RAPTOR MAPS

Solar PV Industry Inspection Methods Comparison: Aerial Thermography vs. I-V Curve Tracing

INTRODUCTION

Within the U.S. solar industry, I-V curve tracing has historically served as the dominant means to inspect and measure photovoltaic (PV) panels' performance. However, in recent years, aerial thermography has gained traction as an alternative leading method to survey and monitor a PV system's health expeditiously.

This eBook examines and compares the two leading methods used to gauge a PV system's operating condition. The topics to be covered are data collection, analysis processes, and the accuracy between I-V curve tracing and aerial thermography.

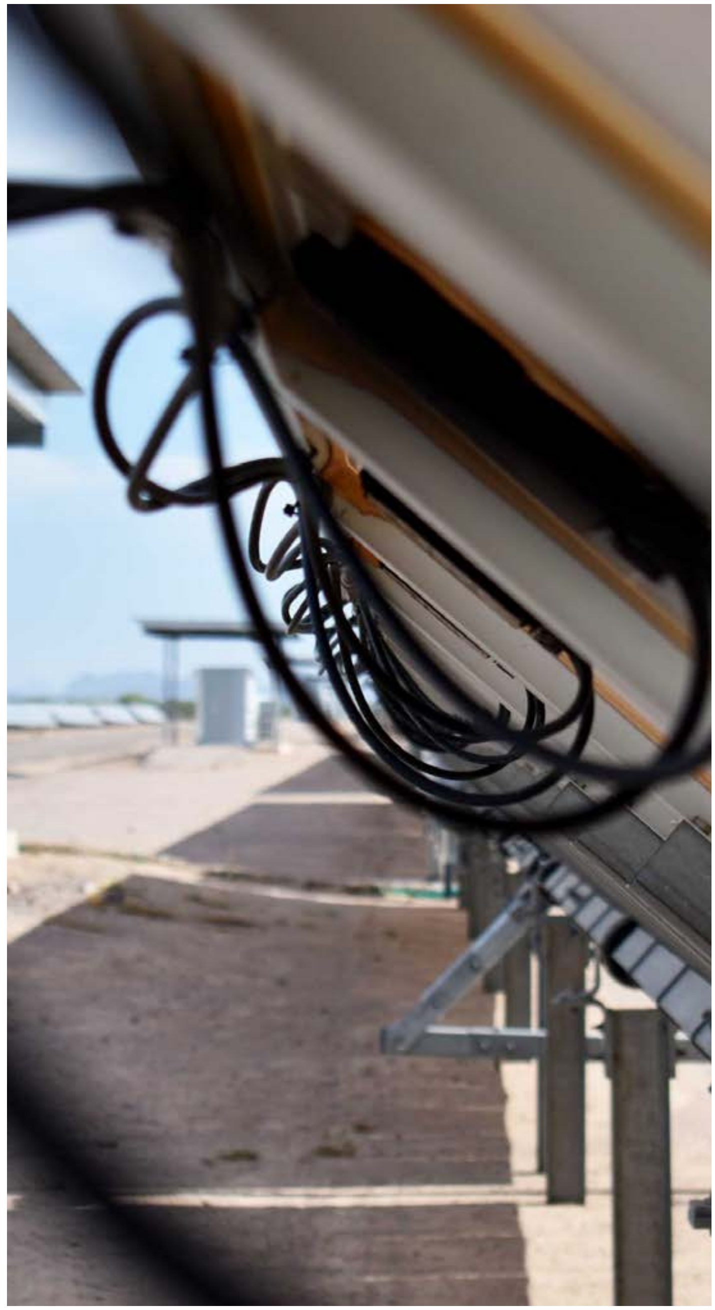
METHODOLOGY

I-V curve tracing requires trained technicians to perform, analyze, and interpret the I-V curve tracing results, and reporting is documented at a per-string level. Aerial thermography requires adequate drone and camera hardware, a licensed and trained pilot, and post-processing analysis reported on a per-module level.

DATA COLLECTION

The aspects of data collection compared include:

1. Coverage & Granularity
2. Collection Time
3. Restrictions
    A. Power Production
    B. Expertise Requirements
    C. Weather Impacts
    D. Safety & Restrictions



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> “Aerial thermography is still the fastest method for inspecting solar PV systems.”

1. COVERAGE & GRANULARITY

I-V curve traces provide insight into the underperformance of a PV system at the combiner and string level. Due to economic and labor limitations, individual modules are typically only electrically tested if anomalies are discovered at the combiner or string level. I-V curve tracing can reveal module-level anomalies in tested offline strings but requires more testing to capture specific details.

