conventional ground-based inspections, which can take several days, UAVs can survey large areas in just a few hours. Multi-drone systems further enhance efficiency by operating synchronously to cover extensive areas simultaneously. This not only reduces inspection time but also enables the timely detection of potential issues, ensuring maximum productivity for solar power plants [2].

For example, conducting a manual ground inspection of a 20 MW solar power plant, which contains approximately 52,630 medium-sized panels (380 W), requires an average of 15 seconds to capture infrared images for each module. This means that a full inspection would take around 220 hours of continuous work. The same plant, covering approximately 26 acres, can be inspected using DJI M300 drones (equipped with H20 + XT sensors) in just 4 hours of continuous operation. Taking weather conditions and breaks into account, the total inspection process would take 1–2 days. The inspection duration can vary depending on the UAV flight altitude: flying higher increases coverage but may result in a loss of detailed information at the individual panel cell level [3].

Beyond significantly reducing inspection time, UAVs are particularly effective for challenging or hazardous locations, such as desert regions, high rooftop installations, and floating solar systems. This leads to substantial cost reductions, improved efficiency, and greater long-term profitability for solar power plant operations [3]. Additionally, UAV use enhances personnel safety by eliminating the need for inspections in hard-to-reach or hazardous areas, such as rooftops or floating solar farms. Remote-controlled UAV inspections reduce worker exposure to risks, making solar plant management not only more efficient but also safer, more cost-effective, and environmentally responsible [4].

Economic efficiency is another crucial factor in integrating UAVs into solar panel management. Despite the initial investment in drones and software, long-term savings on labor costs, early fault detection, and reduced reliance on frequent manual inspections significantly lower overall operational expenses. Moreover, automated data collection eliminates human error in diagnostics, improving analysis accuracy [2].

Another major advantage is the high quality and consistency of collected data. Equipped with thermal imaging cameras, UAVs can detect panel overheating and malfunctions at early stages, preventing severe damage. Automated data analysis systems, integrated with management platforms, enable the storage of historical data, facilitating failure prediction and long-term maintenance optimization [2].

As UAV adoption expands, technological solutions for risk management in solar power plants continue to evolve. The following section outlines the key evolutionary trends in UAV applications within this field.

Table 1 - Evolution of UAV use in solar photovoltaic (PV) system management [8]

Stage	Description	Key technologies
Initial use (fault detection)	UAVs were first used to diagnose faults in large PV systems. Infrared (IR) cameras were employed to detect hot spots, microcracks, and glass damage, problems with the bypass diodes.	Infrared (IR) sensors, thermal imaging, manual analysis
Expansion to construction phases	UAVs began to be used for monitoring the construction of PV plants, helping to identify structural errors, track project progress, and ensure installation quality.	RGB cameras, photogrammetry, structural analysis software
Development of AI and automation	The integration of artificial intelligence (AI) and machine learning enabled UAVs to automatically analyze thermal anomalies and predict failures. The use of IoT platforms improved diagnostic accuracy.	AI models (CNN, SVM), IoT, predictive maintenance, thermographic imagers
Automated detection and localization	AIDI Solar software, equipped with computer vision and GNSS technology, enables processing of data collected from UAVs, detecting defective solar panels, identifying types of damage (cell, bypass diodes, hot spots, com. box, reverse polarity, inverters and string, missing, shadows, dirt, etc.), and improving identification accuracy through deep neural networks.	Computer vision, GNSS, deep learning (U-Net, HSV), automated localization

Note: Systematized by the author based on [6,8]

Artificial intelligence (AI) plays a key role in advancing solar energy, particularly when combined with cutting-edge technological solutions that enhance monitoring, diagnostics, and solar power plant management. Infrared (IR) sensors and thermal imaging, complemented by machine learning algorithms, enable automated detection of hot spots, microcracks, and other defects that impact panel performance. The use of RGB cameras, together with photogrammetry and specialized software, allows for precise analysis of system structures and conditions, which is especially important for rooftop and large-scale ground-mounted installations [7].

AI models, such as convolutional neural networks (CNN) and support vector machines (SVM), combined with the Internet of Things (IoT) and predictive maintenance, significantly improve power plant reliability by minimizing unexpected failures. The integration of thermographic imagers driven by AI algorithms enables fast and accurate real-time diagnostics of panel conditions. Additionally, deep learning techniques (U-Net, HSV) and computer vision facilitate the automatic localization of damaged or inefficient panels, reducing maintenance time and optimizing energy production [10].

