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Powering Industrial-Scale Grid Inspections with AI

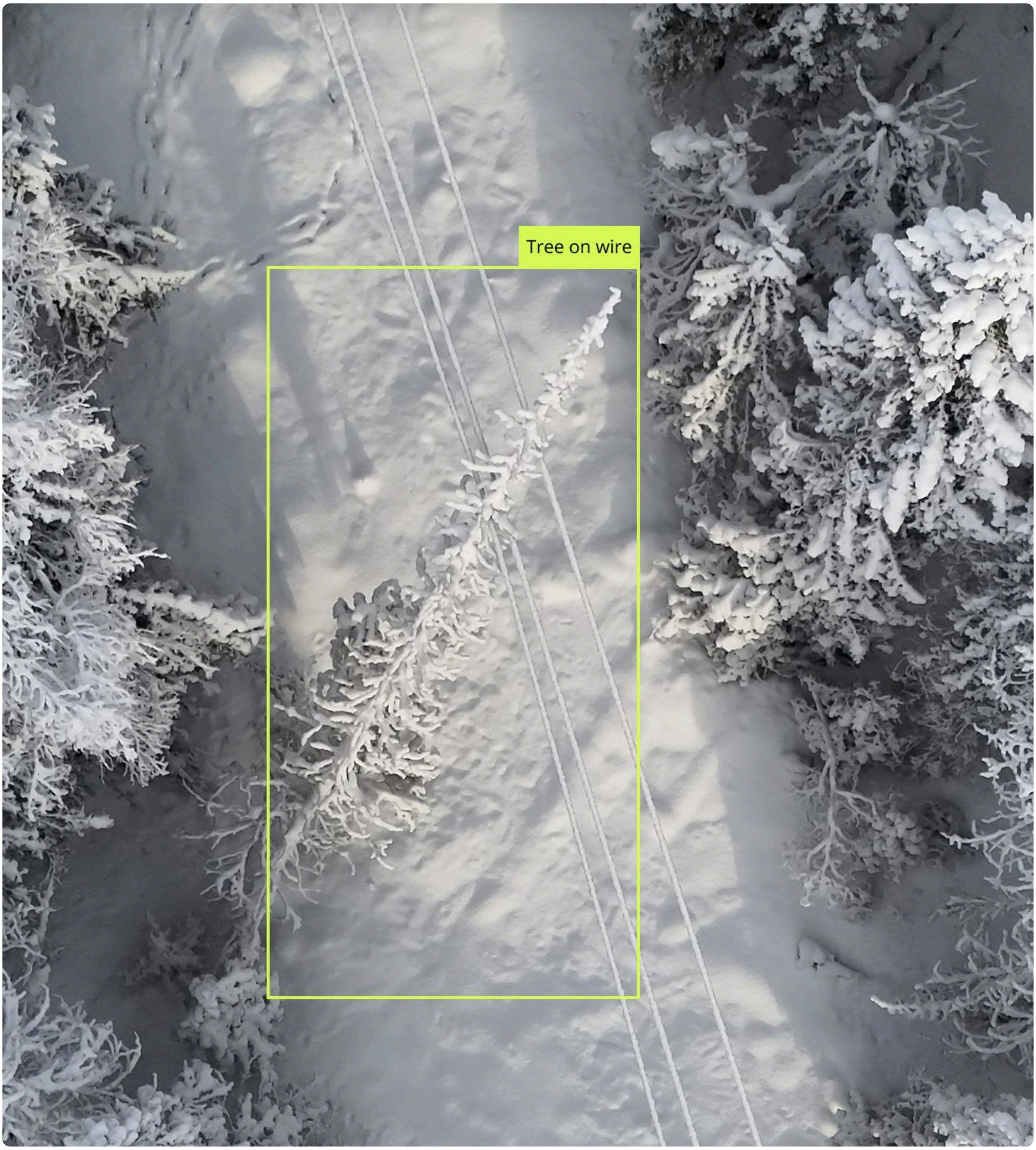


Table of Contents

1. Abstract

Power system operators are increasingly adopting digital inspection methods to improve visibility of infrastructure conditions. However, manual review of large volumes of images and 3D data remains costly, time-consuming, and difficult to scale.

