University of Southern Queensland

Faculty of Health, Engineering and Sciences

ELECTRO-THERMAL MODELLING OF LARGE PV ARRAY DEGRADATION FOR THERMOGRAPHY AND PEAK POWER CONDITIONING MONITORING

A dissertation submitted by

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University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Masters Dissertation Project

(This is a 2 unit research project in a 32 unit Bachelor of Engineering (Honours) program)

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ABSTRACT

Photovoltaic (PV) panels started their long technological development journey at the hands of legendary pioneers such as Edmond Bequerel. He discovered the key solar energy principles in 1839 and following this Heinrich Hertz was credited with the discovery of the photoelectric effect in 1887. Nikolas Tesla developed key patents in 1901 and Albert Einstein published a paper in 1905. This work in 1954 lead to Bell Laboratories producing the first commercial PV cell and since then PV cells have advanced to astronomical levels.

This project aimed to model the effects of degradation of photovoltaic panels. The goal was to observe the effects that PV cell failure has on the cells internal resistance, and then determine what effect this had on the performance of the panel's output. Field trials were also undertaken to detect this heating using an infrared thermograph and to also relate the temperatures to the simulated results.

Results showed that any increase in panel temperature above 25°C caused the panel's output to reduce up to 63% at 90°C. The physical detection of heating or hot spots was successful with six out of the thirty-six arrays having cells with increased temperatures. Additionally, the maximum cell temperature scanned was 61°C which was a 24°C increase from the nominal of the rest of the PV array.

ACKNOWLEDGEMENTS

Special thanks to my two supervisors Andreas Helwig (USQ) and Dr Narottam Das (USQ) for their continued support.

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ACRONYMS AND NOMENCLATURE

$	Dollar
A	Amps
AC	Alternating Current
Cd	Cadmium
CdTe	Cadmium telluride
DC	Direct Current
FF	Fill Factor
I	Current
IRT	Infrared Thermography
JSC	Short circuit current
p.d.	Potential Difference
PV	Photovoltaic
R_{sh}	Shunt Resistance
SI	International Systems of Units
SMU	Source measure unit
SQ	Shockley Queisser
T	Temperature
USQ	University of Southern Queensland
V	Volts
V_{OC}	Open circuit voltage
W	Watts
Z	Zenith angle is the angle measured from the z axis in spherical coordinates

1 CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

Photovoltaic arrays, which have long operational life of up to thirty-five years, have inherent fatigue and degradation processes. Over time these processes cause the panels to age and decrease efficiency. As a result, the production of electricity is reduced for some PV panels in the system. These faster ageing PV panels can affect the whole series string output. In terms of monitoring individual panel efficiency, many of the degradation processes may not be visible to the naked eye. Currently performance monitoring is not built into individual panels, which means the alternative of checking many panels performance by voltage and hall-effect current monitoring is extremely labour intensive and expensive for large PV arrays.

1.2 PROJECT AIM

This project's aim is to simulate the effects of PV array degradation on panel output. Using MATLAB and Simscape to determine if these models validate the real-world observations of hot spots. Also, the project aims to contribute to the improvement of the life cycle assessments of PV arrays and to provide details on the benefits of condition monitoring of PV arrays.

1.3 OUTLINE OF STUDY

The outline of this study consists of research of the history and elements that make up a photovoltaic panel and research of the effects of degradation on PV cells. Also, relevant PV array data will be selected from the solar farm site to provide the expected values for power loss due to heat emitted via calculations and/or modelling.

1.4 THE PROBLEM

This research project undertook a detailed literature search investigation to fully comprehend the effects of degradation on large PV arrays. Each individual cell has an internal resistance that depends on many components ranging from the cell physical structure, current collectors and panel construction. As the PV cells degrade this resistance will increase, with increased thermal loss being evident. This heat is lost energy and can have series circuit impacts that can reduce a total array/strings output performance.

1.5 RESEARCH OBJECTIVES

The project is separated into six principle segments. The principle sections will allow for a full application of the research process and an in-depth understanding of PV array degradation and impacts of peak power conditioning monitoring.

The principle sections are:

- Research background information regarding photovoltaic and thermography technologies.
- Investigate how degradation of the substrate, connections or moisture ingress affects the overall internal resistance of a PV cell and overall panel.
- Investigate expected thermal properties (hot spots) for degraded panels calculated at daily solar peak.
- Model to predict simulation of PV panel degradation and thermal hot spots.
- Justify the benefits of condition monitoring for a large PV array.
- Compile all information (background information, results) into dissertation.

Fieldwork will also supplement this investigation by performing physical thermography scans to detect/measure hot spots.

1.6 BACKGROUND

1.6.1 Electrical

The unit of internal electrical resistance is a Ohm (*Ω)*. The laws of physics require that resistance can only be a positive value as a material cannot add, assist or enhance current flow without manipulating its own properties.

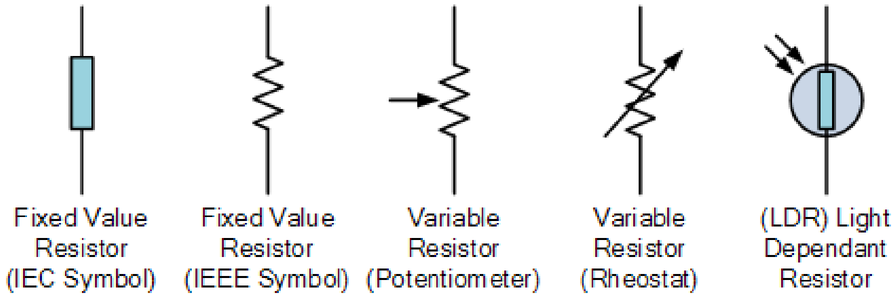


Figure 1.1 - Resistor symbol types (DC Circuit Theory, 2016).

Resistance is defined as the ratio between the voltage across an element and the amount of current passing through that same element (Ohm's Law). Figure1.1 shows various resistor representations. An element with a low resistance would have a resistance less than 1Ω. Examples of elements that are good conductors include metals such as gold, silver, copper, aluminium or special non-metal forms like graphite and graphene. Elements with large electrical resistivity (i.e. > 1MΩ) are termed insulators, common examples including glass, porcelain or plastic.

Certain elements have electrical properties that range between high and low conductivity extremes; these extremes are known as semiconductors. Amorphous carbon (C) coke and silicon (Si) are examples of semiconductors. Depending on the use of other dopants, silicon can be made conductive or non-conductive under certain electrical conditions. This has given rise to the major family of semiconductor electronic components such as diodes, transistors, thyristors, mosfets, GTOs and IGBts. PV cells are made up of semiconductor elements that contribute to a photosensitive diode junction.

1.6.2 Photovoltaic Effect

The photovoltaic effect is defined "…*as the process in which two heterogeneous materials in close proximity produce an electrical voltage when struck by light or other radiant energy*.' (Encyclopaedia Britannica, 2016). When the light in incident upon a material, such as specially prepared germanium or silicon, the photon packets of light energy provide the means for the electrons within the material to move and conduct. This in turn results in an overall electric field voltage to develop. This process will continue as long as the light source continues to strike the material. The photovoltaic effect is the process that makes up every PV system and can also be used for light level detection purposes.

1.6.3 Photovoltaic History

Edmund Bequerel who discovered the key solar energy principles, noted in his work in 1839 that when specific materials were exposed to light they would produce an electric current. The connection between the two has subsequently been developed over many years. Heinrich Hertz is the physicist credited with the discovery of the photoelectric effect during his projects with radio waves in 1887. Nikolas Tesla developed key patents in 1901 as well as Albert Einstein, who published a paper in 1905 on the photoelectric effect and won a Nobel Prize. In 1954 Bell Laboratories built the first PV module, which was named a solar battery, however the high cost prevented the module from gaining mainstream usage.

Space applications were the next advancement for the PV cells, as they required a renewable source of power for space based vehicles and satellites. The predominant demand for PV cells was the rising price of electricity from fossil fuel energy sources. As development of PV cell technology continues, and manufacturing output increases dramatically, the cost of PV cells have reduced drastically. This means they now serve as competition with centralised fossil fuel generation sources. This has also made PV arrays a viable investment for the average household and increasing large-scale solar farms.

1.6.4 Photovoltaic Array Construction and Operation

The construction of PV cells is shown in figure 1.2. Manufacturing is accomplished using a semiconductor, material such as silicon. A thin wafer of the material is treated with a dopant, which creates a layer of material that exhibits dielectric properties. The dopant inclusion in the silicon determines whether it creates an ‘electron hole’ (i.e. a missing electron in the crystal matrix which leaves an overall positive charge) or an excess electron in the silicon crystal matrix resulting in a negative charge.

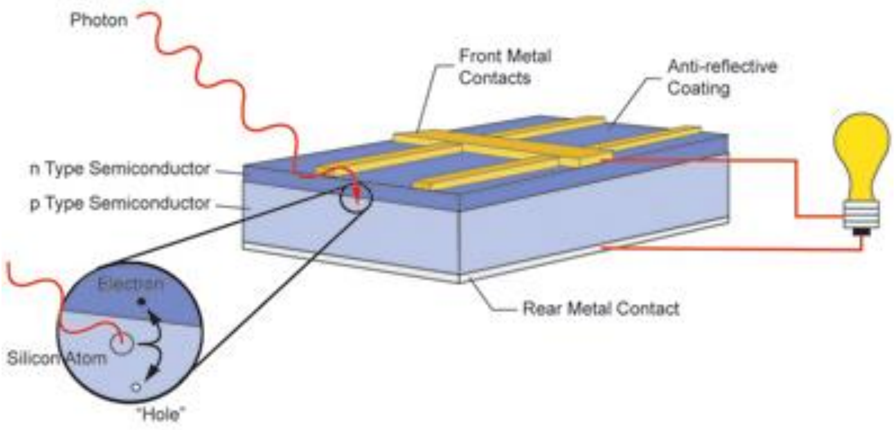


Figure 1.2 - PV effect basic diagram (Viridian, 2016).

As light hits this 'dopant surface arranged' silicon material, electrons are excited sufficiently by the photon packets of energy to pass through the material towards the positively doped material. Hence a DC electric current is produced in solar sensitive material that can be used to do external work in a connected circuit. PV cells are the individual elements that convert some of the light energy directly to electrical energy, which enables the resulting flow of electricity. They can be connected in any number or configurations to make a panel module. Panels can then be connected in any number of configurations to make a larger PV array. Figure 1.3 illustrates these typical series and/or parallel arrangements that are implemented depending on the current and voltage requirements. The current is always directly related to the insolation level of light, which hits the array.

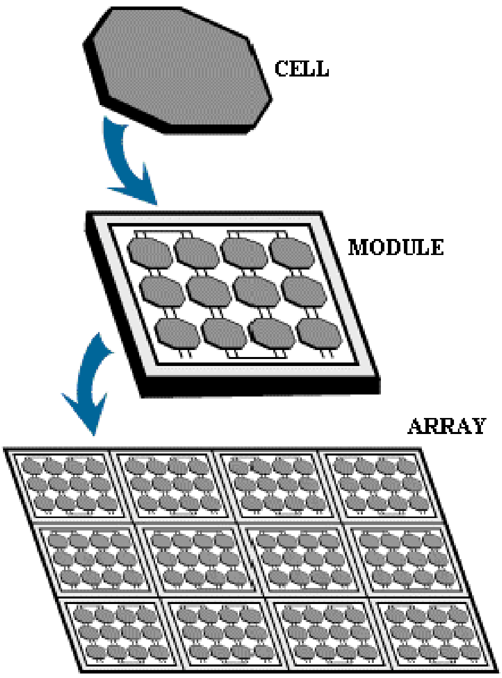


Figure 1.3 - PV array deconstruction diagram (NASA Science, 2016).

Referring to figure 1.4, PV cells use junctions that create the electric field in the semiconductor. For example, a single junction array has a specific band gap and only photons that have energy excitation which is greater or equal to this gap of the semiconducting material, with the resultant displacement of the electrons producing a current, which hence acts as an energy generation source. Therefore the cell only generates energy for the light spectrum that is higher than the band gap of the material. The lower energy photons are not absorbed, which is why modern cells have multi-junction cells which allow a broader band gap and have a proven greater efficiency in light conversion. However the high cost of manufacturing multiple junction arrays means that they are only used in special areas like space applications where there is a requirement for a very small system footprint.

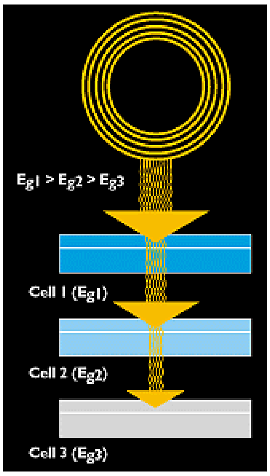


Figure 1.4 - Photovoltaic multi-junction layers (NASA Science, 2016).

Figure 1.5 shows an example of the layers in a multi-junction array. The top cell absorbs the high-energy photons and allows the rest to pass and to be possibly captured at a lower band gap. In comparison, a normal PV array only has one of these junctions.

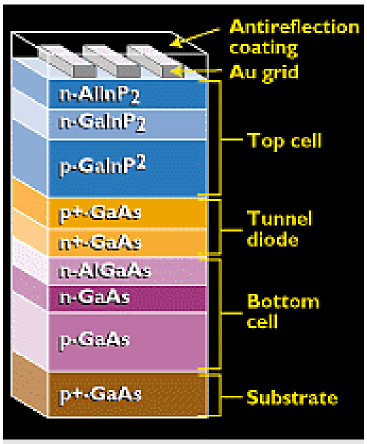


Figure 1.5 - Multi-junction stack example (NASA Science, 2016).

1.6.5 Photovoltaic Price Trends

Figures 1.6 and 1.7 show the historical price reductions and the predicted continual price reduction forecast of PV arrays. This will make any required replacements more feasible due to reduced payback periods in the future.