The combination of GNSS (Global Navigation Satellite Systems) with AI technologies unlocks new possibilities for autonomous drone operations, allowing efficient monitoring of solar plants in hard-to-reach or hazardous locations. This enhances data collection accuracy, automates analytical processes, and enables rapid responses to potential issues [10].

As a result, integrating AI with modern sensor and analytical technologies makes solar power plant management more efficient, cost-effective, and safe. These innovations contribute to increased overall productivity and longevity of photovoltaic systems, which is crucial for the large-scale transition to clean energy.

Even minor technical defects can significantly impact solar plant profitability and the economic feasibility of a photovoltaic installation. The causes of these defects vary, including installation errors, laminate degradation, or gradual damage due to years of exposure to UV radiation and environmental conditions. Thermographic analysis primarily focuses on identifying hot spots, which not only reduce energy output but also pose potential safety hazards. This is particularly important for warranty claims. Additionally, electrical distribution components are tested to detect faulty wiring connections. Thermal imaging can also ensure that live components do not overheat and that cooling systems function properly.

AIDI Solar has made significant strides in reducing operational risks at solar power plants by implementing automated data analysis based on thermal imaging technologies. Their AI- and machine vision-driven solutions enhance the efficiency and safety of photovoltaic systems.

AIDI Solar utilizes UAVs equipped with high-precision thermal cameras to inspect solar power plants at a rate of up to 50 MW per daylight period. The collected thermal images are analyzed using neural networks, enabling the proactive detection of hidden equipment defects and forecasting energy generation. This ensures that system operators receive automatic alerts about potential issues and necessary interventions [1].

Applications and benefits of solar thermography include:

- early fault detection, preventing energy output losses;
- improved operational safety, reducing fire risks;
- fast, safe inspections;
- identification of hot spots, open-circuit modules, short circuits, delamination, cell fractures, corrosion, loose contacts, and overheated connectors;
- added value for solar engineers and system operators [1]

AIDI Solar's thermal imaging technology enables the identification of various issues that could lead to energy loss and potential fire hazards. These problems may arise due to installation negligence, prolonged UV exposure, or material degradation over time. Thermal imaging also helps pinpoint hot spots, which not only reduce energy output but can also lead to warranty claims. Furthermore, electrical distribution components can be tested to identify poor wiring connections, while thermal imaging ensures that live components do not overheat and cooling systems function properly. This technology adds value for both solar engineers and plant operators by enabling fast, safe inspections while preventing energy losses and safety risks.

By implementing these technologies, AIDI Solar's clients have observed a 5–8% annual increase in energy generation, leading to an additional €1.9 million in revenue. Overall, the company has inspected 360 MW of solar power plants and analyzed over 1,000,000 modules.

However, like any innovative technology, UAVs also come with risk factors that must be considered in risk management systems. The primary risks include human error, device malfunctions, and adverse weather conditions.

Table 2 – Risks of UAV inspections for solar panels

Risk category	Description	Possible consequences	Risk mitigation measures
Human error	Mistakes by drone operators, including communication issues, insufficient training, distractions, fatigue, and misjudgment of risks.	Loss of drone control, incorrect threat assessment, increased accident risk.	Regular training, adherence to safety protocols, fatigue management, enhanced situational awareness.
Failure to follow procedures	Violation of standard operating procedures (SOP), which may lead to hazardous flight conditions and accidents.	Safety regulation breaches, increased risk of drone control failure.	Strict procedural compliance monitoring, continuous operational oversight, safety audits.
Drone technical failures	Mechanical or electronic malfunctions of drone components that may result in loss of control and crashes.	Uncontrolled crashes, potential damage to infrastructure or injury to people.	Pre-flight inspections, backup systems for critical components, emergency response plans.
Collision with another aircraft	Unexpected presence of another drone or manned aircraft in the airspace.	Risk of mid-air collision, posing a threat to drone safety and other aircraft.	Airspace monitoring, flight route planning to avoid collisions, use of ADS-B transponders.
Sudden weather deterioration	Rapid weather changes, such as strong winds, rain, or storms, affecting drone stability and control.	Loss of stability, forced landing or crash, potential damage to solar panels.	Use of weather forecasting, risk assessment before flights, real-time weather monitoring.
Navigation system failure	GPS and navigation system disruptions caused by electromagnetic interference from mobile base stations or high-voltage power lines.	Loss of navigation signal, inability to return to base, potential drone crash or loss.	Protection against electromagnetic interference, backup navigation systems, flight restrictions in high-risk zones.

