Identifying Issues on Installed Photovoltaic Systems

Using this information for Trend Analysis

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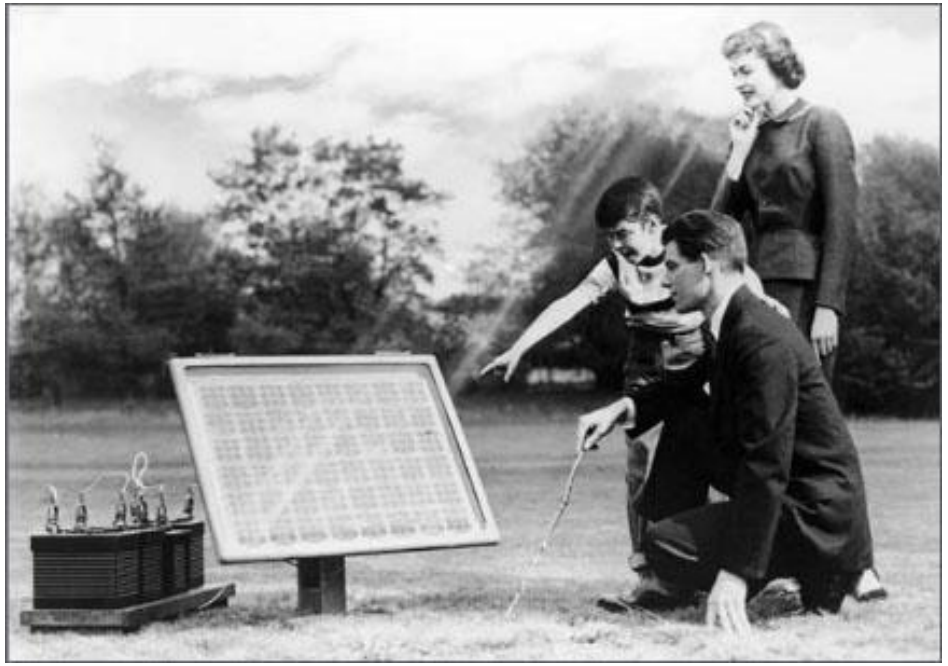
Association of Energy Engineers

Photovoltaics:
The power of the sun



The first commercially viable solar panel cell was developed at Bell Laboratories in 1954

SIMPLE AND EFFICIENT—The ***Bell Solar Battery*** is made of thin, specially treated strips of silicon, an ingredient of common sand. It needs no fuel other than the light from the sun itself. Since it has no moving parts and nothing is consumed or destroyed, the ***Bell Solar Battery*** should theoretically last indefinitely.

New Bell Solar Battery Converts Sun's Rays Into Electricity

Bell Telephone Laboratories demonstrate new device for using power from the sun

Scientists have long reached for the secret of the sun. For they have known that it sends us nearly as much energy daily as is contained in all known reserves of coal, oil and uranium.

If this energy could be put to use there would be enough to turn every wheel and light every lamp that mankind would ever need.

Now the dream of the ages is closer to realization. For out of the Bell Telephone Laboratories has come the ***Bell Solar Battery***—a device to convert energy from the sun directly and efficiently into usable amounts of electricity.

Though much development remains to be done, this new battery gives a glimpse of future progress in many fields. Its use with transistors (also invented at Bell Laboratories) offers many opportunities for improvements and economies in telephone service.

A small ***Bell Solar Battery*** has shown that it can send voices over telephone wires and operate low-power radio transmitters. Made to cover a square yard, it can deliver enough power from the sun to light an ordinary reading lamp.

Great benefits for telephone users and for all mankind will come from this forward step in harnessing the limitless power of the sun.

BELL TELEPHONE SYSTEM

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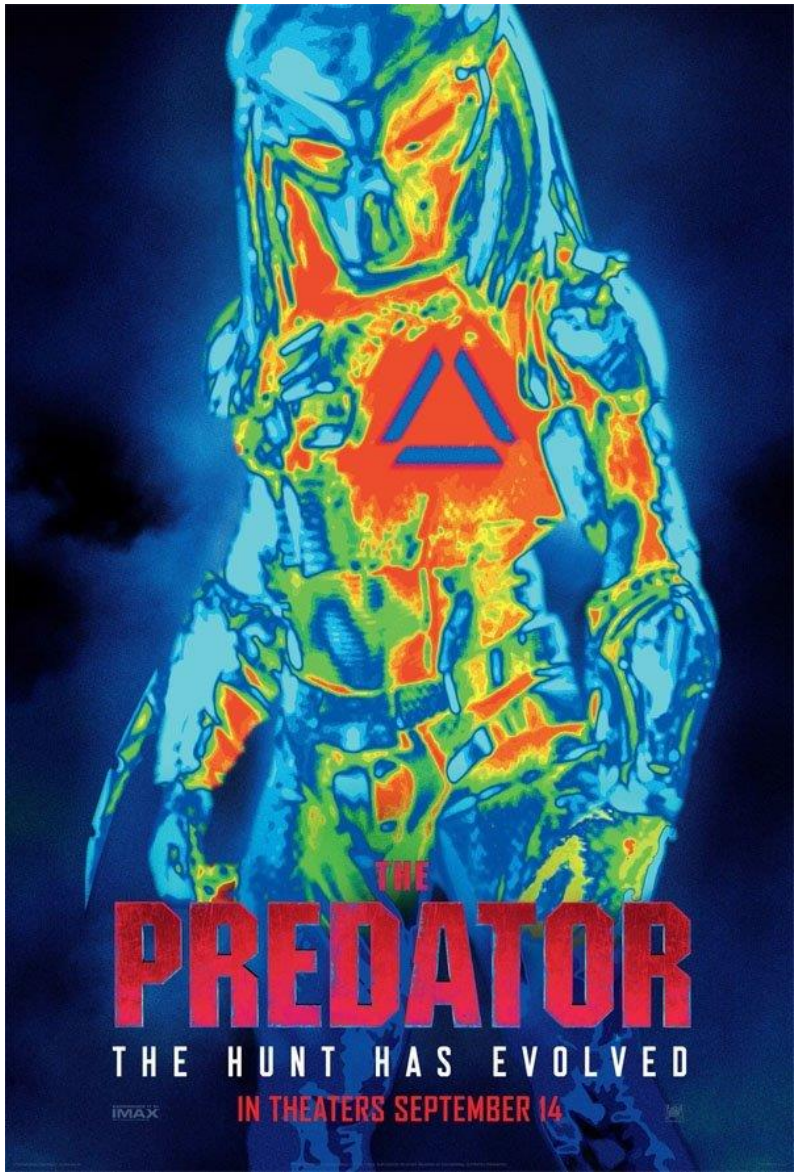
Thermal Imaging

- The first commercial thermal imaging camera was **sold in 1965** for high voltage power line inspections. The first advanced application of IR technology in the civil section may have been a device to detect the presence of icebergs and steamships using a mirror and thermopile, patented in 1913. as per Wikipedia-

Thermal imaging came to be in the public light really in the movie the Predator- people still say, “oh wow like Predator vision”-



As time has passed so has the technology, we now have thermal cameras the size of phones and we now have solar farms not just a single solar panel

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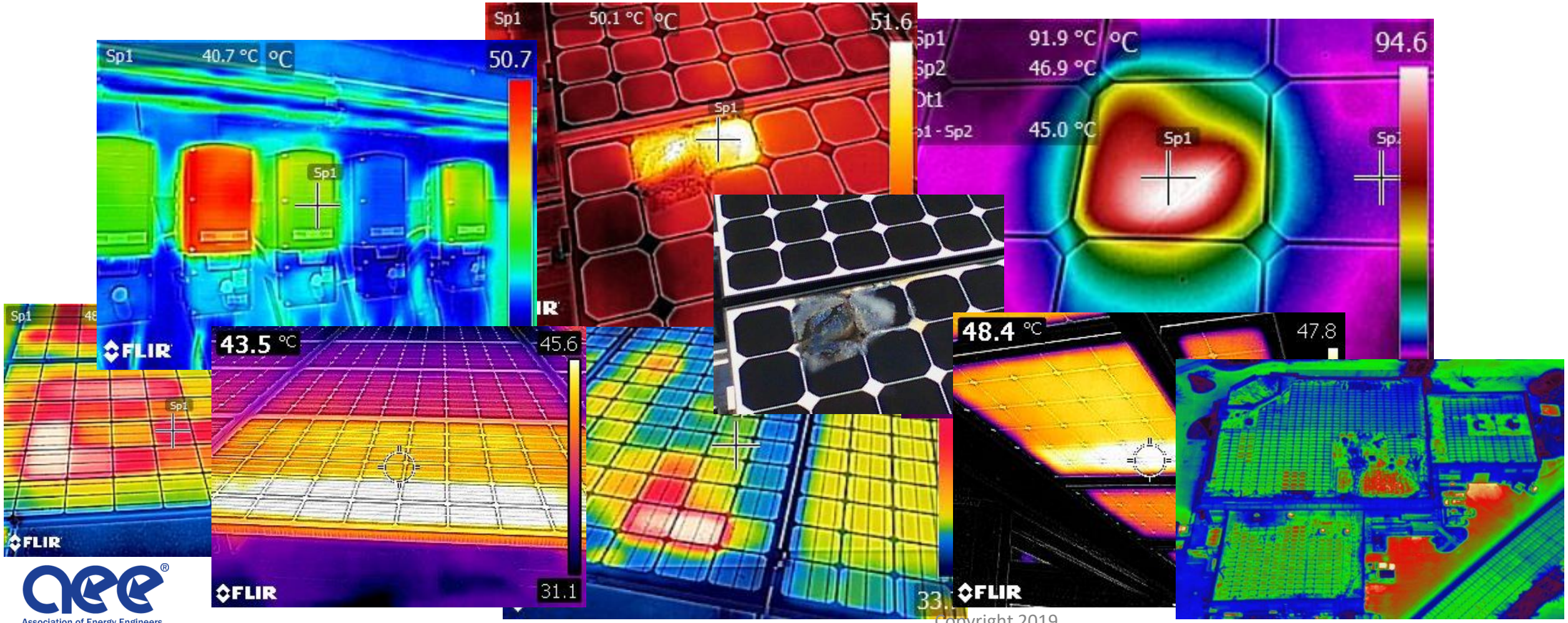
Evolution of PV System Maintenance

- With all things there is an evolutionary process
- In 2009 I started operating the first company in Hawaii solely dedicated to Photovoltaic System maintenance. After a few years I knew there was more to the inspections than meets the eye, and that is when I first became a certified thermographer. That was in 2012
- This was the natural next evolutionary step

It blew the doors open to what I was doing, and this is why I have been saying for years it is one of the most critical tools in a PV O&M toolbox because not all damaged equipment is visible the human eye



General Conditions for an Inspection

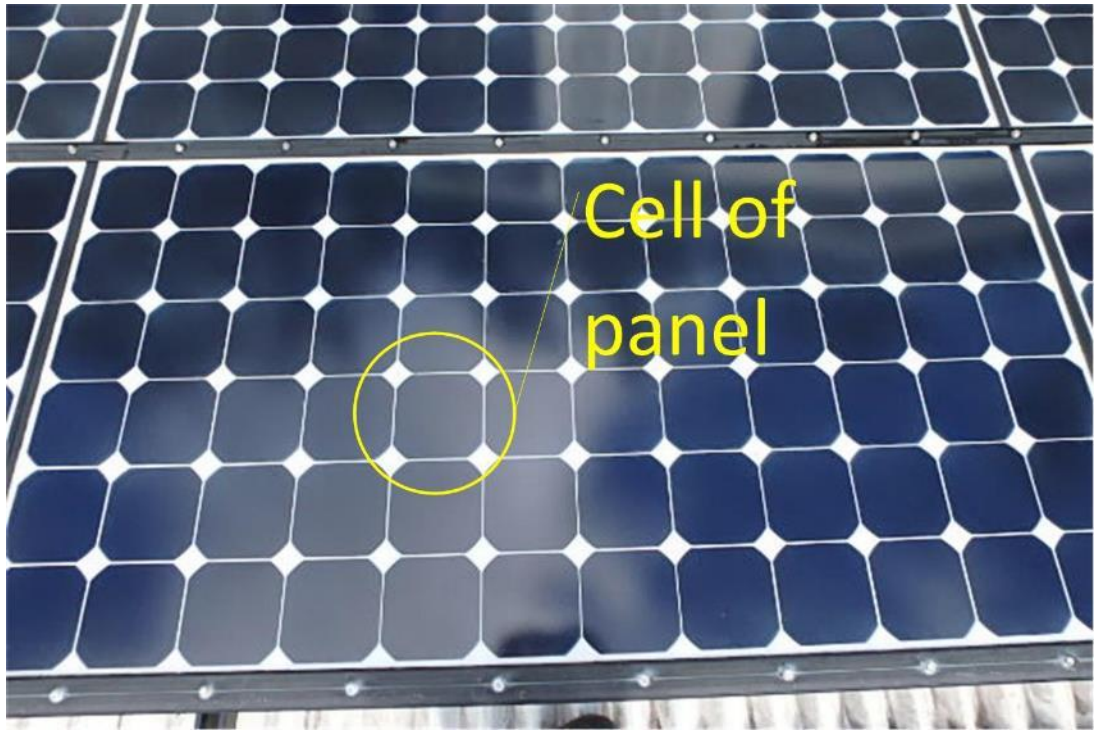
- The Photovoltaic system needs to be up and operating
- We need a basic understanding of the PV system. Is it a central inverter, micro inverter or an optimizer system?
- We want to ideally have clear skies
- We are looking to have an irradiance greater than 500 w/m^2
- You can see anomalies at any level but 500 w/m^2 and greater is where you can really see the anomalies pop
- The main concept is to realize you are looking for anomalies on the system in relationship to the rest of the system, as the equipment should have a uniform heat signature in relationship to each other.

When to do the first inspection and subsequent inspections

- The best-case scenario to do the first inspection is during the commissioning of the system and a minimum of annually thereafter.
- The commissioning starts the baseline. This is part of the thermal imaging scenario. You need to have the baseline, then from there if an anomaly appears you have your trend analysis to start working with
- The year over year inspections is critical as we take care of our systems. One year a panel does not have an anomaly, the next year it does and if you can track this, this will help greatly when working with the manufacturer to start a warranty claim on the panel.
- There are manufacturers now that are using this data and reference of a trend and expediting warranty claims for us, this is something new.

Basic PV terms for reference:

- PV Cell. This is the building block of the pv panel, it is the area where the initial reaction happens to start creating the electricity-



Basic PV terms for reference:

- PV panel or PV module

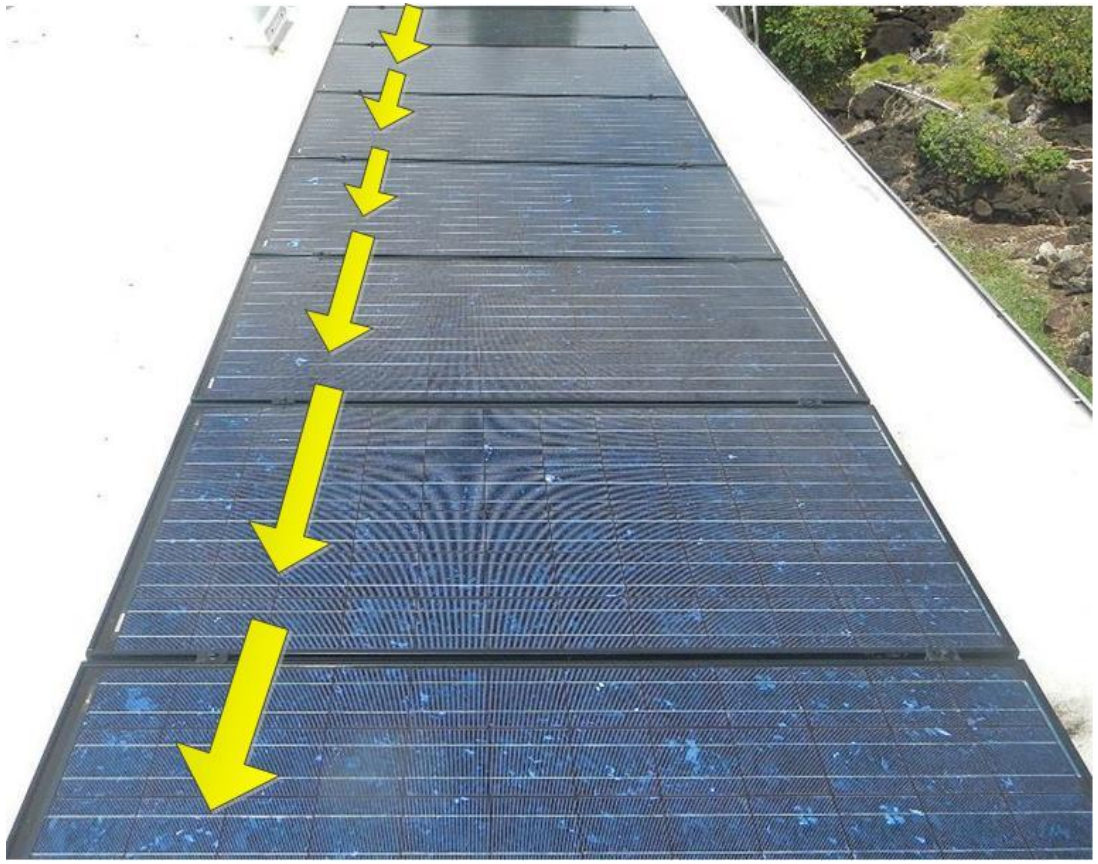
- This is the actual photovoltaic module the whole unit with all the cells connected together inside the frame of the panel.