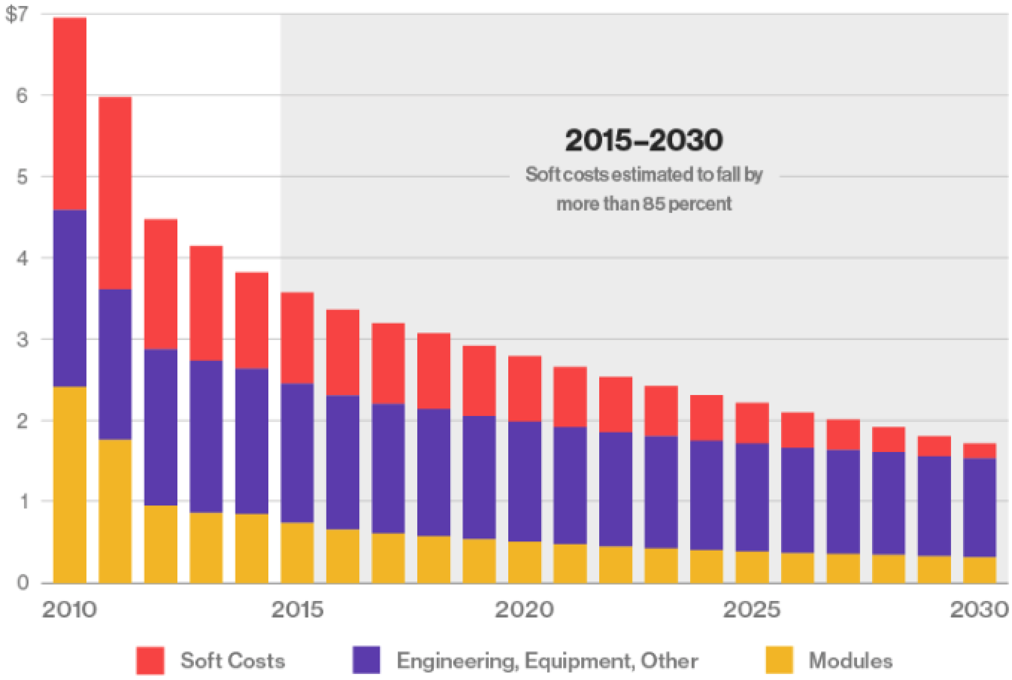


Figure 1.6 - Future prediction for PV cells in $/W (Bloomberg, 2015).

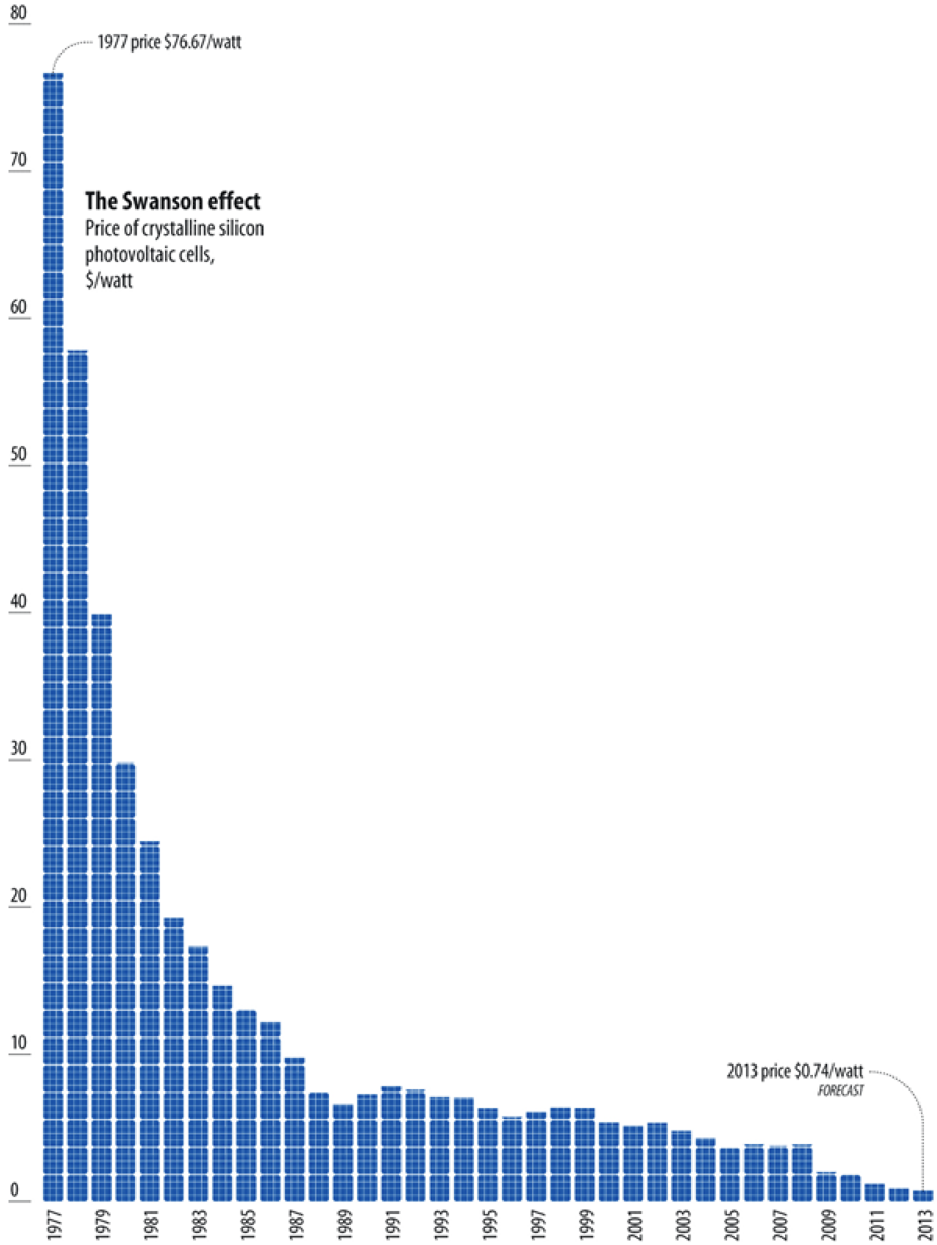


Figure 1.7 - $/W history of PV cells (Bloomberg, 2015).

PV arrays are now a economically viable option for use both in domestic distributed energy production, as well as commercial generation units, with significant cycle lives of 25 – 30 years. However to keep these arrays operating at maximum efficiency, maintenance must be conducted. Therefore this research project will investigate the use of thermal footprints of PV cell panels and electrical connections as a potential determining factor as to when an intervention is necessary to improve or prolong the PV arrays performance life.

2 CHAPTER TWO: LITERATURE REVIEW

Degradation is an important factor when trying to accurately calculate the investment return period for every solar project, currently all panels manufactured have a reduced output over time. Kyocera Solar limited warranty (2016) stipulates that under controlled conditions this reduction would be guaranteed at ten years to be above 90% rated output and above 80% rated output at twenty-five years. Jordan C and Kurtz S (2012) show results from a forty year study where they calculated 2000 different rates of degradation. The reported results found a mean of 0.5%/year, average 5% reduction at ten years and 12.5% reduction at twenty-five years.

2.1 SHOCKLEY QUEISSER EFFICIENCY LIMIT

Shockley and Queisser (1960) discovered that all p/n junctions have the critical limits for energy conversion. Referring to figure 2.1, this limit is defined as the Shockley-Queisser efficiency limit or detailed balance limit of efficiency. As the name defines the maximum energy that can be theoretically converted to electrical form. For a single p/n junction this efficiency is 33.7%. The breakdown is 46.3% transferred to thermal energy (heat), 33.7% is successfully transferred to electrical energy, 18% of photons travel straight through the panel and 2% is lost during the local recombination of the electrons and new creations of holes in the material.

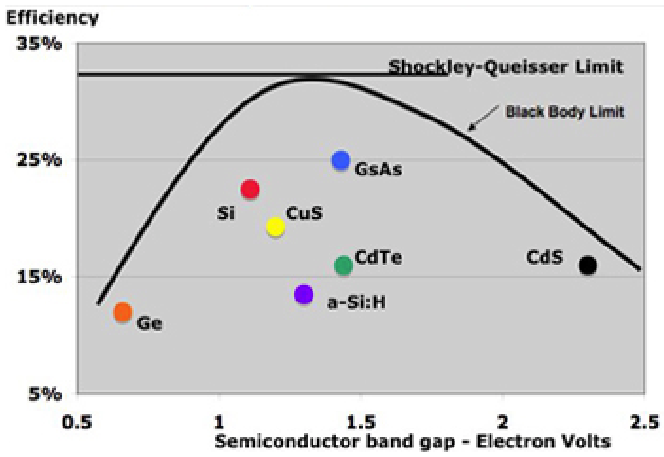


Figure 2.1 - Panel type efficiencies and Skockley-Queisser limit for a single junction cell (Solar Central, 2016).

This theoretical efficiency is raised using multiple junctions, theoretical maximum efficiency for a two-layer cell is 42% and 49% for a three layer junction, however current manufacturing process are unable to attain these theoretical figures. A Solar Central (2016) article referenced that UNSW have had success with a five-layer cell, which recorded 43% efficiency however, this cell is very complex and therefor is also expensive.

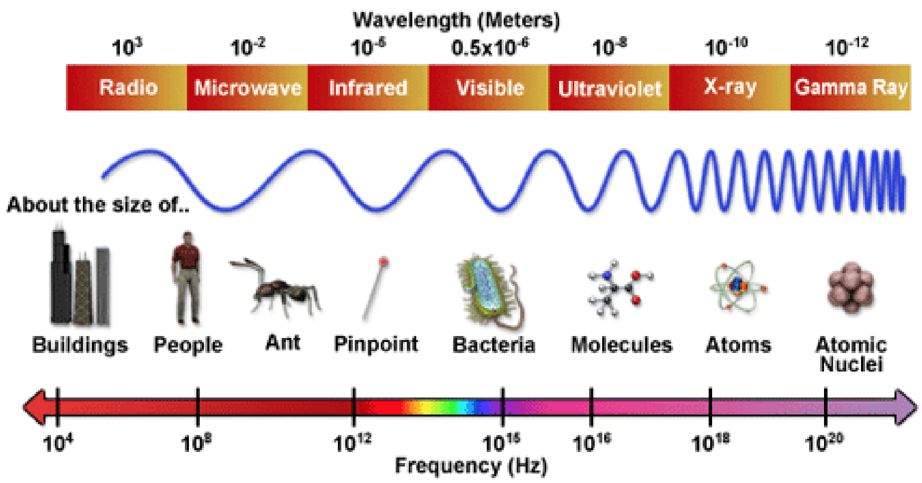


Figure 2.2 - Electromagnetic spectrum (Science UK, 2016).

Figure 2.2 provides a visual on the whole electromagnetic spectrum. It must be noted that the shorter the wave the more powerful the ray. This means gamma rays are the strongest while radio waves are the weakest. For the electron in the semi-conductor element to be transferred to the circuit, it must be excited above its normal valence level, to a greater energy conduction level. In terms of wavelengths, particular wavelengths of infrared waves, all microwaves, and all radio waves are not strong enough to create this electron transfer as they continue to travel through the panel preventing 100% efficiency to be achieved. Figure 2.3 shows the area in blue of the solar spectrum, which is converted by a crystalline silicon cell.

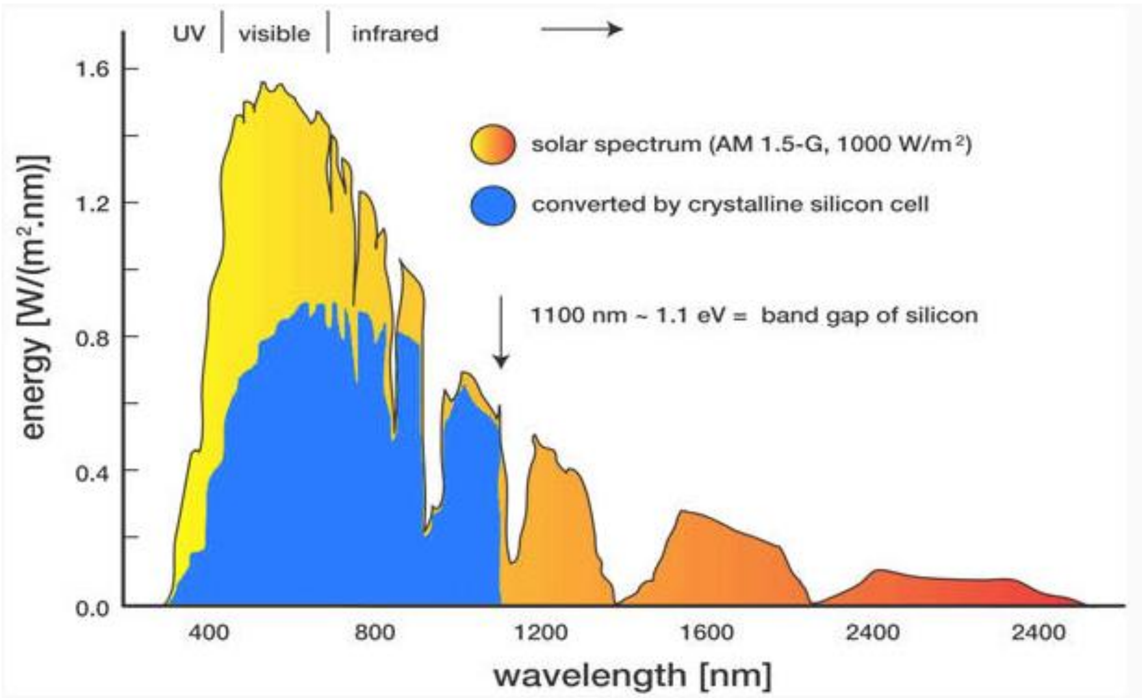


Figure 2.3 - Typical crystalline silicon cell wavelength conversion spectrum (Viridian, 2016).

2.2 THERMOGRAPHY

Infrared thermography (IRT) is the process of transforming the infrared energy emitted from an object into temperature data. The equipment typically converts this infrared energy to an image, which is displayed on a screen. This new image provides greater detail of the objects temperature and distribution. Fluke Ti25 defines its thermograph to have an accuracy of ±2°C or 2% (whichever is larger). It also has a combined digital image to allow for easy identification once both images are overlayed, as shown in figure 2.5. Figure 2.5 is a typical example of the type of digital image with the scale for the false colour image to show temperature gradients that may exist on a PV panel.

