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# SOLAR PANEL PROBLEM OF HOTSPOT AND DETECTION AND THEIR POSSIBLE SOLUTIONS

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***Abstract:*** Photovoltaic (PV) production systems are frequently used to produce green energy, ranging in size from modest domestic systems to big commercial systems. However, problems with PV systems might arise, particularly those brought on by heat. One of the major issues with PV modules is hot-spotting, which occurs when a cell or group of cells heats up substantially more than neighboring solar cells. As a result, less power is produced and the module becomes less reliable. Despite the fact that bypass diodes are widely used to reduce hot-spotting, they cannot completely resolve the problem or the damage it causes.

In order to prevent hotspots in PV systems, this paper will outline various prevention methods and remedies. Investigating PV solar panel degradation is necessary to ascertain how well a PV solar panel and farm are doing overall. Visual inspection is one method for spotting damage, such as cracks, incorrectly soldered connections, mismatched components, cable or frame damage, which may later cause more resistance and hot spots. Another approach that needs expensive (costly) specialized equipment is thermography.

This paper will address the various hot-spotting sources, such as electrical, light, and temperature, as well as the advantages and disadvantages of several detection methods, such as thermography and eye or visual examination. This paper will also discuss some of the hot-spot avoidance techniques, including bypass diodes, module-level power electronics, and micro-inverters. By taking care of the hot-spotting issue from the beginning, a PV system can be made to function effectively and successfully for many years.

## I. INTRODUCTION

Since climate change is one of the biggest issues that modern societies are facing, finding eco-friendly and renewable energy sources is crucial to cutting carbon emissions and regulating global temperature increases. The Paris Agreement, which was agreed in December 2015, established an international framework for a global convention on climate change with a major long-term objective to reduce emissions and keep the planet's average temperature increase to 1.5C°. Renewable energy sources like solar and wind have come to the top of the priority list for sustainable alternatives due to their incredible potential and efficiency. Photovoltaics (PVs), a potential technique for converting sunlight into electrical power, uses semiconducting materials that absorb photons and create electrons through the photoelectric effect.

However, environmental factors including the corrosion, short circuits, and the overheating can affect a PV panel's overall functionality and cause it to malfunction. Hot spots, one of the most common cell defects, can cause a rapid increase in body temperature. Therefore, regular inspections, good maintenance, and fast repair of any issues are crucial to ensuring the high performance of PV systems. We will look at the causes and effects of hot spots in PV systems and discuss potential detection and remediation methods in order to address this issue. By proactively addressing hot spots, it is possible to ensure that PV systems operate successfully and efficiently for a sustainable future.

## II. HOTSPOT?

The consistently heated areas of shaded PV modules exposed to sunlight are usually associated to the development of the hot-spot phenomena.

According to recent research, PV modules function in reverse bias under partial shadowing conditions (PSCs), with the lighted parts acting as loads that produce heat as a result of drawing power from a small reverse current. As seen in Figure 1, this behaviour may lead to the development of hotspots, which are known to result in irreparable cell damage and speed up the rate of thermal degradation.

Hot spots in photovoltaic (PV) panels can have a number of detrimental effects, including as physical harm, a reduction in power output, a loss in reliability over time, and greater manufacturing costs.

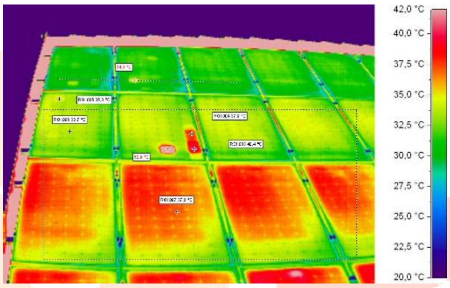


*Figure 1: actual hotspot.*

The production of hot-spots in photovoltaic (PV) cells has been the subject of extensive investigation in recent years. The results show that low-resistance defects in c-silicon PV cells, such as those present at cell edges, junctions, and cracks, can cause the development of hot-spots. In contrast to the modest reverse current produced by the hot-spot phenomenon, these defects have high conductivity and reverse bias, allowing for a lengthy and powerful reverse current to flow through the damaged regions and causing aberrant heating. Such hot-spots present a serious threat to public safety because a PV solar panel and farm as a whole can be severely damaged by temperatures exceeding 60 degrees Celsius at a single point on a cell.

