PV Installation Inspection using Aerial Thermography

November 2018

Amit Rahman, P.Eng, CMRP

EXECUTIVE SUMMARY

Solar power plants, being relatively new, have novel types of failure modes. It should be no surprise that photovoltaic modules and their associated subsystems need periodic maintenance. The maintenance requirements of these systems are lower than traditional power plants which have more moving parts. They also tend to be tougher to detect and are often insidious in that they persist for a long time without being detected[1] - ultimately chipping away at potential ROI.

A solid reliability-centered maintenance plan is key to maximising the performance ratio of utility scale PV installations and keeping unforeseen maintenance costs down. Guidelines for implementing complete reliability programs for PV installations are out of the scope of this white paper - instead we will focus on a central aspect of such a program: Aerial Thermal Inspections. Industry data shows that operators making use of aerial thermal imaging as part of a periodic maintenance program consistently have 1-2% higher average throughput [2] (all else being equal). Despite increased throughput being the most quantifiable benefit derived from aerial thermal imaging, others include site safety and reduced labour costs.

Maintenance of a PV installation begins at commissioning and needs to be continued for the life of asset. Aerial Thermography is necessary for determining baseline system performance at commissioning and comparing asset performance to this level of performance on a regular basis. Aerial thermographic inspections reveal anomalies which are followed up by ground based thermographic inspection and finally with electromechanical diagnosis and repair. Some of the anomalies that can be identified using this method are impossible to identify otherwise[3] - others would take significantly more time for technicians on the ground.

FAILURE MODES AND IDENTIFICATION

Modules that are operating properly convert 15%–20% of incident solar energy into electricity. Modules that are not operating properly convert that same energy into heat. When properly implemented, an aerial inspection campaign can identify a wide range of DC fault mechanisms since many of these leave telltale heat signatures.

Aerial thermal inspections can largely replace labour intensive manual dc I-V curve measurement campaigns (5-10 times faster) and even ground based thermal imaging campaigns (twice as fast) as part of an annual preventative maintenance scope of work[4]. Thermal imaging is non invasive, and reduces DC arc flash risk to workers and wear on the fusing circuit. As an added benefit, aerial inspection of PV arrays allows for the detection of high level fault patterns which would not otherwise be apparent. The following is a breakdown of often-identified anomalies:

Module level faults:

- Individual hot spots on the cells
- Diode failures
- Shattered or dirty modules
- Coating and fogging issues
- Junction box heating

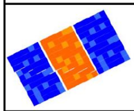
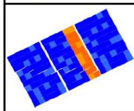
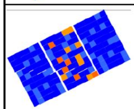
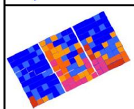
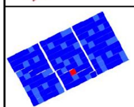
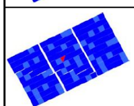
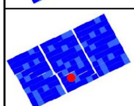
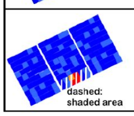
String and system faults:

- Low or no open circuit string voltage
- Low current short circuit or operating current on strings
- Wiring, connector and fuse issues (reversed polarity, frayed cables)
- Inverter failures

Racking and mounting:

- Misalignment

Aerial visible spectrum inspection concurrent with thermographic inspection also serves to uncover problems with discoloration, delamination, vegetation management, soilage, poor drainage, and soil erosion under the racking. Both sets of data can be collected on a single aerial pass.

Pattern	Description	Possible failure reason	Electrical measurements	Remarks, Chapter	Safety	Power
	One module warmer than others	Module is open circuited - not connected to the system	Module normally fully functional	Check wiring	A	System failure
	One row (sub-string) is warmer than other rows in the module	Short circuited (SC) or open sub-string - Bypass diode SC, or - Internal SC	Sub-strings power lost, reduction of V_{oc}	May have burned spot at the module 6.2.7 One diode shunted	B(f)	const. or E
	Single cells are warmer, not any pattern (patchwork pattern) is recognized	Whole module is short circuited - All bypass diodes SC or - Wrong connection	Module power drastically reduced, (almost zero) strong reduction of V_{oc}	Check wiring 6.2.7 all diodes shunted	A *when ext. SC*, B(f) *when Diodes SC*	const. or E
	Single cells are warmer, lower parts and close to frame hotter than upper and middle parts.	Massive shunts caused by potential induced degradation (PID) and/or polarization	Module power and *FF* reduced. Low light performance more affected than at STC	- Change array grounding conditions - recovery by reverse voltage 6.2.5 (PID)	A	C (v,h,t)
	One cell clearly warmer than the others	- Shadowing effects - Defect cell - Delaminated cell	Power decrease not necessarily permanent, e.g. shadowing leaf or lichen	Visual inspection needed, cleaning (cell mismatch) or shunted cell 6.1.1 (delam.)	A B(f)	A, B, or C(m, tc, h)
	Part of a cell is warmer	- Broken cell - Disconnected string interconnect	Drastic power reduction, *FF* reduction	6.2.2 (cell cracks) 6.2.4 (burn marks) 6.2.6 (interconnects)	B(f)	C(m, tc)
	Pointed heating	- Artifact - Partly shadowed, e.g. bird dropping, lightning protection rod	Power reduction, dependent on form and size of the cracked part	Crack detection after detailed visual inspection of the cell possible 6.2.2 (cell cracks)	B(f)	C(m, tc)
	Sub-string part remarkably hotter than others when equally shaded	Sub-string with missing or open-circuit bypass diode	Massive *Isc* and power reduction when part of this sub-string is shaded	May cause severe fire hazard when hot spot is in this sub-string	A, B(f)	A, C