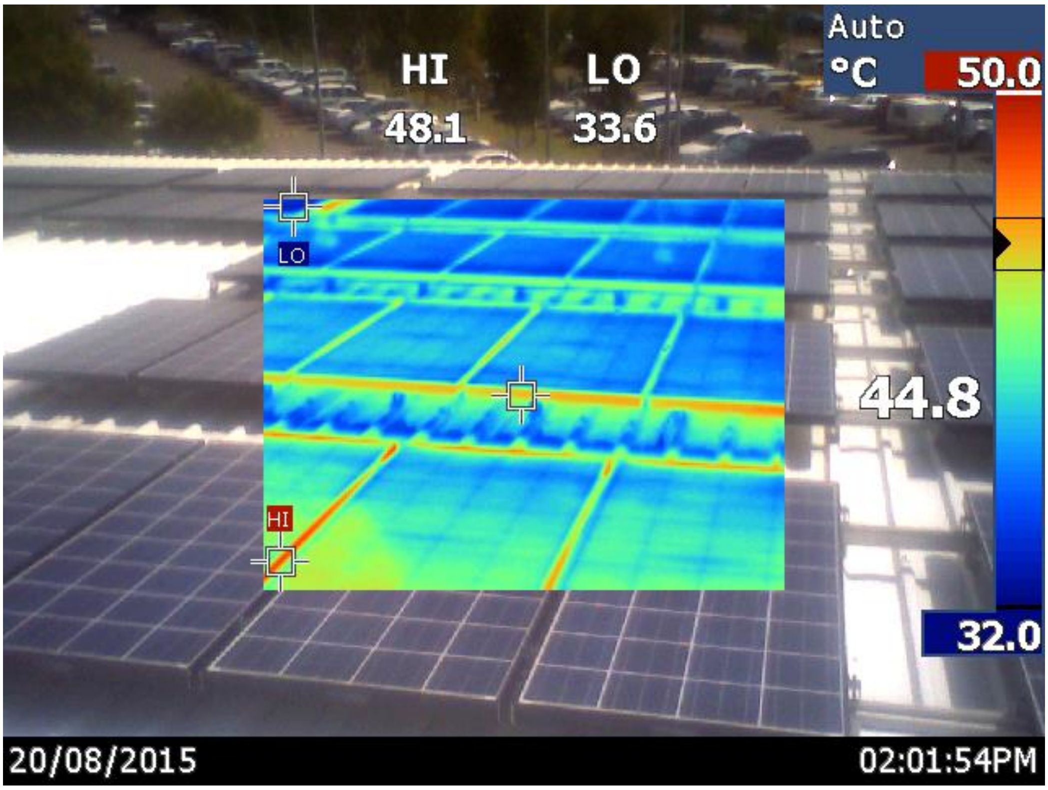


Figure 2.4 - Infrared thermography of PV panels at Townsville RSL Stadium Solar Farm.

A review paper by Bagavathappan Pan *et.al* (2013) provided background into industry usage of infrared thermography for conditioning monitoring. The paper exhibited excellent results with detection of faulty machines, electrical connection degradation, all which created abnormal distribution and/or increase of temperature. The paper documented corrosion and degradation are fault types that will cause a rise of temperature from the normal operational temperature.

2.2.1 Thermography Fault Detection

Tsanakas *et.al* (2016) provides a very detailed paper on the faults associated with PV modules. Research found three classes of faults being; optical degradation, electrical degradation and miscellaneous faults. Firstly, optical degradation includes faults with covering bubbling, delamination, discolouring and cracks or damage to the glass. Secondly, electrical degradation concerns cell cracking, ribbon damage, faulty solder connections, shunts or shorted cells. Lastly mismatches and non-classified faults including broken/shorted/failed diodes or open circuited cells. Figures 2.5 to 2.7 show the different visual and thermography indications.

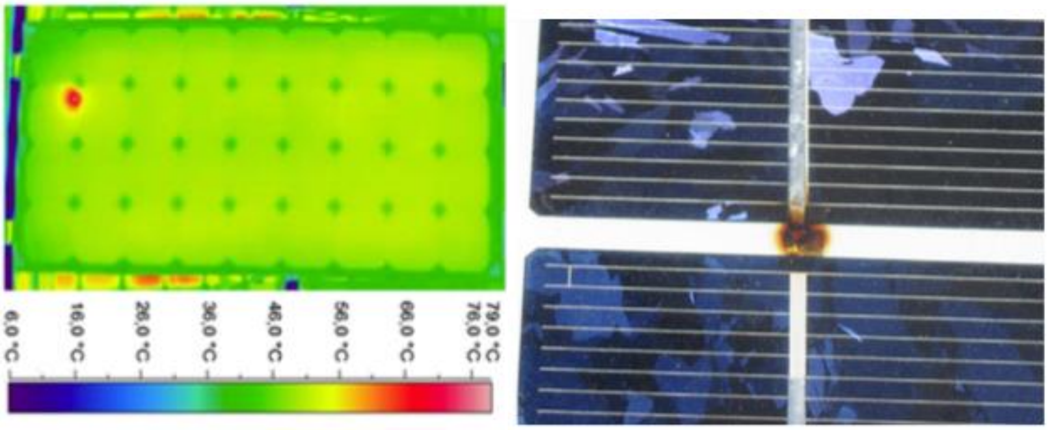


Figure 2.5 - Solder/ribbon degradation small hotspot (left) visual degradation (right) (Tsanakas 2016).

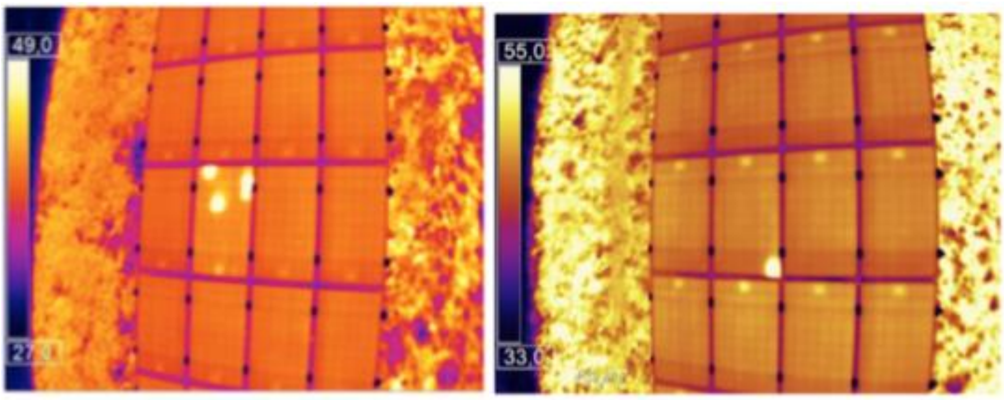


Figure 2.6 - Single cell thermograph hot spot (left) multiple cells failed shown in thermograph hot spot (right) (Tsanakas 2016).

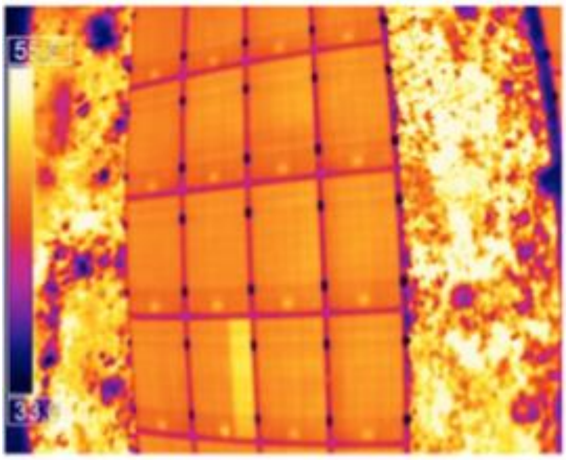


Figure 2.7 - Failed bypass diode, Thermography 1/3 of panel failed (Tsanakas 2016).

Figures 2.5 to 2.7 each show effective detection using infrared thermography. They also provide three basic fault types and are good visual references for real world comparison during physical testing.

2.3 SOLAR RADIATION

Global solar exposure is the total amount of solar energy hitting the ground on a horizontal surface, as defined by the Bureau of Meteorology (BOM, 2016). The solar insolation incident to the ground over a whole day is the daily solar exposure and is typically of the order of 1-36 MJ/m^2.

Diffused solar exposure is the solar energy from all parts of the sky except for the energy produced directly from the sun (BOM, 2016). The maximum values expected in cloudy conditions and minimum during clear conditions is always less than global solar exposure. Solar energy is delivered in two ways to Earth. (BOM, 2016) informs these two are modelled mathematically by:

$$\mathrm{E_g} = \mathrm{E_d} + \mathrm{E_b}\cos(\mathrm{z}) \quad (1)$$

Where E_g = global irradiance at horizontal surface,

E_d = diffuse irradiance,

E_b = direct beam irradiance on a surface perpendicular to the direct beam,

z = Sun's zenith angle.

Irradiance levels are especially important when selecting the location for a solar farm. For example the same solar installation would generally perform better in Australia then it would in the UK due to the solar density as shown by figure 2.8. However selecting an appropriate location is less relevant in domestic use as homeowners are obviously restricted by the existing location of their house roof. Although, even in Australia, as shown in figure 2.8, this variation will mean that each site will give different results, as well as differing throughout the year. Therefore comparable data will be difficult to obtain as irradiance and temperature have dynamic effects on output.

Solar irradiance is a major factor affecting output of PV panels. For example, if a 135W panel has a rated output measured at 25°C and 1000kWh/m^2 irradiance, then an increase in irradiance above 1000kWh/m^2 would increase the panels output (assuming temperature is maintained at 25°C).

2.4 TEMPERATURE AND IRRADIANCE CORRELATION

Generally areas of increased irradiance will have temperatures above 25°C. Krismadinata *et.al* (2012) shows there will be efficiency losses in the panel due to heat increase Comparing figure 2.8 and 2.9 it is clearly visible that the average global temperature map correlates directly to solar irradiance average map.

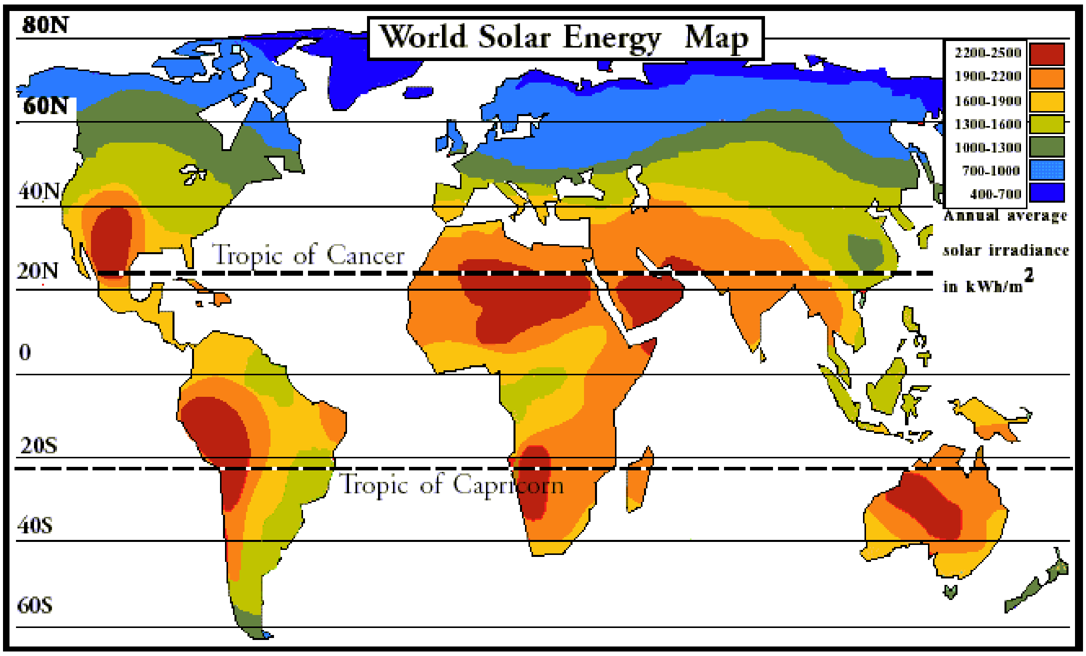


Figure 2.8 - World solar irradiance map (Solary Energy, 2016).

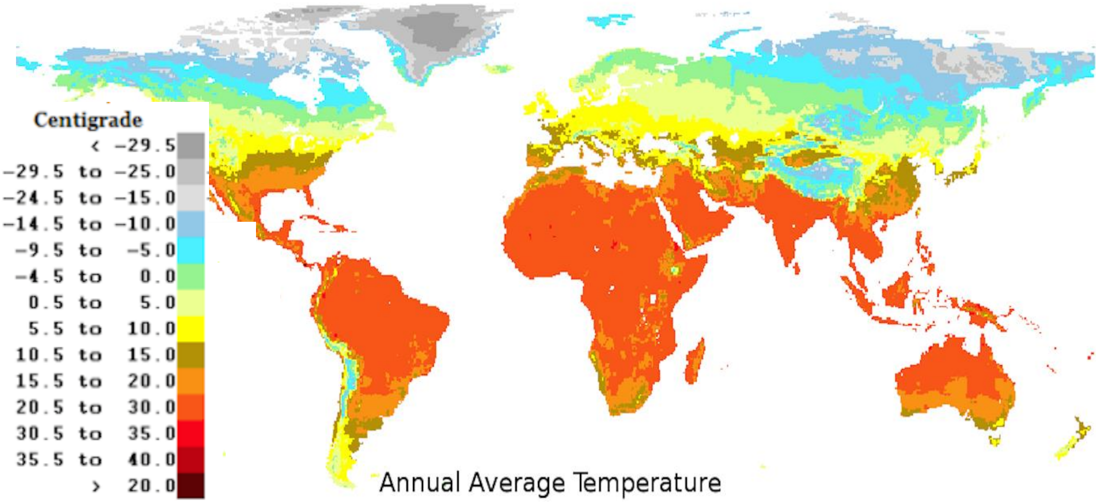


Figure 2.9 - Map of annual average world temperature (Solar Energy, 2016).

In most cases the panel will continue to be limited by the invertor output i.e. if there is 5kW of panels connected to a 5kW invertor the output will not be more than 5kW output. Figure 2.10 and 2.11 shows that irradiance dose not remain a constant value throughout the entire twenty-four hours in a day. In fact, it changes on a seasonal cycle also. Figure 2.10 indicates how cloud cover and other weather elements can cause the irradiance to fluctuate throughout the day. Figure 2.11 illustrates how the output will vary throughout the year, with the peak occurring generally after midday and insignificant irradiance at night. Furthermore, if the irradiance is above the 1,000kWh/m^2 then this maximum invertor output will be obtained faster during the day. It will also be maintained for longer as more irradiance is present. Also notable is each month has different irradiance levels.

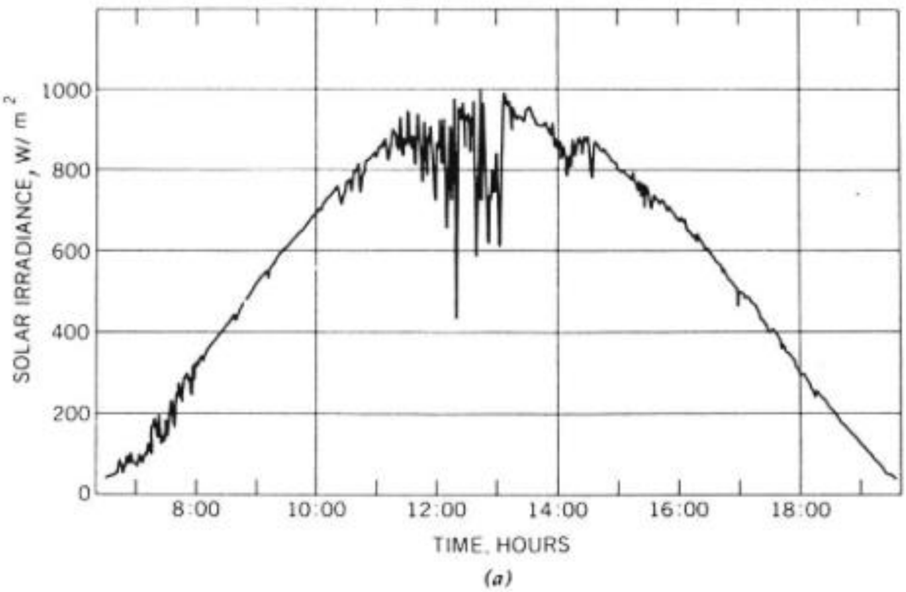


Figure 2.10 - Example of weather effects on irradiance (Thekaekara, 1976).