Our objective here is to suggest effective methods for locating the hot-spot phenomenon in PV solar panels through in-depth investigation.

Workers or inspectors visually inspect items to look for potential damage, such as broken glass, damaged wires or connectors, damaged cables, etc. Alternately, hotspots can be found using thermography, which requires expensive and specialised equipment. PV solar farms and panels can operate safely and effectively by identifying hotspots early and taking the appropriate steps.

## III. SOLAR PANEL HOTSPOTS: CAUSES

Common issue that can significantly reduce a solar panel's performance and longevity and can also produce hotspots. When a particular area of the panel becomes substantially hotter than the surrounding cells, it develops hotspots. They can cause damage to the panel or possibly cause it to fail. There are numerous factors, such as shadowing, manufacturing faults, and electrical problems, that can lead to hotspots on solar panels.

### (a) SHADING:

Shading is one of the most common causes of hotspots on solar panels. A solar panel's partially shaded cells can develop into a significant source of resistance, which can cause them to heat up and create hotspots. This is because the shaded cells produce less energy than the rest of the panel, which could lead to the energy being lost as heat. To prevent shading, it is essential to place the solar panel in an area that receives full sunlight throughout the day.

(b) **MANUFACTURING ISSUES:**

Manufacturing issues might potentially result in hotspots in solar panels. These imperfections may be caused by the process in which the cells were soldered, the quality of the materials used, or even the structure of the panel itself. Hotspots can form in the cells and cause a localised area of resistance brought on by a manufacturing defect. To prevent manufacturing faults, it's essential to get solar panels from reputable vendors and have them installed by a good qualified and trained professional.

(c) **ELECTRICAL FAULTS:**

Electrical problems may turn to be the cause of solar panel hotspots. There could be problems with the wiring, the inverter, or even the electrical connections between the cells. The cells may become heated and form hotspots as a result of a localised area of resistance brought on by an electrical breakdown. To avoid electrical problems, it is essential to have the solar panel system regularly tested, inspected and properly maintained by a well-qualified professional.

Hotspots can significantly affect how effectively solar-panels function, resulting in lower efficiency and perhaps even solar cell damage. If you want to prevent hotspots, it is imperative to get solar panels from reputable manufacturers, place the solar panel in an area that receives full sunlight, and have the system regularly inspected and maintained by a qualified professional. By taking these steps, you can make sure that your solar panel system functions effectively and efficiently for many much more years.

## IV. HOTSPOT GENERATION IN SOLAR PANELS CAN BE CAUSED BY VARIOUS NO. OF FACTORS AND ISSUES

### (a) DEGRADATION OF SOLAR CELLS:

Hot spots can develop and leave burned marks that gradually degrade the quality of solar cells and back sheets, possibly posing a fire risk if they don't get treated in proper time.

*Figure 2: the occurrence of hotspots due to faulty solar cells has the potential to trigger a fire hazard*

### (b) MICROCRACKS ON SOLAR CELLS:

The development of semiconductor processing methods has made it possible to produce solar cells that are extremely thin, reaching about 170 m in thickness, or almost twice as wide as a strand of cotton fibre.

Despite the advantages of thinner solar cells, their fragility has significantly grown, making them more vulnerable to breaking when exposed to even slight impacts. In solar panels, the development of microcracks can obstruct the flow of electric currents through the afflicted cells, resulting in suboptimal energy production and the possibility for hot spots to occur.

Regular solar panel maintenance and inspection can assist to find any microcracks and stop any further system damage.

