QA Quality Assurance

Leveraging Drones for PV Plant Inspections

Drones are reducing labor costs, maximizing performance and providing granular insights for PV systems. In addition to enabling the taking of aerial photos, they support aerial thermography, capturing PV system performance data with thermal infrared (IR) cameras.

Also known as an *unmanned aerial vehicle,* a drone is an aircraft without a human operator aboard. A drone in combination with a ground station, typically a smartphone or tablet and controller, comprises an *unmanned aerial system.* Drones can be either fixed-wing types, which resemble an airplane, or multicopter models, which have several propellers and can hover in place.

O&M providers, EPC firms and asset owners are increasingly adopting drone technology for its lower data acquisition costs and superior data collection and analysis flexibility compared to boots-on-the-ground inspections with handheld analysis tools. In the past 2 years, machine learning and artificial intelligence, improvements in drone hardware and a favorable regulatory environment have combined to push drones to the forefront of aerial thermography.

"This year, we are flying drones over most of our power plants under management," says Angelo Purpura, director of operations at SOLV, a Swinerton company. "Asset owners are recognizing that drones can replace the majority of I-V curve tracing, which enables us to provide a faster, more detailed analysis and maximize output." SOLV recently completed a survey of a utility-scale (200 MWdc plus) installation via drone in less than 6 hours, and the inspection team produced its detailed report in less than a week. Comparable assessment with I-V curve tracing would have required weeks to perform. SOLV's aerial imaging approach resulted in a cost savings of approximately 50%.

Locating the failure point A drone equipped with a thermal imaging camera detected this PV string failure in minutes on a 4 MW installation. The maintenance technician located the failure with the drone before determining the cause of failure in the array field.

Courtesy Raptor Maps

Put Drones to Work for Your Business

Drones put the power of aerial thermal inspections in the hands of EPC firms, O&M technicians and regional drone service providers. They can minimize or eliminate the need for ground site inspections with handheld I-V curve tracers and other analytics tools, improving overall worker safety while lowering O&M cost. Some of the largest national insurance companies, such as State Farm and Travelers, also now use drones for rooftop inspections.

Drones offer some powerful features, such as tunable deliverables. For instance, an EPC firm may opt to obtain an extremely high-resolution dataset on areas of interest, such as a defective subarray for warranty prosecution, or a site-level overview. These tunable variables create flexibility in the type and means of data collection. The rapid growth of the commercial drone sector has fostered the creation of automated, industry-specific software with flexible outputs including paper reports and backend system integration. As a result, aerial inspections typically streamline reporting turnaround time, in some cases allowing preparation of comprehensive reports in a single day.

Aerial inspections complement on-site data collection systems and their cloud-based monitoring counterparts. Asset-monitoring solutions that utilize on-site hardware provide monitoring with a high temporal resolution (the precision of a measurement with respect to time) or constant measurement. These solutions also typically monitor energy and environmental data to optimize asset performance. Drones complement these systems with high spatial resolution that can localize issues to the cell level and also detect possible site-level issues such as vegetation growth or excessive soiling. Monitoring solutions can guide plant operators to determine when and where to send a drone within a PV system.

Keith Aubin, geographic information system manager at Enel Green Power North America, used drones to inspect over 70 MWdc of capacity across nine power plants in 2017. In 2018, he is working to spread this technology to Enel Green Power's O&M teams around the world. "As we standardize our process for localizing string and module-level defects, we expect to save significantly on the labor cost to manually identify, log and correct issues."

