

Abstract:

Our project is set to analyze and detect failures in PV panels. We can detect these failures by infra-red imaging of the panels themselves. Using infra-red images allows us to see where the temperatures accumulate and how failures affect these temperatures. The failure modes that we are trying to detect are initial conditions failure, dust accumulations, and cracks that are in the panels. Initial conditions failures are failures that shows in the thermal imaging in a form of hotspots. Theses hot spots are the result of malfunctioned cells in the panel which produces more current and a significant drop in the voltage. The hotspots are indicators of dropped output that can be detected by infra-red imaging and not by the naked eye. after that the Dust accumulations are failure that are most common in Saudi Arabia because there are sandstorms. These sandstorms leave dust on the panels and can be detected by infra-red imaging as it shows the dust or dirt to be hotter than the rest of the panel. Thus If there are patterns of heat in the imaging its most likely to be dust accumulated on the panel. The last failure mode is the crack in the glass of the panel. As our panels where protected we were forced to break on of them to see the affect in infra-red imaging. After that panels are broken we noticed that the temperatures rise in the cracked part. This raise in temperatures was very obvious and easily detected by the Infra-red camera.

List of Figures:

Figure	page
Figure 1: Example of Infrared camera	7
Figure 2: Photovoltaics Solar Panel Inspections	10
Figure 3: Defects Errors	23
Figure 4: View of PV panels under IR.	24
Figure 5: Seek camera	29
Figure 6: FLIR C3 Pocket Thermal Camera	32
Figure7 : PV Panels	34
Figure 8: FLIR C3	35
Figure 9: Power Domain	36
Figure 10: a-b Normal PV Panel	37
Figure 11: a-b Dust PV Panel	38
Figure 12 Broken PV Panel	39
Figure 13a-b General Failure PV Panel	
Figure 14 Minimum - Difference	40
Figure 15 Maximum - Difference	40
Figure 16 Average - Difference	41
Figure 17 old vs. new camera	46
Figure 18 Tripod	46

List of Tables:

Table	page
Table 1 PV panels specifications	22
Table 2 Seek specifications	23
Table 3 FLIR Specifications	24
Table 4 Stand Specifications	25
Table 5: The Testing Parameters	32
Table 6: Data of Initial Results	33
Table 7 Minimum - Difference	39
Table 8 Maximum - Difference	40
Table 9 Average - Difference	41
Table 10: Tasks & Duration	41
Table 11: Contribution of Team Members	42
Table 12: Project Execution Monitoring	44
Table 13: costs	46

Table of Contents

Abstract:-----	1
List of Figures:-----	2
List of Tables:-----	3
Table of Contents-----	4
Chapter 1: Introduction-----	5
1.1 Project Definition-----	5
1.2 Project Objectives-----	6
1.3 Project Phases-----	7
1.4 Application-----	7
Chapter 2: Literature Review-----	8
2.1 Project Background-----	8
2.2 Previous work-----	15
Chapter 3: System Design-----	18
3.1 Design Constraints and Design Methodology-----	18
3.1.1 Design Methodology-----	18
3.1.2 Design Constraints-----	19
3.2 Engineering Design standards-----	20
3.2.1 PV Panels-----	20
3.2.2 Seek Thermal Compact Imager for iOS-Apple-----	21
3.2.3 FLIR C3 Pocket Thermal Camera with Wi-Fi-----	22
3.2.4 stand for the PV panels-----	23
3.3 Theory and Theoretical Calculations-----	24
3.4 Product Subsystems and selection of Components-----	25
3.5 Manufacturing and assembly (Implementation)-----	26
Chapter 4: System Testing and Analysis-----	26
4.1 Experimental Setup, Sensors and data acquisition system-----	26
4.1.1: PV Panels-----	26
4.1.2: FLIR C3 Camera-----	28
4.2 Results, Analysis and Discussion-----	30
4.2.1: Normal PV Panel Reading-----	32
4.2.2: Dust PV Panel Reading-----	34
4.2.3: Broken PV Panel Reading-----	36
4.2.4: General Failure PV Panel Reading-----	37
4.2.5 software analysis-----	38
Chapter 5: Project Management-----	40
5.1 Project Plan-----	40
5.2 Contribution of Team Members-----	42
5.3 Project Execution Monitoring-----	43
5.4 Challenges and Decision Making-----	44
5.4.1: Camera quality-----	44
5.4.2: Angle-----	45
5.5 Project Bill of Devices and Budget-----	46
Chapter 6: Project Analysis-----	46
6.1 Life-long Learning-----	46
6.1.1: Knowledge Gain-----	46
6.1.2: Hardware Skills-----	47
6.1.3: Time Management Skills-----	47
6.1.4: Project Management-----	47
6.2 Impact of Engineering Solutions-----	47
6.2.1: Society Our project-----	47
6.2.2: Economy-----	48
6.2.3: Environmentally-----	48
6.3 Contemporary Issues Addressed-----	48
Chapter 7: Conclusions and Future Recommendations-----	49
7.1 Conclusions-----	49
7.2 Future Recommendations-----	49
References:-----	50

Chapter 1: Introduction

1.1 Project Definition

Photovoltaic is one of the renewable energy sources. This renewable energy source is considered one of the best alternatives for non-renewable sources. but with photovoltaic we notice that there is some drop of efficiency in the panel in the term of producing electricity; And there are many factors That could affect the panel such as excessive heat and dust. In this cause, the panel should be studied and analyzed along with the data it provides to protect and to choose the best material suitable for the conditions the panel subjected to. One of these studies is infrared imaging. IR imaging detect any cracks and problems in the solar panel where we get to know what should be replaced. Within time the solar panel are subjected to thermal and mechanical stress in which an IR sensor or camera is possible to detect.

Infrared Imaging Defects such as cracks or interconnection mismatches in solar cells are a genuine problem for Solar panels despite the differences in the weather a panel subjected to. They are hard to avoid and it is impossible to quantify their impact on panel's performance during its lifetime. it is reported that as a field solar panel ages and is subjected to thermal and mechanical stresses, which results in an inactive cell with significant hot spot heating effect. One of the indicators using Infrared imaging are hot spots, which are areas on the panel with high temperatures, were used as effective indicators to diagnose the defective portions of the solar panel. Infrared images of panel surfaces are to be captured also to observe temperature distribution over the surface of the solar panel. There are two temperature points to be noted (hottest and coldest point) by moving the scanner across each cell of the panel. The measurements are to be taken during a period of good insolation in a clear sky.

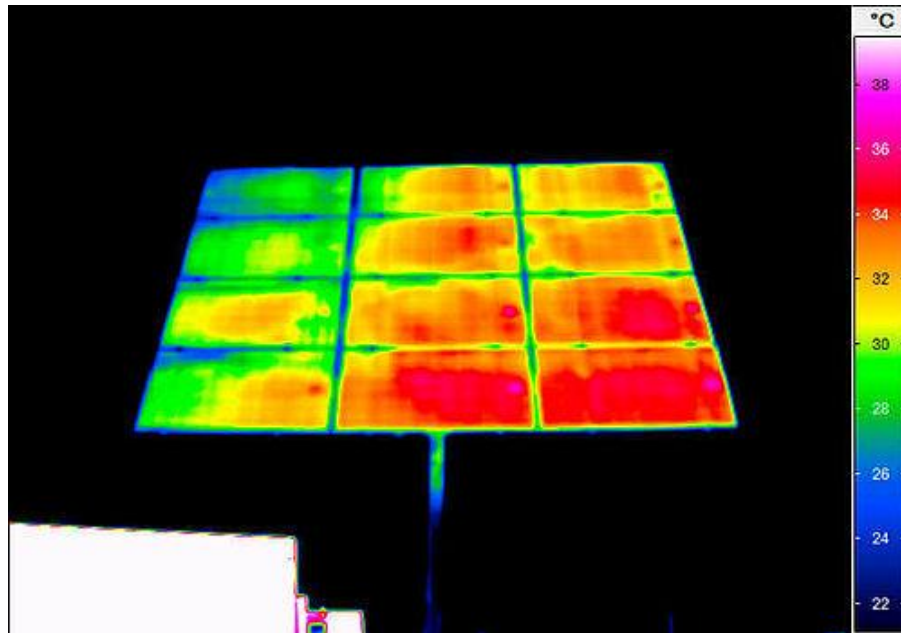


Figure 2: Example of Infrared camera

Infrared cameras photograph heat rather than objects. The camera is a heat-sensor that registers different temperature levels and converts them into a film or video image. Most cameras use digital imaging, but some use chemical infrared film.

1.2 Project Objectives

Infrared Imaging technology has been into many development and upgrades throughout the time. The following are the objectives of the project:

- Learn to instrument the photovoltaic cells with several sensing technologies.
- Learn to filter noise from measurement devices.
- Learn to process and interpret data form multiple sensors and thermal images.
- Learn the fundamentals of Internet-of-Things pertaining to mechanical systems.
- Learn to do experimental study.
- Learn to do modeling using data.
- Learn to integrate various technologies.

1.3 Project Phases

- Studying normal performance of photovoltaic cells under standard conditions. Infrared camera and data logging system will be mounted on a set of photovoltaic cells.
- Studying the cells after being subjected to several deliberate failures (such as wiring problems, dust, breakage, etc.). The heat signature of these cells will be studied and compared with the nominal images. A process to detect the failures will be established.
- Automating the process of image process using Amazon Web Services tools.