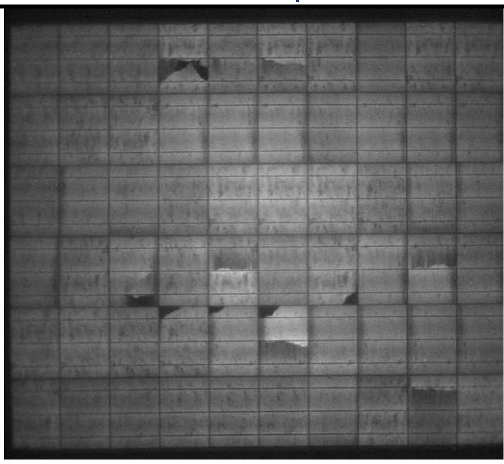

*Figure 3: electroluminescence image of microcracks on solar panels resulting from improper handling techniques.*

**(c) THE PRESENCE OF SNAIL TRAILS MAY INDICATE THE OCCURRENCE OF MICROCRACKS:**

The breakdown of the cell surface and EVA material in the damaged area might arise from any damage to the solar cells because the electric current that results from that damage may pass through the cracks and produce excessive heat. In the presence of water vapour, discoloured snail tracks can develop along the microcracks, lowering energy output and harming the solar panel's aesthetics. Solar panels should be regularly and thoroughly inspected and regularly maintained to detect any cell problems and stop additional harm to the system.

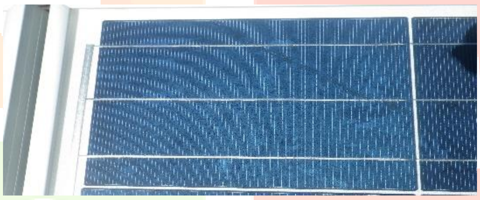

*Figure 4: the formation of snail trails on the surface of solar panels can serve as an indication of the presence of microcracks in the underlying solar cells*

**(d) BROKEN GLASS MAKES SOLAR CELLS:**

A solar module's front glass screen serves as an essential barrier against environmental hazards like rain, dust, hail, and errant items like golf balls. The glass panel used in solar applications must be strong enough to withstand mild stresses like hailstones and golf balls while still allowing the underlying solar cells to absorb sunlight in order to ensure optimal functionality. In the event of glass breakage, the panel's ability to absorb light is not only reduced, but outside substances such as water and dust may also get inside the panel and shade the solar cells, which would ultimately reduce energy output.

Inspecting and maintaining solar panels on a regular basis can help find any problems with the glass panel and guarantee the system will operate as efficiently and as long as possible.

*Figure 5: the presence of broken glass on solar panels increases their susceptibility to potential weather-related damages in the future.*

**(e) BUILDING-UP OF DUST:**

Rainwater may build up in stagnant pools inside the module frames of solar panels mounted on roofs with a slight inclination. The dust that is left behind after the water evaporates might shade the solar cells inadvertently and reduce their ability to produce energy.

The performance and efficiency of the solar panel system may suffer as a result. Solar panel's regular maintenance and cleaning can ensure optimum energy production and the durability of the system by preventing the accumulation of dust and debris on it.

*Figure 6: the accumulation of dust is often observed at the periphery of the module frame.*

**(f) CRACKED BACK SHEET:**

The solar panel components gets subjected to the extreme levels of UV radiation and the temperature fluctuations on a daily basis. Improper component selection can be indicated by the presence of fractured back sheets, which could also allow water vapour to permeate the laminate of the module and potentially harm the solar cells. Monitoring and maintaining solar panels regularly can help identify and prevent any issues with the back sheets.

*Figure 7: the presence of a cracked back sheet fails to provide adequate insulation to the solar cells, rendering them vulnerable to potential water damage.*

**SOME OTHER IMPORTANT POINTS TO NOTICE ARE:**

**(a) POOR CONNECTION IN SOLAR CELL:** After the solar cells are arranged into a string formation, they are joined together using the connection wires/cables that are soldered to form the array within a panel. However, solar panels with poorly, soldered interconnections can have up to one-third of the solar cells open-circuited, which causes an overall reduction in energy output of at least one-third of what is expected to be.

The regular solar panel maintenance and inspection can assist find any problems with the connector cables and stop any further harm to the system.

(b) **A DEFECTIVE JUNCTION BOX:** The main channel for transferring electricity to the outside world is the junction box located at the back of a solar panel. The bypass diodes inside the junction box enclosure, however, there is always a risk becoming short-circuited and malfunctioning if water or dust get inside the enclosure. A broken bypass diode or connector can put the panel in open circuit and prevent it from sending energy forward at all.

The regular solar panel maintenance and thorough inspection can assist to find any junction box problems and help us to stop any further harm to the system.

These were also the some of the factors which could be inspected by the means of the visual inspection.