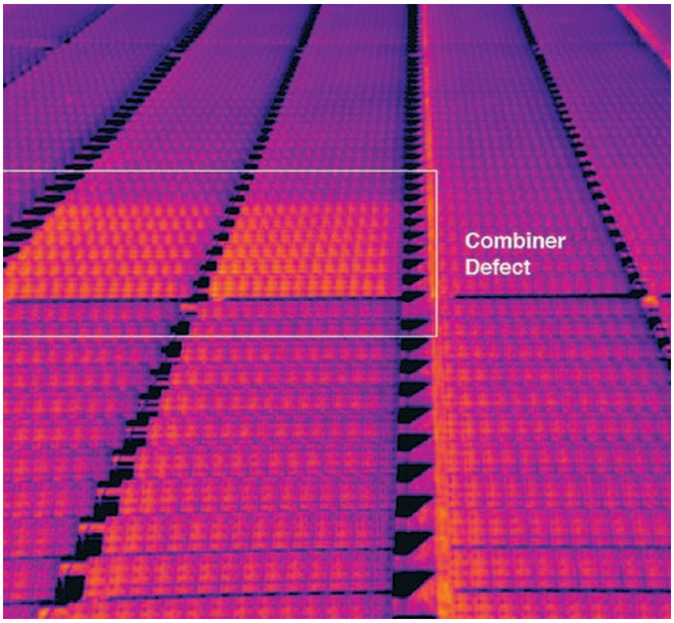
Drones make aerial thermography accessible for commercial and industrial (C&I) solar projects by improving site access to these installations. The fixed cost to deploy a manned aircraft can easily outweigh the benefits for C&I sites. A technician with a drone in his or her vehicle, in contrast, can quickly deploy it during a site visit, completing data capture in minutes. C&I sites tend to be located in more densely populated areas, making it easy to source qualified drone service providers.

Worker safety is another important consideration in favor of using drones to perform inspections. PV arrays in C&I installations are often located on facility rooftops or carports that expose workers to fall hazards. Technicians that perform system inspections on rooftops require special fall protection training and equipment.

What Can Drones Detect?

Aerial thermography provides site-wide coverage for utility-scale and C&I solar installations. According to Randall Warnas, segment leader for global small unmanned aerial systems (sUASs) at FLIR, the world's largest IR camera manufacturer, "Handheld thermal cameras are an industry standard for inspecting PV systems, and drones put that technology in the air. By the numbers, solar has been one of the top applications for thermal drones, second only to law enforcement and emergency services."

In PV applications, drones equipped with infrared and visible RGB cameras can detect module-specific issues such as activated bypass diodes, production batch issues, junction box heating, and cell and multicell defects including cracking. Technicians can also use aerial thermography to identify and document electrical equipment and system-scale issues such as PV array source-circuit failures, reversed polarity, and array combiner box and inverter failures. Aerial site inspections can identify site issues such as shading from new vegetative growth, excessive soiling, tracker failure and security breaches.



Thermal imaging A combiner defect sent 48 PV strings off-line. SOLV, Swinerton Renewable Energy's O&M division, detected the failure using drone-based aerial thermography.

Drone inspections can generate hundreds or thousands of images per site. However, the consistent geometry of PV systems allows for the separation of modules and the use of artificial intelligence to diagnose module defects, while simultaneously assessing and comparing the hierarchy of subsystems such as module versus module or string versus string.

Make Drone Data Actionable

To optimize time savings, you should match drone data capture to the specific management goal, such as identification of off-line PV source circuits or module-level cell defects. No matter how much drone data you collect, proper PV system analytics deliverables should provide four primary components:

A high-level overview. Data should enable a technician to prioritize repairs in a limited time window. Deliverables should specifically call out, in an executive summary, large defects, such as an inverter or combiner failure, and their impact on the plant's overall capacity and production. This summary allows supervisors to triage sites under their management.

Granularity. Results should associate every identified defect with an image, location, classification and affected dc system capacity; give summary statistics for each subarray or array; and allow you to filter results by location and defect category. Technicians can refer back to these results when tracking site conditions over time.

Location. Inspection analytics deliverables should provide defect locations using a localized coordinate system, such as subarray, row, string and module number, as well as GPS locations. GPS identifiers help analysts visualize the distribution of issues, while localized coordinates are more useful for field technicians replacing modules. You can base localized coordinates on a geographic location, such as the number of rows north, or on the asset designations in the as-built drawings.