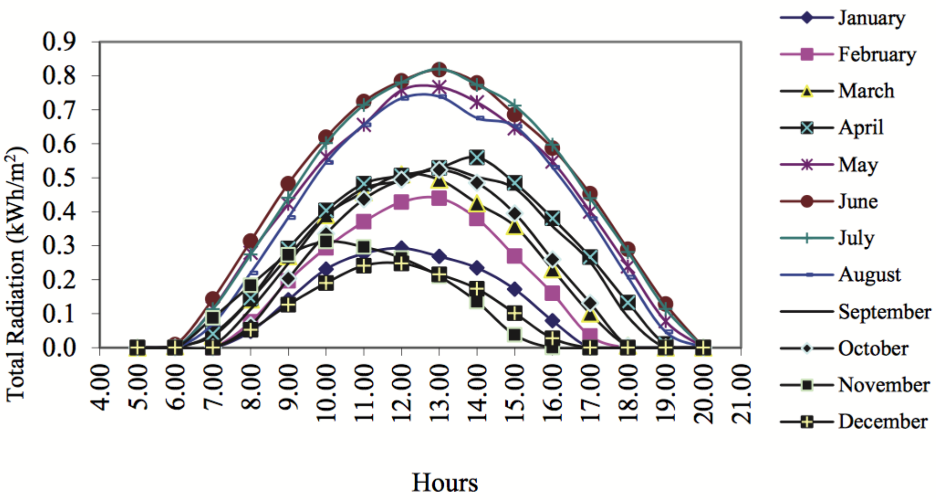


Figure 2.11 - Example of average hour solar irradiation over 12 months (Ekren, 2011).

The NASA image in figure 2.12 shows that the average variation over the past fifty years is within the range of 2W/m^2. This is only a 0.146% variation, with most panels expecting 10-20% output reduction over a twenty-five year period due to this small variation in the sun's cycle. As such this variation can be disregarded.

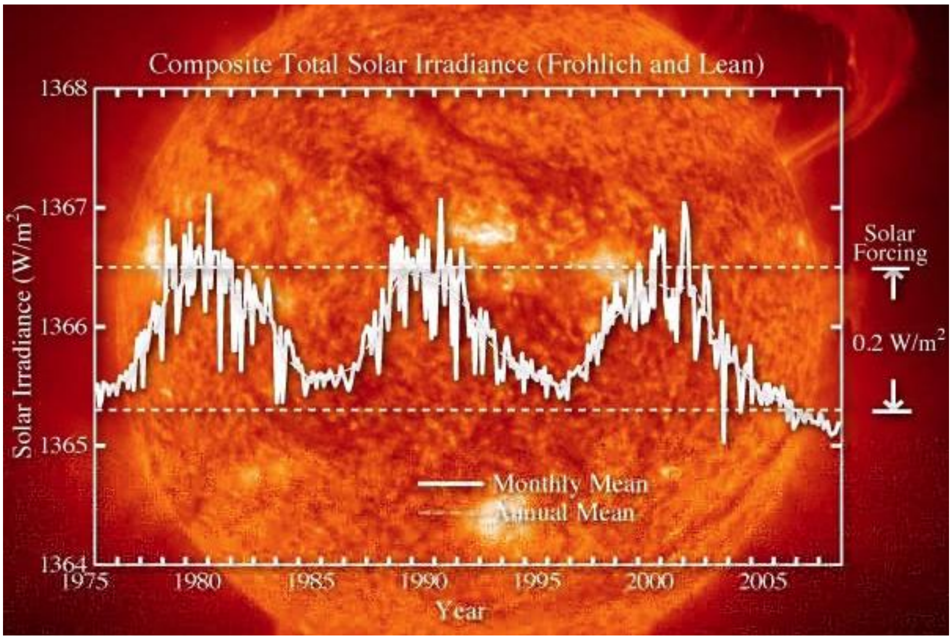


Figure 2.12 - Fifty year irradiance cycle example (NASA, 2009).

The solar exposer varies at every location across the world. Many weather sites such as BOM provide users with daily total irradiance values and yearly averages as shown in figure 2.13. Typically in MJ/m^2, which can be converted to kWh/m^2, using the following conversion factor:

$$\mathrm{MJ/m^2} \;=\; 3.6 \text{ x } \mathrm{kWh/m^2}$$

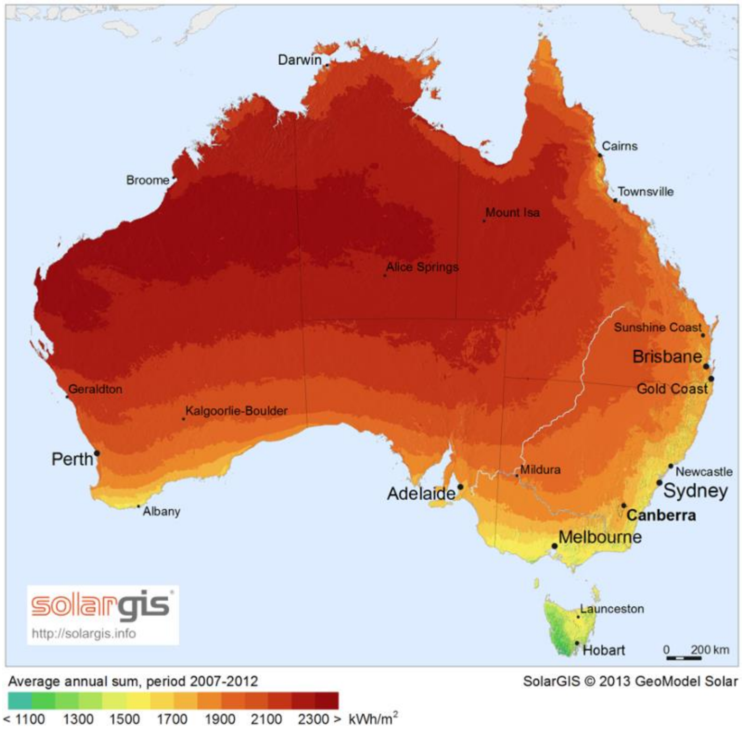


Figure 2.13 - Australia average global horizontal irradiation – (SolarGIS, 2013).

In summary all weather and solar extremes between night and day, as well as seasonally and year to year, are fatigue impacts on the PV panels. Additionally external and internal heat sources and then cooling, frost, rain and other weather events will impact on the construction and assembly viability of a large PV arrays. These extremes provide the continuous thermal expansion and contraction cycles that during the panel's lifetime can degrade:

- Weather seals that protect the PV cells and their current collectors and electrical connectors;
- Promote corrosion of panel framing;
- Promote any edge crack propagation through each PV cell silicon wafer and also top surface current collectors.

All of these fatigue mechanisms impact on the individual panel performance, as well as possibly within the series strings of such panels.

2.5 INTRODUCTION OF LIFE CYCLE ASSESSMENT

It is expected for PV arrays that after twenty to thirty years installation, removal and recycling will become a major decision processes within the life cycle. During this later phase, it is not uncommon for issues to arise, as foresight is rarely employed during the initial developments.

As an example to biased life cycle analysis (LCA) most electric vehicle (EV) life cycle assessments exclude the battery recycling, which is also a new expanding market whereby suppliers emphasise the positives of the technology. An article in Cleaner Cars from Cradle to Grave (2015) reported that EVs, when compared to a fossil fuel powered car over their lifetime will contribute half the amount of pollution to the environment which potentially benefits in global warming targets. However when comparing this directly with the EV, the safe environment re-cycling and disposal of the electrical car's battery components was not taken into consideration. This is a false and short sighted attempt at using an incomplete LCA to support a new technology solution with a marketing segment push.

Furthermore the life cycle assessment for large PV arrays can be quite detailed. Considerations include the manufacturing procedure, the sustainability of such procedures, transportation methods, durability of the products, installation requirements, methods and locations. Inverter technology has a different LCA cycle of only ten to fifteen years, noting that component drift in the later period of this can also cause reduced output and/or output failure. However the de-commissioning and recycling of all PV array technology components require consideration for initial safe design from cradle to disposal or reuse.

2.6 INTERNAL PV CELL ELECTRICAL RESISTANCE

Odden *et.al* (2014) reports the ageing process is a link to a higher value of resistivity in the material, which may lower the peak output. They recorded values for base optimal resistivity of 0.4 – 0.5 Ω / cell. Ageing of both the base silicon material formation for ESS™-based polymorphous silicon cells could result increasing the shunt resistance (R_{sh}). Figure 2.14 shows the reduced output due to this increase.

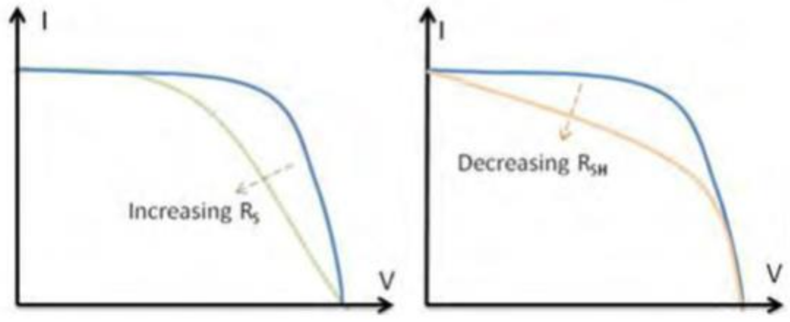


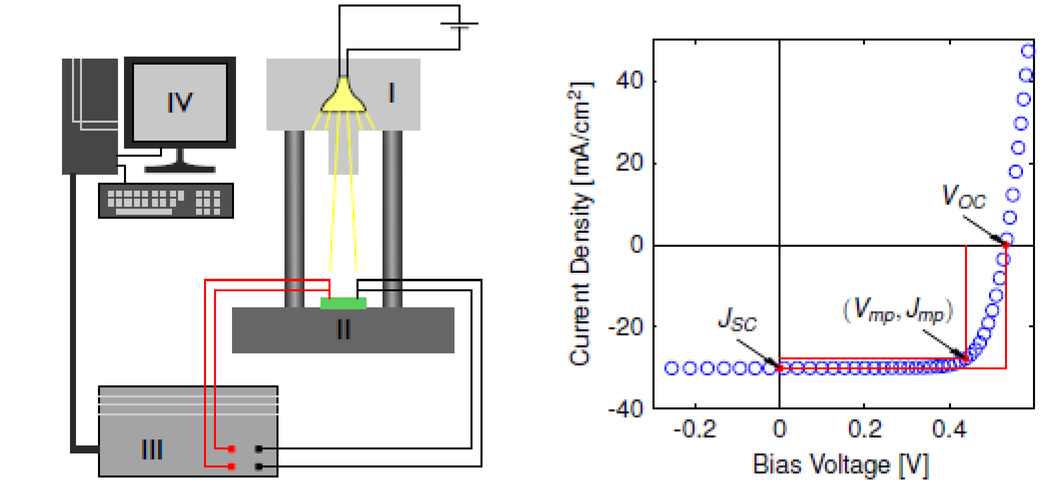
Figure 2.14 - Resistance effects on the I-V curve. (J.O.Odden, 2014).

Figure 2.14 demonstrates the effects on the output from a PV cell due to a change in internal electrical resistance. It is evident from the I-V curve that by increasing the series resistance and decreasing shunt resistance, there will be a decrease in the fill factor (*FF*). This will gradually decrease the output efficiency of the PV cell. To achieve the maximum efficiency, the value of shunt resistance should tend to infinity and the value of the series resistance should tend to zero.

Research from Acta Universities Upaliensis Uppsala (2008) states that although infinite shunt resistance is desired for maximum power output of the PV cell, it is never achieved due to the manufacturing process. Upon production of the PV cell, an alternate conducting path is formed between p-type and n-type semiconductor layers and this results in decreased shunt resistance. The most important characterisation technique for PV cells is the current voltage I-V characterisation. This is used as a routine measurement applied to nearly all cells made in a manufacturing or laboratory environment. It is acquired using a solar simulator.

As seen in figure 2.15(a) the test apparatus typically consists of a light source with sample stages, temperature control, an external source measuring unit (SMU) or a variable load with all outcomes recorded by a data recorder. The measurements are almost always made at a reference temperature of 25°C. The source illumination is configured so it complies with a reference spectrum, with a typical value of AM1.5G. The measurements most importantly record the four PV cell parameters, used to characterize the device. These are short circuit current (*JSC*), open circuit voltage (V_{OC}), *FF* and *h*. These constitute basic tools for evaluation of cell performance, with the short circuit current, *JSC*, indicating the transfer of photons and gathering of the carriers.

The open circuit voltage, V_{OC}, is due to the band gap that material has absorbed, and the number of junctions that the cells have. The *JSC* and the V_{OC} parameters are simply the current and voltage at the two points where the J-V curve intersects the current and voltage axes, respectively. These points are shown confirmed with the red box on the curve in figure 2.15(b). The ratio maximum output power to the product of J_{SC} and V_{OC} is the *FF*. This is a measure of the output J-V curve in the 4th quadrant indicating the squareness. These parameters are used to further study the device operation, with components like series resistance, photo generated current, shunt conductance and the junction characteristics itself. This illustrates how a PV arrays performance depends on both the voltage and current and how sensitive the optimum point is to physical parameters such as clouds, dirt and other ingress.



(a) J-V set-up *(b) J-V* curve example

Figure 2.15 - (a) A schematic drawing of a typical J-V measurement set up (solar simulator); (b) and a typical illuminated J-V characteristics. (Acta Universatis Upaliensis Uppsala, 2008).

Eitner *et.al* (2010) details how a thin semiconductor wafer or layer when struck by a light source can convert the photons to electrons using the photoelectric effect. It also indicates how to model a PV panel using a single diode with series and parallel resistance as shown in figure 2.16. This will be an appropriate model for the simulation and calculations. Based on equation (2) it is possible to simulate the array with an equivalent model using the series resistance and single diode method. This model will obtain the predicted power value due to the panel heating and degradation.

$$\mathrm{I} = \frac{\mathrm{I_{SC}} + \mathrm{K_i} \times \Delta\mathrm{T}}{\left[\exp\left(\frac{\mathrm{V_{OV}} + \mathrm{K_v} \times \Delta\mathrm{T}}{\mathrm{A} \times \mathrm{V_t}}\right) - 1\right]} \quad (2)$$

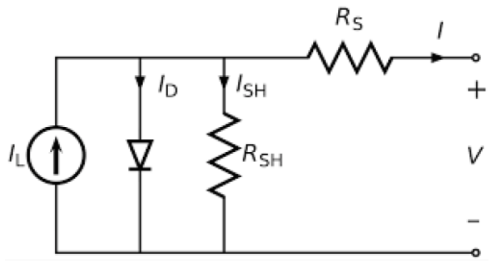


Figure 2.16 - Circuit model, using a series and parallel resistance and a single diode (Eitner *et.al* 2010).