## V. SOLAR PANEL HOTSPOT'S IMPACT ON THE SYSTEM

Solar panels' efficiency and lifespan can be significantly affected by hotspots. A hotspot can harm the cells and potentially cause the panel to fail when it causes localized heating. Reduced efficiency is one of the hotspot's most common side effects since it prevents the cells from producing as much energy as they would produce otherwise in their healthy condition.

A decrease in power output due to this efficiency decrement can may have a significant affect on how well the solar panel system functions as a whole. Hotspots can also damage solar cells, decreasing their lifespan and, in certain cases, possibly resulting in irreversible damage. at order to avoid the negative impacts of hotspots on solar panel performance, it is crucial to install the solar panel at a location that receives full sunlight, buy solar panels from reputable manufacturers, and have the system frequently inspected and maintained by a well-qualified professional/specialist. By following these instructions, you may prevent hotspots from having a negative affect on the performance of your solar panel system and guarantee that it operates successfully and efficiently for as long as possible.

## VI. INSPECTION AND DETECTION

The average expectation of solar panels service time is between 25 and 30 years. However, even tiny flaws in the solar photovoltaic (PV) cells that make up each panel may reduce their effectiveness and efficiency in producing useful power from sunlight or lead to early failure.

These imperfections can result in a significant reduction in the solar panel's overall power output over the course of its expected lifecycle, causing significant monetary losses. Therefore, it is essential to remove cells with even the smallest flaws prior to final assembly to guarantee the solar panel system's maximum efficiency and durability. Regular solar panel inspection and maintenance can also help to spot problems and stop any further harm to the system.

In order to effectively and efficiently convert sunlight into useful power, a solar photovoltaic (PV) cell consists of many no. of layers including front and back metallic electrodes, a silicon layer, and a textured surface with an anti-reflective coating. PV cells can have different visual shades and textures without losing its performance.

However, imperfections like scratches, fractures, bubbles, inclusions, and contact making errors can all affect how effective and efficient the cells will ultimately perform. Different combinations of electroluminescence (EL) imaging, photoluminescence (PL) imaging, and visible light imaging can be used to detect these defects. In order to guarantee maximum efficiency/performance and lifetime of the solar panel system, the regular inspections and the maintenance of solar panels will help discover any problems and prevent any further damage to the system.

Manual inspection procedures might be time-consuming and slow down productivity. Conventional machine vision struggles to ignore acceptable color and texture appearance differences, and it is difficult to program a set of criteria for spotting defects due to the variety of defect types, sizes, and potential locations. As a result, the development of sophisticated machine learning algorithms and systems powered by artificial intelligence can greatly increase the effectiveness and precision of fault identification in solar panels.

As a result, visual inspection is often preferred over the machine vision inspection technique. Regular inspection and maintenance of solar panels can help us to identify any defects and prevent further damage to the system, ensuring the optimal efficiency and longevity of the solar panel systems life.

For a solar panel system to be effective and long-lasting, the hotspots on the panels must be identified. Hotspots happen when a particular region of the panel gets noticeably hotter than the surrounding cells. They can cause damage to the panel or can even cause it to fail. Hotspots can be found using a variety of techniques, including techniques such as visual inspection, thermal imaging, and electrical testing. Solar panel systems can be kept as efficient and long-lasting as possible by doing routine the inspections and maintenance and that can help to identify any hotspots and prevent any additional further harm to the system.

(a) **VISUAL INSPECTION:** Before and after undergoing environmental, electrical, or mechanical stress testing in the lab, a PV module is subjected to a visual inspection. Stress tests are widely used to assess module designs during the pre-production phase, and to test the production quality, and operational durability of the module.

With routine the maintenance and inspection, solar panel systems may be kept as effective, efficient and durable for as long as possible. This can also help identify any issues with the modules and prevent further harm to the system.

Employees or inspectors use visual examination to check for any potential damage, including cracks, incorrectly soldered joints, mismatched components, cable or frame damage, etc. In the long run, these damages might boost resistance and develop into hotspots. On the other hand, thermography can also be implemented for visual examination, which often calls for expensive, specialised gears. In order to guarantee the maximum efficiency and lifetime of the solar panel system, the routine examination and maintenance of the solar panels can help us to identify any problems associated with the system and avoid any further damage to it.