Aerial thermography inspections cover the entirety of a PV system, collecting data for every module. With modern flight-planning applications and Raptor Maps' data uploader, pilots can ensure full data coverage before leaving the site. Aerial thermography can capture sub-module level anomaly detail on each module unless it is part of an offline string. The reason being that the string is already offline and the thermal camera is picking up the heat generated in the entire offline string.

2. COLLECTION TIME

I-V curve tracing takes between 3.5 to 5 hours per MW with module power and string length at 1,000 volts. If sites have a high voltage, then the average time can be between 2 to 3 hours per MW. These variability levels attest to how much needs to be considered upon conducting an IV curve test, including site set up consistency, number of strings per unit, inverter accessibility, hardware utility, and standardize practices.

Aerial thermography inspections with a drone average 10 minutes per MW. Pilots will also need to take time to set up the drone and pilot station and when a site's capacity is greater than 5 MW, pilots will need to change the drone batteries, adding more time. However, aerial thermography is still the fastest method for inspecting solar PV systems.

> "The thermal data will reveal any offline or anomalous inverters, combiners, strings, and modules."

3. RESTRICTIONS

A. Power Production

The combiners or strings being I-V curve traced must first be isolated from the energized system to conduct electrical performance testing. Consequently, during the time of inspection, the offline combiner or string is not producing power.

In contrast, during an aerial thermographic inspection, it is imperative that the site is online through the data capture duration. The thermal data will reveal any offline or anomalous inverters, combiners, strings, and modules. However, thermography is unable to identify any subset anomalies that are present in an offline array.

B. Expertise Requirements

Conducting an I-V curve test requires the expertise of a trained technician with extensive field experience. Said technicians must also be capable of interpreting the data outputs on-site, which will be expounded on later in the eBook.

Drone pilots must have the FAA Part 107 license to capture aerial thermography data of solar PV systems. Raptor Maps offers flight guidelines to enable companies running in-house drone programs to collect high-quality thermal data efficiently. Additionally, Raptor Maps provides turnkey services, which use a global network of vetted drone service provider partners to collect the aerial data.

C. Weather Impacts

Irradiance has an enormous impact on the viability of both the I-V curve and aerial thermography inspections. I-V curve tracing requires a minimum level of irradiance of 400 watts per square meter at the time of inspection to avoid data interpretation errors. Raptor Maps recommends a minimum irradiance of 600 watts per square meter during aerial thermography flights to ensure anomalies are adequately visible. It is highly recommended to fly on a day with clear skies to ensure stable irradiance levels.

In addition, both inspection methods are inhibited by other weather conditions. Technicians performing the I-V curve tracing can face difficulty when the weather is too hot, as they're required to wear personal protective equipment (PPE) and can face heat exhaustion. Whereas aerial thermography needs to be conducted when there is little wind, as high winds can impact the ability to take accurate radiometric measurements. IEC standards for thermal PV inspections set a maximum wind speed of 15 MPH (6.7 M/S).

D. Safety Restrictions

Collecting I-V curve data requires a qualified electrical worker, as defined by the jurisdiction's licensing requirements, to wear appropriate personal protective equipment (PPE), as defined by NFPA 70E. In addition to the technician performing the test, additional technicians are present to watch for any potential risk of electrocution, increasing labor demand.

As an observational form of inspection, aerial thermography does not require pilots to interact directly with the electrical system. However, one must consider airspace restrictions before every inspection. In the U.S., the Federal Aviation Administration (FAA) regulates airspace and commercial aerial vehicles. Pilots need to be aware of the regulations in the area where they will be performing the aerial inspection. Aerial thermography mitigates this human risk by allowing a pilot to be safely stationed while a drone collects data.

DATA ANALYSIS

Once the data is collected using an I-V curve tracer or aerial flight, the findings must be analyzed to gauge the health of a PV system and diagnose the causes of power loss. The aspects we compared are:

1. **Required Expertise**
2. **Data Analysis Time**
3. **Data Accessibility**

1. REQUIRED EXPERTISE

Interpreting the visual data from an I-V curve tracer requires a skilled individual with field experience and context on how environmental factors can impact the outputs. Due to this, I-V curve measurements can easily be misinterpreted, resulting in false-positives, or cause missed anomalies if the individual lacks experience. In contrast, interpreting aerial thermography data does not require advanced technical training. The human eye can detect anomalies from thermal imagery, and software solutions can analyze a large amount of data and detect temperature deltas. Software post-processing can be coupled with quality assurance checks by trained individuals. Therefore, aerial thermography is less prone to interpretation error.

To the right are two images, Figure 1 is from an I-V curve tracing test, while Figure 2 is taken from an aerial thermography inspection. Without training, it is not easy to label these I-V curves as nominal or anomalous, while aerial thermography clearly shows anomalies at a module level.