It is necessary to calculate the effect on the internal heating generated. To determine this, a term was designated by 'a' which is called the thermal voltage, or the identity factor. This is used to investigate how closely a diode characteristic follows the ideal diode equation. It is considered a constant and is chosen according to the technology of the PV cell. The thermal voltage 'a' is generally described by equation (3).

$$a = \frac{N_s \; x \; A \; x \; k \; x \; T_c}{q} \quad (3)$$

Table 2.1 - Model figures of temperature effects on example array (Pan, 2011).

Trial	**1**	**2**	**3**
Temperature (K) →	**313**	**328**	**343**
V_{mp} (V)	26.52	23.68	20.13
I_{mp} (A)	8.297	8.049	7.97
P_m (W) From I-V Characteristics (calculated)	220.03	190.6	160.4
P_m (W) From P-V characteristics	220.3	191.8	160.8
Fill Factor	0.74	0.71	0.67
Efficiency (%)	13.4	11.6	9.79

The research by Pan *et.al* (2011) is summarised in table 2.1, and supports the increase in panel resistance due to degradation. The first major contributions to the degradation was identified as the temperature difference between the minimum and maximum, which created a larger thermal gradient stress. The second contribution to degradation was expansion of the internal circuits and all the panel elements. This increased the series resistance and created more losses, resulting in an increase in panel heating that ultimately reduced power output. It was also reported that the higher temperatures resulted in reduced solder strengths in the PV which can create a break or open circuit. This open circuit will lead to total output loss. The major failure identified from temperature variations was by the bypass diode failures, which were attributed to the increase in temperature experienced.

2.7 TEMPERATURE EFFECTS ON PV CELL

Krismadinata *et.al* (2012) model the effects of temperature on performance in figure 2.17 (Right) and (Left). This clearly supports the claim that an increase in temperature above 25°C will result in a decrease in the PV panels output.

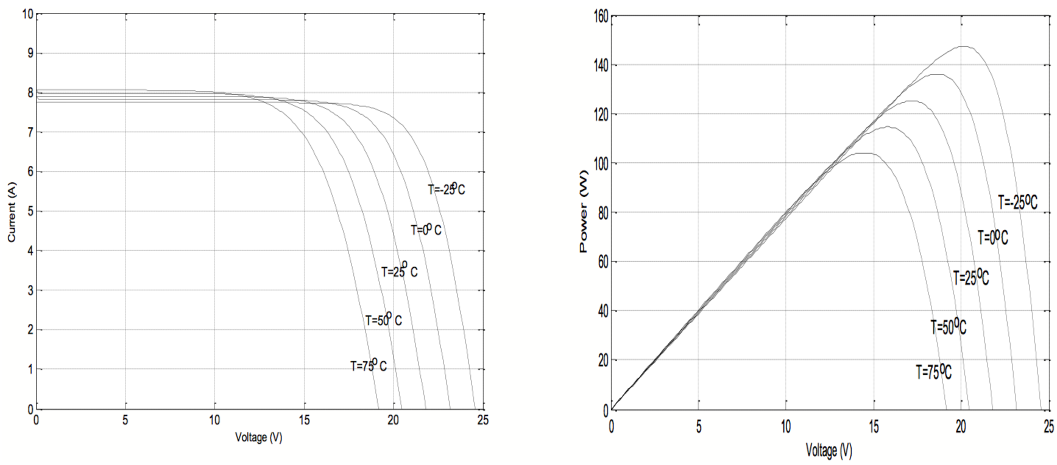


Figure 2.17 - (Left) I-V plots at set temperatures and allocated irradiance (Right) P-V plots Module's P-V plots at set temperatures and allocated irradiance (Krismadinata *et.al*, 2012).

Paggi *et.*al (2015) reinforces that panel resistance is the parallel resistance measurement often referred to as shunt resistance. R_{sh} is used to model the effect of impurities of the p/n junction, this value will increase due to old age and degradation. Additionally this supports the theory proposed in this paper, that deterioration should cause heating that would be detectable using an infrared camera. The thermal images may reveal micro cracked cells and cells with degrading collector contacts or failed circuit connection. It will also show any increase in the functional temperature that should manifest as thermal hotspots or total heating of the panels. This would indicate decreasing performance if panel is above 25°C.

Il *et.al* (2012) reinforces the Paggi statement discussed previously that as temperature and light strength changes, so will the maximum power point. This supports the suggestion that any increase in panel temperature over 25°C will reduce the power output.

Salmi *et.al* (2012) supports the papers proposed theory that any added heat will reduce the arrays output once above 25°C. This is evident in the plot in figure 2.18. For a given solar intensity, if the arrays temperature increases this results in the open circuit voltage decreasing. This does not however increase the current for short circuit conditions. But as shown in the P-V curve, there is an overall output efficiency will decrease as temperature increases.

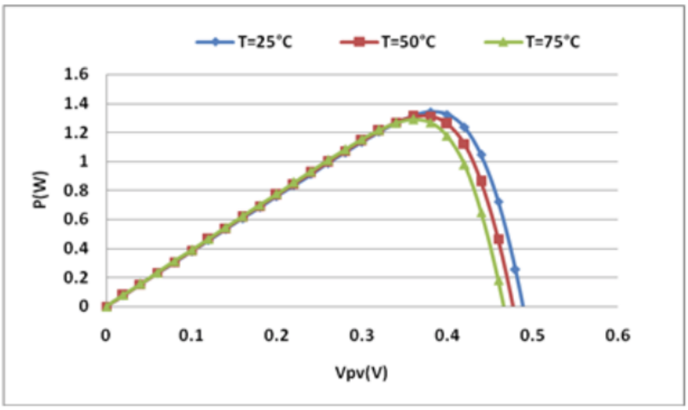


Figure 2.18 - Temperature effects on PV output (Salmi, 2012).

The model developed by Savitha *et.al* (2014) provided calculations on the impact of temperature increase. It also supports the claim that increased heat will decrease performance once above 25°C. Figures 2.19 and 2.20 show how the PV cell will decrease its efficiency when the temperature increases. This will be further amplified if the panel starts to self-heat due to internal failure mechanics resulting from internal PV cell resistance increases.

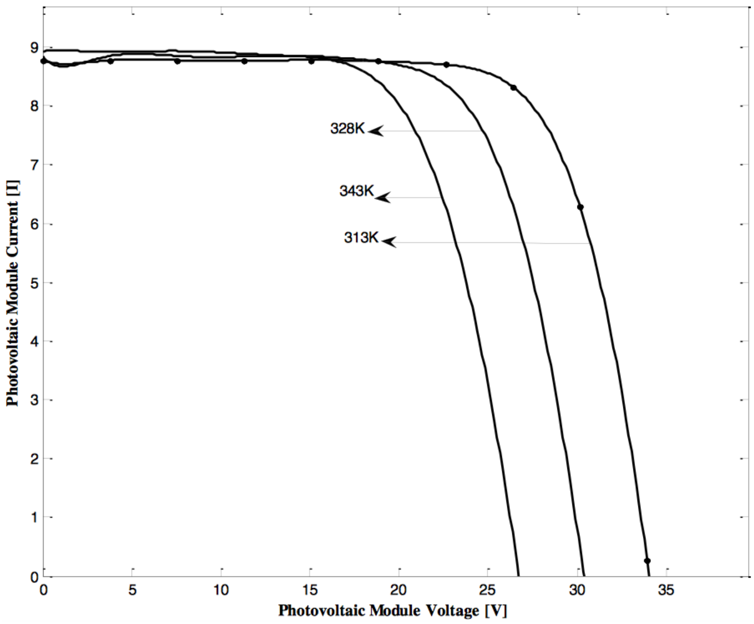


Figure 2.19 - Temperature effects on I-V curve (Savitha, 2014).

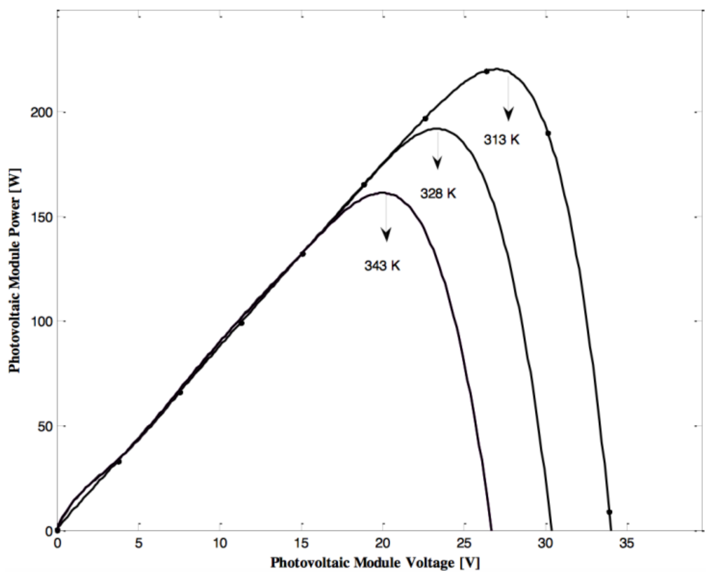


Figure 2.20 - Temperature effects on P-V curve (Savitha, 2014).

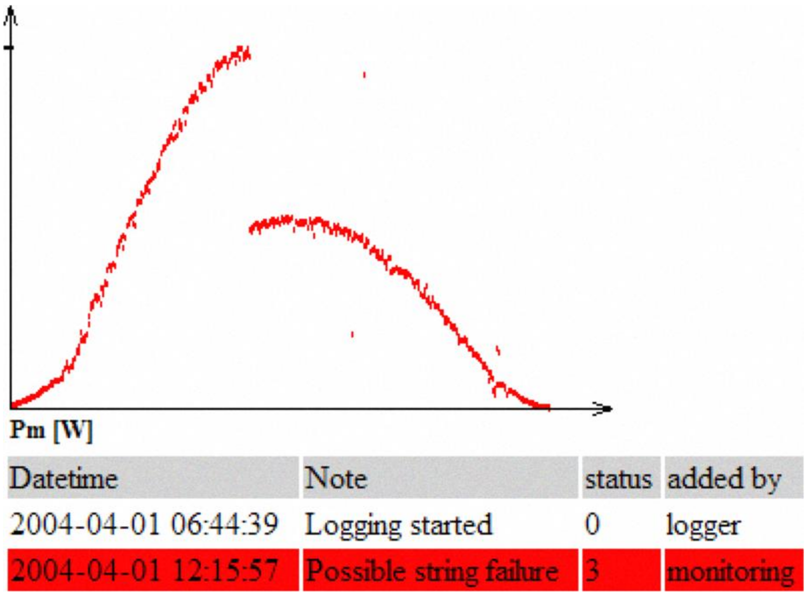
2.8 DEGRADATION AND CONDITIONING MONITORING

Bonkoungou *et.al* (2013) highlights the current process of implementation of a software based monitoring in most invertor's. Their statement supports the methods that are currently used being that *"…Conditioning monitoring can be supported by max point tracking by incremental conductance method or Hill Climbing (Perturbation and Observation)"* therefore by constantly varying the V-I it is possible to find the optimum power point.

GSES (2015) technical paper provided information on micro fractures which are typically caused by either excessive mechanical stress being applied to PV modules or by manufacturing defects. Excessive mechanical stress can usually be attributed to environmental conditions or to mechanical damage caused during manufacturing, transportation or installation. It was determined that losses of up to an additional 2.5% can be experienced in a module with a large number of cracks that do not isolate parts of the cell. Larger losses can be experienced for a module with micro fractures that isolate parts of the cell. Micro fractures also have the potential to produce hot spots. These occur when the internal resistance of the damaged cell rises and causes an increase in cell temperature as the current passes through a reduced cross-section of the material. Hot spots can cause further damage to a cell by ongoing cascade thermal effect, that perpetuates further degradation of that material through continuing crack propagation.

Research by Ando *et.al* (2015) supports the assumptions proposed in this paper on the importance of continuous online monitoring of the entire PV string and detection of which array, module or component is the problem. It is essential to have an effective monitoring system in order to provide efficient identification of faults. This proposed research supports the method of thermal hot spot detection by suggesting that an array can only be monitored individually with a permanent infrared camera to provide check and comparisons to previous data. This would replace the manual infrared scan to be trialled in the field to establish if temperature differences are measurable.

Kolodenny *et.al* (2008) identifies another method of monitoring, using a technician to manually analyse the data. Although this is an extremely time consuming process, once there is a sufficient data analysis tool or method for data graphing, this would provide suitable information to perform the diagnostics. Figure 2.21 is an example of a current monitoring alarm. This would provide the technician with a possible cause that could act as a starting point for the actual failure. A complex system would require detailed schematics and wiring layouts when the panel strings are in large-scale systems in order to reference against this data effectively.



Datetime	Note	status	added by
2004-04-01 06:44:39	Logging started	0	logger
2004-04-01 12:15:57	Possible string failure	3	monitoring

Figure 2.21 - Data showing how detections are logged (Kolodenny *et.al* 2008).

Denio (2011) provided actual results of condition monitoring of photovoltaic systems using thermography. This analysis was performed from hundreds of meters using a thermal camera attached to an aerial drone. The camera captured exceptional detail as can be seen in figure 2.22 and 2.23. Denio reported that due to the significant increase in demand for PV arrays over recent years this has caused massive increase in solar installation sites. Therefore there is also an increased demand to enable accurate detection of which panels need maintenance. However there is currently significant difficulties in identifying potential issues using current methods. For example, in large arrays infrared imaging processes are viable options to allow for accurate detection in minimal time over vast structures. Figure 2.22 and 2.23 highlights the effectiveness of the hot spot identification using an infrared camera on a large-scale solar farm. It is evident from these figures that multiple rows are operating at an increased temperature. This type of finding would trigger further investigation.