The quickest and simplest technique to locate hotspots in solar panels is through visual inspection. The solar panel must be carefully inspected for any signs of corrosion or damage. Hotspots are commonly recognised on a panel by a darker or discoloured area that indicates a concentrated area of heating. However, visual inspection might not always be reliable because some hotspots might be undetectable to the naked sight of humans. Thermal imaging and other methods, such as electrical testing, can also be used to locate the hotspots. By doing the routine inspections and regular maintenance, it is possible to keep solar panel systems as effective and durable as possible. This can help identify any hotspots and prevent the system from suffering further damage.

(b) **INFRARED THERMOGRAPHY:** Infrared thermography is a non-destructive testing method that can be used to locate the hotspots in solar panels. This method involves photographing the solar panel with an infrared camera in order to look for any areas of localised heating. Hotspots can appear for a variety of causes, such as cell damage, shading, or poor cell connections. Infrared thermography can be used to find these hotspots quickly, allowing us to make quick maintenance and repairs to prevent any further damage to the solar panel system.

One advantage of using infrared thermography for hotspot detection is that it is a non-contact technique, requiring no physical touch with or disturbance to the solar panel during the inspection process. This can ensure the effectiveness and safety of the inspection process as well as help avoid any further damage to the panel. Infrared thermography can also be used to locate hotspots in a variety of environmental conditions, such as at night or when there is little sunlight.

The solar panel must undergo a thermal stress test before infrared thermography can be used to find hotspots. This involves exposing the panel to a controlled heat source, like a lamp or heater, to achieve localised heating. The infrared camera is then used to take pictures of the panel, and any warm spots can be identified by looking at the photographs. The images can be used to assess the severity of the hotspots and help to develop a maintenance and repair strategy.

Infrared thermography is a useful tool for finding hotspots in solar panels. With the use of this technology, hotspots can be quickly identified and maintained to prevent any further damage to the solar panel system. Regular use of infrared thermography can help us to maintain the system's longevity and optimum performance.

The images below were captured with the budget-friendly IR thermal cameras. The Flir One Pro camera's higher resolution produces a sharper and more distinct image than the Cat S60 camera's lower resolution, despite the fact that all three cameras exhibit identical attributes. On the other hand, the FLIR TG167 picture has a lower image resolution, which is ideal for integrated image processing because it requires and will use less computer resources.

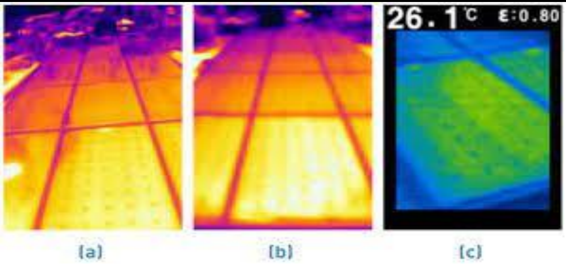


*Figure 8: three distinct cameras were employed to capture an infrared thermal image of a photovoltaic (pv) panel: (a) a flir one pro camera, (b) a caterpillar cat s60 camera, and (c) a flir tg167 camera.*

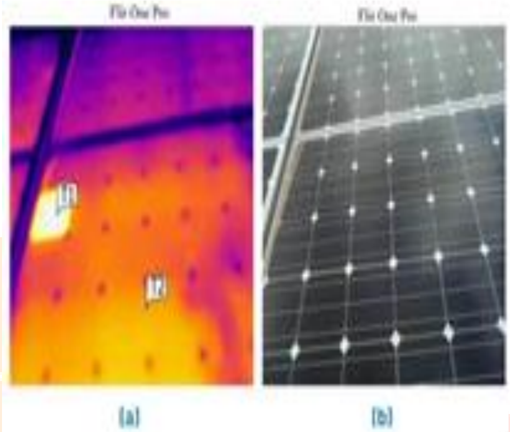


*Figure 9: A FLIR One Pro camera was utilized to capture a thermal image of a PV panel, with (a) an IR thermal image and (b) a normal image provided for comparison*