> **"Once the data is collected using an I-V curve tracer or aerial flight, the findings must be analyzed to gauge the health of a PV system and diagnose the causes of power loss."**

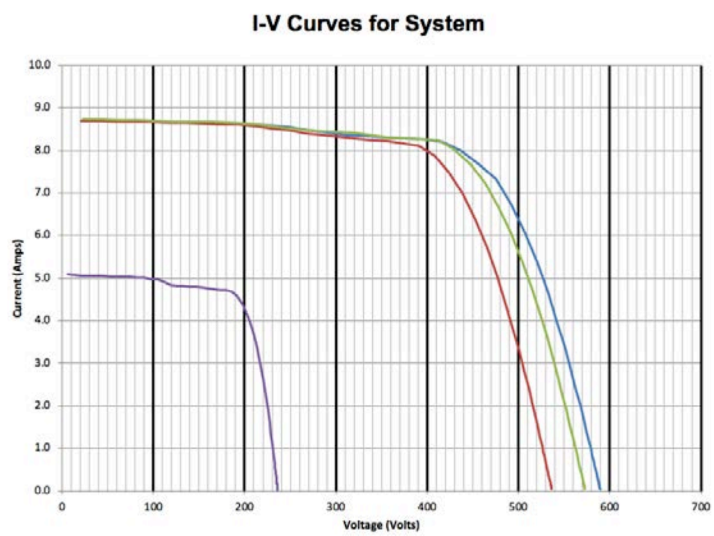


Figure 1: An image taken from an I-V curve tracing test on a string in a solar PV system.

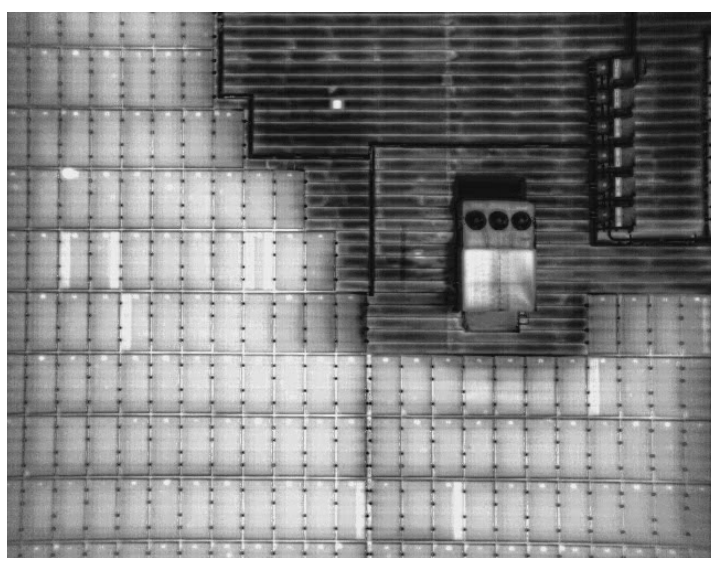


Figure 2: Image with anomalies from an aerial thermography inspection on a solar PV system.