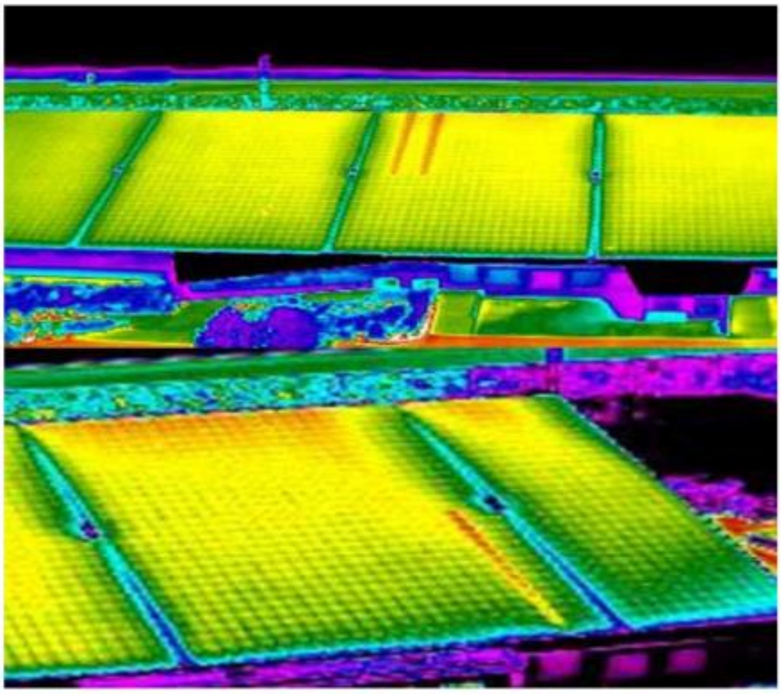


Figure 2.22 - Multiple panels with increased temperatures in this large PV system (Denio, 2011).

Figure 2.23 - Overheated cells taken from underneath an large PV structure (Denio, 2011).

Hu *et.al* (2013) supports the suggestion that thermography can be used to detect hot spots. Hu reported findings of being able to identify hot spots and using this as a method during maintenance work. The information was used to assist in locating faults on the PV arrays that were not contributing to the string or simulating the faulted panel in the string. Figure 2.24 to 2.28 show the simulation and results. Figures 2.27 and 2.28 show the corresponding thermography outcomes for this investigation. Fault location is simulated by covering with a board to ascertain in whether or not cells are contributing to the strings output.

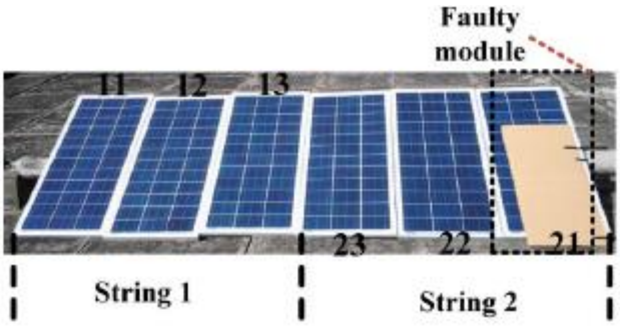


Figure 2.24 - Simulation of faulty panel using a shade shield (Hu *et.al*, 2013).

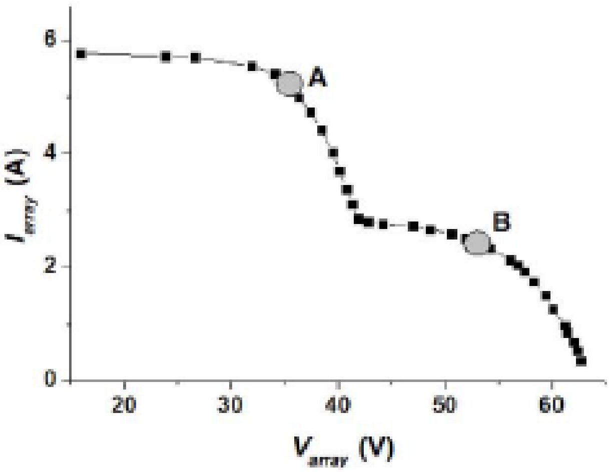


Figure 2.25 - I–V Plot with the module covered (Hu *et.al*, 2013).

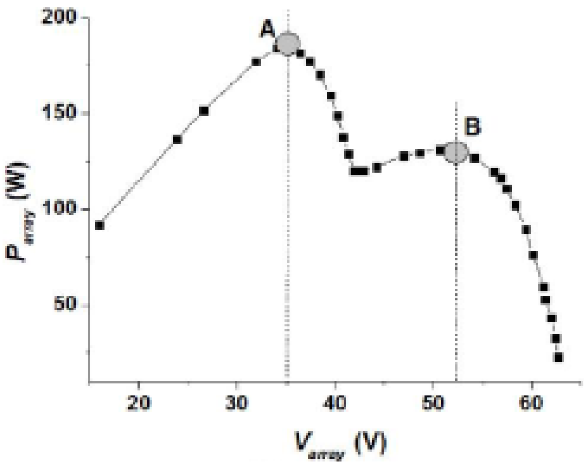


Figure 2.26 - P–V plot with the module covered (Hu *et.al,* 2013).

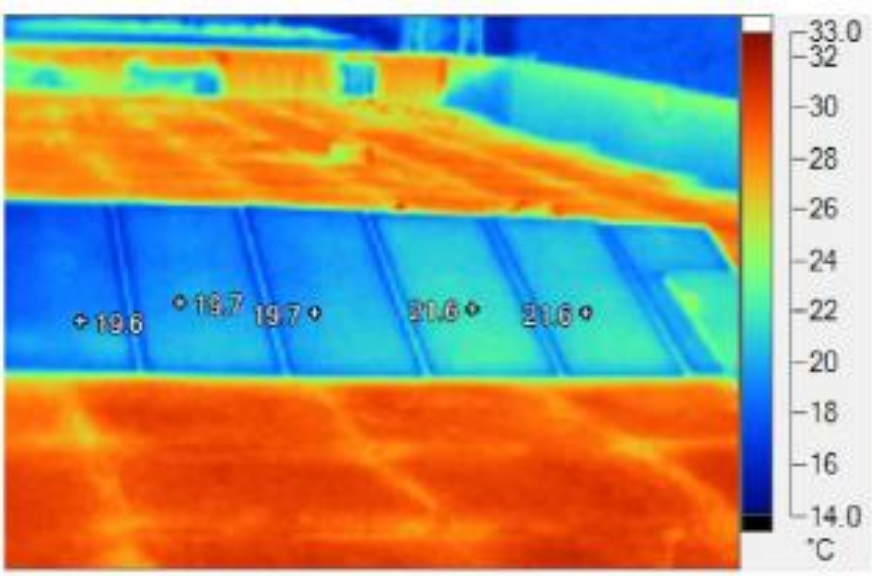


Figure 2.27 - Thermal image at point A from figure 2.25 and 2.26 (Hu *et.al,* 2013).

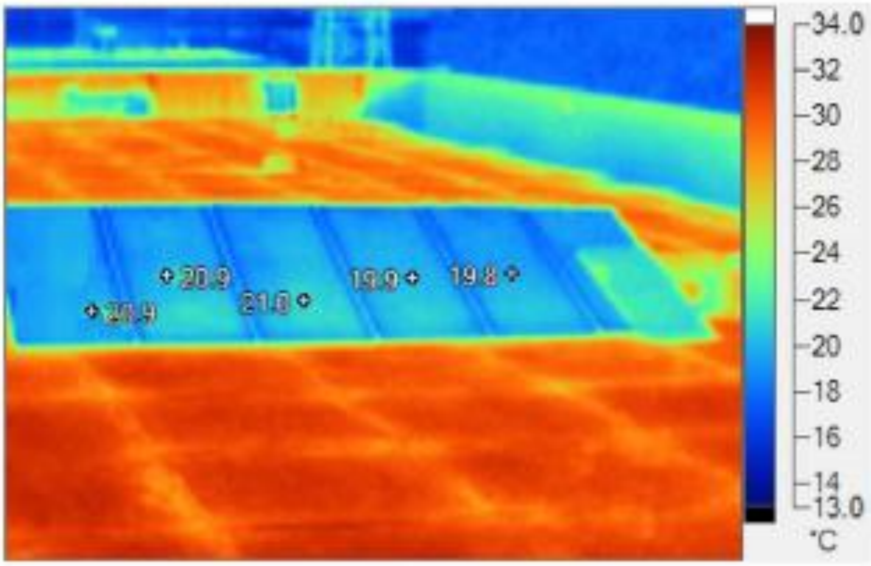


Figure 2.28 - Thermal image at point B from figure 2.25 and 2.26 (Hu *et.al,* 2013).

Wohlgemuth *et.al* (2010) showed that long term 'damp testing' on crystalline silicon cells provides some interesting results. In the initial two thousand hours of contact there was little to no efficiency lost. The 85/85 testing being 85°C at 85% humidity for the next 1,500 hours should result in the panel's output reducing to almost half. This is a significant loss if conditions were present due to external heating and high humidity locations. Ultimately operating for 3,500 hours with exposure to these conditions resulted in a 50% panel output reduction. This is obviously a very significant concern for an investment with over twenty years predicted life cycle. The predominant causative issue was found to be moisture increasing the corrosion rate of the doped oxide. This corrosion is the pathway for the electrical current, which results in an increase in the resistance. This would increase the losses and decrease performance as identified in figure 2.29.

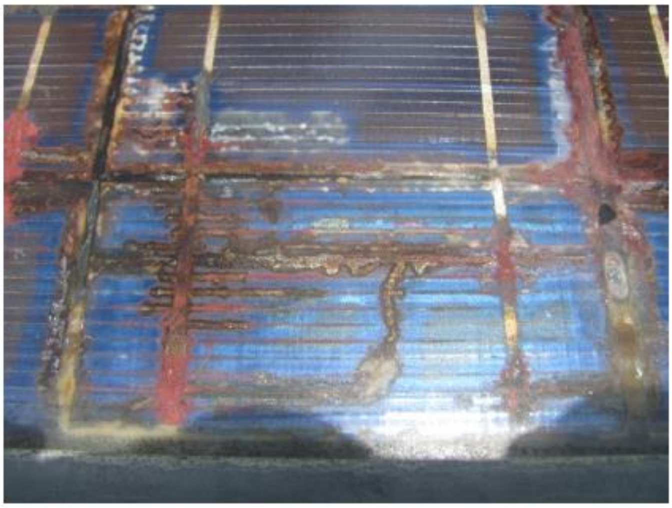


Figure 2.29 - 85/85 cell degradation after 3500 hours in harsh conditions (Wohlgemuth *et.al*, 2010).

SMA Solar Technology (2015) provides monitoring and control solutions for a wide range of their systems. They provided solutions for on demand information to allow for precise and flexible options to monitor the systems yields and in most cases allow remote access to this data. Solutions range from on-board invertor monitoring to cluster controllers. Cluster controllers allow twenty-five invertors to be connected in various slave groups, while still using a standard Modbus interface. This allows for monitoring centralisation and control over the string of invertors. SMA also provide string monitoring systems as illustrated in figure 2.30 which compare and perform analysis of each individual string current connected. This provides precise and dependable monitoring systems for the solar farm. SMA reports that string monitoring provides increased safety and precise detection of string failures.

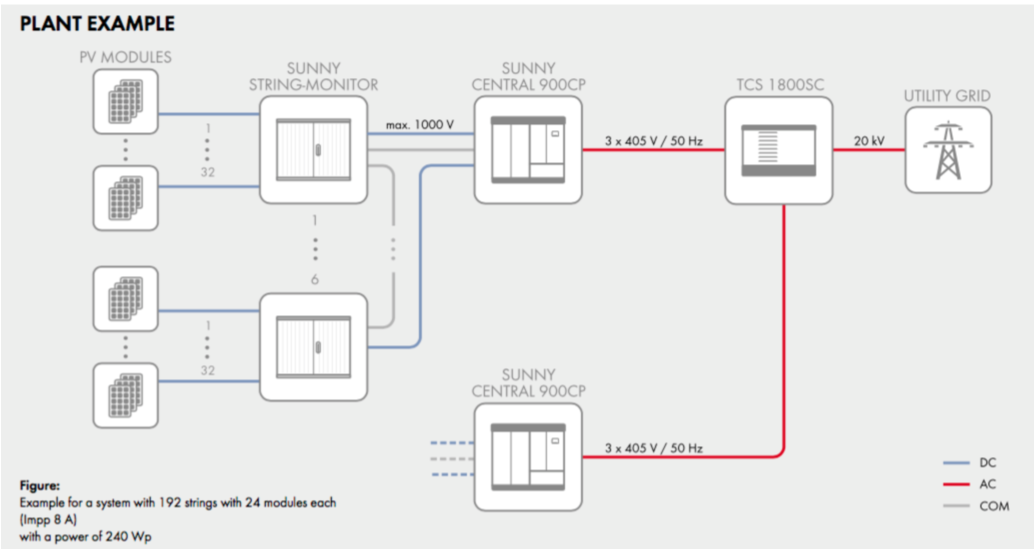


Figure 2.30 - Sunny string-monitor plant example diagram (SMA, 2016)

2.9 PV ARRAY SIMULATION

Below is the block representation of a PV array using a MATLAB/Simscape five-parameter model. The PV array data is used to model a representation of the array, and this model can be used to simulate the effects panel temperature and irradiance has on output due to increased resistance due to degradation.

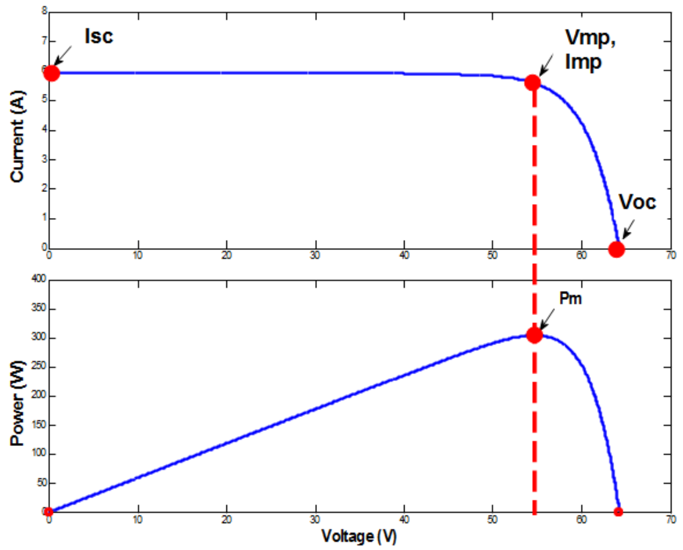


Figure 2.31 – P-I and P-V curve showing maximum power point relationship (Mathworks, 2016).