1.4 Application

Over the last years a remarkable increase of photovoltaic installations for producing renewable energy with both residential and non-residential buildings could be registered. At the same time large solar power plants were installed for using the sun's energy. In the next years the use of renewable energies will become increasingly important.

Over the time many installations are losing part of their initially installed power which leads to a decrease in energy yield. Single cells break down, important components such as inverter do not operate at their maximum efficiency. As a consequence - besides reduced yields - warming and overheating of local faults caused by parasitic currents can cause further damage to the installation and finally lead to fires, too. Using infrared thermography, these faults - also named hotspots - can be located easily due to their thermal signature and subsequently be repaired targeted. Due to the variety of manufacturers of photovoltaic installations that are in use today, a multitude of defects can show most diverse geometry and appearance. A prerequisite for reliable fault detection is the use of thermographic cameras with outstanding features as well as the expertise of skilled auditors.

Chapter 2: Literature Review

2.1 Project Background

The history of infrared detector materials starting with Herschel's experiment with thermometer on February 11th, 1800. Infrared detectors are in general used to detect, image, and measure patterns of the thermal heat radiation which all objects emit. At the beginning, their development was connected with thermal detectors, such as thermocouples and bolometers, which are still used today and which are generally sensitive to all infrared wavelengths and operate at room temperature. The second kind of detectors, called the photon detectors, was mainly developed during the 20th Century to improve sensitivity and response time. These detectors have been extensively developed since the 1940's. Lead sulphide (PbS) was the first practical IR detector with sensitivity to infrared wavelengths up to $\sim 3 \mu\text{m}$. After World War II infrared detector technology development was and continues to be primarily driven by military applications. Discovery of variable band gap HgCdTe ternary alloy by Lawson and co-workers in 1959 opened a new area in IR detector technology and has provided an unprecedented degree of freedom in infrared detector design. Many of these advances were transferred to IR astronomy from Departments of Defense research. Later on, civilian applications of infrared technology are frequently called "dual-use technology applications." One should point out the growing utilization of IR technologies in the civilian sphere based on the use of new materials and technologies, as well as the noticeable price decrease in these high cost technologies. In the last four decades' different types of detectors are combined with electronic readouts to make detector focal plane arrays (FPAs). Development in FPA technology has revolutionized infrared imaging. Progress in integrated circuit design and fabrication techniques has resulted in continued rapid growth in the size and performance of these solid-state arrays. (Rogalski, 2012)

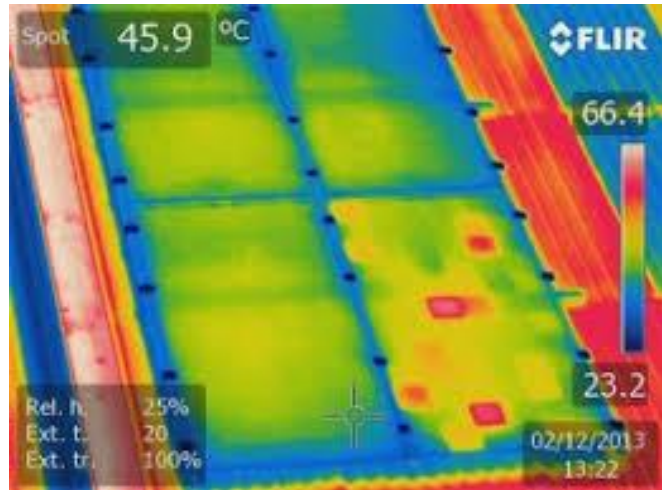


Figure 2: Photovoltaics Solar Panel Inspections

Temperature is one of the most common indicators of the structural health of equipment and components. Faulty machineries, corroded electrical connections, damaged material components, etc., can cause abnormal temperature distribution. By now, infrared thermography (IRT) has become a matured and widely accepted condition monitoring tool where the temperature is measured in real time in a non-contact manner. IRT enables early detection of equipment flaws and faulty industrial processes under operating condition thereby, reducing system down time, catastrophic breakdown and maintenance cost. Last three decades witnessed a steady growth in the use of IRT as a condition monitoring technique in civil structures, electrical installations, machineries and equipment, material deformation under various loading conditions, corrosion damages and welding processes. IRT has also found its application in nuclear, aerospace, food, paper, wood and plastic industries. With the advent of newer generations of infrared camera, IRT is becoming a more accurate, reliable and cost effective technique. This review focuses on the advances of IRT as a non-contact and non-invasive condition monitoring tool for machineries, equipment and processes. Various conditions monitoring applications are discussed in details, along with some basics of IRT, experimental procedures and data analysis techniques. Sufficient background information is also provided

for the beginners and non-experts for easy understanding of the subject. (Bagavathiappan, 2013)

TABLE I. LIST OF TYPICAL MODULE ERRORS

<i>Error type</i>	<i>Example</i>	<i>Appear in the thermal image as</i>
Manufacturing defect	Impurity and gas pockets	“Hot spot” or “Cold spot”
	Cracks in cell	Cell heating, from mainly elongated
Damage	Cracks	Cell heating, from mainly elongated
	Cracks in cell	A portion of a cell appears hotter
Temporary shadowing	Pollution	Hot spot
	Bird dropping	
	Humidity	
Defective bypass diode	n.a	A “patchwork pattern”
Faulty interconnections	Module not connected	Module is consistently hotter

Figure 3: Defects Errors

The reliability of photovoltaic modules has always been one of the most important subjects as reliability and lifetime are the key for overall system performance and warranty. Photovoltaics (PV) reliability has gained increased attention as the photovoltaics industry has rapidly grown and the numbers of module makers have increased too. PV systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day, so the actual output of a solar power system can vary substantial. There are other factors that affect the output of a solar power system. These factors need to be understood so that the customer has realistic expectations of overall system output and economic benefits under variable environmental conditions over time. In the work at hand different types of photovoltaic (PV) defects are reviewed and an experiment is made using nondestructive techniques to analyze visible and invisible defects for the PV array.

However, failure analysis of photovoltaic modules and arrays, analytical techniques are critical for isolating the defect and its source. Photovoltaics have seen an impressive growth in the number of field systems. However, the more systems are built the more difficult it gets to keep

an overview and to learn from the field experience. Most problems regarding photovoltaic systems that were identified and regarding multiple systems were: power limitation by inverter to keep upper limit for line voltage, partial shading in PV awnings by upper rows, PV generator operating voltage below inverter input window, power loss due to undersized inverter, gear thing or isolation faults, bypass diode failure, faulty circuit breakers or switches (given by: module, inverter, battery, conductors). The first of these troubles was solved by reducing the set voltage of the distribution network and thus allowing a larger margin between operational grid voltage and upper limit of grid voltage. Alternatively, inverters outputs have to be reduced. Reliability begins before the first hardware is installed. A good planning and design can boost the system performance as well as poor components can compromise it. Many building integrated PV projects are built to demonstrate innovative science that stands behind photovoltaics by it. They intentional use new materials and systems. The use of new module types, or new mounting systems, is increasing the risk factor of component failures. PV power systems may be subject to unexpected ground faults, like every other electrical system. Installed PV systems always have invisible elements other than those indicated by their schematics. Capacitance, resistance and stray inductance are distributed throughout the system. Leakage currents associated with the PV modules, interconnected array, wires, surge protection devices and conduit add up and can become large enough to look like a ground-fault. PV systems are frequently connected to batteries, standby generators or the utility grid. This complex assembly of distributed power and energy sources, distributed impedance and proximity to other sources of power requires sensing of ground faults and proper reaction of the ground-fault protection devices. The industry has had products out in the field for some time already and effects of aging of modules, connectors and wiring system can be seen all over. Any of these effects combined are leading to an increase in faults developed in systems. Short circuits arise primarily from insulation failure because of poor workmanship. Insulation problems may

appear as casing deterioration due to mechanical failure given by aging, vibration, wear, ultra-violet exposure or exposure to over-voltages (lightning). Short circuits may also result from arcing causing damage to insulation. Positive to negative short circuit faults may appear in areas where the two conductors are in close vicinity such as combiner boxes. A positive to negative fault generally results in catastrophic failure because of the high probability of an arc forming and as a result the whole array voltage and current is potentially available to feed the fault. A module junction box short circuit within a single string may lead to decreased array output but in an array with two or more strings in parallel it may lead to high reverse currents which may, also, lead to either string wiring failure or module failure. The main issue with bad joints is that though overheating or because of fracture may lead to an interruption of current or to an arc. Bad joints may occur within modules due to poor quality control by the manufacture. If a failure occurs within a module under normal forward conduction an arc will not usually result if bypass diodes are fitted and operational. In order to protect shadowed solar cells from breakdown, bypass diodes are applied. Bypass diodes for hot-spot protection of large area modules are sometimes left out. Protection from hot-spots is totally ignored or sought by other means, for example by using several parallel cell strings within a module. Experience shows that this is a risky path. Paralleling several cell strings within a module does not protect the modules, if partial shading from nearby objects occurs regularly. Because the series connection of the PV generator forces all cells to operate at the same current (string current), the shaded cell within a module becomes reverse biased which leads to power dissipation and thus to heating effects. If the cell is shaded, its short circuit current is less than the string current so that it is operated at reversed characteristic, leading to power being dissipated. Leakage currents originate in cell defects and impurity centers in the semiconductor and can be represented by a shunt resistance. At low bias voltages the current is distributed over the whole cell area and heating takes place more or less uniformly. The maximum current density is below

the critical limit and the characteristics are stable against thermal effects. If we want to maximize energy output over lifetime of the PV system, we need to be able to recognize when there is a fault or a reduction in output. We also want to find out what has caused the loss of output and find a solution as quickly as possible, but we don't want to waste too much time and man power on this. PV modules are usually reliable systems, but in practice right balance being the key.