This paper evaluates whether AI-powered asset analytics combined with human verification can reliably detect powerline deficiencies at scale while reducing human workload and cost. Empirical results are presented from a 15,000 km inspection of Sweden's medium and low voltage distribution grid, comparing three approaches: conventional helicopter patrols, manual review of digital imagery, and AI-assisted digital inspection, where humans review only AI-flagged structures. Digital inspections were performed using Arkion's AI-powered defect-detection platform.

The results demonstrate that AI-assisted inspection reduced inspection time by a factor of 24 and lowered cost per deficiency by a factor of 21 compared to manual digital review. The digital inspection identified 1,439 deficiencies in total across 30+ categories, 5× more critical deficiencies than helicopter patrols.

Human inspectors reviewed only 4% of collected data and captured 84% of total deficiencies when assisted by AI. Long-term operational data from early-adopter regions demonstrates a decrease in Average Interruption Frequency. These results confirm that AI-augmented inspection enables scalable, cost-efficient, and preventive asset management for distribution grids.

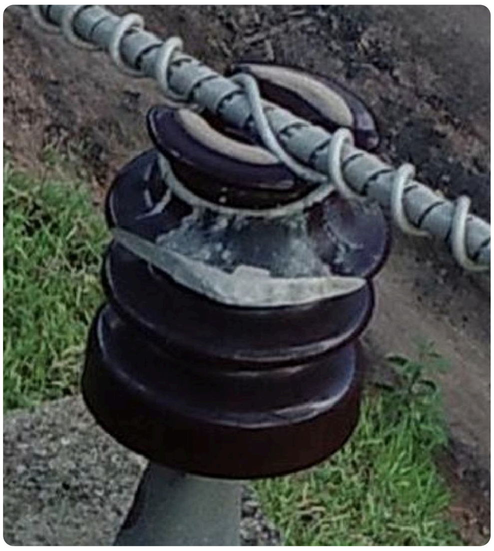
2. Background

The utilities sector is undergoing a major transformation. With the rise of drone technology and the increasing affordability of powerful cloud computing resources, utilities now have the ability to collect massive amounts of data.

But this influx of data brings its own set of challenges. Analyzing millions of images and extracting meaningful insights is no longer scalable with traditional, manual methods. Utilities are now turning to innovative solutions based on AI as recent advancements in AI have opened new doors, particularly for industrial applications like grid inspections. AI offers the potential to analyze vast stretches of infrastructure at scale. However, deploying AI solutions at an industrial level is far from straightforward. It requires overcoming challenges such as managing terabytes of data, handling diverse conditions, and building robust infrastructure for training and deployment. Further, privacy concerns, such as the removal of personal information from images (e.g., faces and license plates), must be addressed to comply with data protection regulations.

This brings us to the key question: ***Can AI truly enable utilities to detect and address powerline equipment deficiencies efficiently and reliably in real-world conditions?***

Addressing this key question, we present a case study with empirical data highlighting how Arkion successfully navigated these challenges. We provide a comparative analysis of inspection times and effectiveness between human inspectors using AI tools and those conducting inspections manually. We evaluate key performance metrics to demonstrate how AI-powered inspections enable industrial-scale operations at a lower cost, offering a reliable and scalable solution for large-scale grid monitoring and maintenance in real-world environments.



Broken ceramic pin insulator used for training an AI-model

An undamaged ceramic pin insulator used for training an AI-model

3. Methodology

To evaluate the effectiveness and demonstrate the real-world utility of AI, we conducted a comparative analysis of two inspection processes: **Manual digital inspection**, and **AI-powered digital inspection**. Further, we compared the performance of these methods against the traditional helicopter-based methods as the baseline.

For this study, we analyzed **10,000 miles** of the Swedish medium and low-voltage distribution network. The objective of this case study is to assess reliability and cost-effectiveness of AI in grid inspection, using real-world data, to determine their technical and economic scalability. The evaluation focused on three key metrics: **time taken** to analyze the grid, the **number of deficiencies** found, and the **cost** per deficiency found.

The following section explains the difference between the three inspection methods and the process involved briefly.