Compatible results. Finally, analysis and report deliverables should come in an open format, such as a spreadsheet or KML file, that the client can easily import into a variety of software systems. As drone-based thermography, analysis and reporting technology become more widely deployed, that sets the stage for an open data standard that allows asset owners and O&M companies to track site progression regardless of who collected the data. Given the multitude of solar monitoring and aggregation software platforms, an open data standard will also make it possible to reduce software integration complexity.

Camera and Image Considerations

Thermal imaging drones previously required aftermarket integration, but turnkey systems with high-quality cameras are now commonplace.

Camera types. There are three main considerations when deciding which thermal camera package to purchase with your drone: resolution, radiometry and lens size.

Thermal cameras for drones are typically available in two resolutions: 640 by 512 pixels and 336 by 256 pixels. The higher resolution will cover a footprint four times larger in area than the lower resolution, resulting in a significant time savings when inspecting a PV system.

Many cameras are available in both nonradiometric and radiometric versions. Radiometric cameras are more accurate, typically within 2°F–4°F. Most important, radiometric cameras have infrared measurements in each pixel, required for automated analysis. The camera you select should output radiometric JPEG or thermal TIFF files.

Drone thermal cameras are available with a variety of lenses, from 7 mm to 25 mm and beyond. A 7 mm lens causes fisheye effect, while a 25 mm lens has an extremely narrow field of view. For PV system inspection, 13 mm lenses tend to be the most versatile.

Raptor Maps makes software to analyze drone data and report findings. It applies machine learning and artificial intelligence to automate the processing of thermal infrared and color images. To date, its software has processed data from more than 5 million modules, in sites ranging from small rooftop systems in Europe and the Northeast US to utility-scale plants in the Southwest US. Based on the data from these millions of inspected modules, we recommend the following camera type for drone-based solar site inspections: A 640-pixel resolution, radiometric camera with a 13 mm lens consistently produces high-quality input data.

Color images. Color photos are an important complement to thermal imaging. Software can overlap RGB

Courtesy Raptor Maps

Flight planning Drone operators can tune the resolution of thermal scans by varying flight altitude. While high-altitude flights result in a faster survey, low-altitude flights provide more detail regarding defects.

color drone images to create large high-resolution site maps. This is particularly useful for older sites that may not have accessible as-built drawings or for newer sites that may not have updated high-resolution aerial or satellite imagery in services such as Google Maps.

Flying a drone at 400 feet with an RGB camera to make a map can take as little as 10 minutes on a 20 MW site. Color images also help software identify the root cause of issues at the module level. For example, soiling and cracking issues may appear similar in a thermal image, but a color image enables you to easily distinguish them.

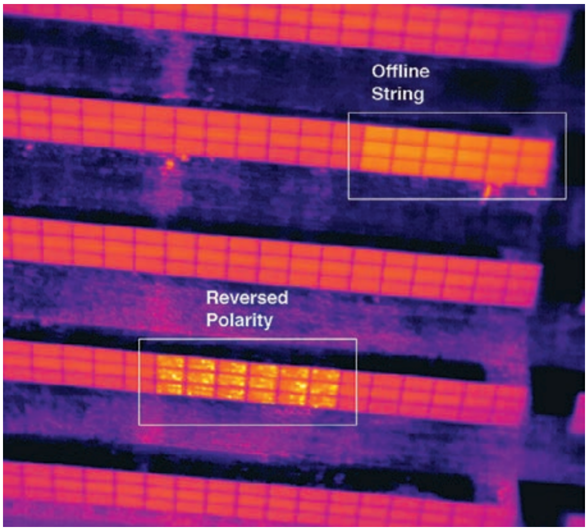
Plan Your Data Capture

Whether you are considering drone training or have been authorized to fly an sUAS, the following best practices will help you do so safely and capture high-quality thermal images and color photographs for solar installation inspections.