2. DATA ANALYSIS TIME

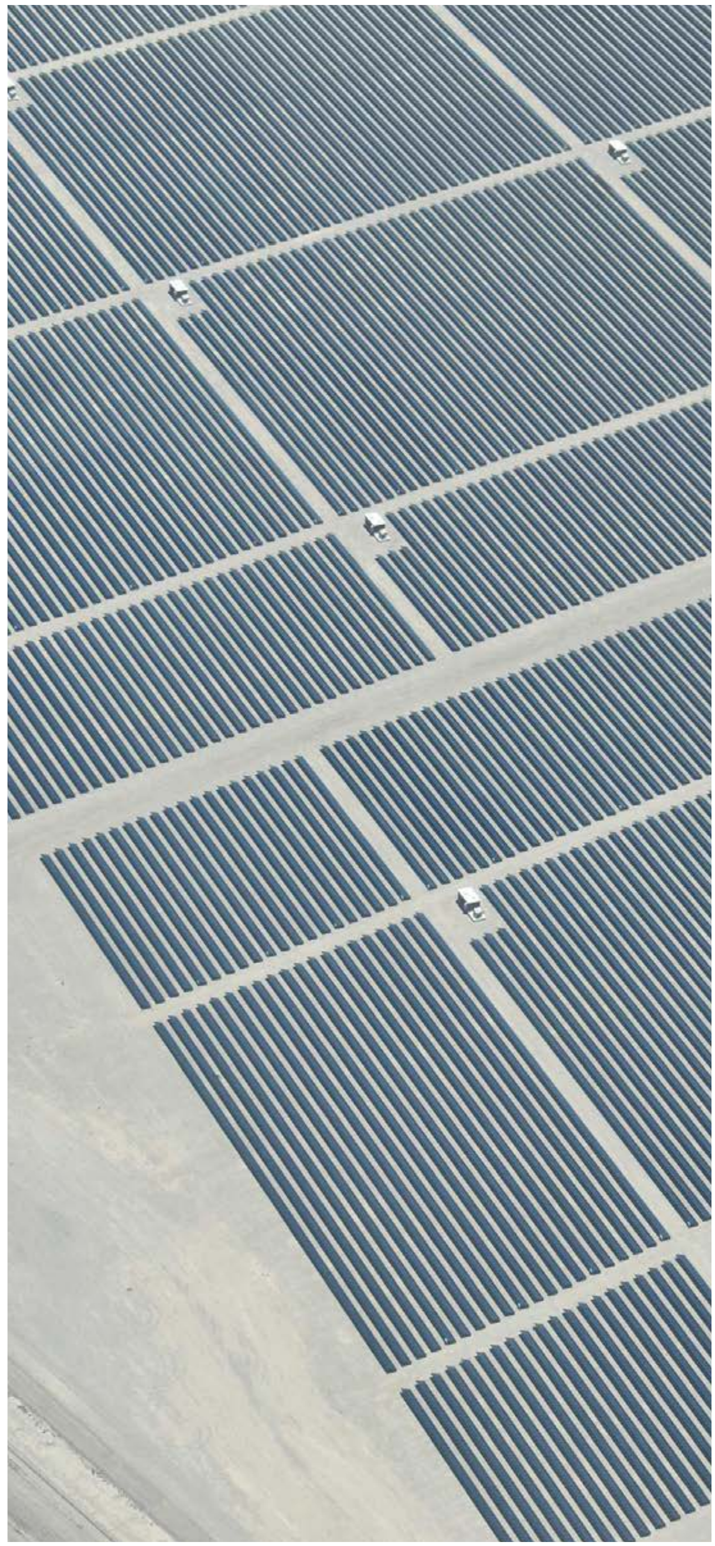
Depending on the type of solar PV system, i.e., ground mount, rooftop PV array, and system specifications, I-V curve tracing analysis time can vary. If the data is properly documented and analyzed by a trained technician that also performed the inspection, it can take 30 minutes to analyze 1 MW. However, if the PV system has a complicated string and wiring system, it can be extended to multiple hours to analyze 1 MW. Aerial thermography data can be analyzed with software, including upload time, processing, and analysis, in 3 hours per MW.

One notable benefit of I-V curve tracing is real-time results, assuming the technician conducting the test is trained to interpret the data. This can help avoid a "second truck roll," and remediation can happen during the trip if the necessary equipment is on hand. With aerial thermography, the collected data is typically post-processed offsite, and after the results are generated the Operations and Maintenance (O&M) teams can begin remediating the system issues. It is worth noting that aerial thermography still prevents the first "truck roll," and O&M teams only need to arrive on-site to fix the problems and are equipped with the anomalies' quantity and location.

3. DATA ACCESSIBILITY

Regardless of the method used to inspect a PV system, it's critical that the collected data is accessible to all relevant parties in a decipherable format. Data transparency can ensure a level of trust in organizations that outsource their inspections and allow for third-party audits and warranty claims. For I-V curve tracing, depending on the instrument used, output formats will vary as there is no industry standard. Any further analysis or confirmation of analysis, beyond the technician's interpretations, would require another qualified specialist to parse through the on-site findings. Organizations relying on outsourced I-V curve inspections are at the mercy of the field technician and their conclusions.

Conversely, when aerial thermography inspections are analyzed by software, they offer a standardized and transparent final report. Raptor Maps has rigorous flight guidelines that drone pilots need to follow, further cementing a standardized practice. Aerial inspections result in an approximate ratio of 200 images per MW, and as PV system size increases, it leads to large amounts of data to analyze. However, with software solutions performing the post-processing, aerial thermography can scale exponentially and meet the demand of asset owners and O&M teams as their portfolios grow. Raptor Maps addresses these market gaps through its online platform, which offers



services for organizing, sorting, and annotating large amounts of thermal data. Raptor Maps' software leverages the metadata from drone images to add geospatial context to the findings. A digital model of the PV system is created in the Raptor Maps platform, which displays the inspected system's electrical diagram and enables O&M teams to find anomalies quickly. With the software tools available, aerial thermography data becomes completely transparent, and results are digestible to audiences of all backgrounds within the solar industry.

CONCLUSION

In conclusion, aerial thermography offers a more prudent and scalable method of inspection by generating comprehensive and actionable analytics. From data collection to report generation, the entire process of aerial thermography requires less capital and has a higher potential to scale with automation than I-V curve tracing today. As well, by leveraging metadata from drones and software tools, the aerial approach to inspecting a solar site provides geospatial contextualization to save time remediating found faults.

To contact Raptor Maps or to learn more about our industry solutions, software, or turnkey services visit us at www.raptormaps.com

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