3.1 Process

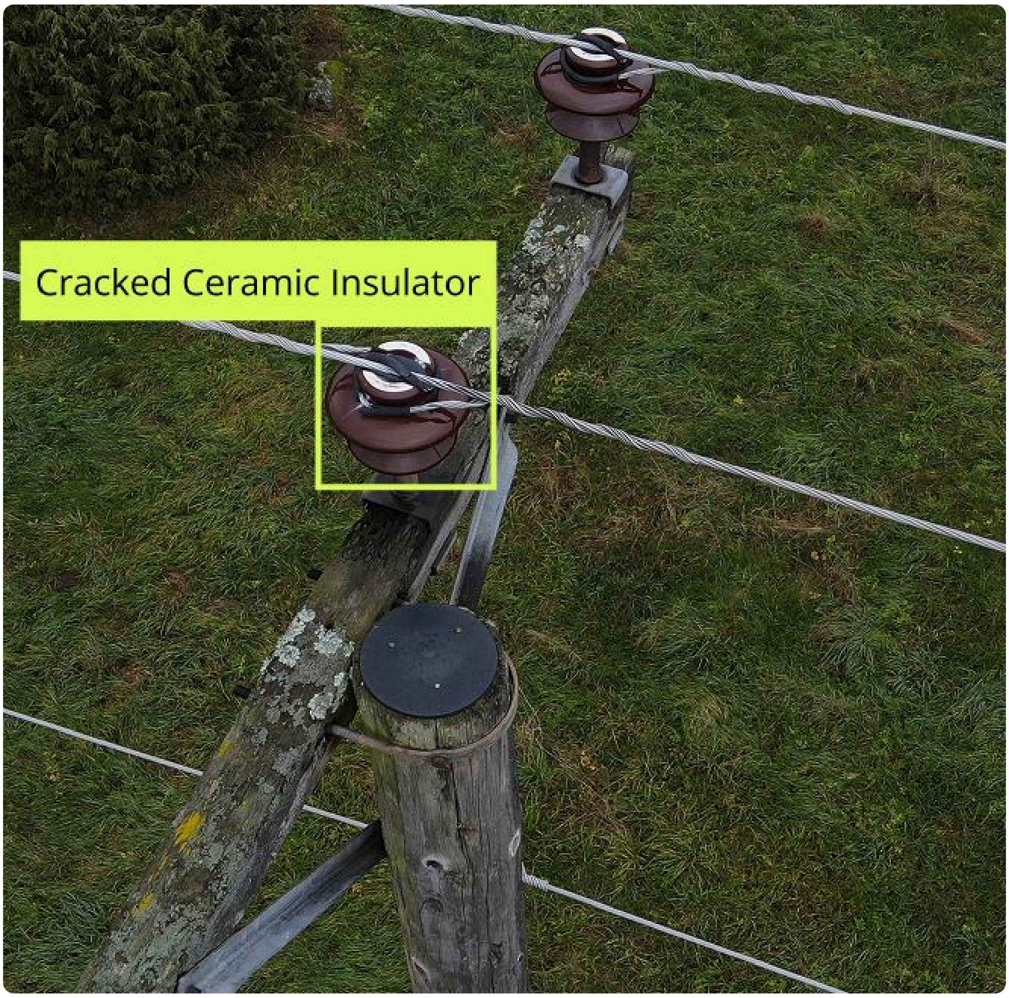
The traditional inspection method typically involves inspectors flying in helicopters to visually examine the grid infrastructure. Unlike traditional inspection method, digital inspection leverages data collected by sensors mounted on drones or helicopters, enabling flexible and asynchronous analysis. The sensors can include RGB cameras, LiDAR, thermal imaging, and more, capturing detailed and diverse data types. These datasets can be stored and revisited as needed, allowing for deeper insights and enabling utilities to move beyond the limitations of real-time, in-flight assessments.

231.1 Manual Digital Inspection

In the manual digital inspection process, human inspectors analyze each and every structure manually. This analysis is performed on digital platforms, where inspectors can zoom in, annotate, and reanalyze the data at their own pace. The flexibility of digital tools enhances the inspector's ability to identify issues, but the process remains slow and labor-intensive due to the sheer volume of data that needs to be reviewed manually. Additionally, the reliance on human effort makes scaling to inspect larger networks challenging and costly.