Typical photovoltaic systems suffer from numerous problems that prevent them from realizing their true potential. Many of the present problems stem from power losses – whether due to module mismatch, orientation mismatch, ground faults or partial shading. Other problem comes from system design limitations and constraints, lack of monitoring or lack of analysis abilities. In addition, the absence of safety features poses risks to both workers and maintenance personal. Current PV systems are typically built from ten to a few hundred PV modules connected in a series-parallel connection. Several panels (10 to 15 typically) are series connected in a string of modules so that a voltage high enough for DC/AC inversion (150V to 800V) is achieved. More power can be added to the system by adding strings. Since the strings are connected in parallel, they have to match the other strings in all parameters, including orientation. The entire array is connected to a solar inverter which is responsible for harvesting the electrical energy. The inverter handles maximum power point tracking the entire array. This is done by finding the DC working point in which the most power is harvested from the array. The resulting power is inverted and fed into the power grid. The inverter is also responsible for conforming to the electrical and safety regulation requirements. The manufacturing process of PV cells produces cells with relatively large tolerances in their power output capability. To reduce the difference between cells in the same module, they are sorted during manufacturing to different power categories (bins) and modules are assembled with cells from the same bin. This produces panels with smaller tolerance variances in output power. The panels themselves

are not sorted, so that today panels that are on the market have a 3% tolerance in output power. For solar cells the most important mechanism in junction breakdown is the avalanche multiplication which has the origin in the high electric field, into the depletion layer that is generated by the bias voltage. Cells do not have a homogeneous structure, regions with higher impurity concentration of centers exists. At high bias voltages if the current density exceeds a critical limit the cell is irreversibly damaged by thermal breakdown (burnout) that forms a shunt path in the cell structure. At reverse bias the current is locally concentrated, focal-point heating is caused and damage to the cell encapsulation is to be expected (hot-spot). To avoid thermal overload and the formation of hot spots, sub-strings of cells inside the interconnection circuit of modules are bridged by bypass diodes. This measure limits the bias voltage of the shaded cell and therefore dissipated power too. Partial shadowing has been identified as the main cause for reducing energy output for grid-connected photovoltaic systems. Impact of the applied system configuration on the energy output for partially shadowed arrays has been widely discussed. Nevertheless, there is still much confusion regarding optimum grade modularity for such systems. Shading effect occurs when part of the panels array is shaded which can be caused by a number of different reasons, like shade from the building itself, light posts, chimneys, trees, clouds, dirt, snow and other light-blocking obstacles. Shading on any part of the array will reduce its output, but this reduction will vary in magnitude depending on the electrical configuration of the array. Clearly, the output of any shaded cell or module will be lowered according to the reduction of light intensity falling on it. However, since this shaded cell is electrically connected to other shade less cells, their performance may also be lessened since this is essentially a mismatch situation. The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next and is called module mismatch and is in the amount of to at least 2% loss in system power. Power is also

lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to keep them below 3% for the all system. Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. Although typical dirt and dust is cleaned off during every rainy season, it is more realistic to estimate system output considering the reduction due to dust buildup in the dry season. Cell manufacturers generally provide no information about the behavior of their cells under reverse biased condition, but an infrared image can provide the needed feedback to anticipate any internal cell decaying process. (Adomavičius & Kaminickas, 2015)

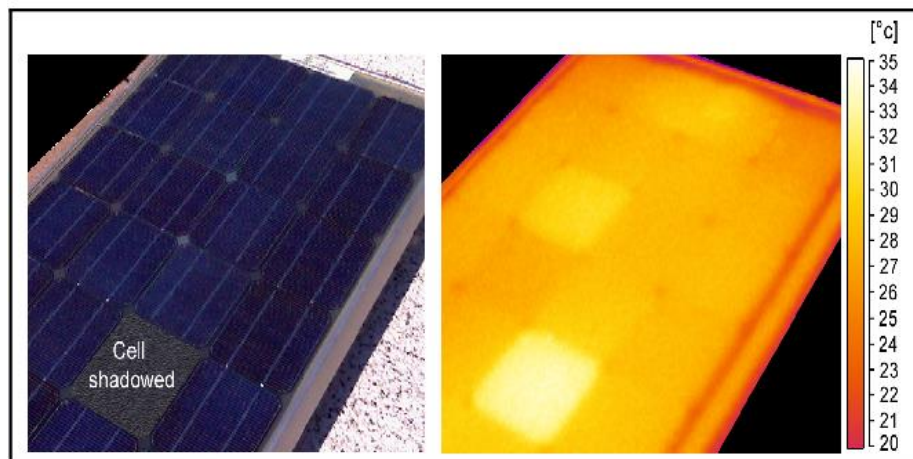


Figure 4: View of PV panels under IR.

2.2 Previous work

- **Application of Thermography in Solar Cell Research and Industry**

Shunts, images in solar cells under bias, were first studied with infrared thermography in 1990. A reverse bias was applied to the solar cell while monitoring with an IR camera. Shunts in solar cells are indicated as higher temperature because of the increased current, and thus are called hot spots. In addition to use in research, IR cameras are increasingly being used for solar panel quality control and maintenance after being installed. Figure 2-9 shows thermal imaging with

a FLIR brand (FLIR Systems, Inc.) camera to inspect the hot area or bad modules over large area of solar panels. As shown above, a thermal image can clearly show the areas that are hotter in a solar panel. Because several shunt types exist in solar cells, hot spots and hot areas can give some, but not all, information about such shunts, especially in crystalline silicon solar cells, depending on the shape and location. For example, interconnection problems, not the problems within the cells, can cause heating of an entire module. Also, bypass diodes can cause strings of cells to heat up, showing up as a patchwork pattern. Shunts, Shadowing and cracks in solar cells appear as hot spots under IR camera. (Chen, 2014)

- **Hot Spot Detection in PV Modules**

Without going into the details of the electrical equivalent of a PV cell or module, let's use the battery analogy to exemplify a common behavior. If we have a series of batteries, the worst battery sets the electrical current. A PV module is made of a series of PV cells, and, if one of these cells by some reason (crack, soldering problems, shading or mismatch error in the cell sorter) is producing less current than the rest of the cells, the module will develop a hot spot due to the heat dissipation of that particular cell. The long-term effect of hot spots is the degradation of the module (solder melting, delamination), cell damage, and, of course, as the final consequence, loss of output power. The hot-spot phenomena has long been observed, since the early spacecraft days. In 1979, damage caused by the hot-spot effect was observed at a test site at Mead, NE, and Arlington, TX. Present-day research results are able to track hot-spot effects back to the small-scale structure of the material. This effect is so important for the module production lifetime that the certification standard for terrestrial PV modules includes a test to evaluate the ability of the module to withstand hot-spot heating that can result, for instance, in solder melting or deterioration of the encapsulation. Thermal imaging is an important tool for mapping temperature distribution, as is the case with hot-spots phenomena. The increase in temperature in a particular cell or cells can be of the order of 30° C. To

exemplify this, we used short-circuited polycrystalline Si module exposed to natural sunlight with an irradiance of 1066 W/m². In Figure 1, we show the temperature map after 5 minutes of exposure, and in Figure 2 after 30 minutes of exposure. When a cell is generating less current than the rest of the module, we should expect a temperature increase, since the current through each cell in the string must be the same (as they are a serial circuit). The warmer cell can be cracked, or it's a current mismatch error (the cell is only able to generate a lower current than the rest of the cells). Such a module, if installed in a production facility, should be removed and tested (IV characteristic) since, in many cases, we can observe a significant decrease in power.

The monetarization of hot spots with thermal imaging in PV power plants may prevent future losses of energy production and, consequently, the protection of the initial investment based on a pay-back period that may not be exact, should these effects arise. The mapping of individual cells is also important to detect eventual problems in the manufacturing process. Typical 156 x 156 mm polycrystalline Si cell. The hot spot at the bottom black line (interconnection between the copper wires and the solar cell) may indicate the presence of a shunt caused by a faulty soldering process. Thermal imaging is growing in importance in the PV industry. Cameras from €4,000 (\$5,700) to more than €30,000 (\$43,000) are available at the market. It's really a question of how much you are willing to pay. (Zimmermann, 2010)

- **Inspection by Infrared Thermography, Suggestions and Guidelines**

Inspection by use of infrared thermography is more powerful, because in the infrared spectrum one can observe certain faults that are not visible to the naked eye. Infrared thermography makes visible a temperature representation of the installed panel's surface, without any need of disassembly or placement of probes. Regions of higher panel surface temperature that are readily observable at infrared (hot spots), are candidate places of faults. The manufacturers of thermography equipment have developed technical guides for thermographic inspection, avoid

faults in the procedure that could spoil the results of the inspection. According to these guidelines, the measurements should be made in good insolation conditions in the range of 500 – 700 W/m², clear sky conditions to avoid cloud shading during shooting. Measurements in calm weather conditions are required for the temperature field not to be affected by enhanced convection. The camera maybe aimed to the front or the back of the PV panel. Infrared recordings from the front of the PV panel exploit the fact that the protective glass cover has an emissivity of $\epsilon=0.85-0.90$ at the wavelength range of 8-14 μm (long wave) where most of the panel's emitted power occurs. Thus, the temperature field of the panel surface becomes more readable. The reflections from the sun or surrounding objects on the glass may spoil the overall infrared image. For this reason, the shooting should be done not directly perpendicular to the panel, but at 5-60o angles. On the contrary, infrared images taken from the back of the panel take advantage of the absence of reflections, without compromising image quality, because of the fact that the tedlar polymer material of the back sheet has a high emissivity at the range of interest ($\epsilon=0.90$). Shooting from the back has the disadvantage of the blocking of the view by the metallic supporting frame members, making certain parts not accessible to thermography. Due to the above reasons, shooting from the front and the back faces of the PV panel are combined, selecting the necessary viewing angles and field of view to extract useful information and avoid the problem of “false hotspots”. (Roumpakias, Bouroutzikas, & Stamatelos, 2016)

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1 Design Methodology

The goal is to use infrared (IR) imaging detect any cracks and problems in the solar panel, and to find the best time to do the imaging. By changing the independent variables (time of

the day, deliberate failures) to reach the optimal power output. There are two controlled factors, the position and the angle to the sky of the PV panels. There some uncontrolled variables such as the clouds, humidity and temperature.