Mathworks (2016) defines characteristic equation for the diode I-V for a single array as

$$I_d = I_0\left[\exp\left(\frac{V_d}{V_T}\right) - 1\right] \quad (4)$$

$$V_T = \frac{kT}{q} \text{ x nI x Ncell} \quad (5)$$

I_d	= diode current (A)
V_d	= diode voltage (V)
I_0	= diode saturation current (A)
nI	= diode ideality factor, a number close to 1.0
k	= Boltzman constant = 1.3806e-23 J.K-1
q	= electron charge = 1.6022e-19 C
T	= cell temperature (K)
Ncell	= number of cells connected in series in a module

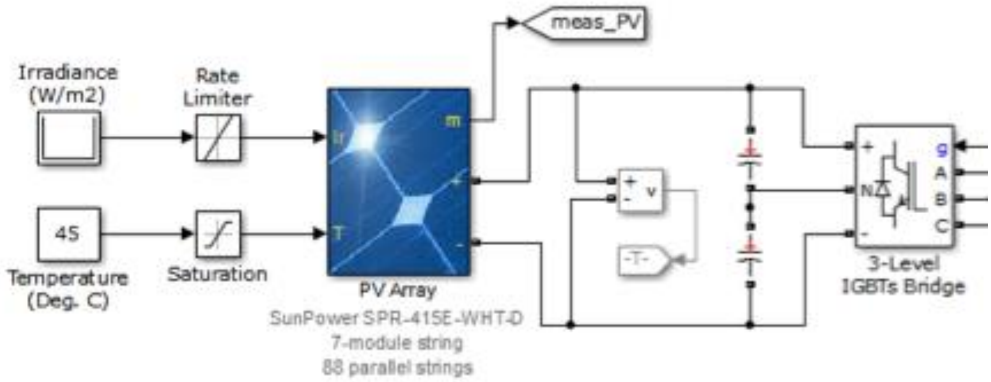


Figure 2.32 - PV array example showing irradiance and temperature control (Mathworks, 2016).

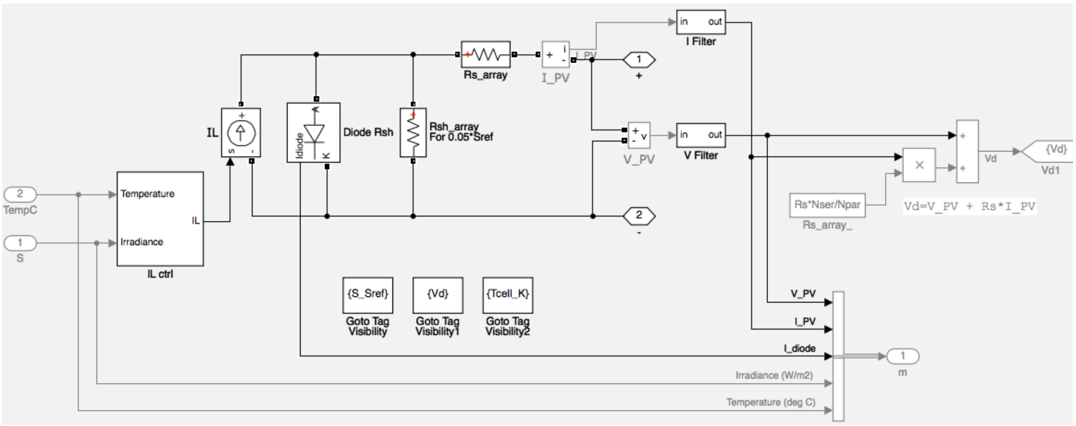


Figure 2.33 - Detailed Simscape PV array logic (Mathworks, 2016).

Figures 2.31-2.33 provide some detailed examples of the PV array Simscape models. Figure 2.32 shows the knee point of the V-I and V-P curves this is calculated using an incremental step function. This function varies the voltage and current to solve for the maximum power point which is the knee point. This Simscape PV array allows for cell temperature and irradiance values to be controlled.

Schuss et.al (2016) identifies that PV simulation models are required to compute the characteristic nonlinear output behaviour of PVs at different environmental conditions. The current–voltage (*I–V*) curve illustrates the amount of output current that can be obtained at a particular output voltage level. The single diode method is commonly used as a comparable electric circuit to simulate PV arrays. Boltzmann's constant is used along with the shunt resistance to make equation (6). This can be used to calculate theoretical figures to compare with the simulations and physical results.

$$\mathrm{I} = \mathrm{I_{ph}} - \mathrm{I_s}\left(\mathrm{e}\frac{\mathrm{q(V+IR_s}}{\mathrm{AkT_c}} - 1\right) - \frac{\mathrm{V+IR_s}}{\mathrm{R_{sh}}} \ (6)$$

2.10 LITERATURE REVIEW SUMMARY

Current literature supports the methodology prospects for utilising infrared thermal cameras to detect hot spots in PV arrays. Major factors contributing to degradation that would have different indicators in the hotspot gradient picture are:

- Installation and environment locations exposed to accelerated corrosive environments etc. including salt water or extreme heat source;
- Temperature cycle/variation; any temperature above 25°C will decrease the output of the panel. Furthermore the greater the temperature variation, the greater the increased risk of further cracking and degradation and reduced output;
- Damage from external factors etc. such as wind, dust, sand and rain.

Review of literature indicates various methods to simulate the PV arrays non-linear performance due to the effect of temperature increase. Simulation will focus on temperature and irradiance variation only. Physical testing methods such as using an external source for light and heating of panels and manually increasing panel resistance will not be performed for this project.

3 CHAPTER THREE: METHODOLOGY

3.1 SIMULATION

The method will simulate modelling for large PV array degradation in order to show the effects that self-internal heating or added temperature has on the panel's output. This is based on the theory that all panel degradation will increase panel resistance, in effect increasing the cells operating temperature. The model temperature and irradiance are the parameters that require variation in the simulations to show the effects on panel output. This data will be used to show the benefits for peak power conditioning and monitoring. The data will also allow for an estimated real world revenue losses. Energy to create and maintain heating will not be investigated in this simulation.

3.2 SIMULATION MODEL

The simulation was performed using MATLAB/Simscape to provide a theoretical basis to unpin the different theoretical ageing and fatigue processes, which would degrade cell performance. This will allow identification as to how each cell's individual temperature can contribute to the overall output of the strings performance.

3.3 TEMPERATURE SIMULATION

All the temperature simulations are created using Kyocera KD135GH-2PU 135W panel data (more information in Appendix A3). This will allow direct comparison of simulated results to the physical scan temperature results. The string model built will allow the cell temperature and irradiance to be controlled. The Simscape model calculates many values, and can provide detailed plots, *Pmax* (Maximum Power) the value of most interest. This *Pmax* is shown in figure 3.1 for a single 135W panel with the red dot indicating maximum power point *Pmax* or knee point. *Pmax* values are tabled to allow comparison at different temperatures and irradiances.

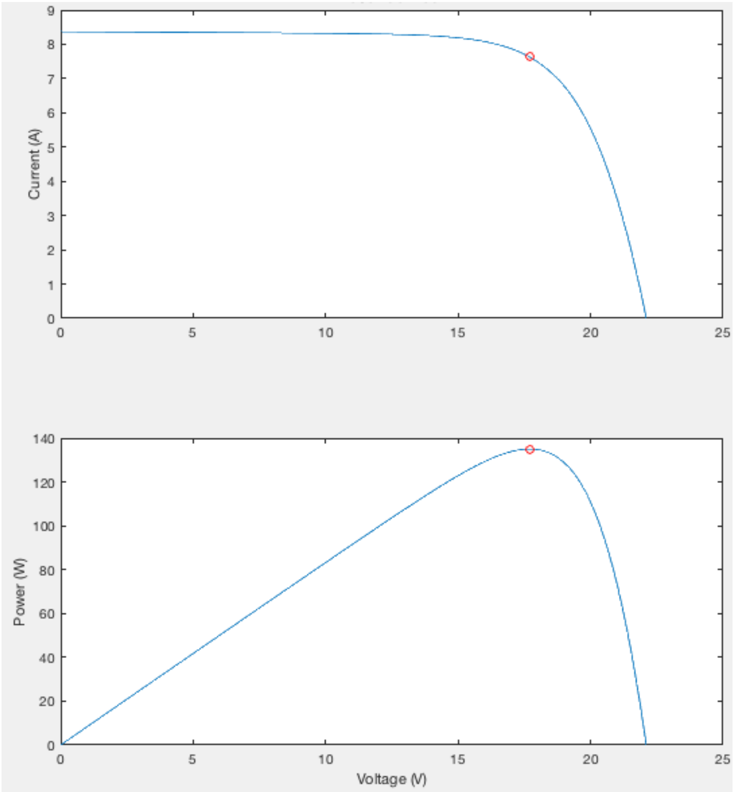


Figure 3.1 - Single panel @1,000W/m^2 at 25°C – 135.04W.

3.3.1 MATLAB/Simscape Model Design

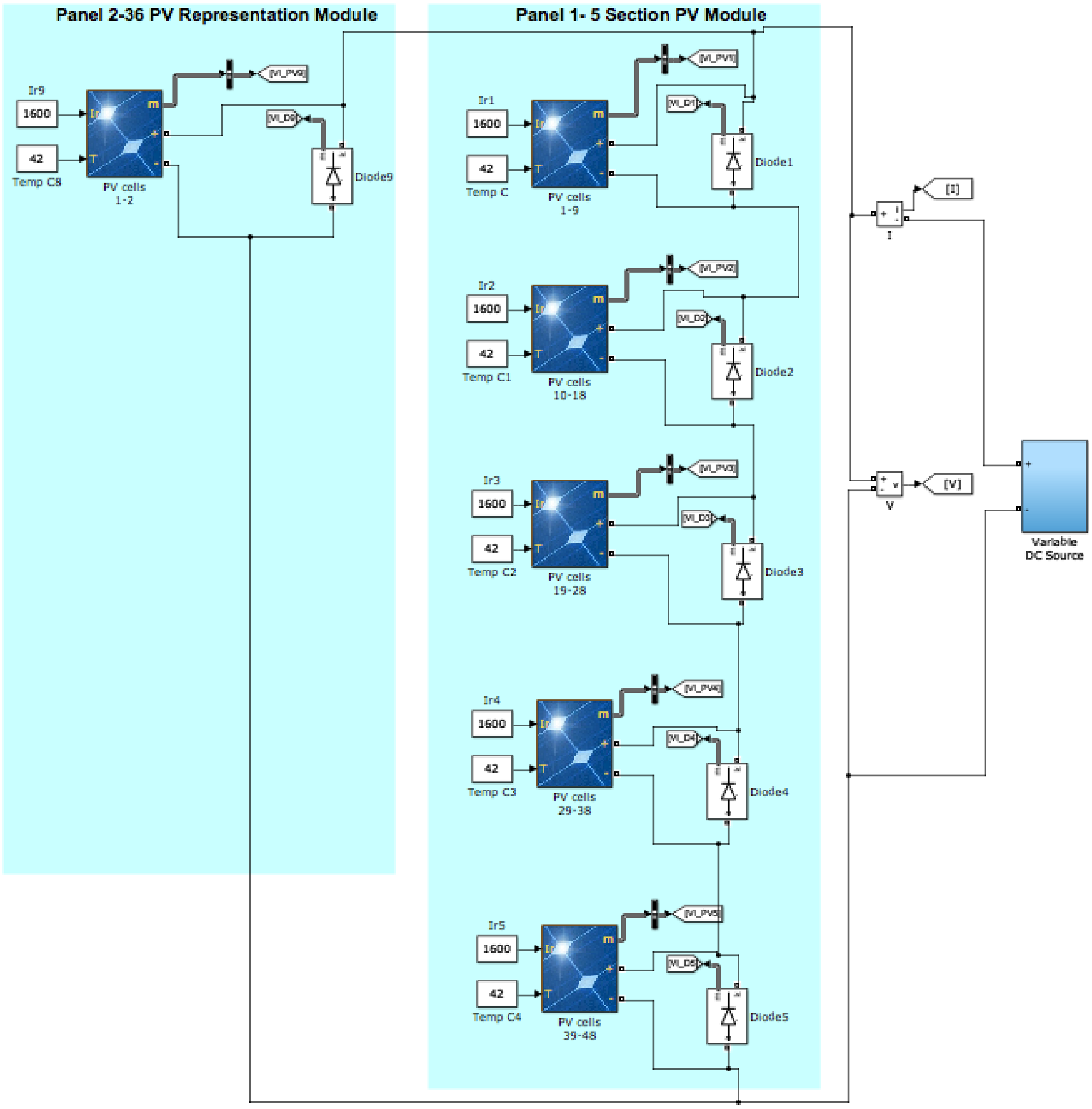


Figure 3.2 - Two panel Simscape model.

The above model represents thirty-six 135W Kyocera panels. The final design had to be condensed to allow a 1,000 block student version limitation to be met. The model has two modules. The first represented the thirty-five panels in the string. The other module is a single panel with five sections, allowing four individual cells to be varied and the other thirty-two cells to be varied as one. Effectively panel 1-5 is five individual smaller panels connected in series to represent one 135W panel.

Figure 3.3 - Five-section cell layout representation.

Figures 3.3 and 3.4 provide a visual representation of which cell groups on the five-section panel it is possible to control. This configuration allows for up to four individual cells and then the entire panel and string to have the temperature and irradiance set to simulate the effects on the strings output.

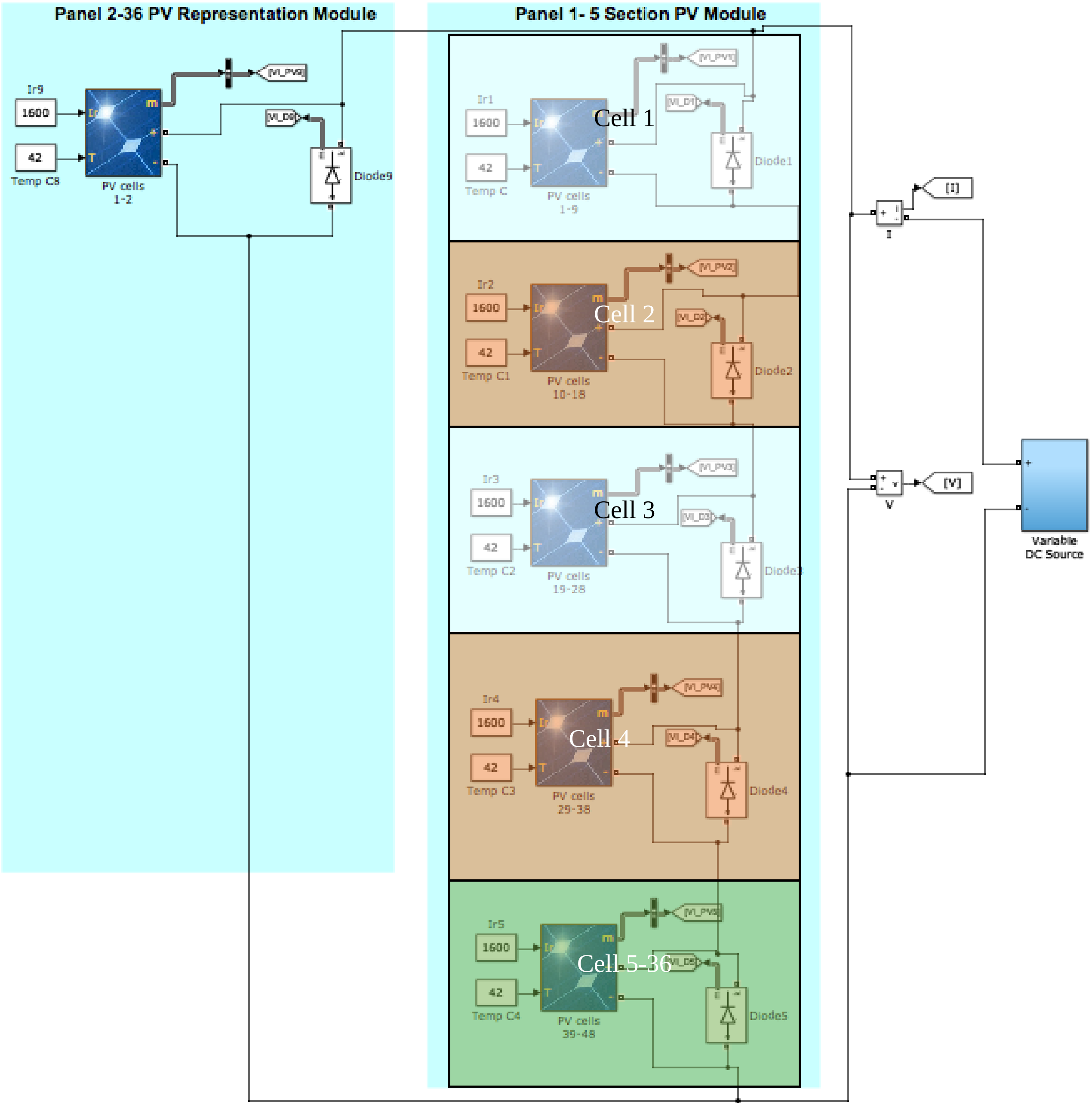


Figure 3.4 – Thirty-six panel Simscape model, panel 2-26 = thirty-five 135W string, panel 1-5 = 135W five section model.