3.1.2 AI-Powered Digital Inspection

In AI-powered digital inspection, human inspectors only analyze structures that are flagged by AI. This process significantly reduces the workload by allowing the AI to handle the initial data review and identification of potential deficiencies. The flagged structures are then reviewed by human inspectors, who can focus their expertise on verifying and addressing the identified deficiencies. Over time, as the AI learns from feedback provided by human inspectors, its performance improves, leading to better detection capabilities.



3.2 Ensuring Privacy and Leveraging Analytical Tools

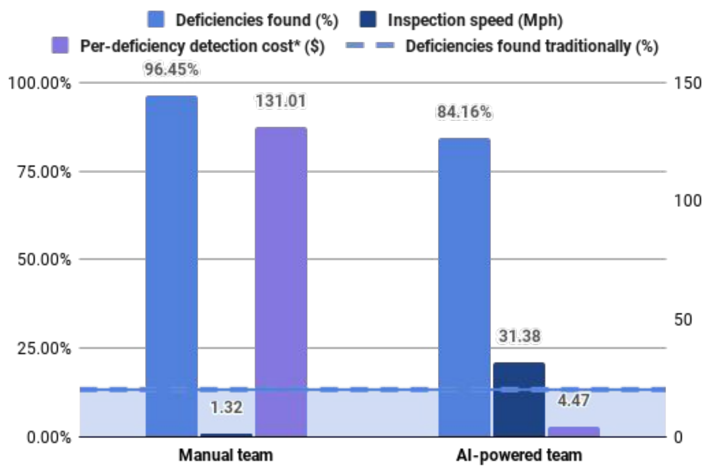
Both Manual Digital Inspection and AI-Powered Digital Inspection follow strict protocols to ensure compliance with data protection regulations. One critical step is the removal of Personally Identifiable Information (PII), such as faces or license plates, from the collected data before showing the data to the inspectors.

Additionally, both inspection teams utilize Arkion's Visualization Platform for data analysis. This platform provides a unified and user-friendly interface for inspecting and annotating sensor data, whether reviewed manually or with the help of AI algorithms.

4. Results

Once the inspection is completed by both the teams, the results have shown that **AI-powered method far outpaced in efficiency.** The AI-powered inspection team only took **318** human-hours to inspect 10,000 miles in comparison **7,576** human-hours taken by the manual inspection team. This makes the AI-powered team 24 times faster than their counterpart. To put that into perspective, a team of 4 inspectors having been augmented with AI can digitally inspect a grid of size 10,000 miles in **10 working days** which is less than the time it takes to fly the entire grid. In contrast, the same team without AI would require a staggering **237 working days** to complete the same task.

The difference in efficiency is underscored by the Per-deficiency cost. Using California's hourly minimum wage of $16 as a reference, it cost **$131** per deficiency for the manual inspection team, compared to just **$4.50** for the AI-powered team.



In terms of deficiencies found, there were 1439 deficiencies found in total belonging to more than 30 different deficiency categories. Out of which **1388** deficiencies were found by the Manual inspection team while **1211** deficiencies were found by AI-powered inspection team. These figures represent **4 to 5 times** the number of deficiencies typically detected using traditional helicopter-based inspection.

Although the Manual inspection team found 12% more deficiencies than their counterpart, the true efficiency lies in the the amount of data they had to look at. The AI-powered team had to look at **only 4% of the data** to find 84% of the deficiencies unlike Manual to who had to look at the 100% of the data to find 96% of the deficiencies. This is the key to why the AI-powered team is both faster and cheaper.

5. Analysis

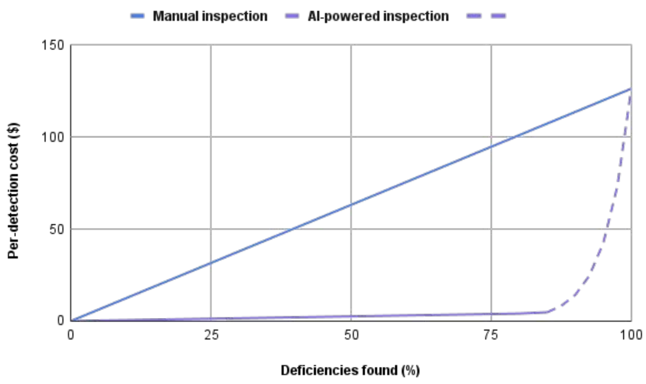
The results clearly demonstrate that leveraging AI for industrial-scale grid inspection is both significantly cheaper and more reliable. However, a 12% gap between the AI-powered and manual teams remains. Closing this gap efficiently is a natural next step, and one of the easiest ways to do so involves optimizing the precision-recall trade-off.