Basic PV terms for reference

- Junction box- this is on the back of the pv module. It is where after all the cells are connected to each other on the panel, this is the connecting point from panel to panel or panel to optimizer or micro inverter.
- Junction box
- Optimizer

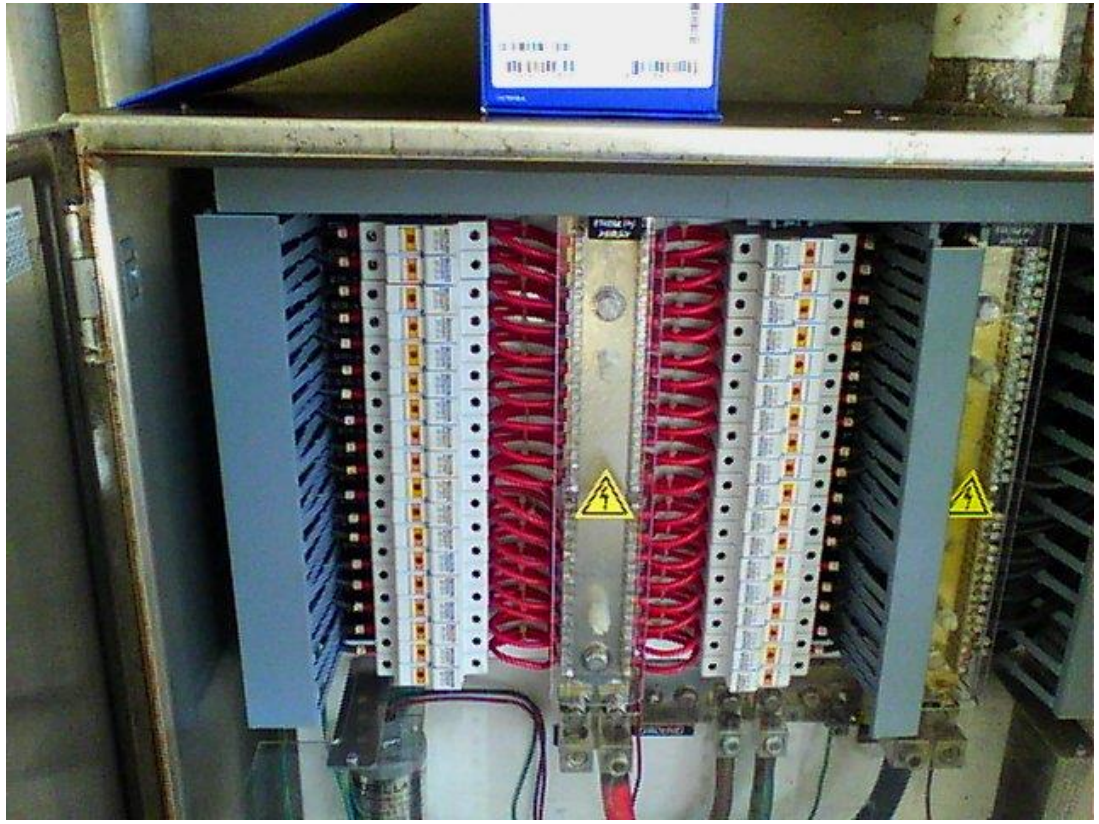
Basic PV terms for reference:

- String- this is on a central inverter system the panels are connected into a series called a string.



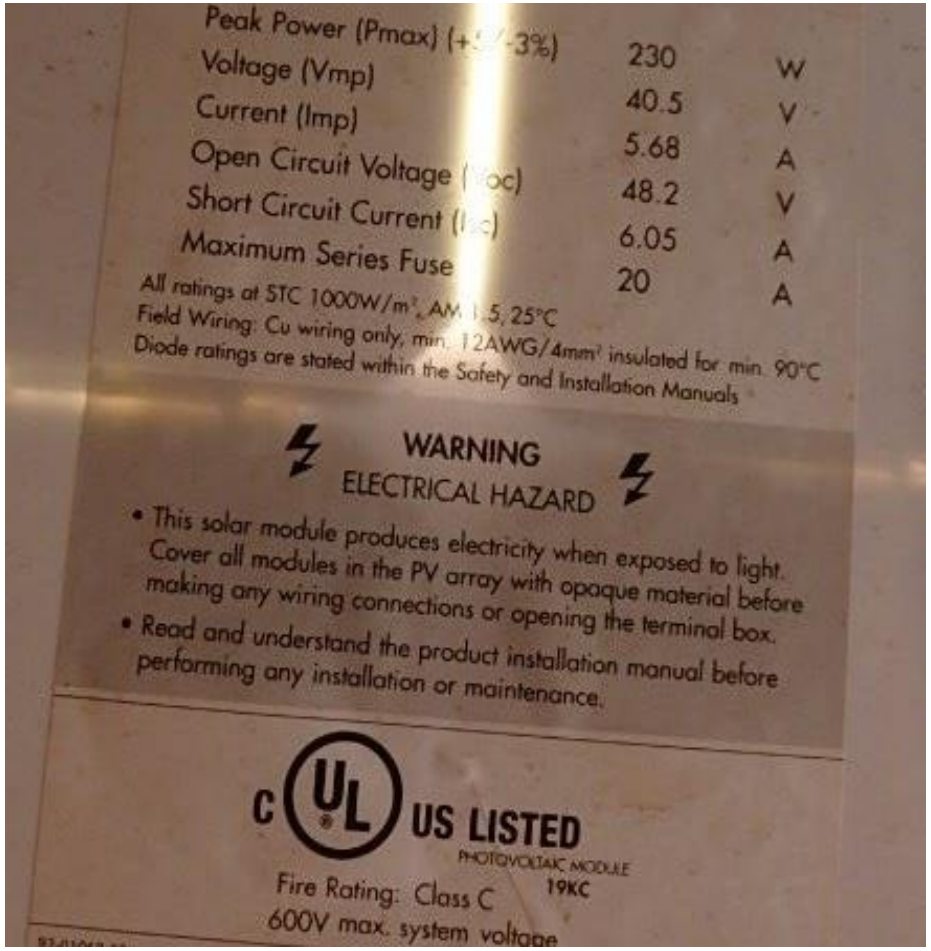
Basic PV terms for reference:

- Combiner box- where all the strings come together and combine and from here go to the inverter- Thermal scanning can identify if these strings are torqued properly, or if a string is not working.



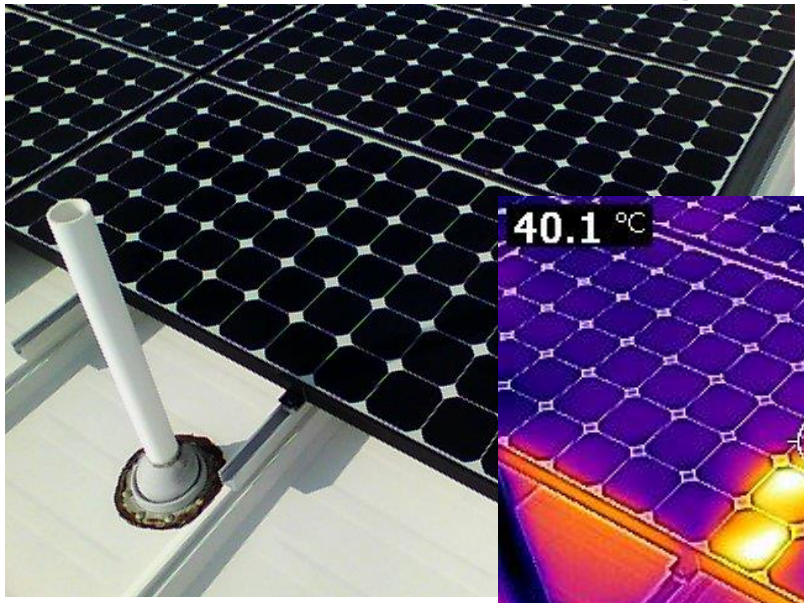
Basic PV terms for reference:

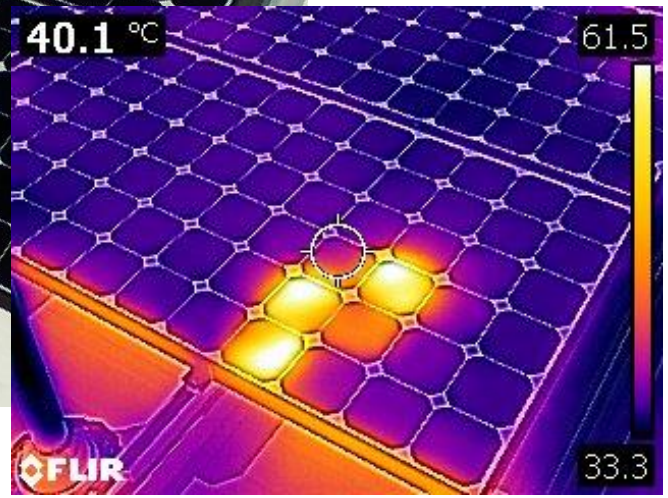
- STC – Standard Test Condition this is for testing each PV panel.
- 25°C, 1.5 ATM, 1000 w/m^2
- The temperature refers to the cell temp
- 1.5 ATM is the air mass condition above the panel
- 1000 w/m^2 This is the Irradiance which is just the radiant energy per unit – but this is a critical item to keep in mind
- These conditions will correlate directly to what is the expected energy production of the panels
- For example – If the irradiance condition during testing of this panel was at 500 w/m^2 we can expect to have 115 watts not 230

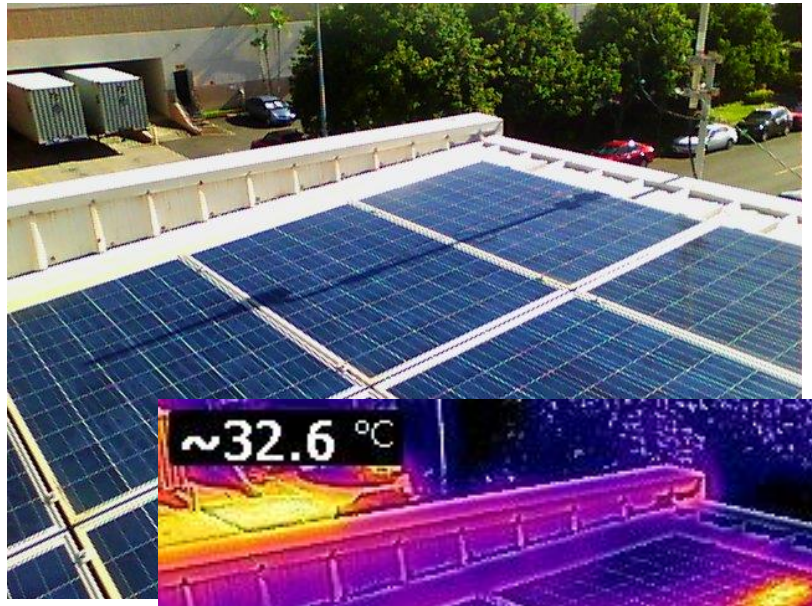


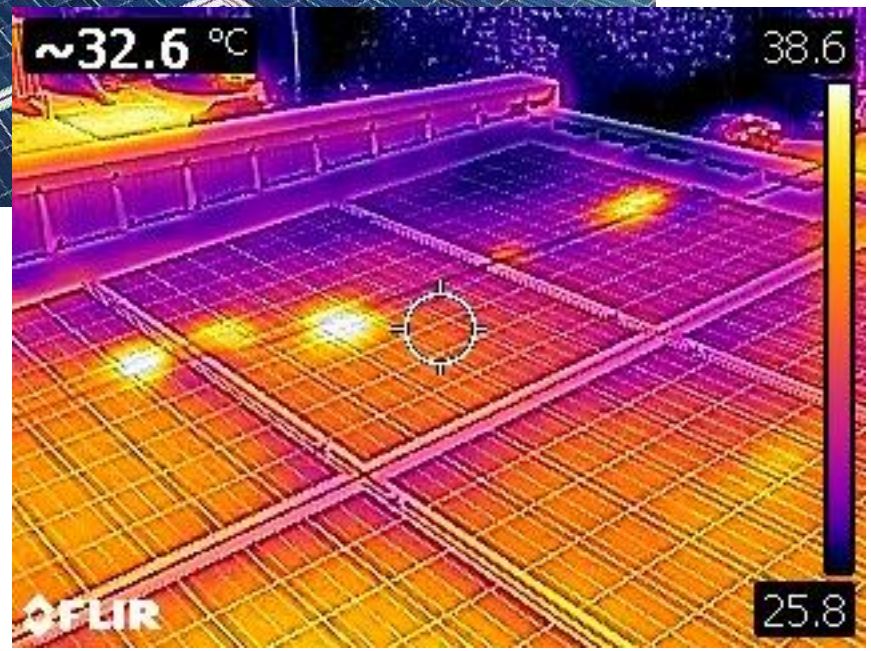
Basic PV terms for reference:

- Diodes:
- Allow current to pass a damaged or shaded cell and stops current from flowing backwards- These diodes are working!









Terms Used in PV System Thermal Imaging Reports

- Anomaly- This means it is a deviation from what is normal or the standard. Any item we find we label as a thermal anomaly.
- Hot spot- this is a spot on a panel or any area that is the anomaly in reference and its' thermal signature is greater than the surrounding areas.
- False Anomaly/ False Hot Spot when there is something external causing the issue
- Failed Optimizer- Some PV systems utilize DC optimizers on the individual panels, and you can identify this with a thermal scan
- Failed Micro inverter- Some PV systems utilize a micro inverter on the back of each of the panels to invert the DC at the panel directly to AC at the panel level.
- Panel not plugged in-

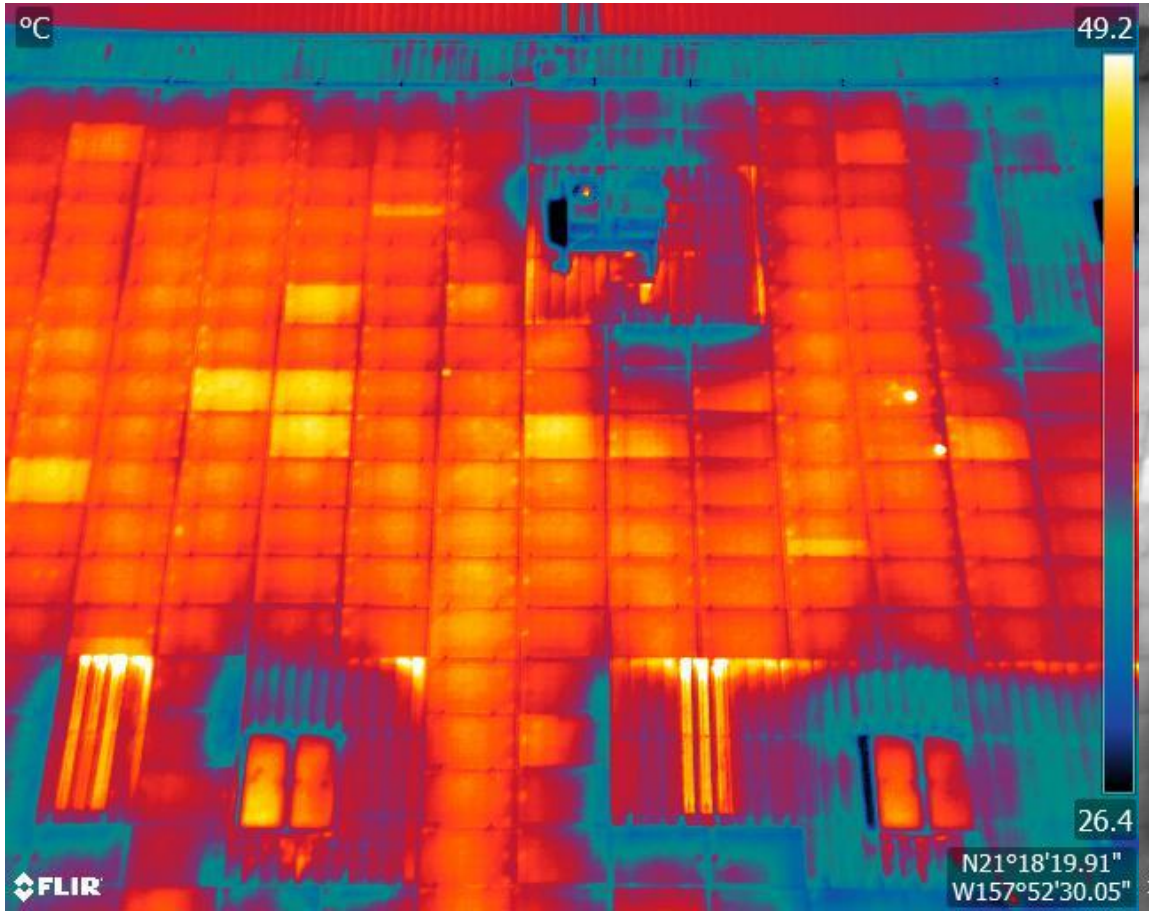
Terms Used in PV System Thermal Imaging Reports

- Diode issue/ Diode failure- The PV panels are equipped with diodes on the panels blocking diodes to prevent the back flow of the DC current in the panels. They sometimes fail. This can be seen when you see an anomaly on what looks like a whole string of cells
- Downed String- On central inverter systems you can identify if a whole string of panels is out with a thermal scan, due to the thermal difference.
- Dead string/ hot string – this is inside of a combiner box system. It can be caused by a dead fuse, system not plugged in or torqueing issue
- Improper fan cooling/ fan not working- this is in reference to the inverter's inspections