## (c) ELECTROLUMINESCENCE (EL) IMAGING

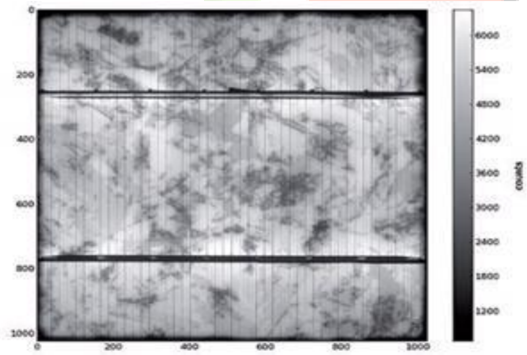


*Figure 10: Electroluminescence (EL) imaging*

Electroluminescence (EL) imaging is an effective way to find hotspots on solar panels. This process involves utilising a dedicated camera to take pictures of the solar panel while it is under electrical stress. The camera is able to detect localized heating and damage because of the light that the solar cells emit.

EL imaging uses a voltage applied to the solar panel to cause the cells to emit light. The camera takes a picture of the panel using this light, which can be used for finding localized heating and damage. Hotspots will appear as darker patches on the EL image, denoting the intense heating and reduced efficiency.

Using EL imaging for the solar panel hotspot detection has the advantage of providing a more complete picture of the panel's internal structure. The EL picture can reveal any cell defects or damage that might be hidden by other methods of detection. This technology could assist us in identifying the hotspot's origin and providing a more targeted and better solution.

Another advantage of using EL imaging for the detection of hotspots on solar panels is the ability to assess the hotspot's impact on the efficiency of the solar panel with better accuracy. The EL picture, which can provide a comprehensive view of the temperature distribution over the panel, which can be used to assess the severity of the hotspot and its impact on the panel's efficiency. Through the routine inspection and maintenance of the solar panels using EL imaging, the longevity and maximum efficiency of the solar panel system can be ensured.

- **WE SHOULD ALSO NOTE THAT:**

Each method for identifying hotspots for solar panels has the advantages and disadvantages of its own. Visual inspection is a quick and simple method that can be done without much specialized equipment, although it might not be able to locate all hotspots, especially those that are invisible to the unequipped human eye. Infrared thermography is a more accurate method that can detect hotspots that are invisible to the naked eye and provides a precise assessment of the impact of the hotspot on the panel's efficiency. However, it requires a lot of effort and could miss certain hotspots, especially those that are barely warmer than the cells around them. However, Electroluminescence imaging is time-consuming and expensive, it provides a precise picture of the panel's internal structure and has the ability to locate hotspots that are hidden from the naked eye.

A more accurate method of locating and resolving hotspots in a solar panel system can be obtained by combining these strategies. For instance, after visual inspection to identify any apparent hotspots, infrared thermography can be used to locate any hotspots that are not visible to the naked eye. Electroluminescence imaging makes it possible to more clearly examine the panel's internal structure, which makes it possible to pinpoint the root of the hotspot. Combining these techniques enables the early detection of hotspots, preventing serious damage to the solar panel system, and allowing for quick correction.

The size and complexity of a solar panel system can have an impact on the effectiveness of any detection method. For instance, in a bigger system, infrared thermography might be more effective than visual inspection at finding hotspots. In order to ensure the quick identification and correction of any hotspots, it is essential to have the system regularly inspected and maintained by a well-qualified professional/specialist.

## VII. SOLUTIONS FOR SOLAR PANEL HOTSPOTS

The effectiveness and lifespan of a solar panel system are significantly impacted by the solar panel hotspots. Many approaches have been proposed to address this issue, including bypass diodes, module-level power electronics, and micro-inverters.

(a) **PREVENTION:** As it is been said that prevention is better than cure, the same is also true for hotspots and not only hotspots but it is true for any kind of faults in any kind of system. We should take every kind of precautions to prevent the faults from occurring, such as choosing proper brand, choosing right size, buying good quality product with good rating to ensure its long-lasting-ness.

**(b)** **BYPASS DIODES:** The Bypass diodes are a simple and affordable way to solve the hotspots in solar panels. Current can be directed away from the damaged solar cells by connecting bypass diodes in parallel with them, reducing the chances of hotspots and increasing the overall effectiveness and efficiency of the solar panel system. This method can be applied to both new and old solar panel systems, and it is an affordable way to deal with hotspots.