To briefly explain: **Precision** measures the accuracy of the AI's predictions (i.e., the percentage of flagged issues that are actual deficiencies), while **Recall** measures how many of the total deficiencies are detected. These metrics are inversely related—improving one often leads to a decrease in the other. By intentionally lowering the precision of our models, we can boost recall, meaning the AI identifies more potential deficiencies by examining additional data flagged through statistical methods.

However, this approach has a caveat: the marginal cost of finding additional deficiencies increases as more data is analyzed. Initially, the AI-powered team needed to review only 4% of the data to uncover 84% of the deficiencies, showcasing its efficiency. Intuitively, one might think analyzing an additional 1% of data would yield the remaining 16% of deficiencies, but this is rarely the case. As the analyzed data volume expands beyond 4%, the rate of new deficiencies discovered diminishes significantly.

5.1 Closing the gap

In the worst-case scenario, increasing the data analyzed too far could lead to the AI team effectively examining all structures. This would negate the efficiency and cost benefits of the AI-powered approach, bringing it closer to the inefficiencies and high costs associated with manual inspection. Careful calibration of the precision-recall balance is essential to maintain efficiency while minimizing the gap in deficiency detection.



5.2 The key to success

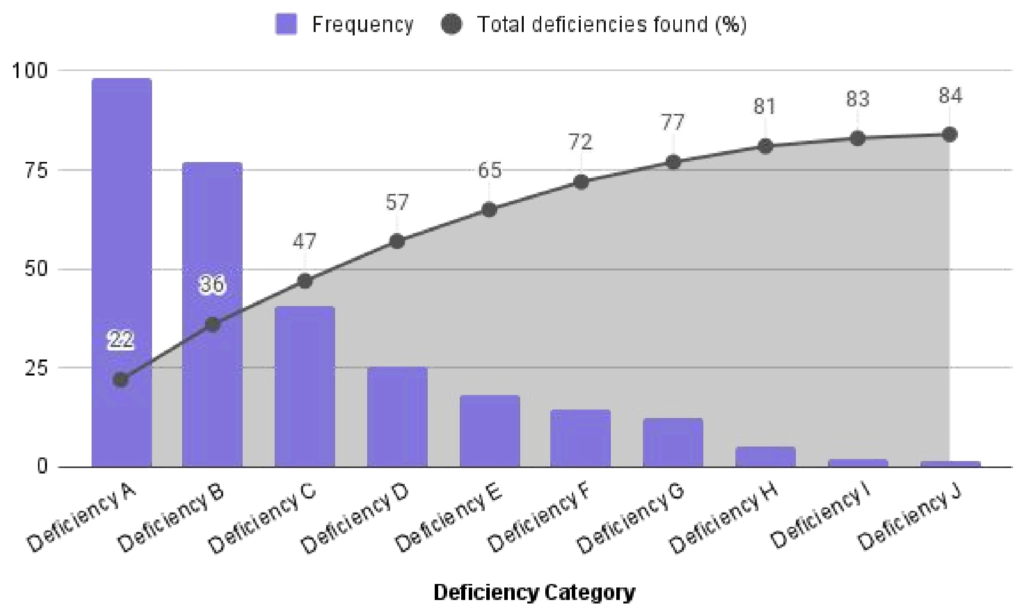
A key success factor of the AI-powered method was its ability to prioritize the most frequent deficiencies, which constituted the majority of the overall issues identified. This approach aligns with the **Pareto Principle**, or the 80/20 rule, which states that 80% of outcomes are often driven by 20% of the causes. In this case, 80% of the deficiencies stemmed from just 20% of the deficiency categories. By focusing its efforts on these high-frequency categories, the AI-powered inspection process achieved remarkable efficiency and accuracy.