Power loss category	Description
A	Power loss below detection limit <3%
B	Exponential-shaped power loss degradation over time
C	Linear-shaped power loss degradation over time
D	Power loss degradation saturates over time
E	Degradation in steps over time
F	Miscellaneous degradation types over time

Safety category	Description
A	Failure has no effect on safety.
B(f,e,m)	Failure may cause fire (f), failure may cause electrical shock (e), failure may cause physical danger (m), if a follow-up failure and/or a second failure occurs.
C(f,e,m)	Failure causes direct safety problem (definition of f,e,m see B).

Table 1: Thermal failure identification at various levels

Courtesy of IEA-PVPS Review of Failures of Photovoltaic Modules [5]

CONTRACTOR SELECTION

Aerial Thermographic inspection can yield a superior return on investment compared to most other PV array inspection methods - but this is contingent on performing a quality inspection. The scope of aerial thermography of requires interdisciplinary subject matter expertise to achieve results. Choose a contractor or technician that meets the following requirements:

- Is legally allowed to fly unmanned vehicles for commercial purposes (in Canada, this means that the contractor has a Special Flight Operations Certificate from Transport Canada)
- Is trained and certified in the operation of drones (legal requirement)
- Is adequately insured for liability (legal requirement)
- Is trained and certified infrared thermography (this is typically an insurance requirement)
- Is familiar with power systems and typical failure modes of the system to be inspected (this is the building block of a successful inspection)
- Provides a thermal ground resolution of 19cm/pixel or better for analysis

PLANNING AND EXECUTION

Prior to conducting the inspection the following should be done:

- The client should agree upon the scope of deliverables for the contractor (level of inspection detail, whether visible spectrum inspection will also be performed, required ground resolution, deliverable format)

The inspector should:

- Use general arrangement drawings and single line diagrams to plan inspection route, altitude, camera headings and image identification
- Plan for inspection to take place when irradiance is above $600W/m^2$ (IEC 62446-3)
- Time inspection such that there is less than $100W/m^2$ deviation in irradiance over the course of an inspection
- Time inspection on a sunny day
- Fly 150-220 feet above ground level when inspecting for defects at the panel or string level. Fly at 50-120 feet when inspecting for issues with individual diodes or cells. Higher altitudes should be flown to create radiometric maps or to get thermal imagery of the entire site.
- Fly parallel to strings

REPORTING

Relevant and actionable data is sought by PV Asset O&M operators. This is the ultimate goal that should be kept in mind when performing an aerial inspection. An inspection report may be reviewed by individuals occupying different roles within a company - namely management, engineering and technicians.

Reporting should include a summary of faults by criticality, likely cause, and proposed action to present a global picture.

This data should also be visually presented by overlaying fault data on a general arrangement drawing of the site to provide relative locations of issues.

Raw data should also be available and aptly labelled/categorized for investigation and repair - this is often invaluable for warranty, technicians and for trending of failures. Reporting format should be compatible with client's CMMS system.

ABOUT TELEDRONE

Teledrone specializes in using UAVs and thermal imaging technology to provide thorough and efficient surveys, audits, inspections, and asset care.

Teledrone is protected with up to 1,000,000$ of liability insurance (higher amounts can be requested for special projects).

The Teledrone team consists of highly qualified professional engineers, licensed pilots and ITC certified level II thermographers.

We are based in Montréal, Québec and we cover the Greater Montreal Area. We provide service Canada-wide for projects with a large scope.

SOURCES

1
https://solarprofessional.com/articles/operations-maintenance/leveraging-drones-for-pv-plant-inspections#.XBvqGLYZNp8

2 Andrews, R. 2012. Open Solar Photovoltaic Systems Optimization. NCIIA OPEN 2012

3 Best Practices in Photovoltaic System Operations and Maintenance 2nd Edition NREL/Sandia/Sunspec Alliance SuNLaMP PV O&M Working Group P.56-58

4 International Energy Agency PVPS - Review of IR and EL imaging for PV field application, Report IEA-PVPS T13-10:2018 P.13

5 International Energy Agency PVPS - Failure Modes of PV Modules Report IEA-PVPS T13-01:2014