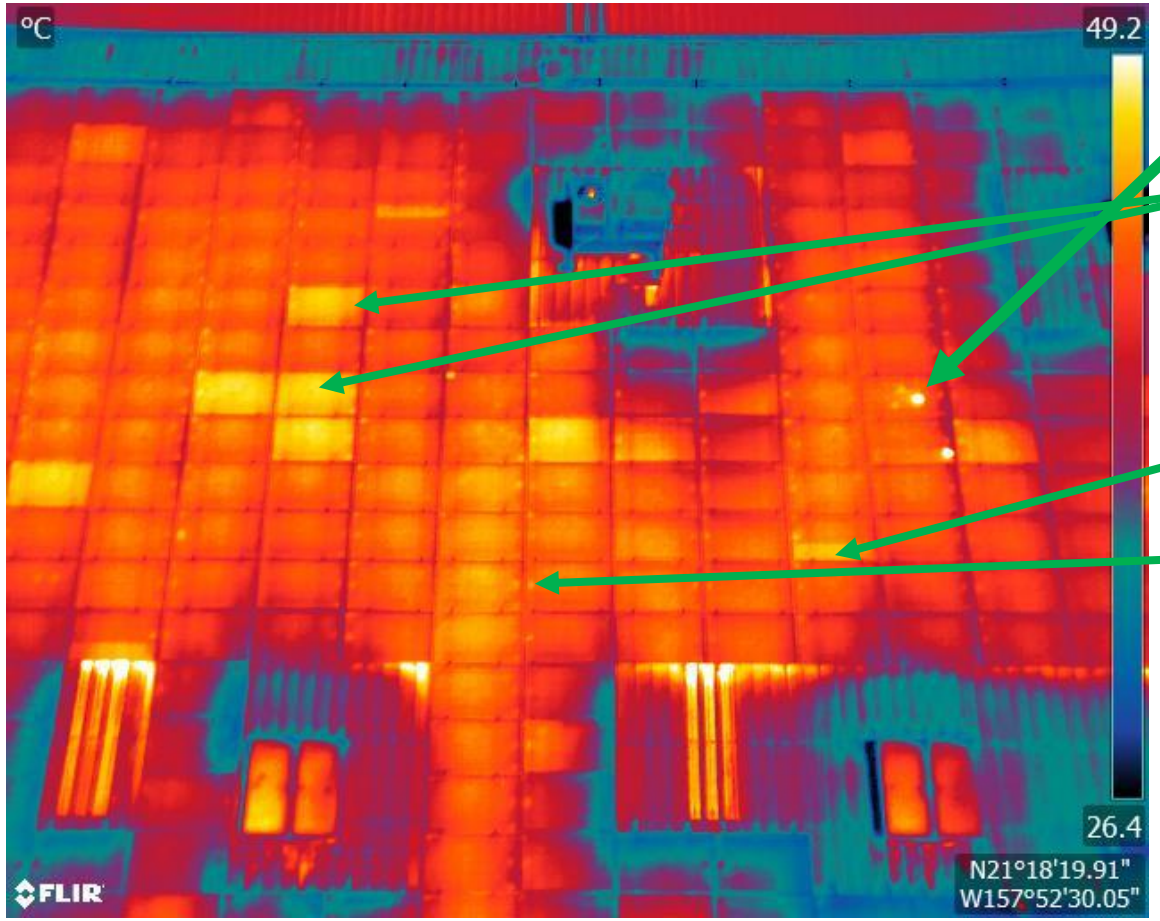
Time to Thermal Scan the PV system

- We want to make sure the system is running
- Knowledge of the system
- We have good conditions (not going to rain and not having a lot of passing clouds)
- We want to have an irradiance meter with us (we recommend to take intermittent images of the irradiance during the scanning)
- Your thermal camera is calibrated and charged!
- Big smile and good attitude-

Thermal Anomaly- Look We Found a few!



Thermal Anomalies at a glance



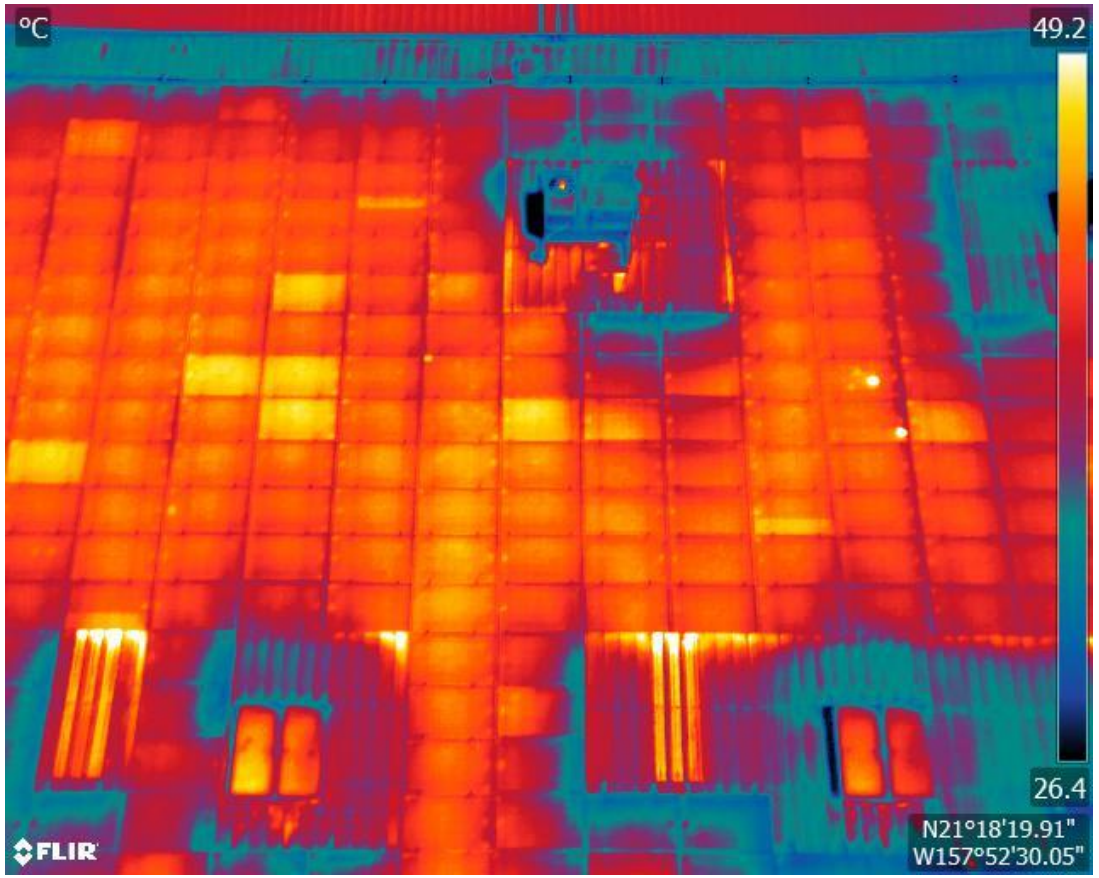
Hot Spot

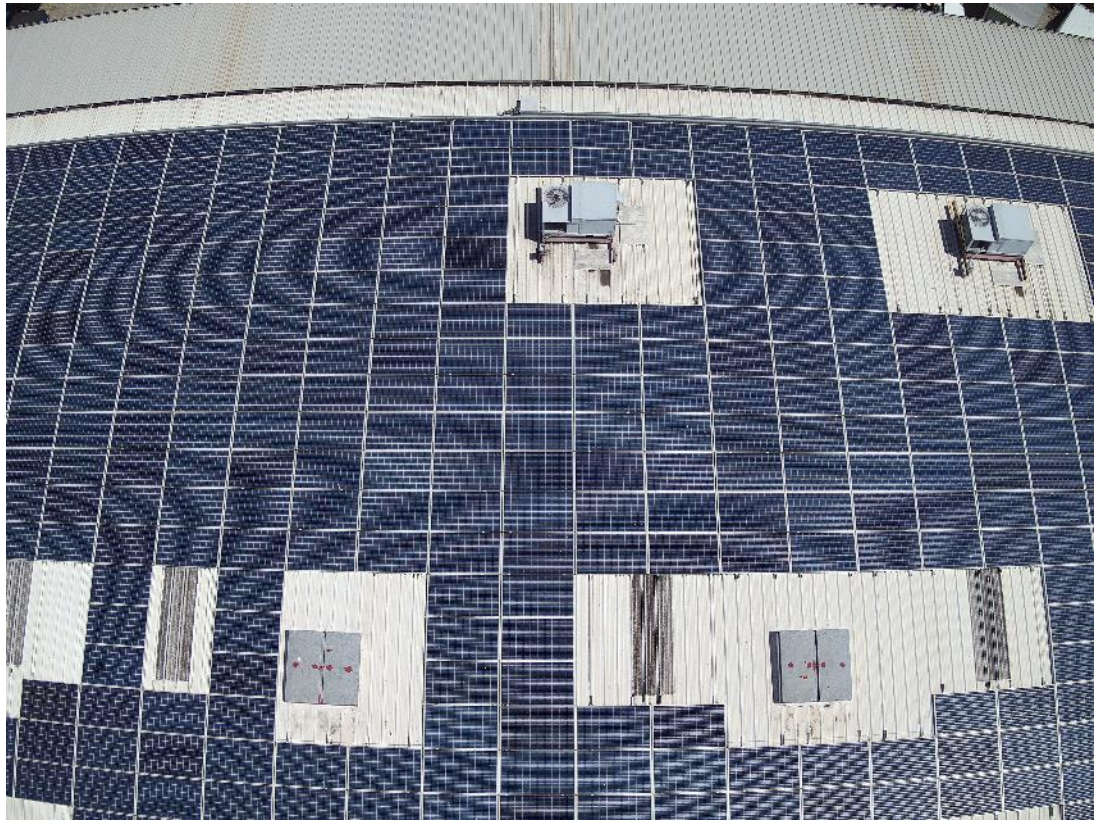
Possible-Non-Working panel- (possible optimizer failure this particular optimizer)

Possible Diode Issue

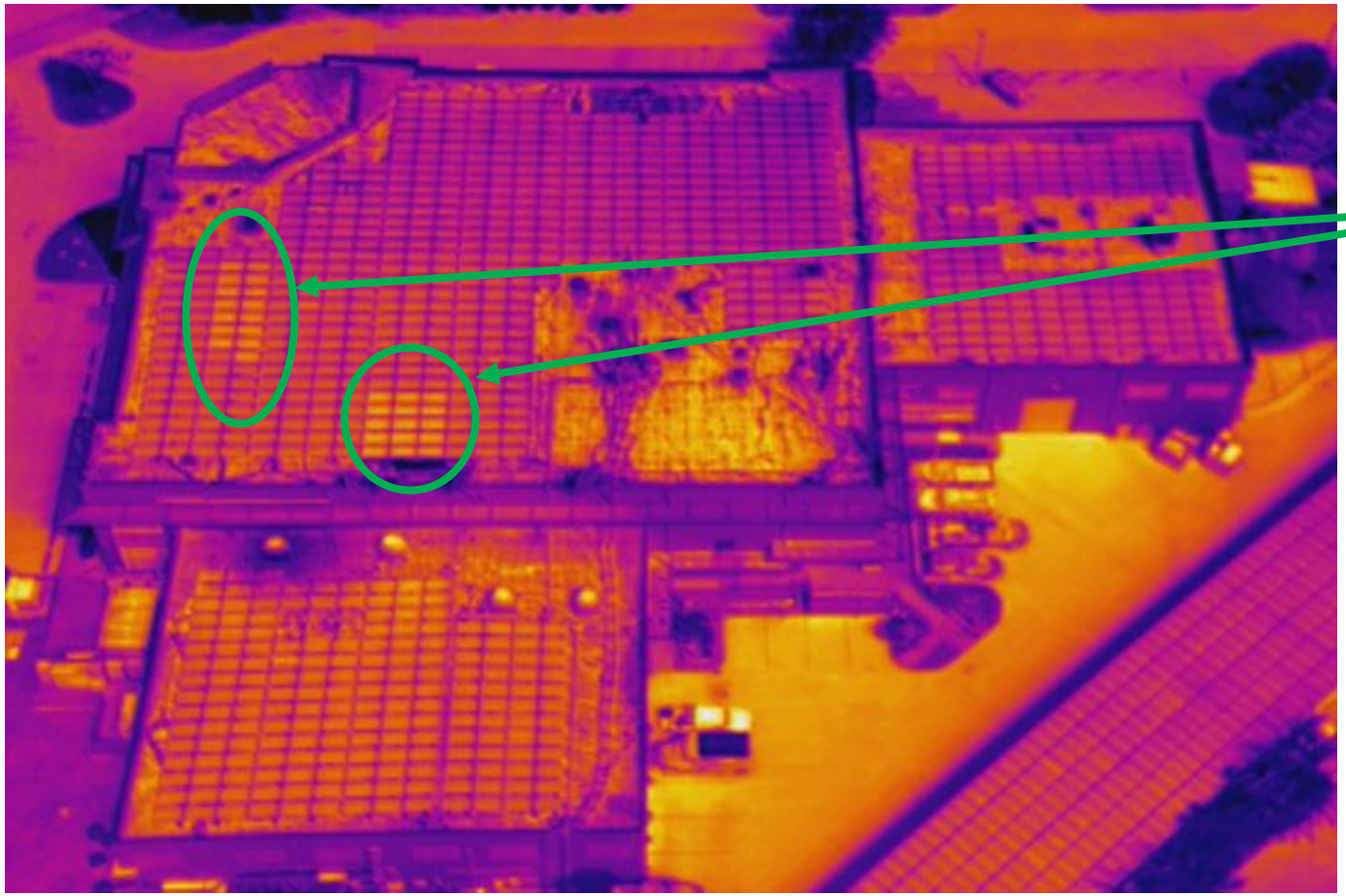
Junction box and optimizer working on the panel- yes you can see that from this distance-