5.3 Long-term impact

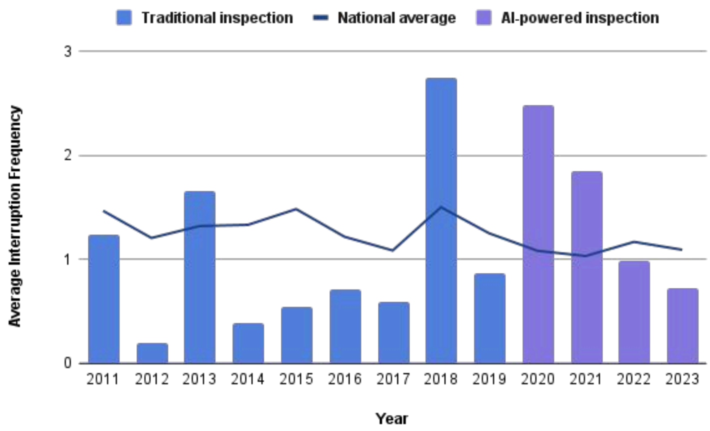
The long-term impact of adopting AI-powered inspection methods is critical to understanding their value beyond immediate cost and efficiency gains. The Swedish energy regulator, **Energimarknadsinspektionen**, has monitored grid reliability indicators for over a decade to evaluate the performance of electrical grids across the country. To explore the broader implications of this technology, we analyzed a region in Sweden that was an early adopter of AI-powered inspections.

Before transitioning to the modern inspection methodology, this region relied on traditional helicopter-based manual inspections. By the end of 2020, just before implementing the AI-powered approach, the region reported an **Average Interruption Frequency (AIF)** of 2.4 interruptions per customer which was more

This strategic prioritization allowed the AI-powered method to maximize its impact while minimizing the data it needed to analyze. Rather than expending resources on rarely occurring deficiencies, the AI concentrated on areas with the highest likelihood of problems. This targeted approach not only improved the speed and cost-effectiveness of the inspection process but also ensured that the most pressing and common issues were addressed promptly. Moving forward, refining the AI's ability to detect less frequent deficiencies without compromising efficiency could further enhance its effectiveness and close the detection gap with Manual digital inspections.



than double the national average of approximately 1 interruption per customer. Following the adoption of AI-powered inspections, the region's AIF steadily decreased year over year, reaching an impressive **0.75** interruptions per customer in 2023. This figure not only reflects a substantial improvement for the region but also places it well below the national average of 1.1 interruptions per customer.



This improvement reflects the long-term effectiveness of AI-powered inspections, enabling grid operators to identify and resolve issues before they escalate into outages.

6. Summary

This comprehensive study compared Manual and AI-powered digital inspection methods for grid infrastructure, evaluating their efficiency, cost-effectiveness, and long-term operational impact. The AI-powered approach demonstrated remarkable superiority, completing a comprehensive 10,000-mile grid inspection in merely 478 human-hours—a process 24 times faster than traditional methods and consequently 29 times more cost-effective.

The results revealed the AI methodology's strategic alignment with the Pareto Principle, leveraging its analytical capabilities to maximize efficiency by identifying 84% of infrastructure deficiencies using only 4% of the data. While the manual inspection team identified 12% more deficiencies, the AI method's significant temporal and economic advantages were unequivocally evident.

The potential of AI-powered inspections was compellingly illustrated through a case study of a Swedish regional grid. Following the implementation of AI-driven inspection methodologies in 2020, the region experienced a dramatic reduction in grid disruptions. The Average Interruption Frequency (AIF) plummeted from 2.4 to 0.75 interruptions per customer by 2023—a performance substantially below the national average.

These findings underscore the profound implications of AI technologies in grid inspection, demonstrating their capacity to revolutionize grid reliability, substantially reduce operational costs, and enhance overall system performance at an industrial scale.

About Arkion

Founded in Sweden 2019, Arkion has worked with over 40 utilities across the globe improving their inspection process by deploying AI-powered digital inspections. Arkion’s solution that transforms inspection data—including images, thermal, and lidar—into precise insights on the condition and health of power grids ranging from low to high voltage.

Utilizing cutting-edge Machine Learning and AI technologies, Arkion efficiently transforms vast volumes of images and 3D data points into structured insights regarding grid health. Arkion's ability to rapidly train models to detect a vast majority of common and critical defects on grids stems from our unparalleled database of high-fidelity data. Employing a Human-in-the-Loop methodology and harnessing the full spectrum of available data, we rapidly develop robust AI models, offering a swifter and more cost-effective alternative to safeguarding the world’s energy grid.

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