- independent variables; time of the day, deliberate failures.
- dependent variable; power output.
- controlling factors; position, angle to the sky.
- uncontrolled variables; clouds, humidity, temperature.

3.1.2 Design Constraints

a. Environmental

The environmental constraints are the major issue because they are uncontrolled variables. Such as the clouds, humidity and temperature. Clouds can cover the sun and make shadows on the PV panels, which will affect the IR imaging readings. So to eliminate this issue the imaging will be taken on clear days. Humidity can penetrate into the solar panel frame, this can reduce the panel's performance and it cannot be discovered by IR imaging. When the temperature is high it can reduce the power output which can be misleading. For that the ambient temperature will be recorded.

[2]

b. Economical

Considering one of the aims of the project is to make a cost efficient process as possible, the prototype should follow the same concept. However, due to the nature of the project, certain components were no to be found within the country and had to be ordered from overseas. As a consequence, the price of certain elements was expensive. The delivery processes are time consuming due to far geographical location and constant authentication and details about whom the part is delivered to.

Optimization of the expenses and acquiring methods will be clear after validating the hypothesis by running the porotype.

c. Social

skepticism and unacceptance for the new technology is a big challenge. Nevertheless, the global stream directed toward renewable energy and the innovative methods to provide it is compelling the audience to acknowledge it.

3.2 Engineering Design standards

3.2.1 PV Panels

We used three panels with the same specifications

Table 5 PV panels specifications,

SPECIFICATIONS	DESCRIPTION
Size	1000*670*35mm
Weight	9.0KG
P_{max}	100W
V_{mp}	18V
I_{mp}	5.82A
V_{OC}	21.8V
I_{SC}	6.18A
Output tolerance	0-+3%
Operating temperature	-40°C to +85°C
Max.Sys.Voltage	1000VDC
Model Type	DT-100W-P Class A

3.2.2 Seek Thermal Compact Imager for iOS-Apple



Figure 5 Seek camera

We used this camera in the beginning and found the quality lacking

Table 6 Seek specifications

SPECIFICATIONS	DESCRIPTION
Thermal Sensor	206 x 156
Detection Distance	300 Meters
Field of View	36 Degree FOV
Temperature Range	-40°C to 330°C
Frame Rate	< 9 Hz
FOCUS	Adjustable FOCUS
Lens Material	Chalcogenide
Micro bolometer	Vanadium Oxide
Pixel Pitch	12 microns
Spectral Range	7.5 -14 Microns
User Interface	Free Seek Thermal Mobile App
Temp. Display Scale	Fahrenheit or Celsius
color Palates	9 Options
Storage Media	Stores Directly to Smart phone

Battery	Powered by Smartphone. Consumes up to 280 MW
Phone Compatibility	IPhone and Android

3.2.3 FLIR C3 Pocket Thermal Camera with Wi-Fi



Figure 6 FLIR C3 Pocket Thermal Camera

After using the Seek camera, we decided to buy the FLIR C3 because of the quality of images and the independently from the phones

Table 7 FLIR Specifications

Specifications	DESCRIPTION
IR Sensor	80*60
Thermal Sensitivity/NETD	<0.10°C
Field of View (FOV)	41°x 31°
Minimum Focus Distance	Thermal: 0.15 m
Image Frequency	9 Hz
Focus	Focus free
Spectral Range	7.5 -14.0 micro m
Digital Camera	640 x 480 pixel

Digital Camera Focus	Fixed focus
Object Temperature Range	-10°C to 150°C
Accuracy	+2°C or ±2%, whichever is greater, at 25°C nominal
Battery Type	Rechargeable Li-ion polymer battery
Battery Operating Time	2 hours
Charging System	Charged inside camera
Charging Time	1.5 hours
External Power Operation	AC adapter, 90-260VAC input - 5V output to camera
Operating Temperature Range	-10°C to 50°C
Storage Temperature Range	-40°C to 70°C
Weight	0.13 kg
Dimensions	125 x 80 x 24 mm

3.2.4 stand for the PV panels

Table 8 Stand Specifications

Dimensions	
Length (base)	170cm
Width	100cm
Height	120cm
Angle	35°
Length (panel sheet)	208cm at 35° from the base

3.3 Theory and Theoretical Calculations

Photovoltaic (PV) solar energy recorded an exponential growth, in worldwide scale, over the last decade. Inevitably, mature PV markets are becoming highly competitive, boosting the need for research and development on efficiency and reliability optimization, maintenance and fault diagnosis of PV modules.

Temperature is one of the most common indicators of the structural health of equipment and components. Faulty machineries, corroded electrical connections, damaged material components, etc., can cause abnormal temperature distribution. Infrared (IR) thermography could be an important diagnostic tool for assessing the performance of photovoltaic panels. Malfunctions, material and insulation defects can be detected easily and fast without complicated proceedings. The testing of Photovoltaic (PV) systems by infrared thermography is used for more than a decade and is becoming increasingly an important standard; this method in fact is relatively fast, simple and inexpensive. Infrared analysis allows a reliable evaluation of the state of health of the plant and at the same time the detection of the actions needed of the maintenance.

In particular, we introduced the potentiality of IR thermography for the identification of possible malfunctions, material defects, and as a diagnostic tool for assessing the performance of photovoltaic panels.

I_{array} and V_{array} are the current and voltage of the PV array, respectively. I_H and I_f are the currents of healthy and faulty strings, respectively. V_H is the module voltage of a healthy string, V_H' is the voltage of the healthy module in the faulty string, T_H is the module temperature of a healthy string, T_H' is the healthy module temperature within a faulted string, and T_F is the healthy cell temperature in a faulty power unit.

the faulty PV cell cannot generate electricity and becomes a resistive load (R_{eq}). Owing to the series connection structure, the healthy cells supply power to the faulty PV cells (released

as heat) and then create some hotspots. where V_{sf} stands for the voltage generated by the healthy PV cells in a faulty PV string, and R_{load} is the load resistance.

The electric characteristics of a faulty PV string are as follows:

$$\begin{aligned}
 V_{sf} - I_f R_{eq} &= V_{array} \\
 I_f &= \frac{V_{sf}}{R_{eq} + R_{load}} \\
 R_{eq} &= \frac{V_{sf} - V_{array}}{I_f} \\
 \Delta V &= V_{H'} - V_H \\
 \Delta I &= I_H - I_f \\
 I_f^2 \cdot R_{eq} &< I_f(m - m_x) \frac{V_{H'}}{m \cdot n}
 \end{aligned}$$

where ΔI is the current difference between the healthy and unhealthy strings, ΔV is the voltage difference between the healthy modules in healthy and unhealthy strings, and m_x is the number of faulty PV cells.

3.4 Product Subsystems and selection of Components

PV panels were selected to be of 100W Peak Power which is most commonly used. For the camera selection we used Seek Thermal Compact at first but the images quality was not good enough the hot spots were merging and it was dependent on an iPhone to be used which meant that the team members who had other phone brands couldn't record data. so we ordered the FLIR C3 Pocket Thermal which is more professional and independent on phones. The stand is made from aluminum because it's light and easy to fabricate. For the ambient temperature we used an Arduino board to record it. Using in LM35 temperature sensor connected to the board and a sim card module to send the data to the cloud.

3.5 Manufacturing and assembly (Implementation)

First, we fix two bars of the aluminum base on the ground of the roof, keeping distance in between as of the PV holder; the bars oriented to the south west as it's the facing destination of the panels. Then we install the frame on the heads of the two bars fixed earlier giving limited movement for the frame to acquire a specific angle. Two supporter bars are installed on the ends of the fixed ground bars. Carefully, the frame is positioned on the specified angle and then fixed by supporting it with the two bars from the back. After securing the stability and installation of the aluminum base, the PV panels are integrated into the frame one by one to ensure safe and stable integration process. The Arduino is placed in a special weather resistance box installed on the ground under the PV panels to be in the shaded area for more accurate readings. The electrical wires from the Panels will be connected to a battery to be charged or to the ground.

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and data acquisition system

4.1.1: PV Panels

In this part, we did three different experimental setups. The first one was taking thermal imaging on normal PV panels to monitor the heat accumulation and hot spot. The second one was taking thermal imaging on dusted PV panels to monitor the heat accumulation and hot spot and understand how does the PV panels work in different weather conditions. The third one was taking thermal imaging on broken PV panels to monitor the heat accumulation and hot spot through the panels.