The Camera Sees Things We Can Not-



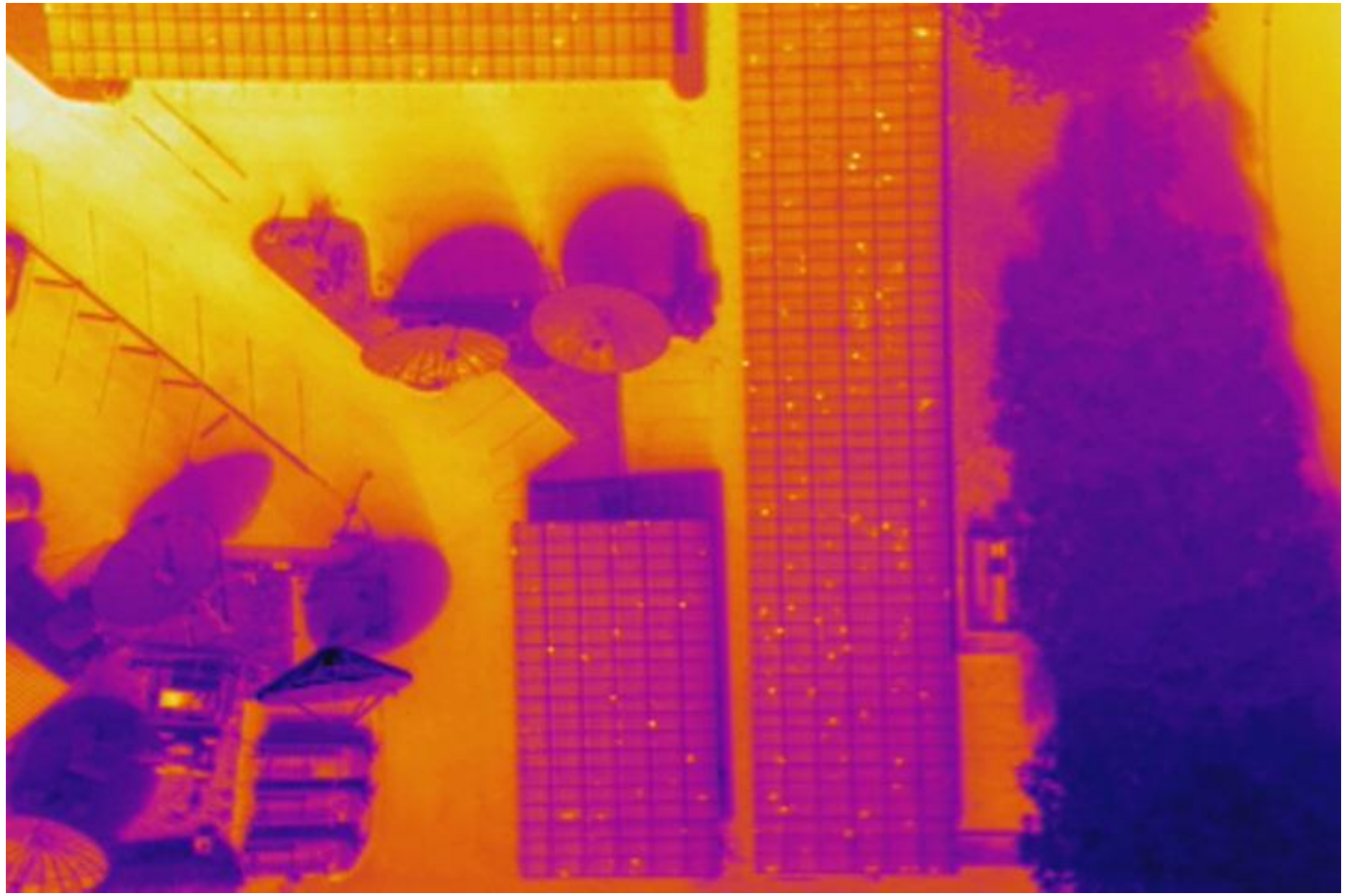


Thermal Anomalies on a String System



Non working string
whole string is out

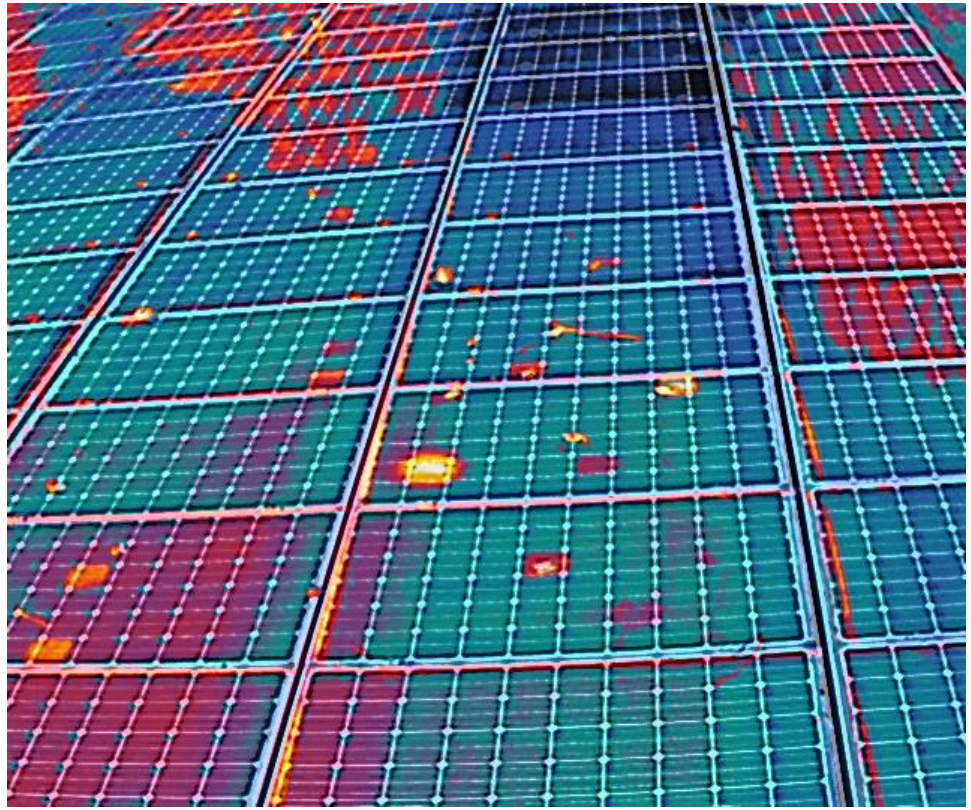
Anomalies are found but you need to verify to really name them. That is why I say possible issue.



Too many anomalies to use an arrow here- You will state there are anomalies and can say hot spot possible diode, but you would need a closer look to verify them

Coming in to get a closer check on the anomalies you want to verify what it was-

Thermal anomalies



Digital image showing leaves and twigs

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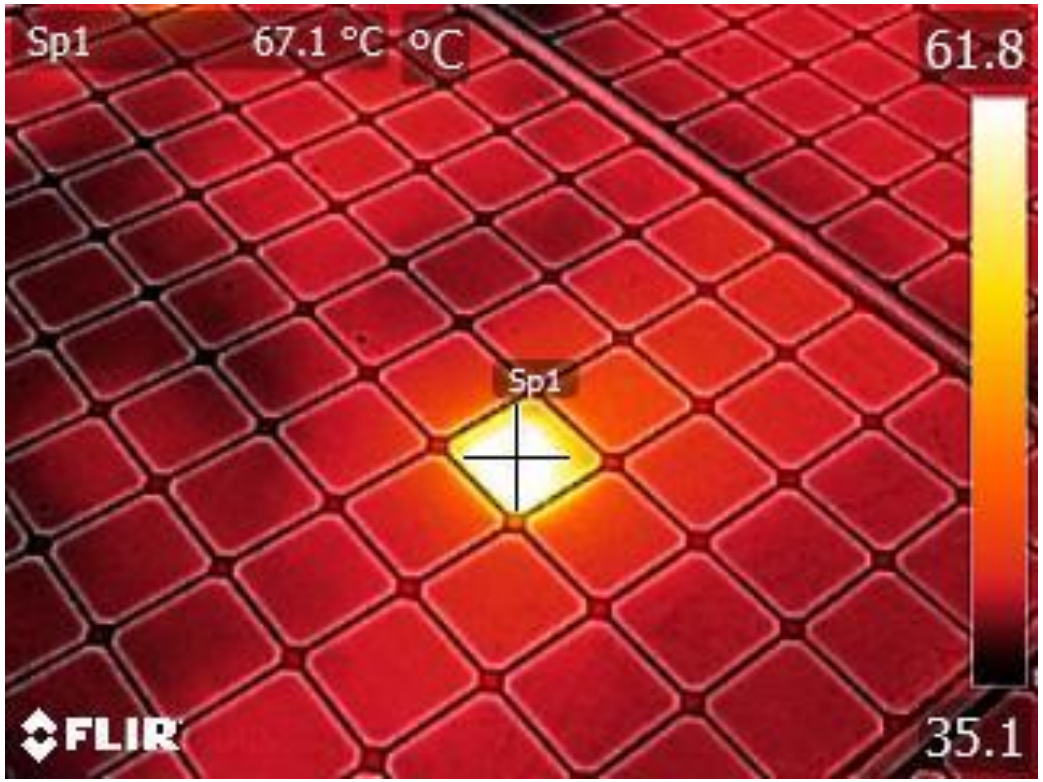
Hot Spot Found – Now what -

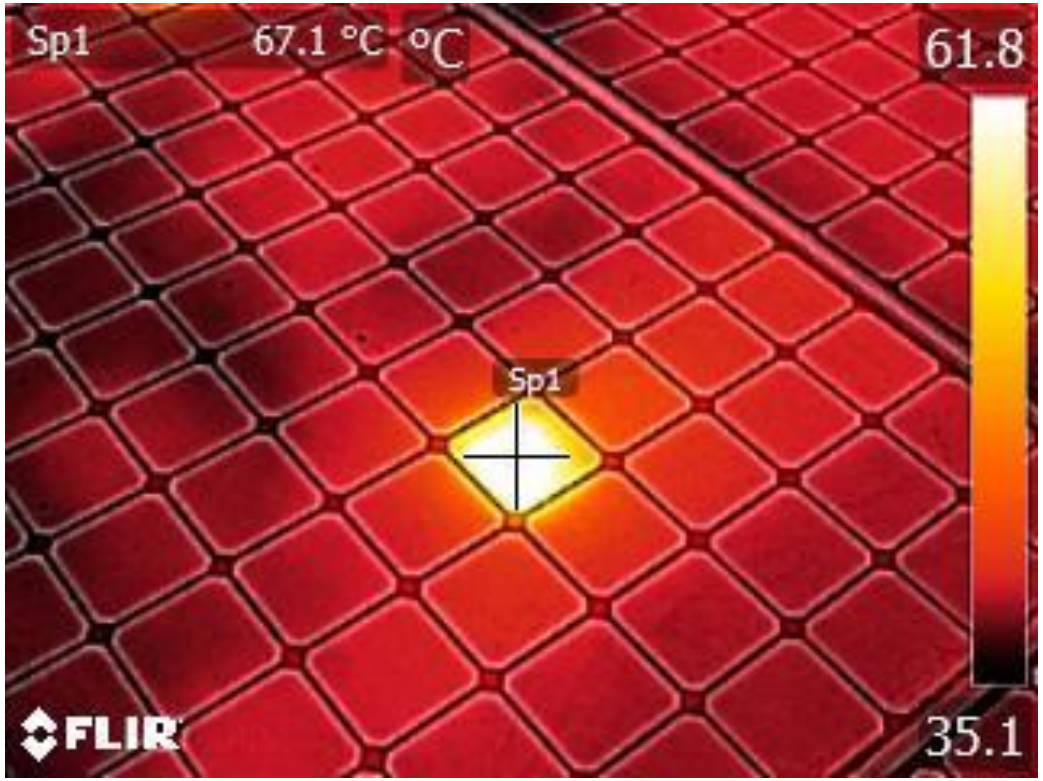
Thermal Hot Spot Found



Quick picture of your irradiance meter – this iss for reference on reports and for your RMA with the manufacturer

Hot Spot Found – Now what -

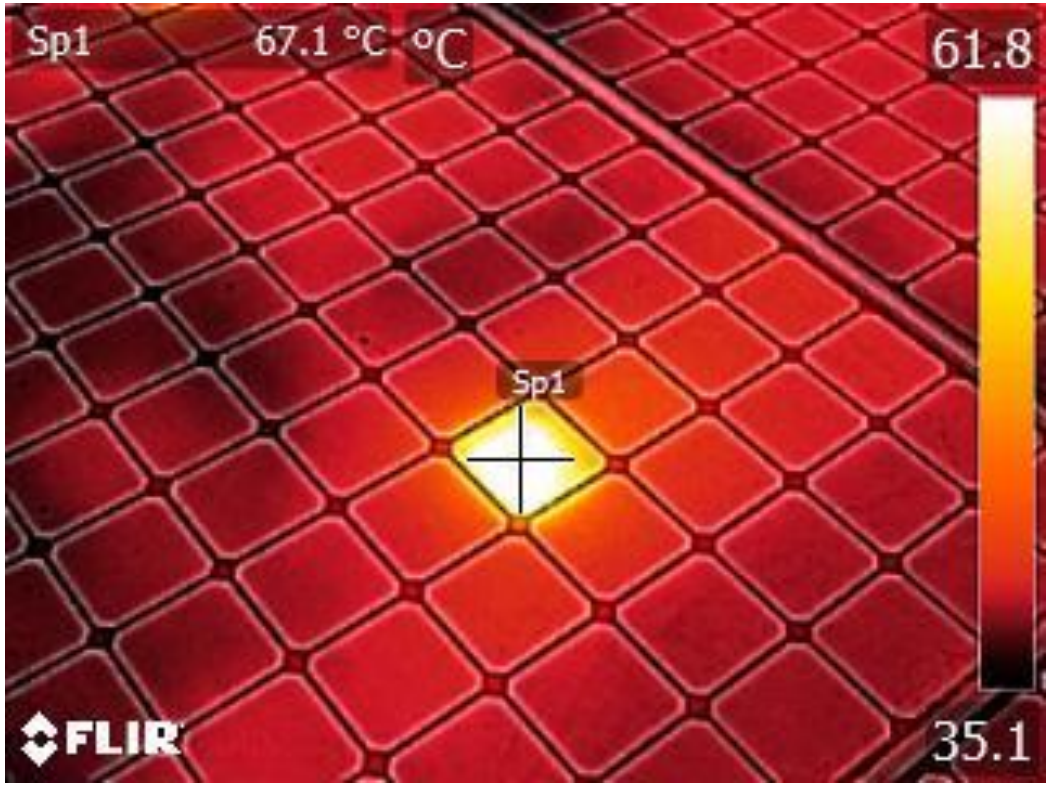
Thermal Hot Spot Found



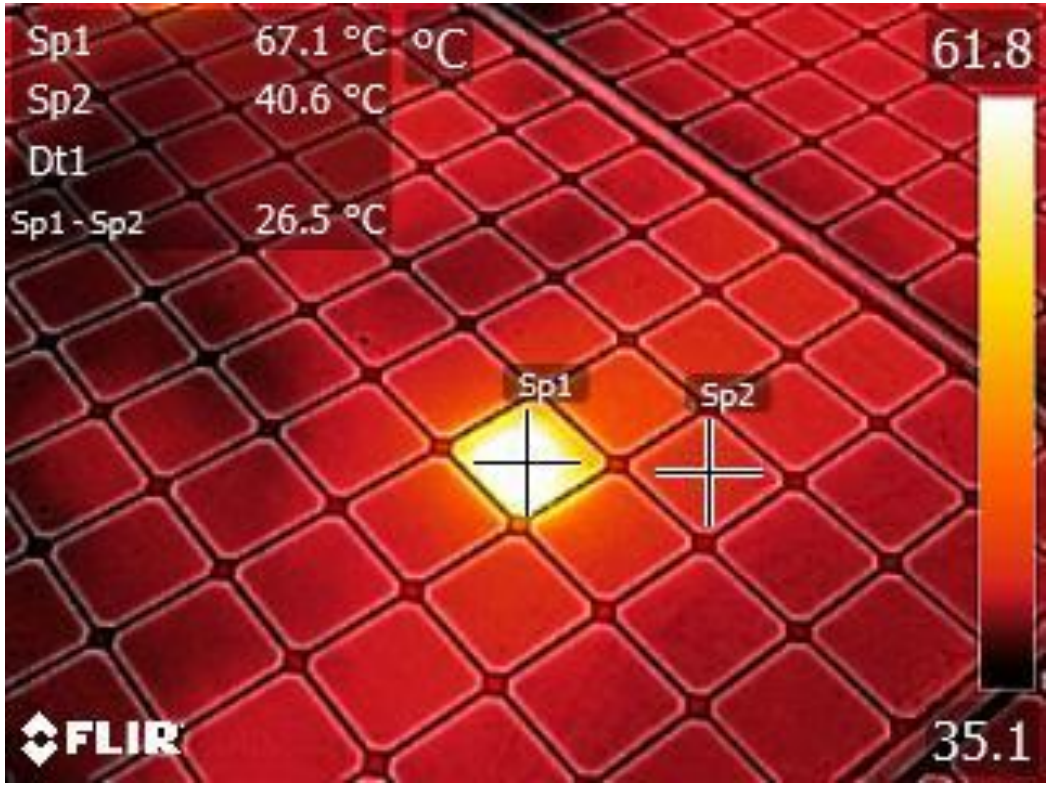
Look to see if you see visible damage – this one actually had a visible marking