Note: Systematized based on research [5]

Based on the reviewed literature, modern technologies, particularly the integration of artificial intelligence and the use of drones, significantly improve risk management in the renewable energy sector. For example, AIDI Solar utilizes UAVs equipped with thermal imaging cameras for solar panel inspections, which not only drastically reduce diagnostic time but also enhance defect detection accuracy, minimizing the risks of unexpected downtimes and operational losses.

Based on this analysis, the following recommendations can be made to optimize risk management in the renewable energy sector:

- Increased use of automated monitoring and diagnostic technologies: Deploying UAVs for regular inspections of solar panels and other equipment ensures early defect detection, preventing costly emergency repairs.
- Development of AI-based data analysis systems: Implementing machine learning algorithms for analyzing collected thermal images and predicting potential failures helps prevent unplanned losses in production capacity.
- Improvement of training and certification programs for drone operators: Ensuring a highly skilled workforce capable of effectively managing UAVs minimizes human error as a potential risk factor.

These measures will not only enhance operational efficiency but also reduce maintenance costs, ensuring the stability and reliability of renewable energy production.

Conclusions

The implementation of UAVs with thermal imaging sensors and artificial intelligence significantly reduces solar power plant maintenance costs by automating inspection processes. Traditional inspection methods require substantial human and financial resources, whereas UAVs enable fast and efficient monitoring of large solar panel areas. The use of machine learning algorithms improves defect detection accuracy, minimizing the risks of unplanned downtimes and operational losses.

Statistical analysis of AIDI Solar® solutions in real projects demonstrates a significant economic impact. The integration of UAVs and AI increases energy generation efficiency by 5–8% annually, contributing to an additional €1.9 million in revenue. Overall, the company has inspected over 360 MW of solar power plants and analyzed more than one million solar modules, confirming the technology's effectiveness in mitigating operational risks.

To further optimize risk management in renewable energy, it is recommended to enhance the integration of automated monitoring technologies, expand the use of machine learning algorithms for equipment failure prediction, and improve training programs for UAV operators. The combination of these measures will not only improve maintenance efficiency but also ensure the long-term stability and profitability of solar energy.

References

1. AIDI Solar (2024). About. URL: https://aidi.solar/en#about

2. Flyproaerial. (2024). How UAV solar inspections improve operational efficiency. https://www.flyproaerial.com/blog/how-uav-solar-inspections-improve-operational-efficiency

3. Jahn, U., Herz, M., Köntges, M., Parlevliet, D., Paggi, M., & Tsanakas, I. (2018). Review on infrared and electroluminescence imaging for PV field applications: International Energy Agency Photovoltaic Power Systems Programme: IEA PVPS Task 13, Subtask 3.3: Report IEA-PVPS T13-12:2018. International Energy Agency. https://iea-pvps.org/wp-content/uploads/2020/01/Review_on_IR_and_EL_Imaging_for_PV_Field_Applications_by_Task_13.pdf

4. Kiryati, D. (2024). The advantages and challenges of using multi-drones for utility solar farm inspections. vHive. https://www.vhive.ai/the-advantages-and-challenges-of-using-multi-drones-for-utility-solar-farm-inspections/

5. Kobaszynska-Twardowska, A., Łukasiewicz, J., & Sielicki, P. W. (2022). Risk management model for unmanned aerial vehicles during flight operations. Materials, 15(2448). https://doi.org/10.3390/ma15072448

6. Matuszak, J. (2024). Top 10 innovative technologies in the sustainable energy sector. KnowHow. URL: https://knowhow.distrelec.com/energy-and-power/top-10-

innovative-technologies-in-sustainable-energy-sector/

7. Mohammad, A., & Mahjabeen, F. (2023). Revolutionizing solar energy: The impact of artificial intelligence on photovoltaic systems. International Journal of Multidisciplinary Sciences and Arts, 2(1). https://doi.org/10.47709/ijmdsa.v2i1.2599

8. Olayiwola, O., & Camara, F. (2024). Challenges and opportunities for autonomous UAV inspection in solar photovoltaics. Web of Conferences, 572, 01003. https://doi.org/10.1051/e3sconf/202457201003

9. SEIA. (2024). Solar installations skyrocket in 2023 in record-setting first full year of Inflation Reduction Act. URL: https://www.seia.org/news/solar-installations-skyrocket-2023-record-setting-first-full-year-inflation-reduction-act

10. Ukpanah, I. (2024). Maximising solar energy output with artificial intelligence (AI). GreenMatch. URL: https://www.greenmatch.co.uk/blog/ai-for-solar-panel-optimisation