Specifications:

SPECIFICATIONS	DESCRIPTION
Size	1000*670*35mm
Weight	9.0KG
P max	100W
Operating temperature	-40°C to +85°C
Max.Sys.Voltage	1000VDC
Model Type	DT-100W-P Class A



Figure7: PV Panels.

4.1.2: FLIR C3 Camera

In the second setup, we took the three PV panels up roof of the engineering building and we start to take IR images of the panels. We fixed the stand and the distance of the camera to take all the image from the same angle and distance. This setup was done under the supervision with Dr. Nassim Khaled and Mr. Stephen John Limbos the lab technician. The Thermal Camera has many mode of image but we choose the IRON MODE because it shows all the hot spot and easy to analyze the image.

An IR camera images and measures the infrared temperature emitted from the sample being tested, which is also a function of the surface temperature. However, the temperature received by the camera does not only come from the sample surface but also the reflection of surroundings, which is influenced by atmosphere absorption. As a result, there are always several other parameters, besides the real temperature, that affect the reading of the temperature of the test sample, such as emissivity, reflection radiation and absorption of the atmosphere. In order to account for these factors, the camera must be calibrated. To do so, five parameters are measured and entered into the camera software, including:

- Sample Emissivity
- Reflected temperature of sample surface
- Distance between sample and camera
- Relative humidity
- Temperature of the atmosphere

Emissivity is the most important sample parameter, qualifying how much radiation is emitted compared to a black-body. Reflected temperature is used to compensate for the radiation reflected in the sample. Both parameters can be measured with IR camera.

Specifications:

Specifications	Description
IR Sensor	80*60
Thermal Sensitivity/NETD	<0.10°C
Field of View (FOV)	41°x 31°
Minimum Focus Distance	Thermal: 0.15 m
Image Frequency	9 Hz
Focus	Focus free
Spectral Range	7.5 -14.0 micro m
Digital Camera	640 x 480 pixel
Digital Camera Focus	Fixed focus
Object Temperature Range	-10°C to 150°C
Accuracy	-+2°C or ±2%, whichever is greater, at 25°C nominal
Battery Type	Rechargeable Li -ion polymer battery
Battery Operating Time	2 hours
Charging System	Charged inside camera
Charging Time	1.5 hours
External Power Operation	AC adapter, 90-260VAC input - 5Voutput to camera
Operating Temperature Range	—10°C to 50°C
Storage Temperature Range	—40°C to 70°C

Weight	0.13 kg
Dimensions	125 x 80 x 24 mm

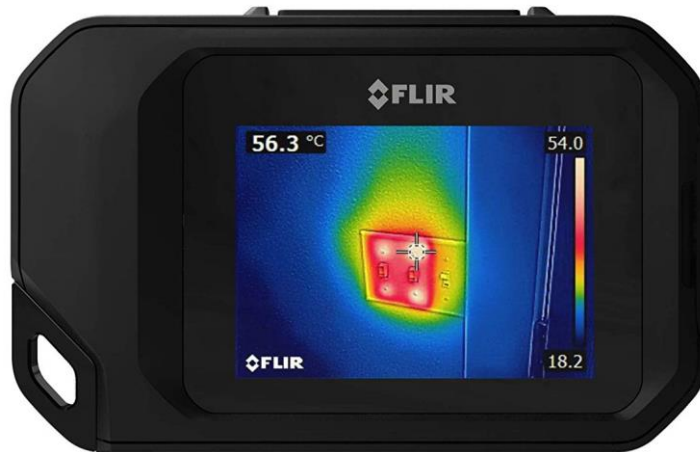


Figure 8: FLIR C3

Table 5: The Testing Parameters

Testing Parameters	Objective
Tripod	To fix the camera on specific angle
Three PV Panels	To test them on different conditions
FLIR C3 Camera	To take the IR image.

4.2 Results, Analysis and Discussion

In this section, we are analysis three Failure mode on the PV Panels and the phases are:

- Studying normal performance of photovoltaic cells under standard conditions.

Infrared camera and data logging system will be mounted on a set of photovoltaic cells.

- Studying the cells after being subjected to several deliberate failures (such as wiring problems, dust, breakage, etc.). The heat signature of these cells will be studied and compared with the nominal images. A process to detect the failures will be established.

Table 6: Data of Initial Results

#	Failure mode	Results
1	Significant drop in efficiency	PV mean temperature will be lower than the rest
2	Dust accumulation	Infrared signature will be higher at the accumulated dust on the panel
3	Crack	Local temperature gradient on the cracked surface is higher

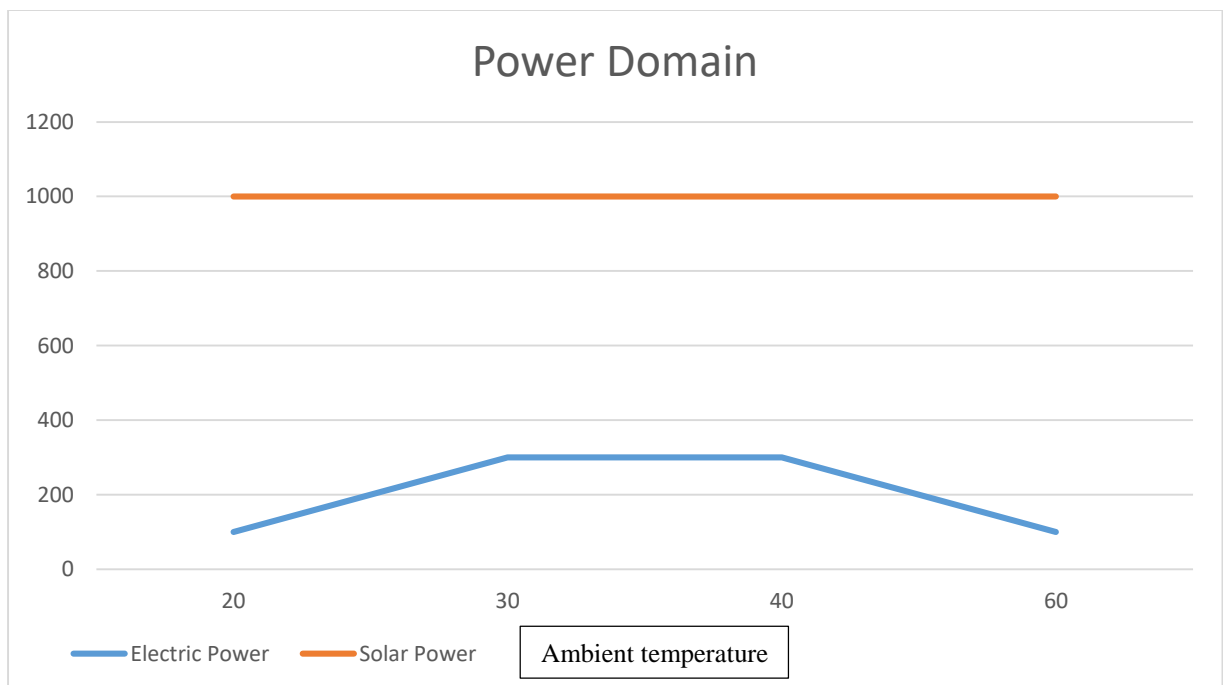


Figure 9 Power Domain

As we see in this figure, the average of solar power obtained in a clear weather condition is $1000 \text{ W}/\text{m}^2$. depending on the efficiency of the panel used, the power that can be generated from solar radiation is calculated. However, the ambient temperature which directly contribute to the panel's temperature can affect the efficiency significantly. The more heat buildup in the panel the less efficient it gets.

4.2.1: Normal PV Panel Reading



Figure 10a Normal PV Panel

Photo taken at 8-9 AM at atmosphere temperature 23C



Figure 10b Normal PV Panel

Photo taken at 11-12 AM at atmosphere temperature 30c

As shown in the figures, the PV panels work normally and absorb the heat. While we notice the left one has an open loop and the right one is connected to battery. As it shows the heat accumulation is higher in the open loop as there is no heat transferred into electric power. While the other one has lower temperatures as more of the heat accumulated in the same amount and same conditions is transferred into electricity. This shows us that a PV panel that is connected has lower temperature than the disconnected PV panel. Thus, we can detect the heat difference if the PV panel is connected and working or not.