Hot Spot Found – Now What

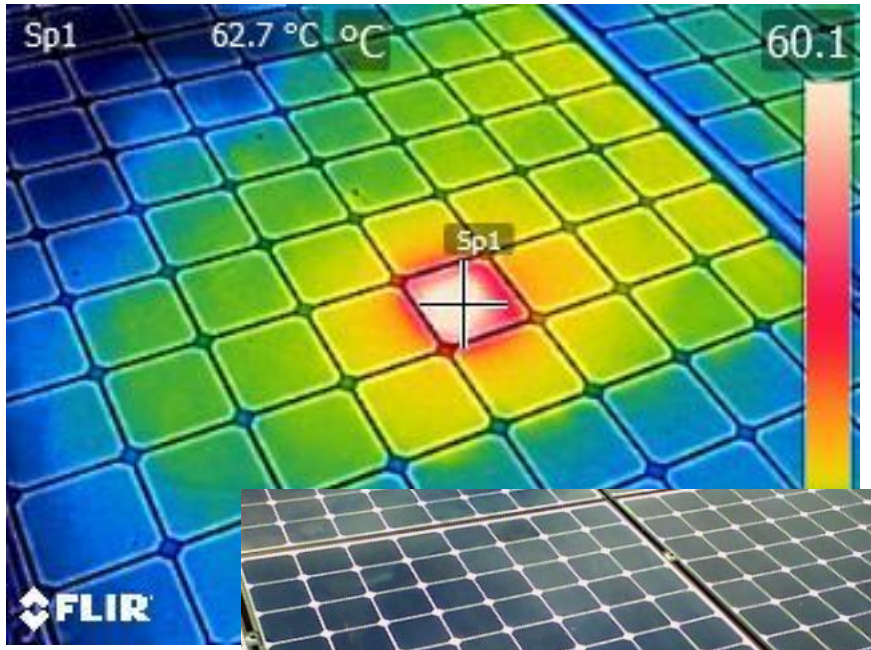
Original Thermal Image

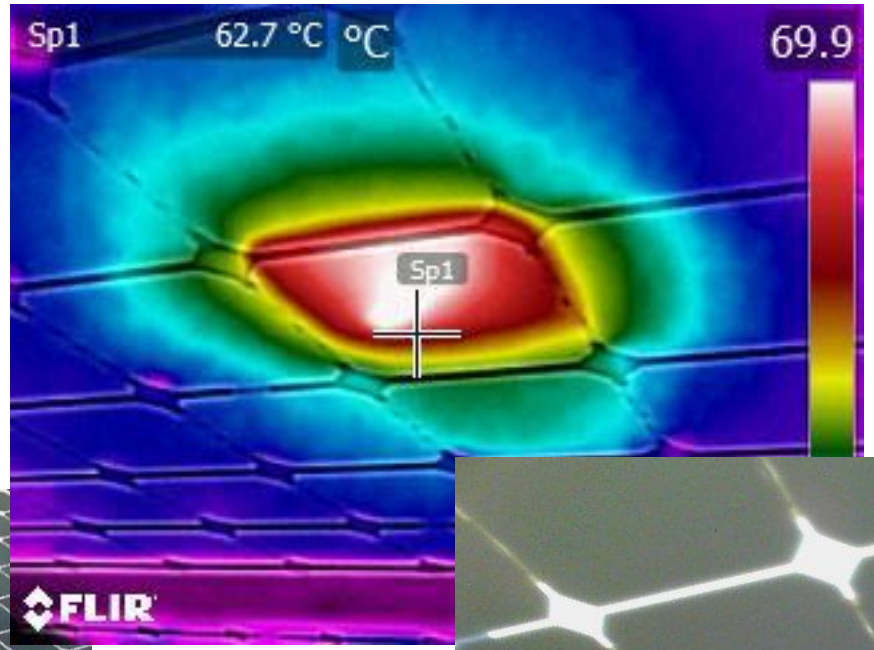


With Differential Temperatures



You can take above and below shots





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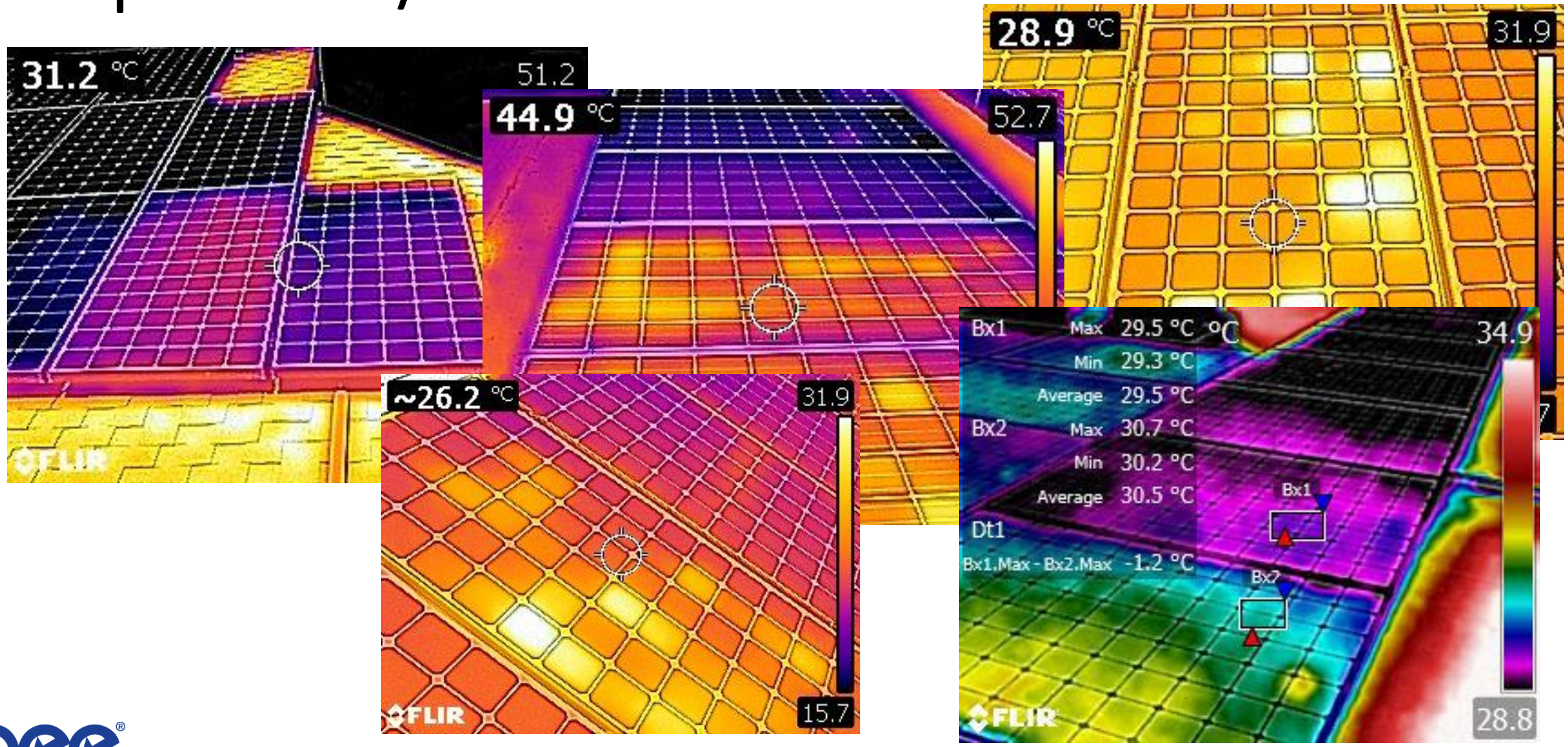
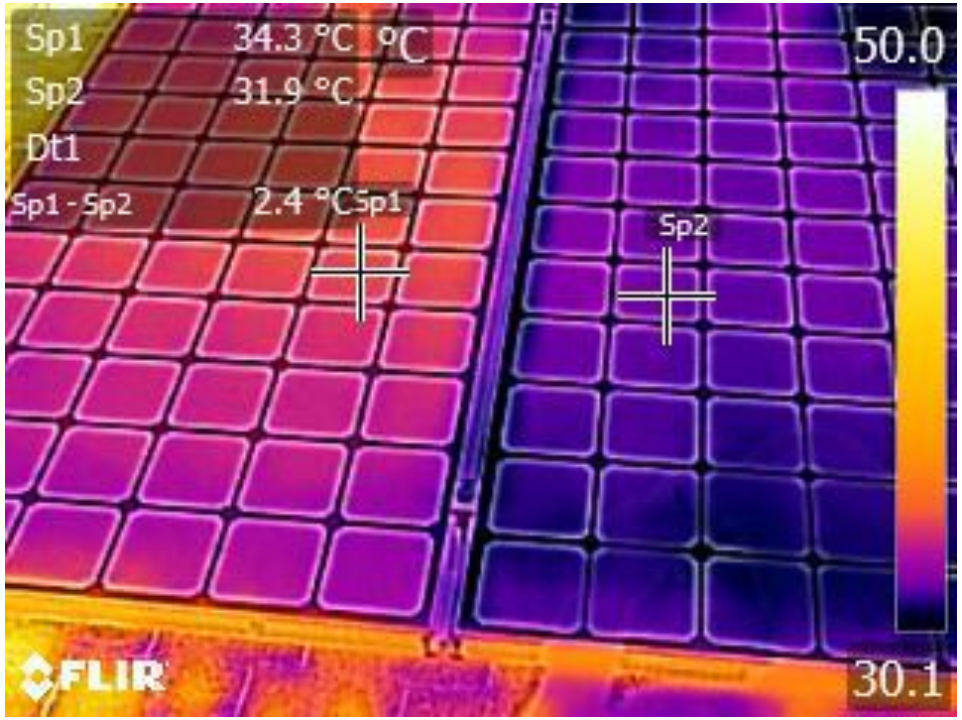
Optimizer / Micro Inverter Out



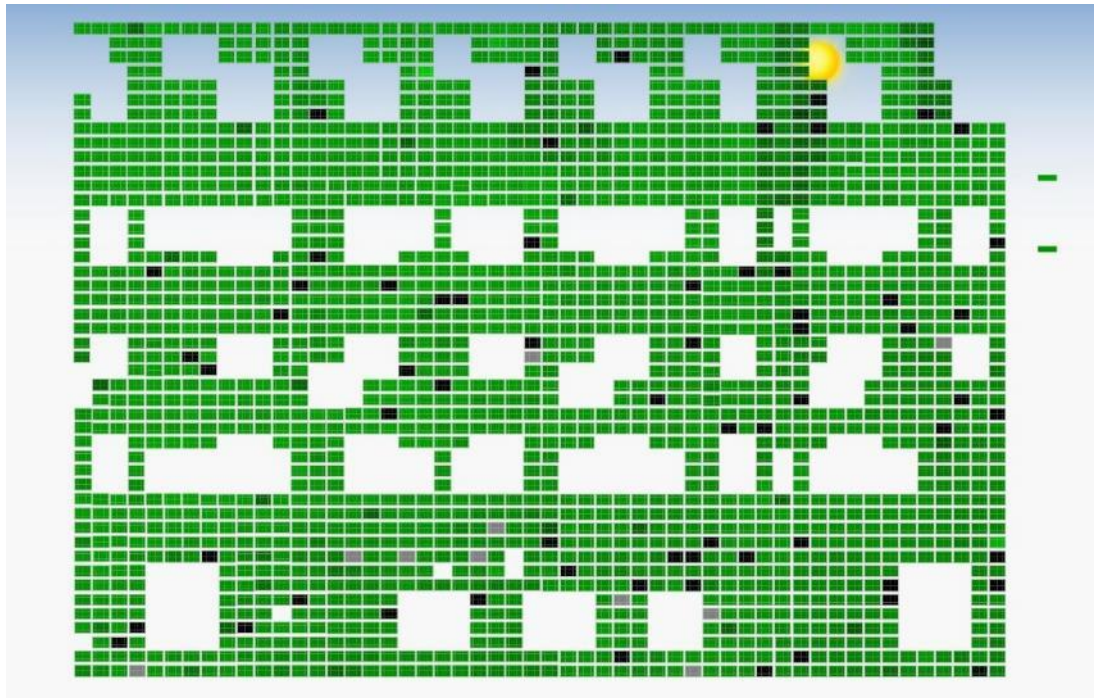
Optimizer and Micro Inverter

When looking at these systems you have to be able to identify minor differential temperatures and understand the layout of the system-
This is critical to understand how to work with your camera and the situation



Optimizer and Micro Inverter

- This identification of bad units will come in handy during initial commissioning of a system as you can identify if a panel is out
- It is a great baseline to see your panels and that all are working
- If you come across a scenario you have to swap units and the map is wrong- this can turn into a bad game of Whack a Mole-



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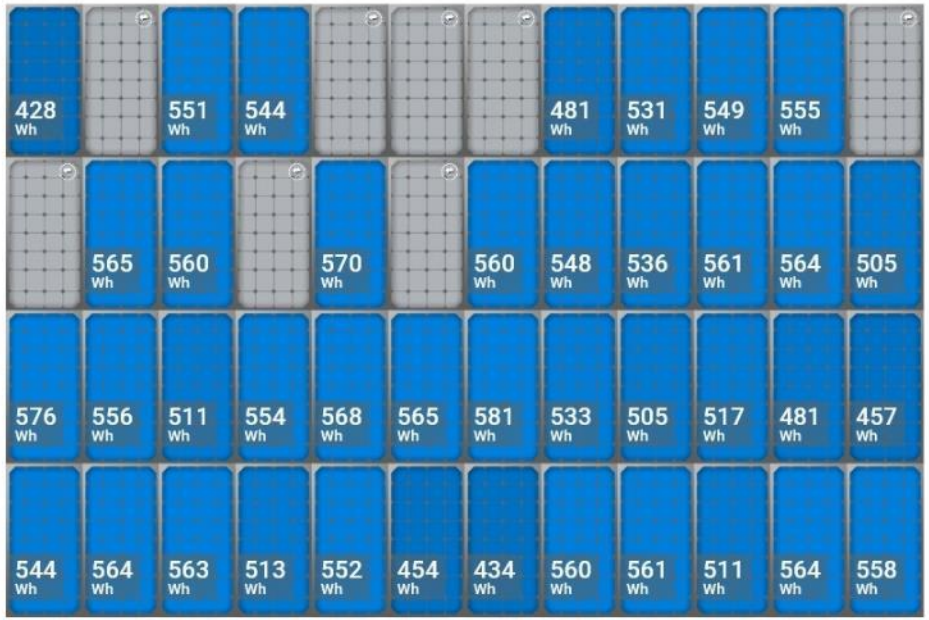
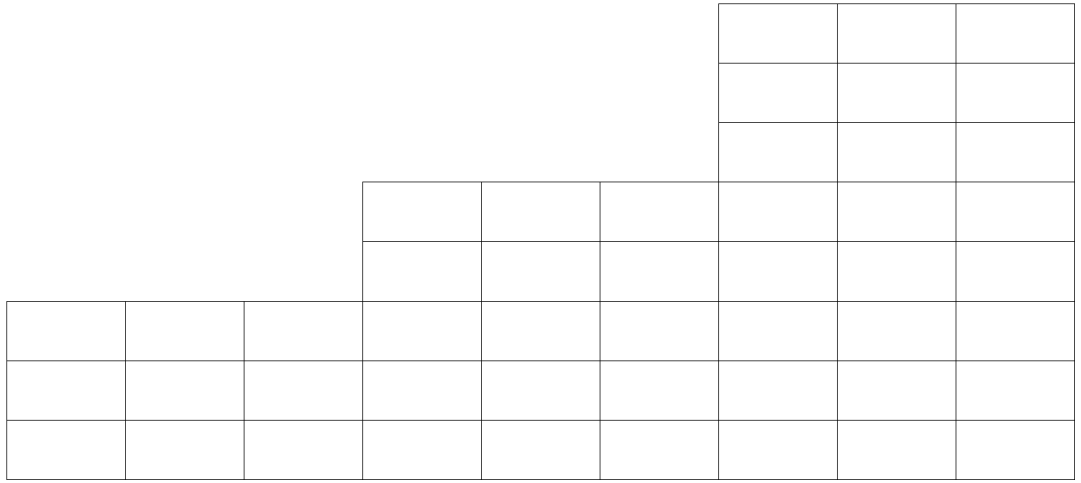
Optimizer and Micro Inverter

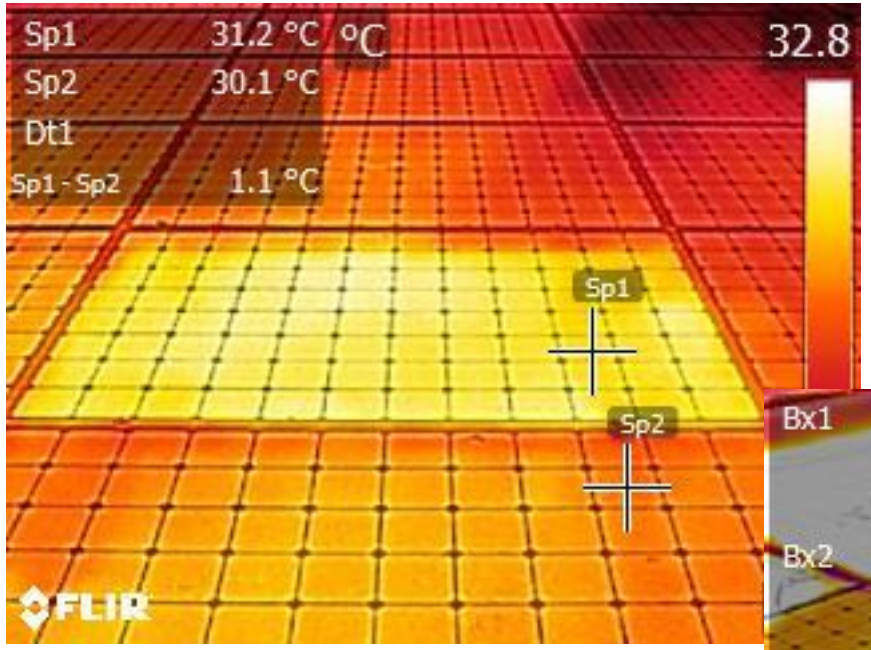
How it is on the map by the installer and online



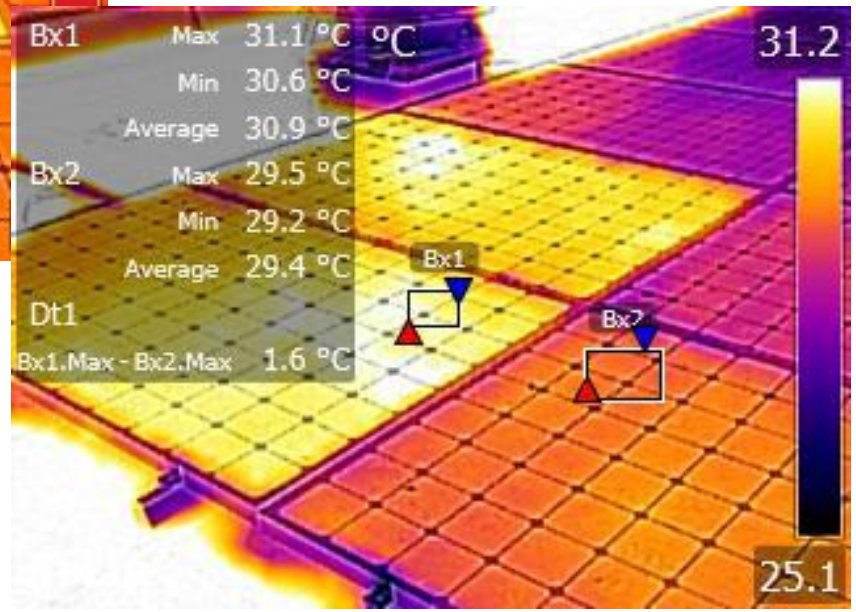
How the system was really laid out when we got there to swap out the units