Check the airspace. Part 107 of the Federal Aviation Regulations authorizes sUAS pilots to fly up to 400 feet in uncontrolled airspace. For flights in controlled airspace, such as those in proximity to airports, the Federal Aviation Administration (FAA) has published online maps to aid in the waiver process. When applying for a waiver, allow yourself up to 90 days to complete the application, and remember that submitting an airspace authorization does not obligate you to fly. The FAA is also beta-testing the new industry-developed Low Altitude Authorization and Notification Capability (LAANC) application, which allows real-time processing of airspace notifications and automatic approval of requests. SunPower was the first solar company to utilize LAANC, in October 2017.

Plan a flight pattern. You can plan the entire flight with a few taps on your electronic device. Flight planning apps, also known as ground station apps, allow you to box the boundaries of the PV system you are going to survey and automatically create a lawnmower pattern for complete coverage. You can fly the drone manually if you are inspecting for a specific issue, such as a combiner box failure that is impacting multiple strings. However, capturing the complete site is typically recommended, because there are many issues you cannot simply detect on the tablet's screen—they require analysis. Additionally, the tracking of features helps software-based analytics solutions measure motion and automatically localize defects. Generally, you need high overlap in the direction of flight and low overlap between passes. Choose a non-oblique direction, either parallel or perpendicular.

Plan altitude and heading. Drones give you the ability to tune the resolution to achieve your desired granularity. Checking for functional module strings during commissioning may require a high-altitude survey, while a warranty claim for a batch of modules with defective cells may require low-altitude flights that result in a higher resolution. As an example, the recommended camera setup flying at 130 feet above the array will spot a 6-inch defect in a given module, while the same setup flying at 30 feet will spot a 1.5-inch defect.



Courtesy Raptor Maps

Failure modes Thermal infrared imaging can help determine different types of common failures in PV systems, such as off-line strings and dc source circuits with reversed polarity.

Follow safety procedures. Routine on-site practices already incorporate many of the safety considerations for drone flights. These include awareness of surrounding hazards, knowledge of who is on the job site and a strong safety culture. Recommended personal protective equipment for drone operators includes helmets, sunglasses and safety vests.

Fly in good conditions. Sunny days with calm winds are the best time to fly your drone. The National Renewable Energy Laboratory recommends an irradiance of 600 W/m^2, so pay extra attention when flying at high latitudes in the winter during low-irradiance conditions. Also keep in mind that calmer wind conditions make it easier to keep your drone on course and preserve its battery life.

Avoid glare. Glare is the reflection of sunlight into the camera, which results in false readings. Software for automated defect identification and localization can tolerate a gimbal tilt by up to 20° off nadir to avoid glare. Set the drone to maintain its heading so that it does not turn around with every pass. This keeps the camera angle consistent relative to the tilt of the modules.

Avoid motion blur. While it may be tempting to set the drone to the maximum speed, this can result in blurry images. If you want to survey the PV system faster, increase the flight altitude instead.

Check data quality. Check your data before leaving the field to ensure that it is free from glare and motion blur, contains files in the correct format and covers your entire flight. Finally, always take the time to back up the memory card. This simple and often overlooked step can make the difference between completing an aerial solar asset survey successfully and having to spend time and money repeating it.

Drone Operator Trends

In 2016, the FAA updated Part 107 of the Federal Aviation Regulations, which covers the use of commercial drones, and removed major roadblocks to the commercial operation of drones. Operators are no longer required to hold a traditional pilot's license. Instead, they must pass a written aeronautical knowledge test at an FAA-approved testing center, pass a TSA background check and be at least 16 years old to qualify for a remote pilot certificate.

In the 18 months since enactment of these new regulations, the FAA has authorized more than 100,000 remote pilots to fly an sUAS in the US. Several drone schools with weekend courses train new operators. This has made it easier for solar professionals to train their technicians to use drones and to find qualified regional drone service providers. The quick pace of advancement and the rapid maturation of the drone industry make leveraging its technology for PV system O&M activities increasingly applicable to both large and midsize solar EPC firms and integration companies.

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