4.2.2: Dust PV Panel Reading

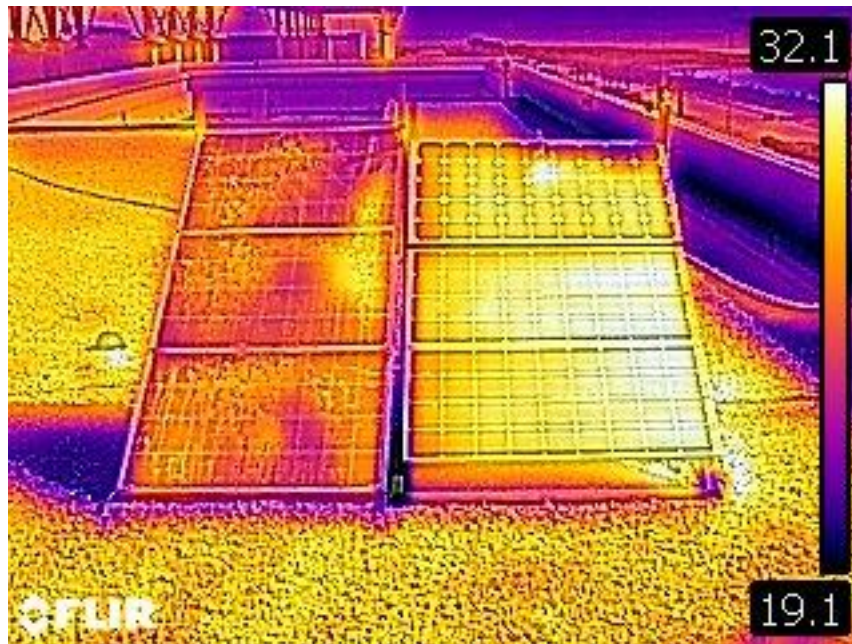


Figure 11a Dust PV Panel

Photo taken at 8-9 AM at atmosphere temperature 23c

As shown in the figures, the PV panels on the left side are dusted while the right side work normally and absorb the heat. As shown we see that normal one has normal contains and the three are heat and radiation transferred into electricity. While the dusted one as shown there is only heat accumulation on the sand itself while the panel is dimmer than the sand part. As if we removed the hot sand we will notice that the region that is covered will have colder temperature thus it will affect the efficiency and output of the panel. In this condition the PV panels must be cleaned so we get the desired amount of output. Based on this the heat difference and detection of sand accumulation becomes easier and more obvious. This helps us in our project and in the future as the 2030 vision focus on the green power with detection of the dust accumulations in the panels. This kind of failure could take weeks to inspect each panel to assess on which panels are dusted and hard to be detected. As our project ease up the process of inspection for these types of failure.



Figure 11b Dust PV Panel

Photo taken at 2-3 PM at atmosphere temperature 27c “rainy weather”

As shown in the figures, the PV panels this was in normal day and it rained. As noticed the imaging while there is rain won't be in any good because the rain will cool the panels and detection of any malfunction is impossible.

4.2.3: Broken PV Panel Reading

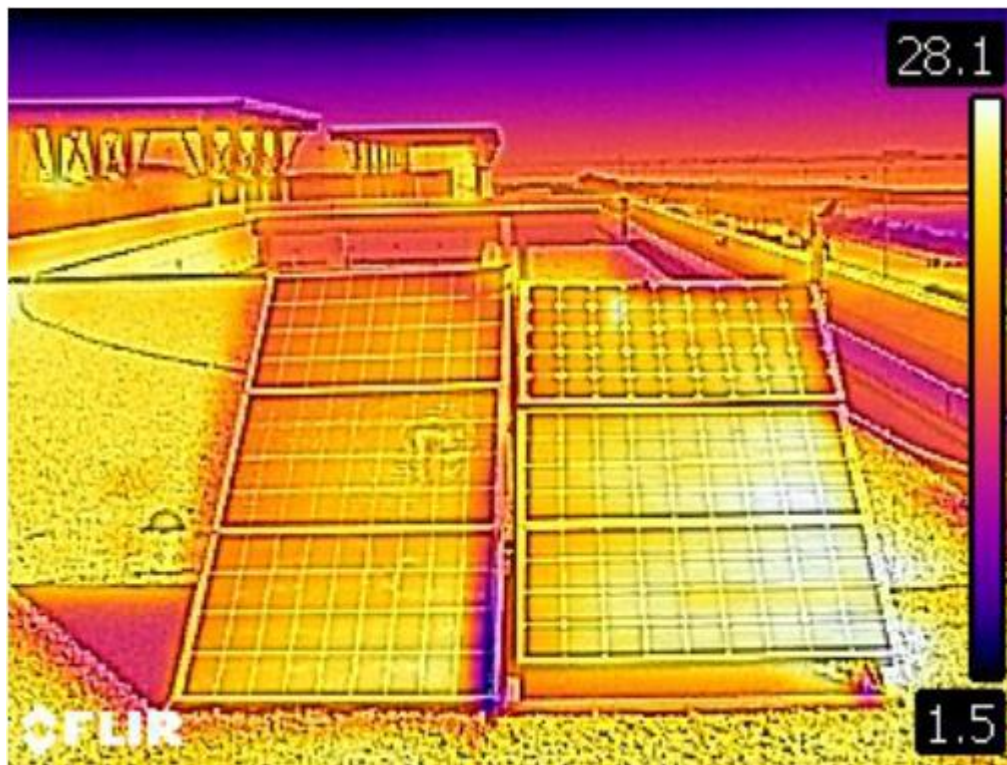


Figure 12 Broken PV Panel

Photo taken at 8-9 AM at atmosphere temperature 24c

As noticed the broken PV shows us more heat accumulation than the other panels. This increase in temperature is concentrated on the crack and not on the cell itself. That's why a drop of power output and efficiency will occur, as there is not good amount of heat in the cells. This damage as mentioned has effect on the output and the panel must be replaced. This damage on the PV could happen if there is a sandstorm which could carry rocks or objects that could impact the PV panels. These are one of the causes which could damage the panels in the in the farm. These farms are large in size as inspecting the damaged panels could take time but the thermal imaging could make the process of the inspection much easier and less time to do.

4.2.4: General Failure PV Panel Reading



Figure 13a General Failure PV Panel

Photo taken at 8-9 AM at atmosphere temperature 23c

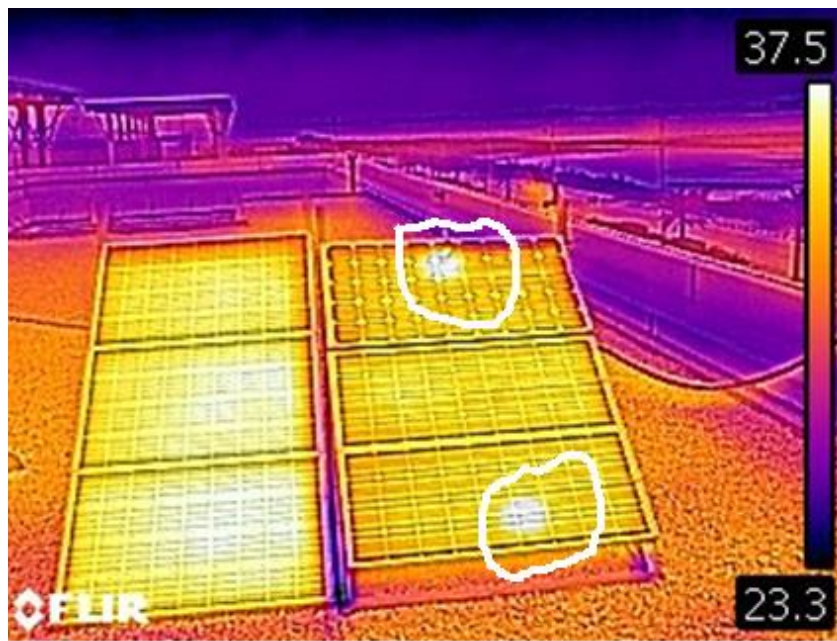


Figure 13b General Failure PV Panel

Photo taken at 9-10 AM at atmosphere temperature 27c

As shown in the figures, the PV panels are in normal conditions and there are two spots in the right panel. This is a type of failure that could be detected by infrared imaging, which is called hotspots. These hotspots decrease the power output and the efficiency of the panel because these cells are producing more current thus heating up, the accelerating increase in the current result in the drop of voltage. As this failure occur the panel they have these hotspots must be replaced so we get the desired output. These types of failure are sometimes impossible to detect with eyes thermal imaging is the best solution to detect these types of failure. These types of failure even in the output observation of the output is hard to detect as these could show small difference. The technicians could be mistaking it for other types of failure like dust accumulation but with thermal imaging it could be easily detected.

4.2.5 software analysis

Table 7 Minimum - Difference

Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
8	0	-1.7	0.1	0.8	-2.2	-1.4
9	-0.4	-4.3	-2.5	-2.8	-2.5	-3.55
10	-1.1	-1	-2.7	-0.7	-1	-2.4
11	-2	-1.6	-1.05	-2.8	-2.4	-7.7
12	-1.8	-4.3	-3	-0.7	-3.7	0.2
13	-0.3	-4.1	-3.3	-0.5	-1.4	-1.4
14	-0.3	-1.2	-0.1	0.3	0.6	-1.8
15	0.1	-0.2	-1.2	-0.2	1.8	2.9
16	-0.8	0.1	-1.2	-2.7	0.2	-0.9