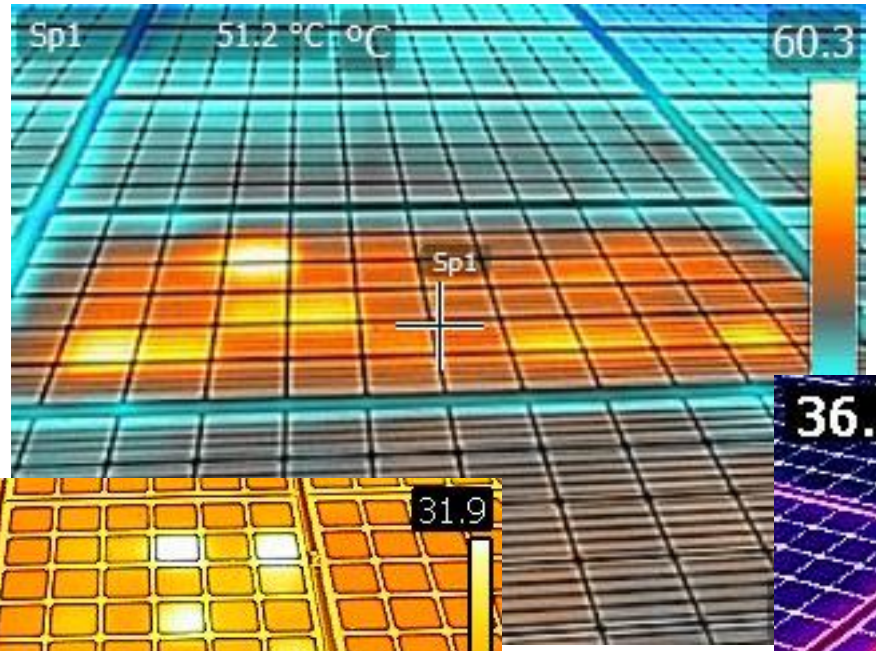
Optimizer and Micro Inverter



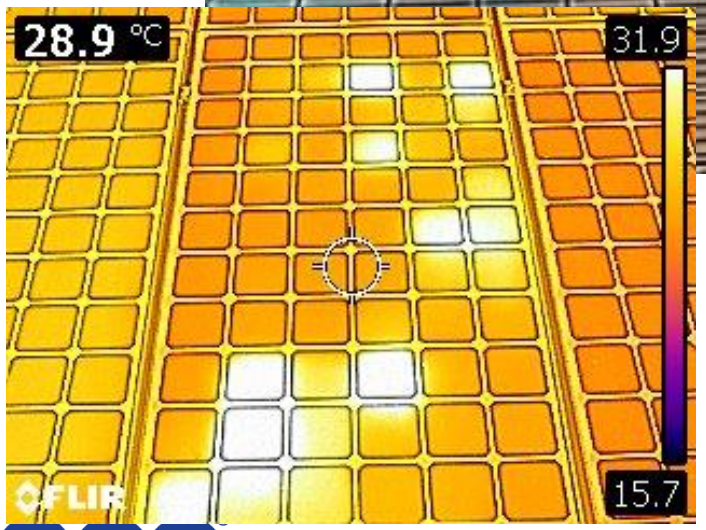
During a commissioning check we found panels not connected to there optimizers. It is a very small differential temperature to note and can be quite subtle, but it is identifiable, 1.1°C and 1.6°C in these images

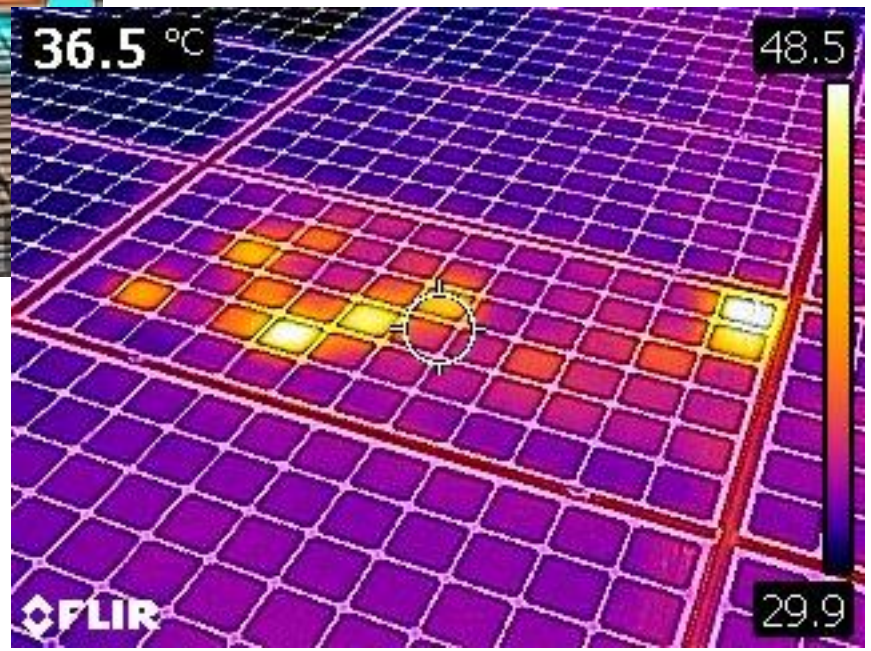


Optimizer and Micro Inverter

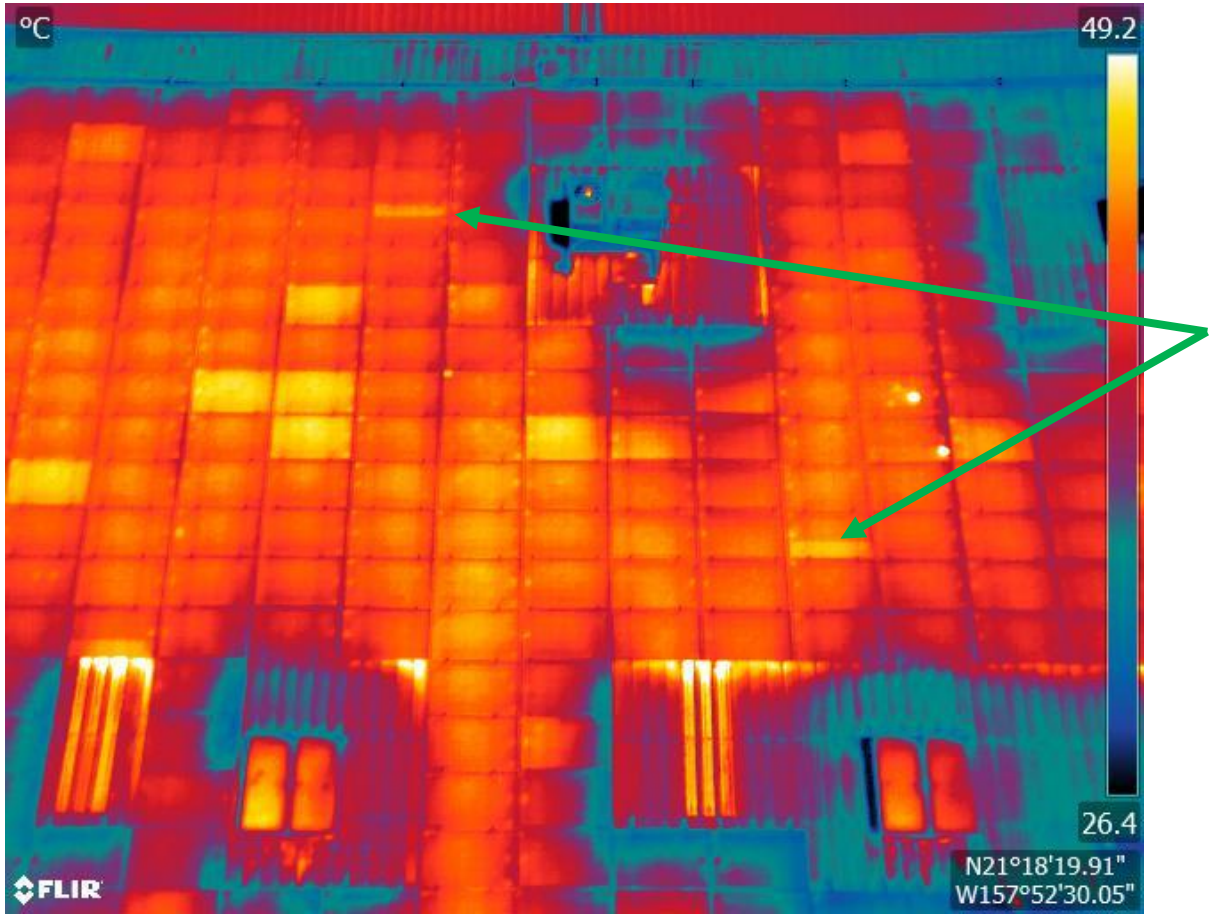


This is the thermal signature from a certain optimizer that has failed on a panel.





Diode Items



From the initial drone fly assessment I stated a possible diode issue on these two panels
Identification of diode issues came from a job we did years ago and could not figure out the lower production in certain areas. Then the thermal camera identified the anomaly. The map matched and that was the answer – Failed Diodes-
Those sites by the way are being completely changed out, as the trend kept showing more and more failures

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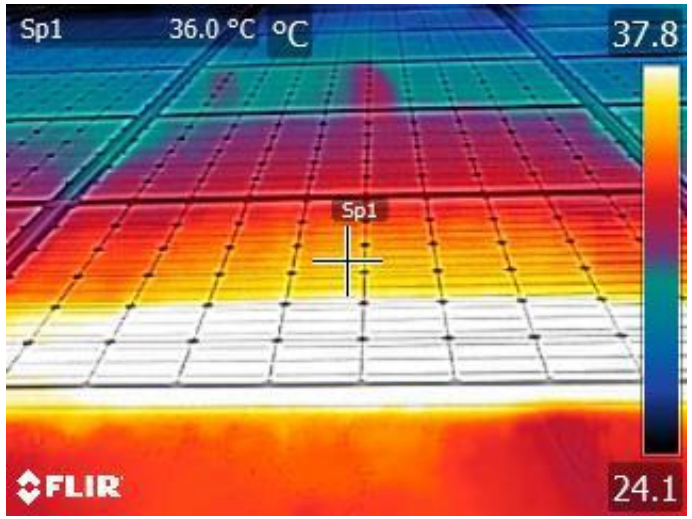
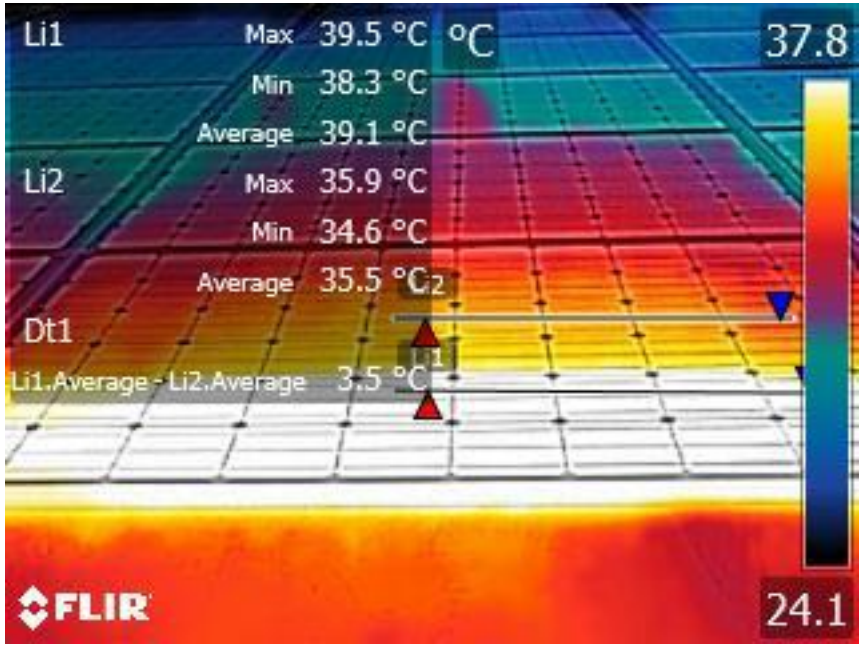
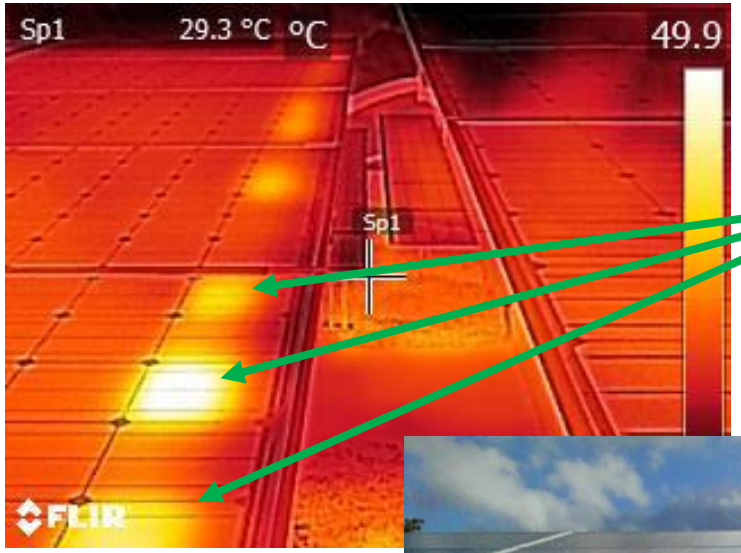
Diode Items

The diode failure on this shows one third of the panel with a heat signature difference. In this image we had a 3.5°C Δt. These panels had 3 sets of diodes and you can see that one whole set has failed.





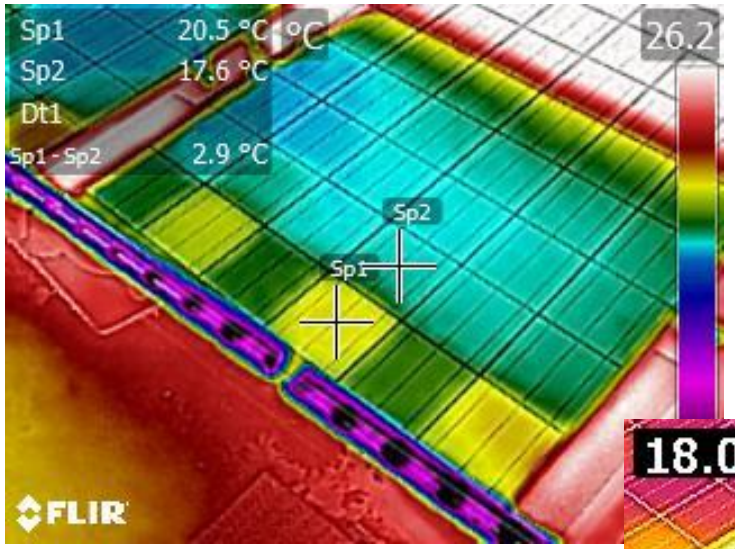
Diodes

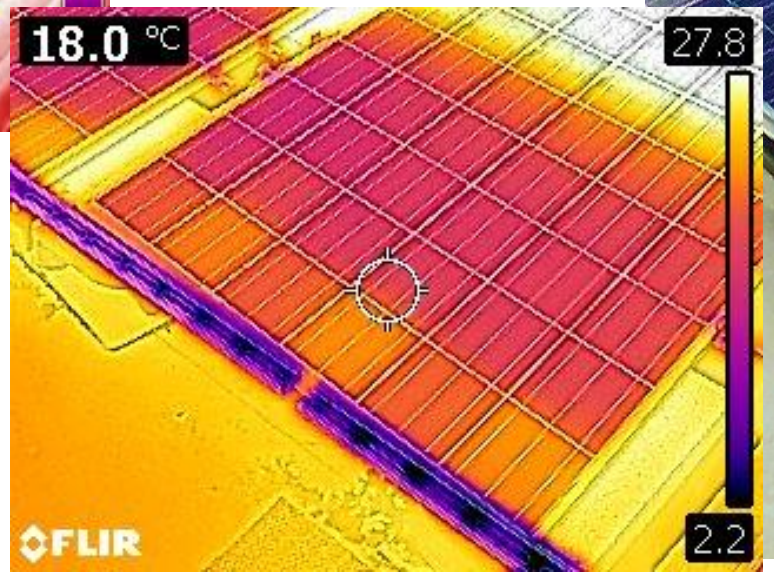


This is the same panel type from the previous slide. This shows the diodes working. You can see three diodes on this panel. From the install you can see it was shaded daily, but we will not go into that debacle.

Diodes

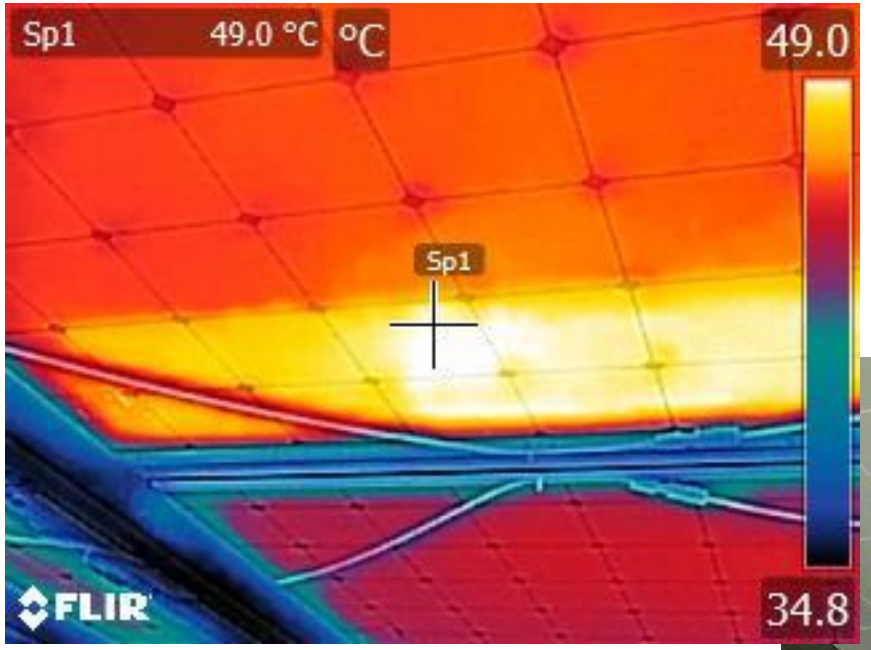
This is another panel shot we took that shows properly working diodes. This panel has three and you can clearly see the shadowing on the panel to make the diode operate as intended.