**(c)** **THE MLPE (MODULE-LEVEL POWER ELECTRONICS):** The MLPE (module-level power electronics) is another approach for addressing the hotspots in solar panels. A requirement of the MLPE is the installation of power electronics at the module level, which can enhance the performance of each module. By ensuring that each module is running as effectively as possible, this can aid in the prevention of the hotspots. The real-time monitoring and diagnostics are also provided by MLPE, enabling the early identification and treatment of any potential hotspots. Although MLPE can be more expensive than bypass diodes, it can offer a greater degree of control over the operation of each module.

(d) **THE MICRO-INVERTERS:** Micro-inverters are another option for dealing with the hotspots enhancing the performance of the solar panels. The DC power supplied by each module is converted by these inverters, which are installed at the module level, into AC electricity for use in a domestic or commercial space. By ensuring that each module is operating at its peak efficiency, micro-inverters can help in the task of prevent from the hotspots. Additionally, they can also provide real-time monitoring and diagnostics, allowing for the early detection and treatment of any possible hotspots. Micro-inverters can provide the highest level of control and module optimization, although being more expensive than the bypass diodes or the MLPEs.

- **WE SHOULD ALSO NOTE THAT:**

Each method for removing the solar panel hotspots has the benefits and drawbacks of its own. A simple and cheap way to prevent localized heating and damage to the solar panel system is to employ bypass diodes. But they might be unable to successfully stop hotspots in sizable solar panel systems and are unable to provide the real-time monitoring and diagnostics.

Every module's performance can be enhanced by ensuring that it is running as effectively as it can, and MLPE can do this by offering real-time monitoring and diagnostics that can aid in the elimination of hotspots. In big solar panel systems, MLPE use can may be more expensive and less successful at preventing hotspots than bypass diodes.

The Micro-inverters can offer the maximum level of control and optimisation for each module, as well as real-time monitoring and diagnostics. By ensuring that each module is running at its optimum level of efficiency, micro-inverters can help to prevent hotspots. However, because they can be the most expensive choice and may not be successful in reducing hotspots, large solar panel systems might not benefit from micro-inverters.

## VIII. THE CASE STUDIES

*(source: internet )*

Un-identified Solar panel hotspots have a substantial impact on the efficiency and lifespan of a solar panel system. To solve this problem, a variety of detection and resolution methods have been proposed and applied. Several case studies of solar panel hotspots and the methods used to identify and resolve them are shown below:

- **CASE STUDY NO. 1:** In a Californian solar panel system, hotspots were located through visual inspection localized heating and solar cell breakdown brought on by adjacent trees' shadowing caused the hotspots. In the affected modules, bypass diodes were fitted to redirect the current away from the problematic cells. This method effectively protected the solar panel system from further damage.

The hotspots caused by the shadowing of nearby trees were successfully identified by the visual inspection technique used in this case study. Bypass diodes were installed, successfully protecting the solar panel system from further damage. Overall, the detection and repair methods used in this case study were successful in addressing the hotspots.

- **CASE STUDY NO. 2:** Using infrared thermography, hotspots in a German solar panel installation were found. The hotspots on the solar cells were produced by a manufacturing fault that resulted in localized heating and damage. To fix the problem, new modules were substituted for the damaged ones, which had no manufacturing flaw. The solar panel system wasn't further damaged thanks to this technique.

In this case study, the infrared thermography technique was successful in identifying hotspots brought on by manufacturing flaws in solar cells. The solar panel system was effectively shielded from more harm by exchanging the damaged modules for new ones. Overall, the strategies used in the case study for detecting and correcting the hotspots were successful.

- **CASE STUDY NO. 3:** Hotspots in a solar panel installation in Australia were found using electroluminescence photography. Hotspots, which led to localized heating and damage, were brought on by an imbalance in the current generated by the solar cells. The problem was solved by installing micro-inverters at the module level, which enhanced each module's performance. This approach increased the solar panel system's total efficiency while preventing future damage.

In this case study, hotspots brought on by an imbalance in the current generated by the solar cells could be found using the electroluminescence imaging technique. By utilizing micro-inverters, the solar panel system's total efficiency was increased and additional damage was avoided. Overall, the hotspots may be addressed thanks to the detecting method.