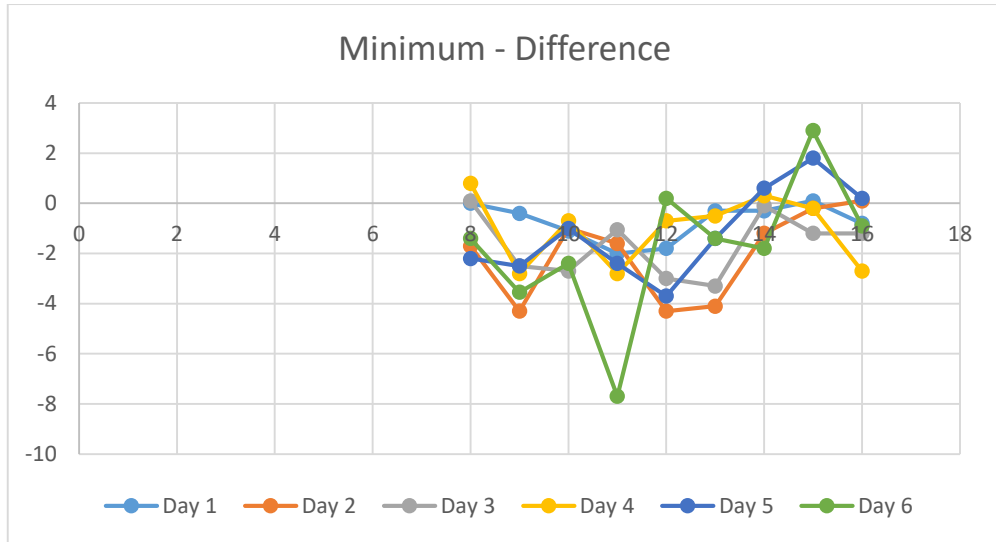


Figure 14 Minimum – Difference

Table 8 Maximum – Difference

Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
8	3.5	1.3	1.3	2.9	2.6	1.2
9	0.2	-0.2	0.2	0	0.4	1.1
10	0	1.3	0.7	0	0.2	0.9
11	0	-0.2	0.1	0.4	0.3	0.1
12	0.7	0	-0.5	1.2	-0.7	0.5
13	0.3	-0.7	-0.7	2.1	-0.5	0.6
14	0.1	0.2	0.7	-0.4	0.2	0.7
15	3.5	-0.5	1.2	-0.1	0.4	0.2
16	1.2	1.1	1.3	0.1	2.1	0.3

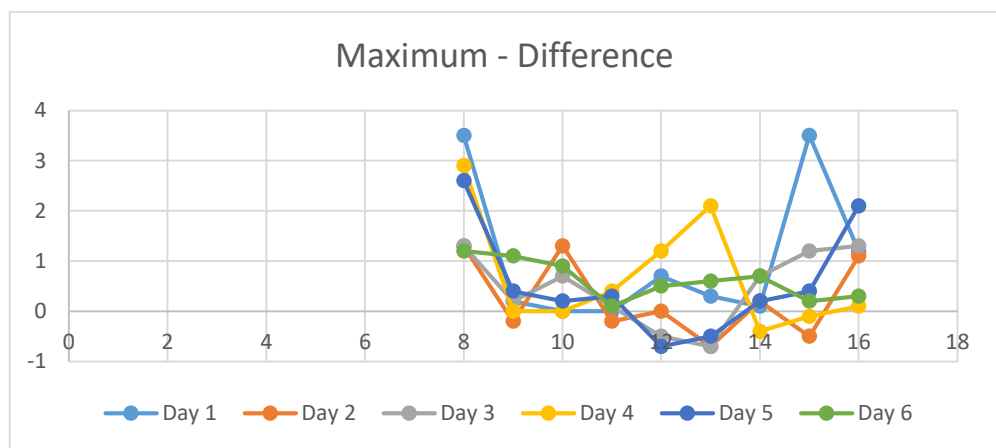


Figure 15 Maximum – Difference

Table 9 Average – Difference

Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
8	0	-0.2	3.9	3.9	0.8	2.9
9	-1.7	-1.2	0.4	-0.2	-0.1	2.4
10	-1.6	1.2	-0.1	-0.8	0.5	1.8
11	-2.1	-0.4	-0.7	-0.7	-0.1	-0.4
12	-2	-1.1	-0.9	-1.1	-2.18	-0.3
13	-0.9	-1.1	-2.7	-1.2	-1.5	0.7
14	-0.4	-1.4	0.2	-1.6	0.4	0.5
15	0.1	-1.7	-0.6	-1	0.6	0.3
16	-0.4	-0.2	-0.7	-1.5	0.5	0.4

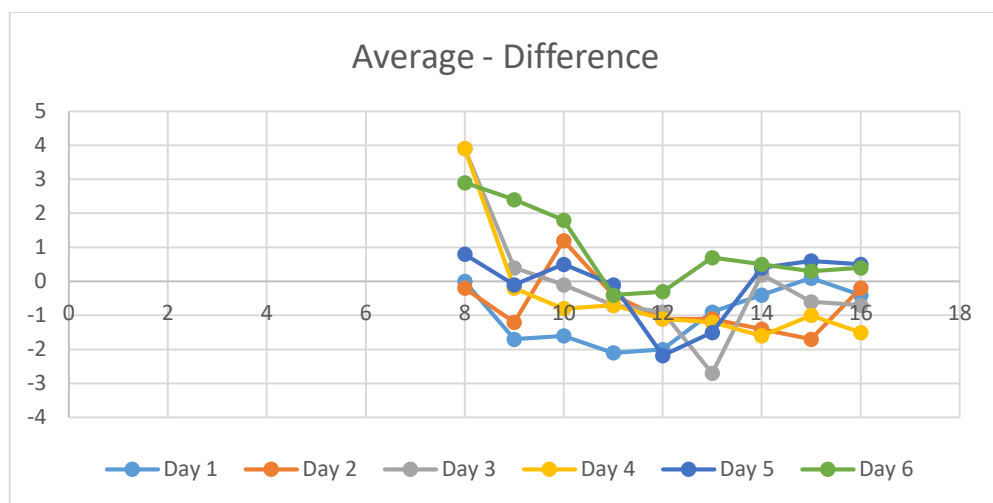


Figure 16 Average – Difference

Chapter 5: Project Management

5.1 Project Plan

In our project, there are many tasks included. Each task is assigned to one or more members.

Here is the all information about the tasks, team members, and the duration of each task to be completed. table 5.2 for the assigned member.

ID's	201300600 - 201600011 - 200901232 - 201400667 - 201302053	Start Date	Days To Complete	Total Days	Notes
Task 1: Brainstorme					
1	Identifying Projects	1/6/2019	3	6	Ali Al-momen
2	Choose An Advisor	1/9/2019	1		Ali Al-momen
3	Discuss Idea With Our Advisor	1/10/2019	1		All Group
4	Determine Objectives	1/10/2019	1		All Group
Task 2: Searching And Purchasing					
5	Buying Infrared Camera Online	1/11/2019	7	20	Yazeed Algandi
6	Buying Arduino Kit	1/11/2019	1		Yazeed Algandi
7	Seach For Photovoltaic Power Station	1/11/2019	5		Ali Al Suliman - Hosin Alali
8	Searching For Photovoltaic Plates	1/12/2019	2		Ali Al Suliman - Hosin Alali
9	Buying Three Photovoltaic Plates	1/13/2019	1		Ali Aowaiwi
10	eaching For The Engineering Incharge In Armco For The Photovoltaic Proje	1/13/2019	3		Ali Al Suliman
11	Arrange Meeting With Eng. Abdulaziz In Armco	1/16/2019	---		Ali Al Suliman "Saftey reasons"
12	Meet With Stephen John "PMU" To Teach Us About Arduino Kit	2/3/2019	1		Yazeed Algandi - Ali Al-momen
Task 3: Obsevation and Testing					
13	Taking IR Images	2/10/2019	25	25	Ali Aowaiwi
14	Testing Different Weather Condions	2/11/2019	25		Yazeed Algandi - Hosin Alali
15	Testing Malfunction In PV Panel	2/12/2019	25		Hosin Alali - Ali Aowaiwi
16	Testing On Multiple PV Panels	2/13/2019	25		Hosin Alali - Ali Aowaiwi
Task 4: Anlysis					
17	Analysis IR Imaging	3/6/2019	20	20	Ali Al-momen
18	Analysis Of Heat On The PV Panel	3/7/2019	20		Hosin Alali
19	Analysing And Notcing Faulty Panels	3/8/2019	20		Ali Al Suliman
20	Reporting And What Type Of Failure In PV Panel	3/9/2019	20		Ali Aowaiwi
21	Arduino Weather And Tempterute Setup	3/10/2019	20		Yazeed Algandi - Ali Al-momen
Task 5: Conclusion					
22	Writing Final Report	3/23/2019	7	19	All Group
23	Presentation Preparation	3/30/2019	5		
24	Fake Presentation	4/3/2019	7		

Table 10: Tasks & Duration

5.2 Contribution of Team Members

The tasks in this project was assigned each member. It depends to the ability of doing the task and the time required to complete the task and the members with how many percentage of contributing for each member

Table 11: Contribution of Team Members

#	Task		Assigned	CONT. %
1	Chapter 1: Introduction		All Group	100%
2	Chapter 2: Literature Review	Project Background	Ali Alsulaimn - Ali Almomen	100%
		Previous Work	Ali Aowaiwi – Yazeed Algamdi	100%
3	Chapter 3: System Design	Design Constraints and Design Methodology	Hosin Alali – Ali Alsualiman	100%
		Engineering Design standards	Yazeed Algamdi – Hosin Alali	100%
		Theory and Theoretical Calculations	Ali Aowaiwi – Ali Almomen	100%
		Product Subsystems and selection of Components	Hosin Alali – Ali Almomen	100%
		Manufacturing and assembly (Implementation)	Ali Alsulaimn - Ali Almomen	100%
4	Experimental Setup, Sensors and data acquisition system		All Group	100%

	Chapter 4: System Testing and Analysis			
		Results, Analysis and Discussion	All Group	100%
5	Chapter 5: Project Management	Project Plan	All Group	100%
		Contribution of Team Members	All Group	100%
		Project Execution Monitoring	All Group	100%
		Challenges and Decision Making	Yazeed Algamdi – Hosin Alali	100%
		Project Bill of Devices and Budget	All Group	100%
6	Chapter 6: Project Analysis	Life-long Learning	All Group	100%
		Impact of Engineering Solutions	Ali Alsulaimn - Ali Almomen	100%
		Contemporary Issues Addressed	Ali Aowaiwi – Yazeed Algamdi	100%

5.3 Project Execution Monitoring

During this term, we had some important dates, meeting and outside help that improved our senior project.