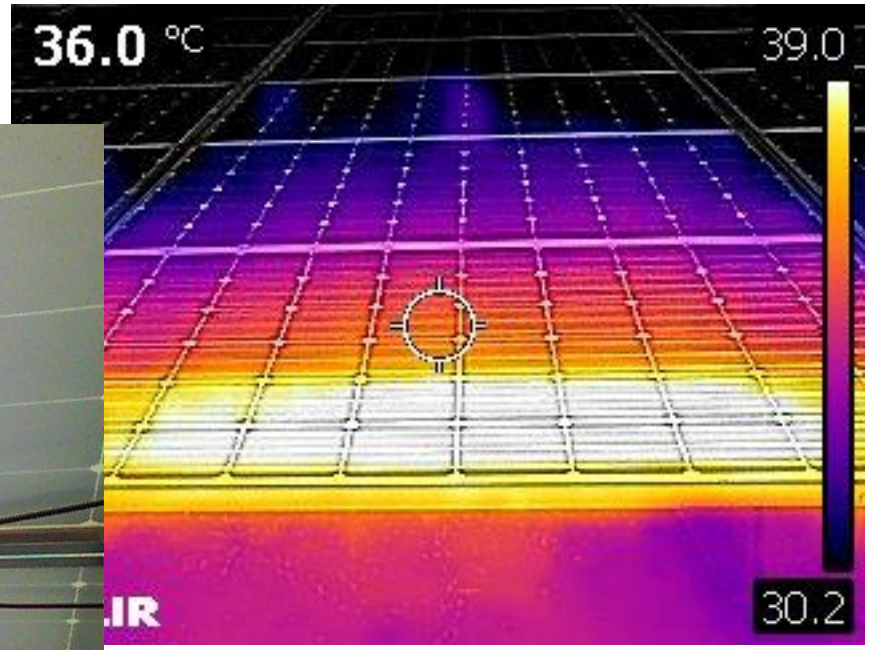




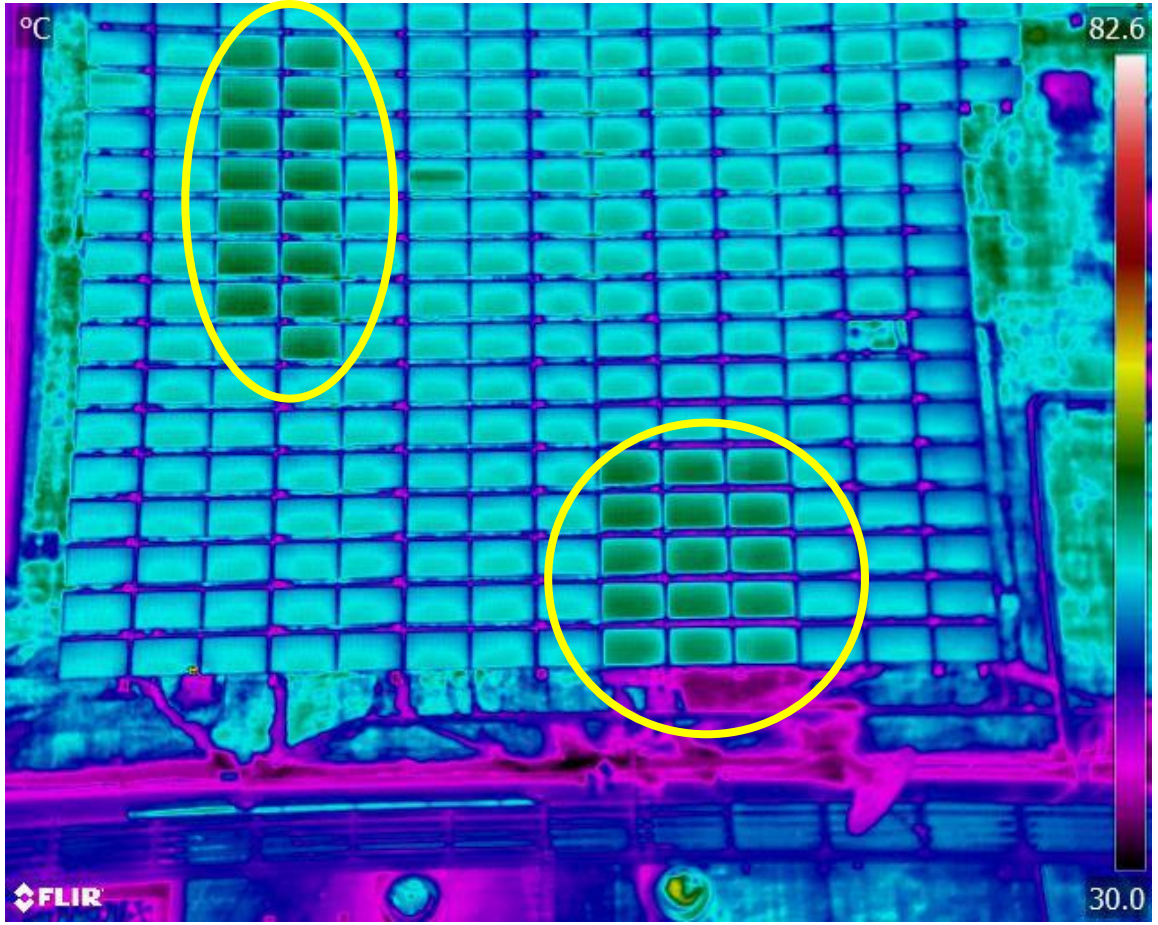
Diodes

As with all items on a PV panel system, one thing to remember is you can identify thermal anomalies from the top side or underneath. As with all thermal imaging outside you need to be aware of the sun's location.





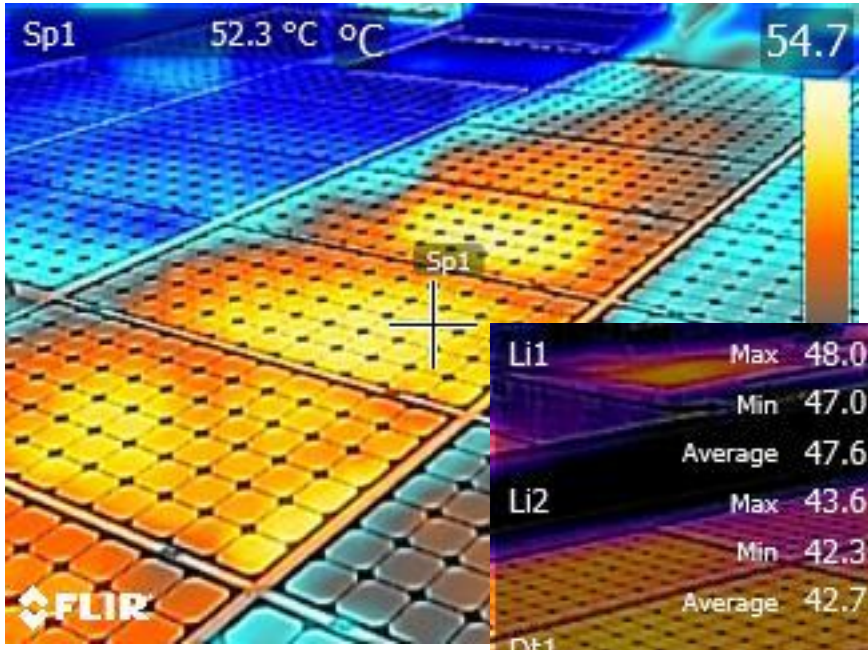
Downed String (s)

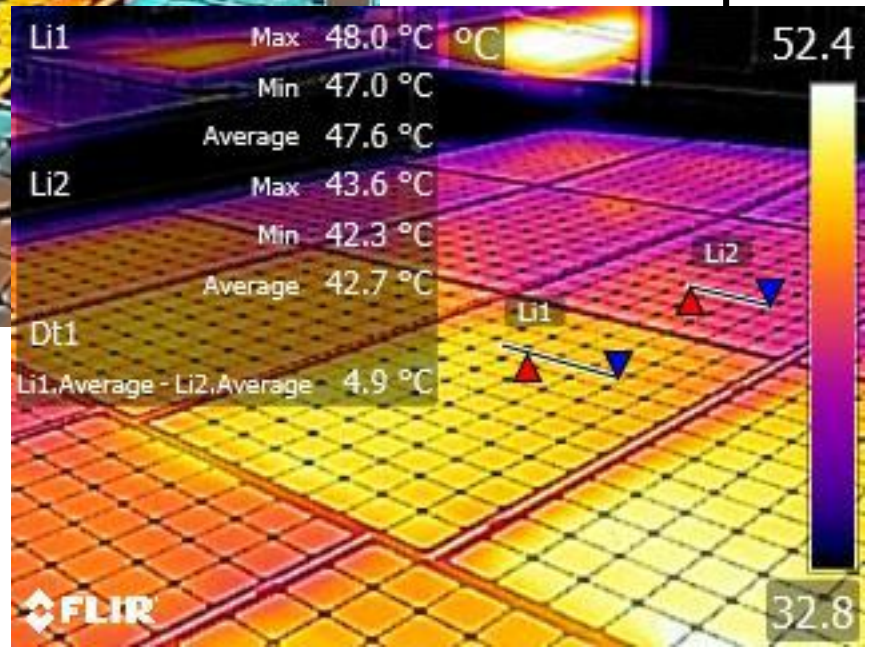


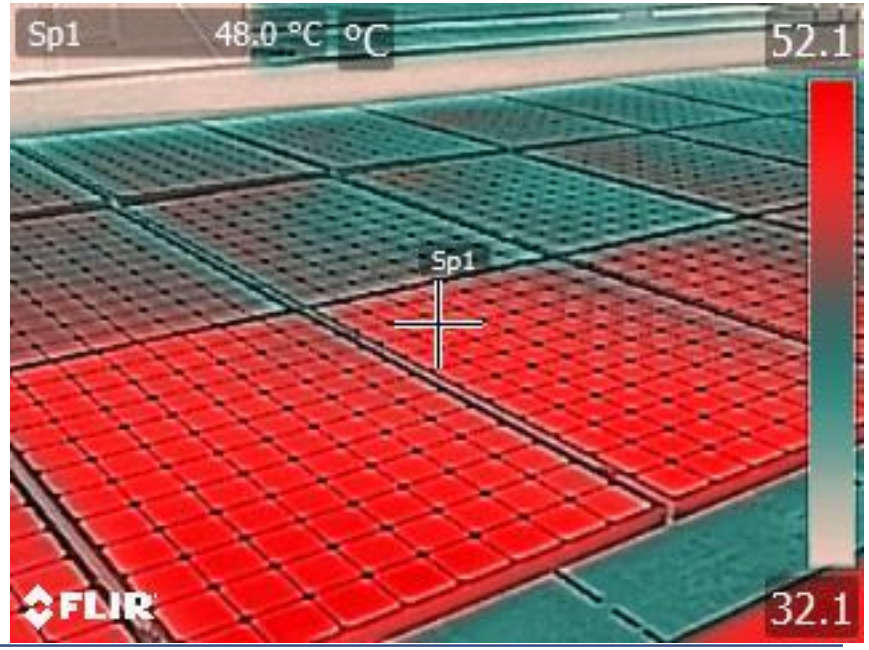
We can see the thermal anomaly difference on this image, we had the knowledge to know the system was in strings of 15 panels. This thermal anomaly came up and we can see the strings were down. Further testing did prove it, but this is pretty obvious. It helps you find a downed string quickly if you did not have a proper string map and happened to have tested first and found the downed string. This is a great way to find it.

Downed String (s)

The downed strings show about an even thermal signature difference across the line in the ones below it about a 5°C Δt. Knowledge of the system and the use of the thermal camera identifies these issues quickly.

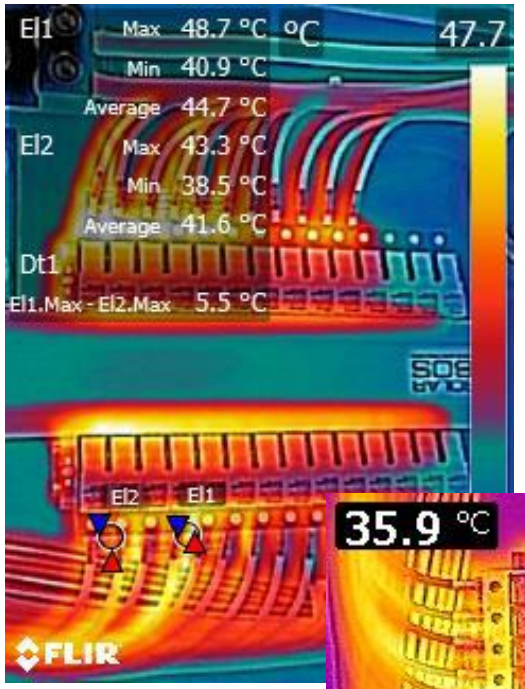


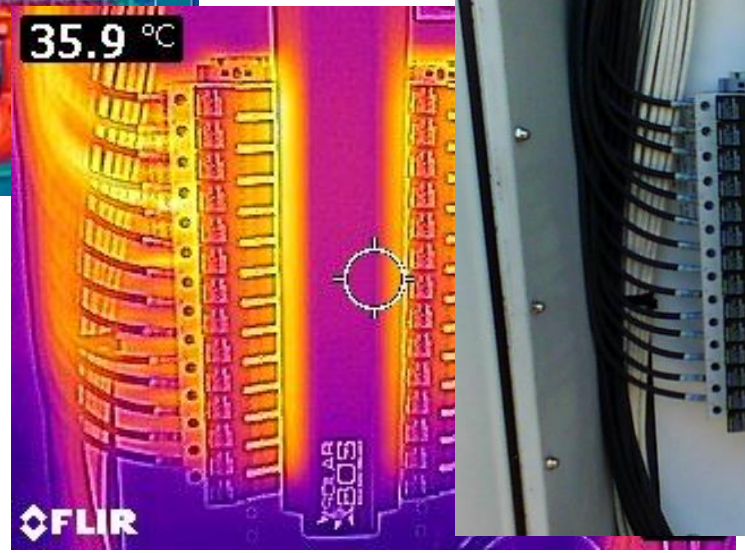


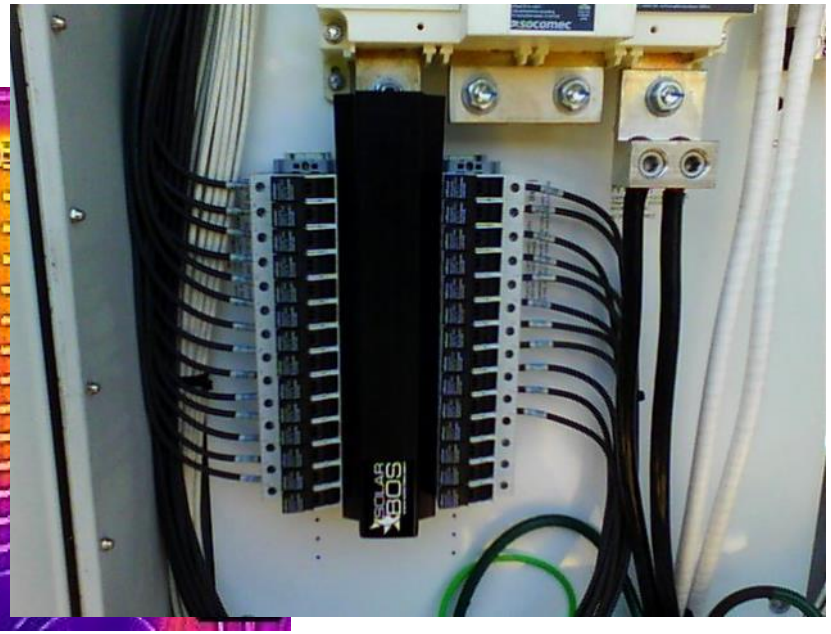


Combiner box items

The thermal anomaly in this item is a hotter string during operations of the system. This was then torque checked and found to have strings that were not torqued to specification. After we torqued them, the thermal signatures balanced out.