- **CASE STUDY NO. 4:** Infrared thermography was used to identify hotspots in a solar panel installation in India. The hotspots were brought on by a defective bypass diode, which additionally damaged the solar cells by locally heating them. It was replaced with a new bypass diode to address the problem. This procedure successfully stopped additional harm to the solar panel system.

The infrared thermography method worked well in this case study to identify hotspots brought on by malfunctioning bypass diodes. In order to prevent future harm to the solar panel system, the damaged bypass diode was successfully replaced. Overall, this case study's detection and remediation techniques were successful in addressing the hotspots.

## IX. POSSIBILITIES

As per with the development of Ai technology and machines and robotics technology, there is a huge change in the productivity and efficiency. We can make and employ machines and robots to do required tasks, we can also make programs to control these machines remotely or by predefined and programmed instructions.

There are many further advancements which can be done in the field of solar panel detection, one of such improvement robotics for visual inspection and data collection.

Where we can mount can mount the visual inspection system setup on a free moving robotic machine, which can move around the field and collect the required visual, such as broken frame, broken or damaged wires and cables, and broken glass. And help us to prevent any further damage to the system.

Similar approach is also possible with other detection tools, such as,

Mounting the infrared thermography setup and electroluminescence setup on a drone (to collect more data at a larger scale), allowing us to get more data with more mobility.

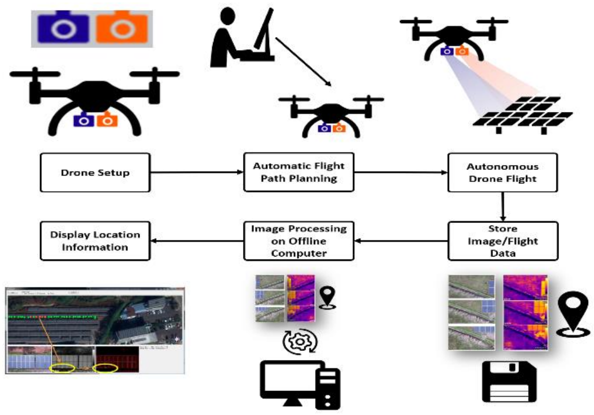


*Figure 11: The basic process of automation (automated flying plan, automated flight, data collection and data processing and then providing to base)*

We can also use machine learning and programming method to further utilise this and automate the tasks such as further creating report of damage or sending alerts.

Overall, we can say that we can-not totally rely on one particular method or approach, but if we combine some tools such as using thermographic and electroluminescence detection tools with robotics and drones, and utilize the technology such as machine learning, we can make solar panel operation and protection to be more efficient and easier with less labour and human effort.

## X. CONCLUSION

To ensure the efficiency and durability of solar panel systems, hotspots on solar panels must be identified and fixed. The case studies included in this paper show how several detection and resolution approaches, such as visual inspection, infrared thermography, and electroluminescence photography, can be successfully applied. These methods were successful in locating hotspots brought on by a variety of elements, such as localised heating, solar cell deterioration, production faults, and faulty bypass diodes. The use of corrective measures, such as the installation of micro-inverters, the replacement of damaged modules, and the insertion of bypass diodes, protects the solar panel systems from further damage and raise their overall efficiency.

Overall, the paper's findings emphasise the significance of routine solar panel system maintenance and inspection to quickly identify hotspots and fix them. Advanced detection methods, such as electroluminescence photography and infrared thermography, can help in the early discovery of hotspots, allowing for prompt repair and the averting of further harm. This paper's case studies demonstrate how these strategies can be successfully used to increase the efficiency and longevity of solar panel systems. While the visual inspection is the cheapest and economically friendly method of fault detection, which requires a well-trained and qualified professional person for the inspection purpose. But its accuracy and efficiency can be low.

While the other tools such as thermography and electroluminescence require more high-cost equipment, but its accuracy and efficiency can be low. But considering the longevity and time of use the high cost can be neglected.

So, if cost is the concern than we can go with a more economic cheaper option, and if the priority is the accuracy than we can go with a more accurate but a costly option.

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## XII. FIGURE SOURCES


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