Table 12: Project Execution Monitoring

Date	Occasion
Weekly	Meeting with group members
Weekly	Meeting with Dr. Nassim Khaled
Each two week	Meeting with Stephen John Limbos the lab technician
21 March, 2019	Midterm presentation
21 March, 2019	The new camera arrived
04 April, 2019	Testing the PV Panels “Till now”

5.4 Challenges and Decision Making

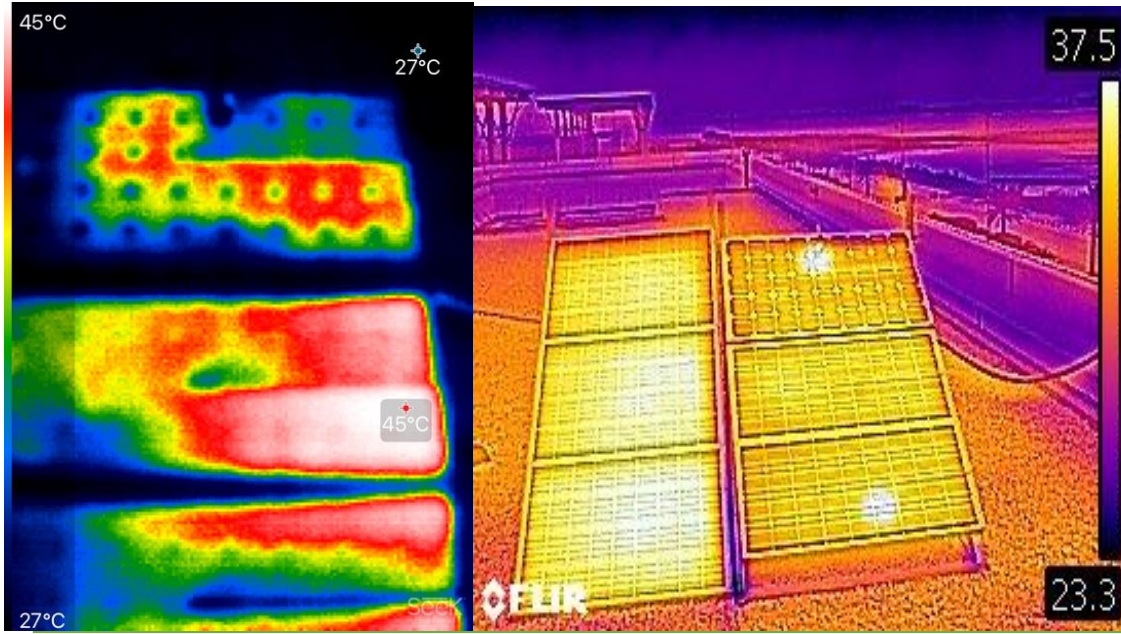
During the project phases, we faced some challenges that effect the progress of the project.

Following challenges are the main challenges we have faced:

- Camera quality.
- Angle

5.4.1: Camera quality

At we bought a camera that is attached to a phone. This camera had bad quality and hard to analyze the images. Then we ordered another camera with better quality from amazon. Amazon sent us medical books instead of the camera. Then we returned the books and order the same camera again and two weeks later we got our camera.



Old Camera

New Camera

Figure 17 old vs. new camera

5.4.2: Angle

Our second problem had to come with both of the cameras as they were zoomed in and we couldn't get the full panel. When we found a high tripod we adjusted our angle and the angle of the frame that holds the panels so we could get a view of the full panel.



Figure 18 Tripod

Tripod to fix the angle

5.5 Project Bill of Devices and Budget

Table shows the devices that we purchased and their costs in Saudi Riyals (SR).

Table 13: costs

Materials	Costs (SR)
Seek Camera	996 SAR
FLIR C3 Camera	2750 SAR
PV Panels	690 SAR
Stand	600 SAR

Chapter 6: Project Analysis

6.1 Life-long Learning

While working with the team we learned to search and analyze researches and extract important information's. By learning that we gained the knowledge on how to approach the project objective and how to complete it. We as a team also learned to work with each other and manage our tasks to be done in time. This helped us to increase the ability to communicate between each other and how to meet our deadlines by working as a team.

6.1.1: Knowledge Gain

In this project, we have learned various skills and experiences such as how to control the heat transfer, how PV Panels work in different weather conditions, how does thermal camera works and how to do analysis to the thermal images.

6.1.2: Hardware Skills

During our project, we used some new devices that aim us to collect the data such as Arduino to measure the temperature.

6.1.3: Time Management Skills

As our project proceeded and more tasks was being done, we realized that we couldn't do any of that without the help of the Gantt chart. In this chart we arranged our tasks and divided them according to priority. After that we distributed each tasks equally so that everyone work and no one would hold us back. We kept within update of the chart as we need to monitor our progress during the process of the project. In the end we learned that without this chart and without the constant update on the chart we couldn't have gone nowhere. we kept updating the Gantt Chart with our advisors to keep them in touch about what we have done weekly.

6.1.4: Project Management

In our project, we divided the work between members of the group. Each one of the members had tasks, which should be done individually. Then, we had a meeting two times a week to discuss and collect the work that has done by that member. Mostly, our group has divided to two teams. The first team was focusing on the research and report. While, the other team was focusing on the collecting data and analysis.

6.2 Impact of Engineering Solutions

Our project has various impacts in terms of society, economy, and environment. In this section, there are all the impacts of our project in terms of what previously mentioned.

6.2.1: Society Our project

Our project would really help the society, as it is the easiest and the most efficient way to inspect Photovoltaic panel. As it requires less time to inspect a farm of Photovoltaic that than the usual inspection which is inspecting each one alone.

6.2.2: Economy

Our project assists the people in terms of economy, mainly because the cost of operating vehicles and people to inspect is higher. As of that the future application of the project would be a drone that is applied to the area that fly's and collect images and sending them to the cloud. This would be automated so the cost of purchasing and operating the drone is much less than the regular inspection.

6.2.3: Environmentally

Our project helps the society to produce clean energy and prevent the drivers of the automobiles of using the engine power during going around the farm and inspecting. As of these the drones are electric and could be charges by the power produced from the panel. So no extra pollution need to be done so we could need power for application. This is also applicable if there is at every area a fixed camera which also be powered by the farm itself.

6.3 Contemporary Issues Addressed

One of the major aspects of 2030 Saudi vision the Renewable Energy Program. ” *The Ministry of Energy, Industry and Mineral Resources launched the Renewable Energy Program, which included achieving 3.45 gigawatts in renewable power generation by 2020 and 9.5 gigawatts by 2023. The initiative is being implemented by the Renewable Energy Projects Development Office.* ” (NILDP). So we addressed the issue of monitoring the Photovoltaic panels without requiring large manpower by using IR imaging. The next step is to use drones equipped with IR cameras to cover large areas.

Chapter 7: Conclusions and Future Recommendations

7.1 Conclusions

Our goal was to test and analyze our adviser's Dr. Nassim idea, which is monitoring PV panels using IR imaging, to detect multiple modes of failure. At the beginning we made a benchmark by taking images of healthy panels. Then we did the first mode of failure we coated the panels with a layer of dust, we found that there is heat accumulation on the sand itself while the panel is dimmer than the sand part. The second mode we tested is breaking the cells and cracking the glass. We noticed that the broken PV shows us more heat accumulation than the other panels. This increase in temperature is concentrated on the crack and not on the cell itself. That's why a drop of power output and efficiency will occur. One of the challenges we faced is finding a solar farm, we couldn't find solar farm that will allow us to do imaging, that's why we resorted to buying our own PV panels. Another challenge is finding IR camera reasonably priced.

7.2 Future Recommendations

better precision could be achieved by using larger number of samples, and other techniques must be employed. Also using a drone equipped with IR camera.

References:

- Rogalski, A. (2012). History of infrared detectors. Opto-Electronics Review,20(3). doi:10.2478/s11772-012-0037-7
- Infrared thermography for condition monitoring – A review. (2013, March 24). Retrieved from <https://www.sciencedirect.com/science/article/pii/S1350449513000327>
- Adomavičius, V., & Kaminickas, M. (2015). Analysis of PV power future development possibilities. Energetika, 60(4). doi:10.6001/energetika.v60i4.3019
- Chen, J. (2014). Evaluating thermal imaging for identification and characterization of solar cell defects. Iowa State University Capstones, Theses and Dissertations. Retrieved from <https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=4980&context=etd>.
- Zimmermann, C. G. (2010). Electroluminescence And Thermal Imaging Applications In The Photovoltaic Industry. 2010 35th IEEE Photovoltaic Specialists Conference. doi:10.1109/pvsc.2010.5615896
- Roumpakias, E., Bouroutzikas, F., & Stamatelos, A. (2016). On-site Inspection of PV Panels, Aided by Infrared Thermography. Mechanical Engineering Department, University of Thessaly, Volos, Greece. doi:10.1109/sst.2017.8188671.
- Khaled, Nassim (2005). Landmine detection using infrared images and 3D numerical thermal simulator (master's thesis). Amerinca University of Beirut.
- Khaled, Nassim and Bibin Pattel (2018) Practical Design and Application of Model Predictive Control, Book, Elsevier.
- Delivery plan for the National Industrial Development and Logistics Program, <https://vision2030.gov.sa/download/file/fid/1579>