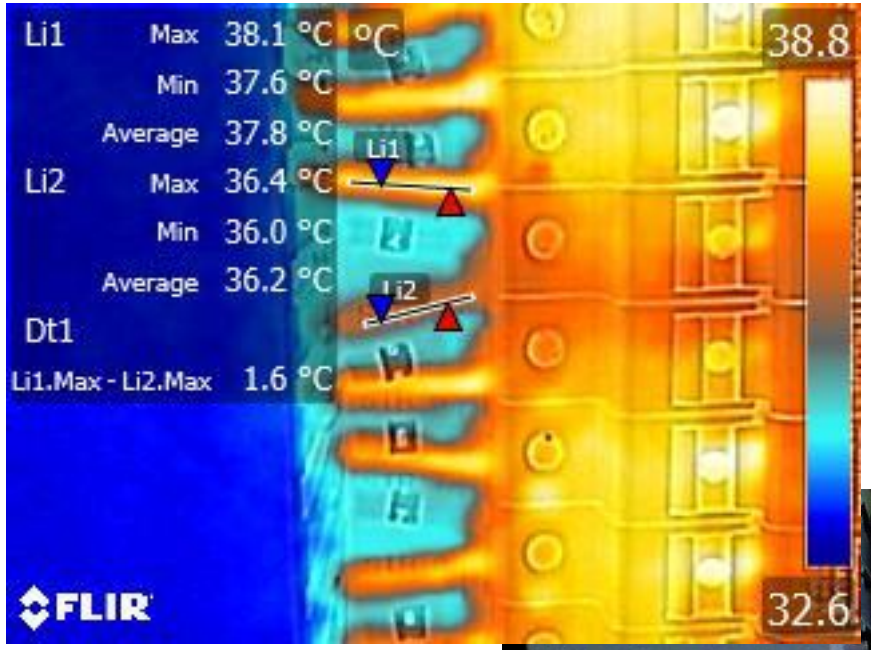


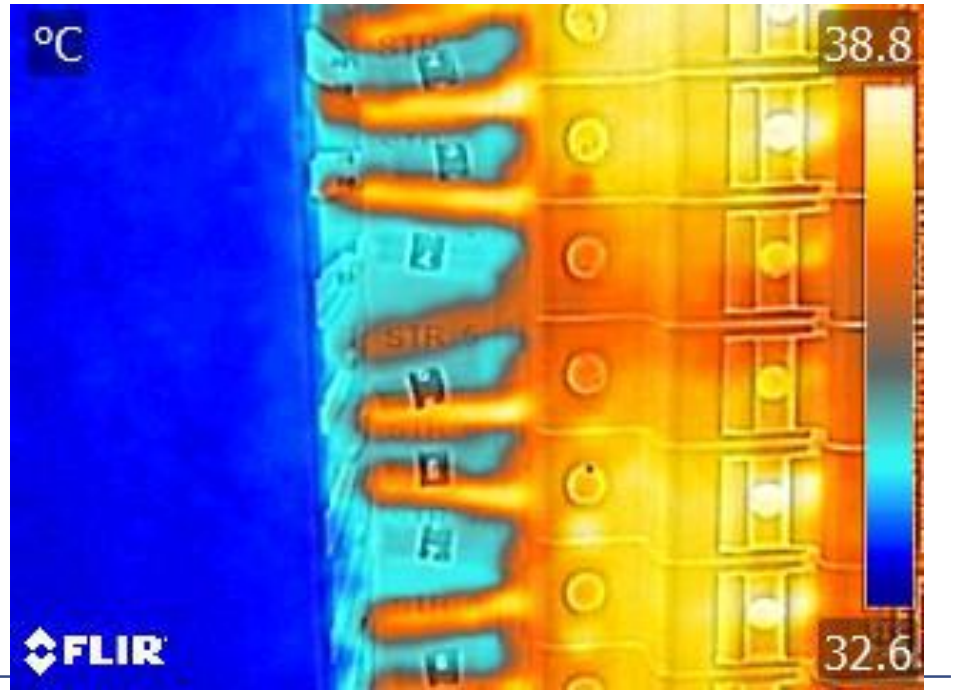




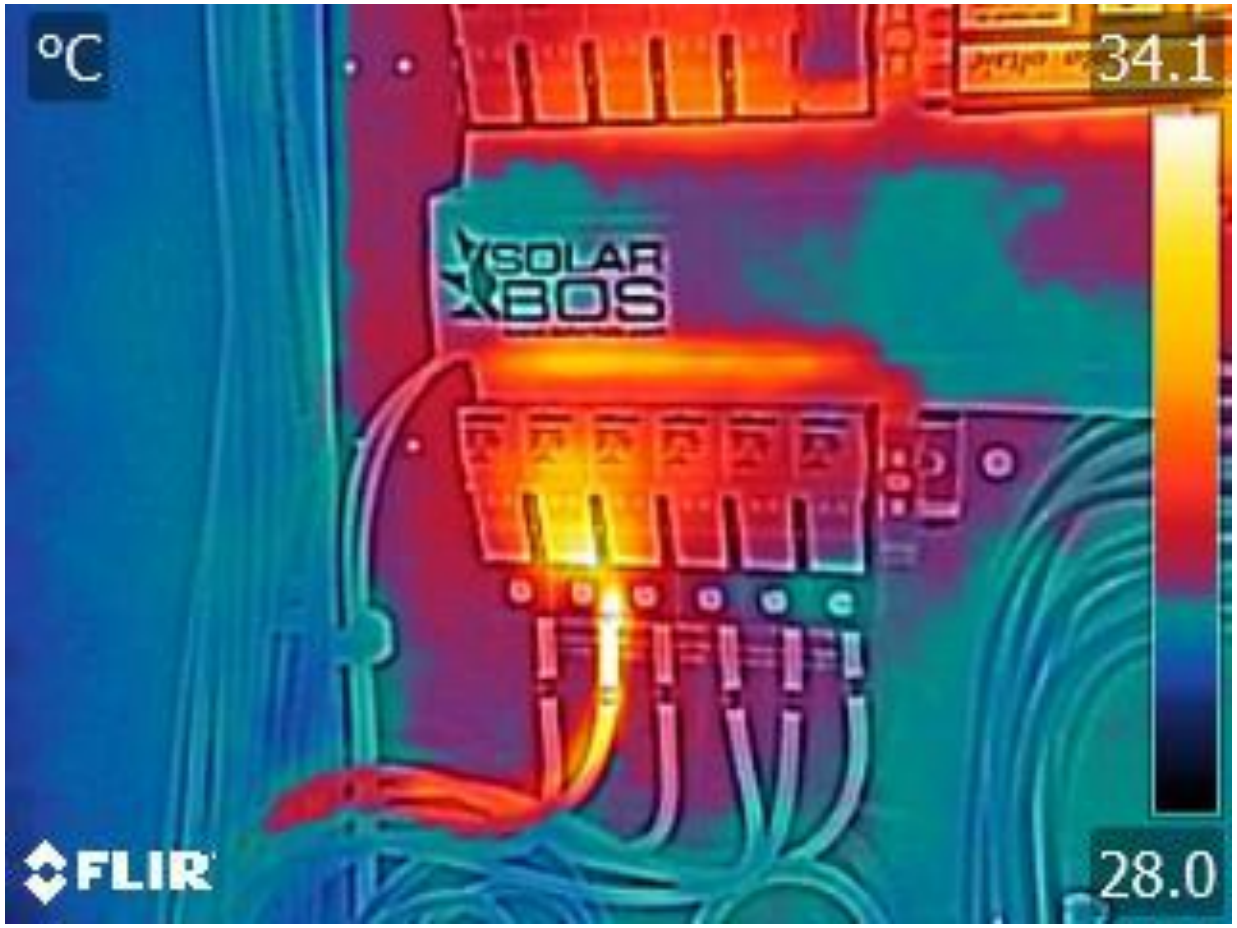
Combiner Box Items

The thermal image you see on here shows a thermal anomaly that is a lower thermal signature than the others. This showed us the string was down. Had a Δt of 1.6°C



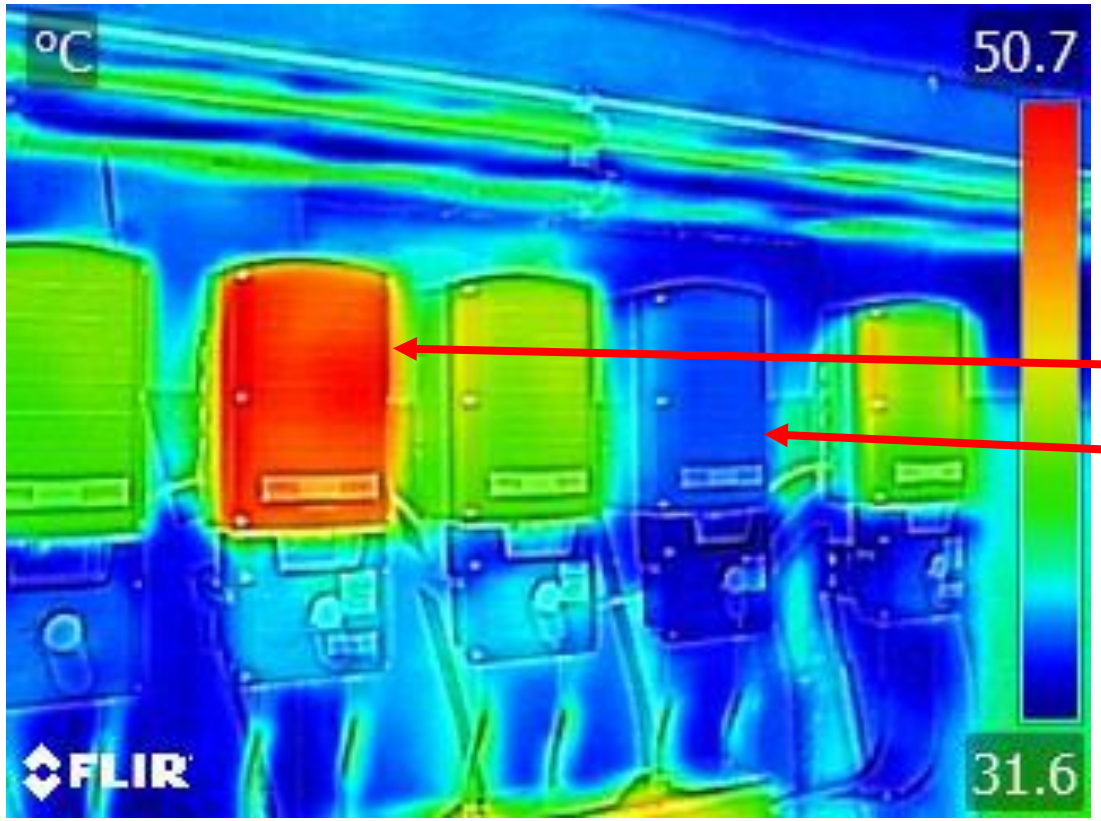


Combiner box items



One of my favorite finds and helps us greatly on a optimizer system, this was a ground faulted string that faulted the inverter. The system was down not operating. Yet you can see this heat signature and it is showing you production, this strings was producing on itself. This saves on time in a major way to identify the string in question. This system had almost 50 strings to it. This was one of many combiner boxes.

Inverter Items



Inverters on a wall side by side quick glance with the thermal camera and we can say

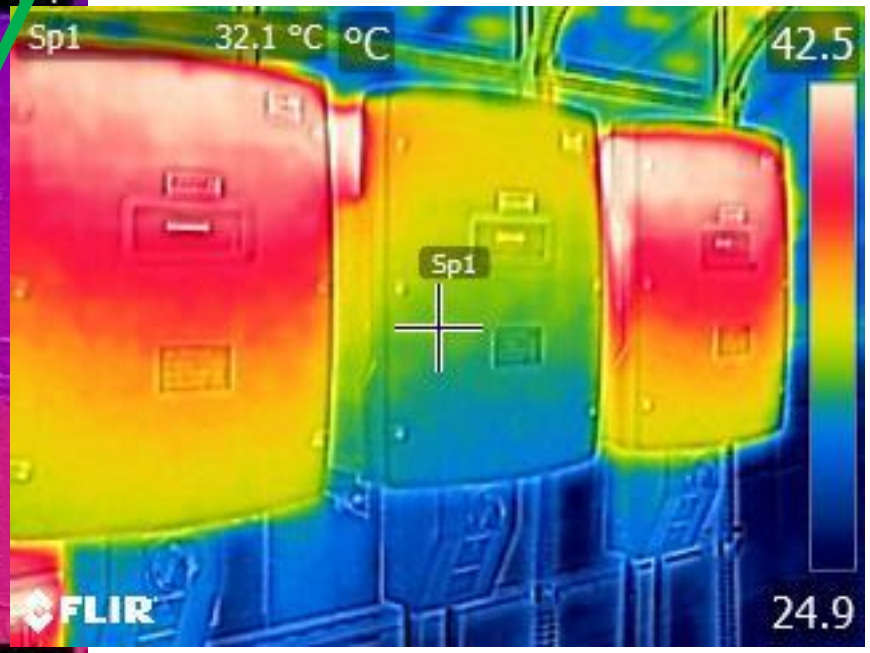
Fan not working

Unit not running

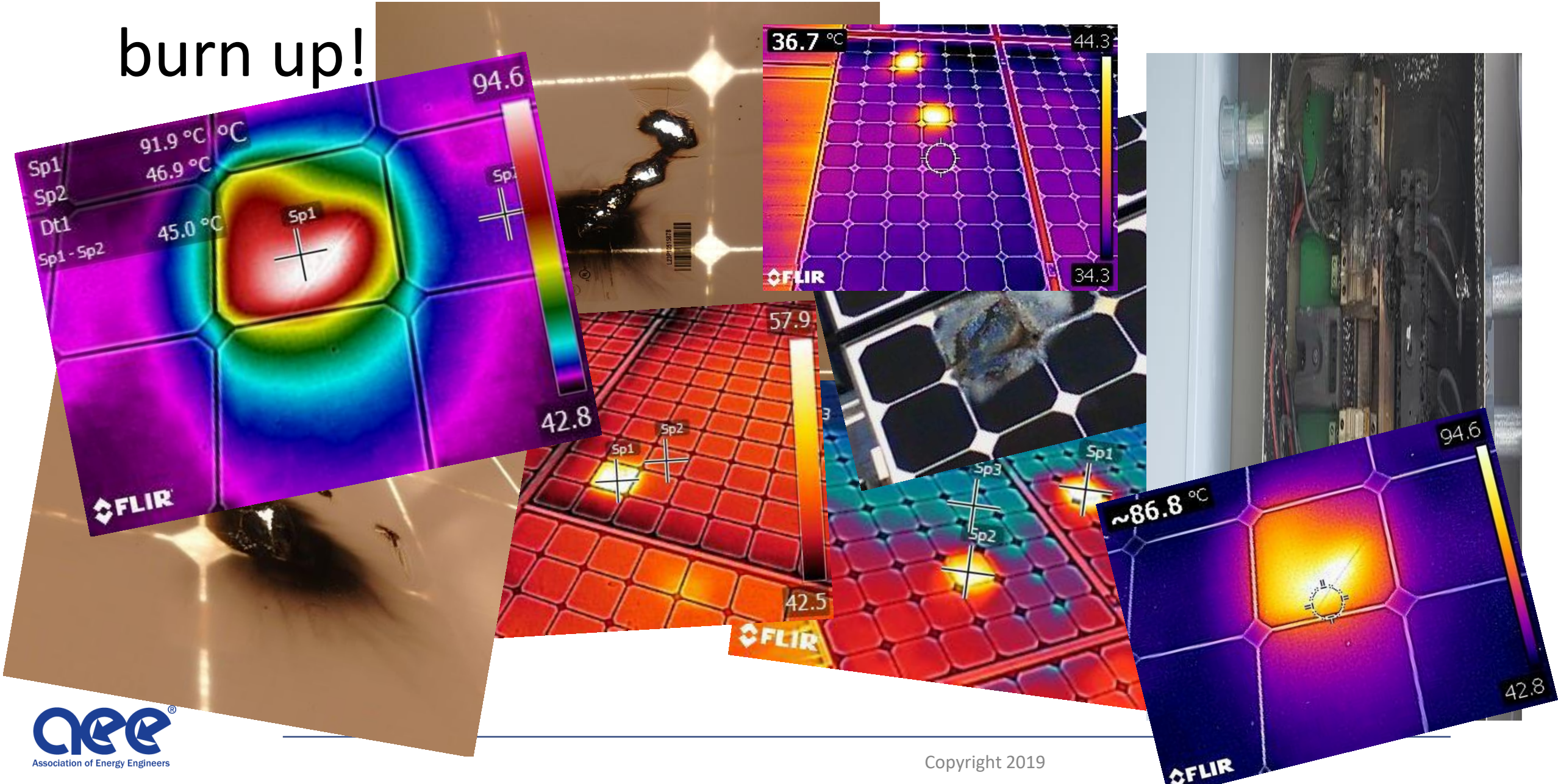
Others operating as expected

Inverter items

You are easily able to see which units may or may not be running and on a bigger unit you can see after you shut it off and open them, which blower may not be working. This one overheated and was burnt out



Protect That Solar Investment don't let em burn up!



Items for a quick recap-

- You can identify thermal anomalies relatively quickly using a thermal camera.
- You want to know the conditions during the testing, as that is a big part of the certification of becoming a certified thermographer
- The more knowledge you have of the system the more informative your thermal images will be.
- To get an overall scan on the system is a great idea but remember false hot spots and an anomalies are there, and you want to make sure you have a real anomaly. Dirt, bird droppings, paint and shadows can all create false anomalies. They can also show up and you find out the system is actually working like in the diode situation.

Thank you very much for joining me today!

- I want to thank AEE for inviting me to speak at such an amazing event
- Thank the team at Flir and the Infrared Training Center for the years of working with me and training
- Mike Elliot of Drone Services Hawaii for being my drone flying partner and taking incredible footage and imagery
- I want to thank you all for choosing to join me today and to listen to me speak about this subject matter which I truly enjoy. I am honored to have been speaking about this subject matter for years and continue to learn more on a regular basis and enjoy sharing it.
- I am Fred Brooks – My contact information is
- fred@pacificpanelcleaners.com
- www.pacificpanelcleaners.com
- You can contact me at my office at 808-772-4705
- Aloha and Have an Amazing Day!

QUESTIONS?

- Any questions, you can email me at

fred@pacificpanelcleaners.com

You can message me via Linked at

https://www.linkedin.com/in/fred-brooks-cem-cea-b5238217/

Mahalo once again, I have been thermal imaging photovoltaic systems since 2012 and I keep learning. It is a great experience.