3.3.2 MATLAB/Simscape Panel Validation

For confidence in the simulation, validation of manufacturers panel data against the simulated data was required. The curves shown in figures 3.5 to 3.8 compare the Kyocera panel data (Appendix A) against the simulated Simscape single 135W output. Temperature was simulated over the same increments. Comparing the plots provides confidence in the simulation data.

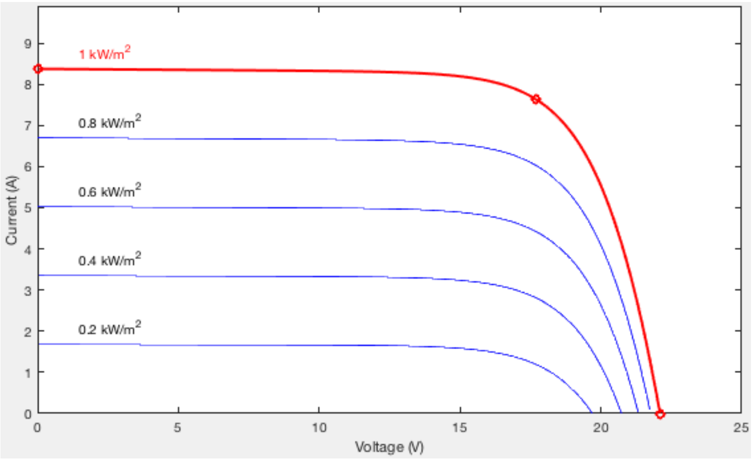


Figure 3.5 - Kyocera KD135GH-2PU I-V output MATLAB model @25°C and multiple irradiances.

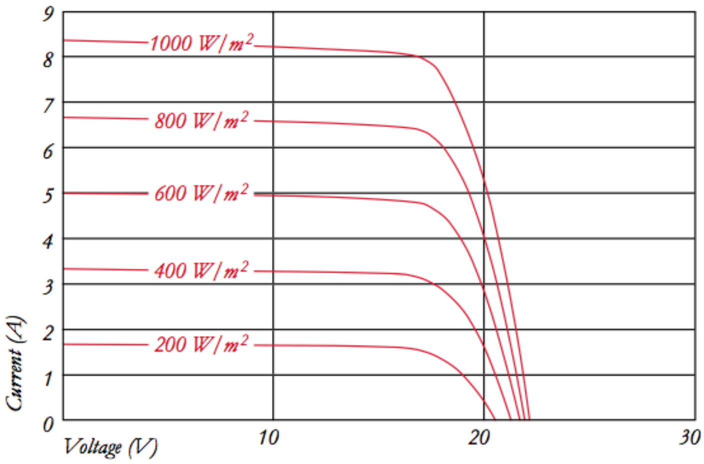


Figure 3.6 - Kyocera KD135GH-2PU I-V data sheet characteristics @25°C at various irradiance levels, (Kyocera, 2010).

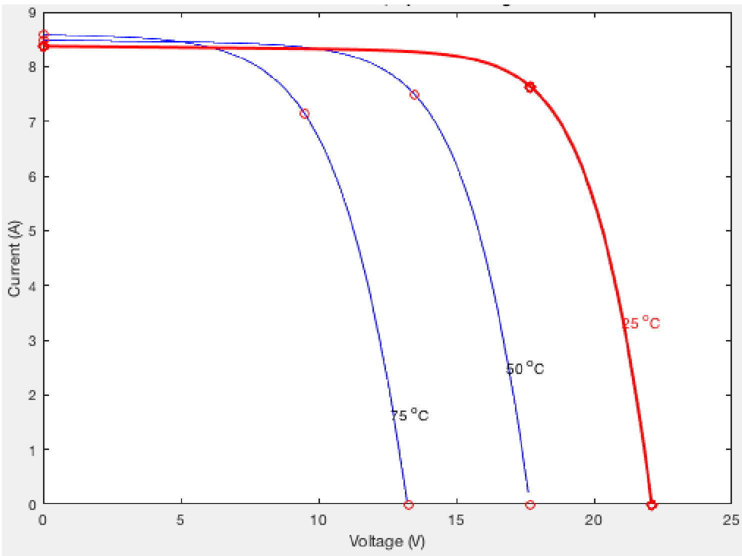


Figure 3.7 - Kyocera KD135GH-2PU I-V output MATLAB model @1000W/m^2 at various cell temperatures.

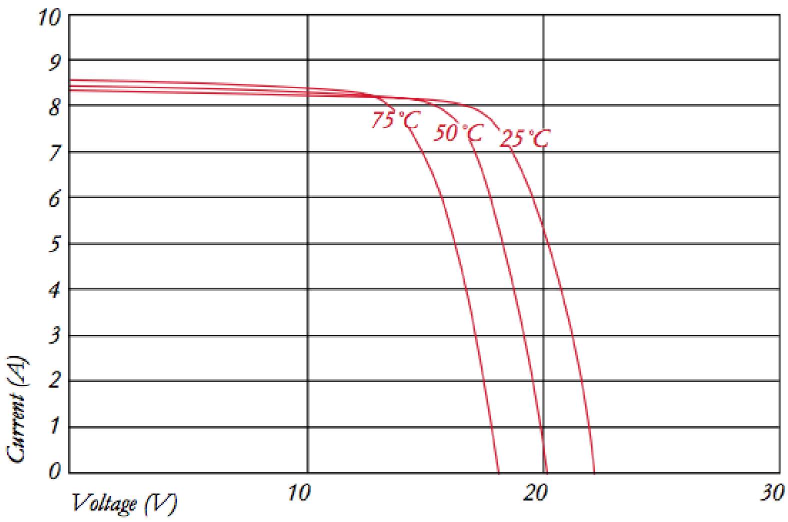


Figure 3.8 - Kyocera KD135GH-2PU module I-V data sheet characteristics @1000W/m^2 at various cell temperatures (Kyocera, 2010).

3.3.3 MATLAB/Simscape Student Version Limitations

The model in figure 3.9 below failed due to the student version software limitations. This limitation only allowed 1,000 blocks per model, which was quickly achieved. Figure 3.9 shows the model as six panels with four sections per panel when this limit was reached. Figure 2.33 showed that each PV array complex block is made up of more than seventeen smaller blocks, which was the major factor contributing to the limit being reached.

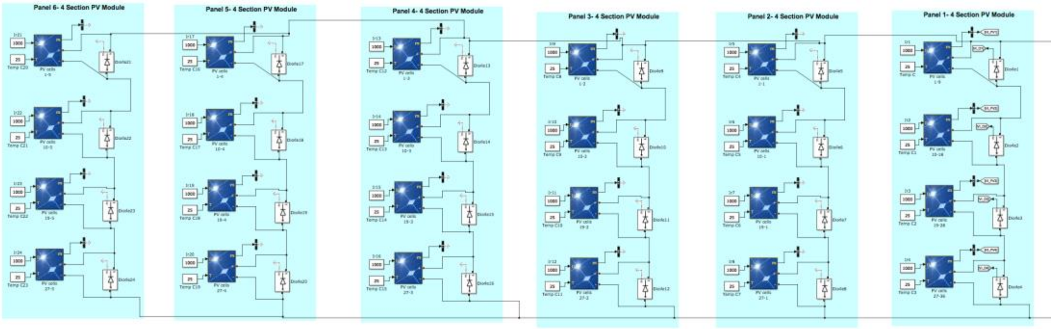


Figure 3.9 - Six panel model with four sections per panel.

3.3.4 Preliminary 135W Simulation Predicted Results and Analysis

The single 135W panel was simulated to show the individual impact that temperature has on a single panel's performance. Figure 3.10 shows the effect 90°C has on a single 135W PV panel. Table 3.1 shows the reduction of output as the section increases in heat and coverage 63% reduction at 90°C. This was performed to allow the five cell representation model to be compared to the single panel in order to validate the results. Table 3.1 indicates when a single panels output would be reduced by 10% and 20%, which are the ten and twenty-five year output manufactures guarantees.

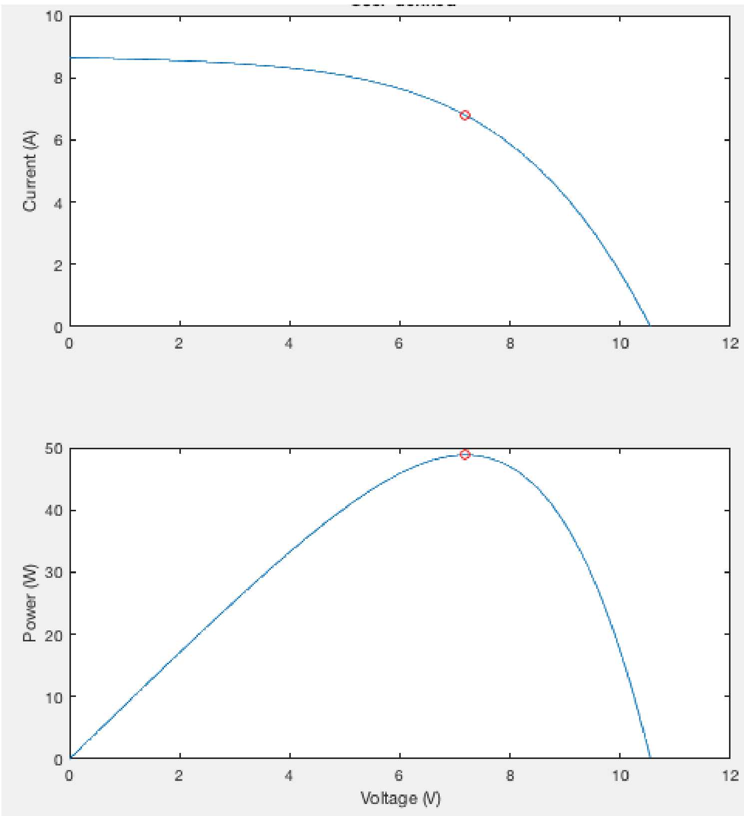


Figure 3.10 - Single panel @1000W/m^2 and 100% panel 90°C – 48.80W.

Table 3.1 - Heating effects on a single panel with 4 sections varied.

Single Panel @1000w/m2 Irradiance all cell values (°C)					
Cell 1-9	Cell 10-18	Cell 19-28	Cell 29-36	Output(Watts)	Output Reduction %
25	25	25	25	135.04	0.00
38	25	25	25	130.60	3.29
51	25	25	25	126.15	6.58
64	25	25	25	121.69	9.89
77	25	25	25	117.26	13.17
90	25	25	25	112.86	16.42
90	38	25	25	108.47	19.68
90	51	25	25	104.07	22.93
90	64	25	25	99.67	26.19
90	77	25	25	95.29	29.44
90	90	25	25	90.94	32.66
90	90	38	25	86.61	35.86
90	90	51	25	82.29	39.06
90	90	64	25	77.98	42.25
90	90	77	25	73.71	45.42
90	90	90	25	69.53	48.51
90	90	90	38	65.26	51.67
90	90	90	51	61.08	54.77
90	90	90	64	56.95	57.83
90	90	90	77	52.84	60.87
90	90	90	90	48.80	63.86
45	45	45	45	107.80	20.17

Table 3.1 was created to test the simulation from a single 135W panel four section in Simscape. This simulation shows the effects on an individual arrays output due to temperature increase. It is evident that when just over one quarter of the panels temperature is increased to 90°C, the panels output is below 20% which would void the manufacturers twenty-five year output guarantee. The panel would be outside this if it is above 45°C the whole panel or a 20°C temperature rise.

3.3.5 4725W Panel Calibration Model (35 x 135W)

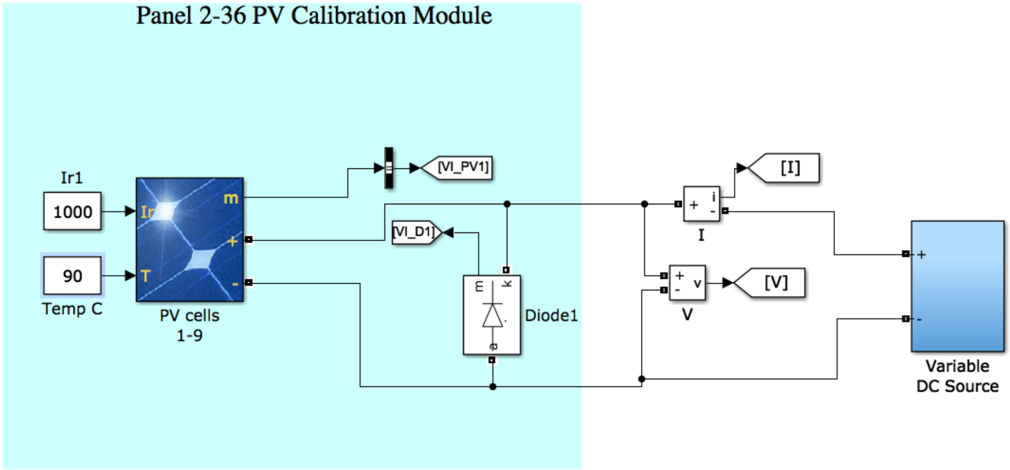


Figure 3.11 - Panel 2-36 calibration model.

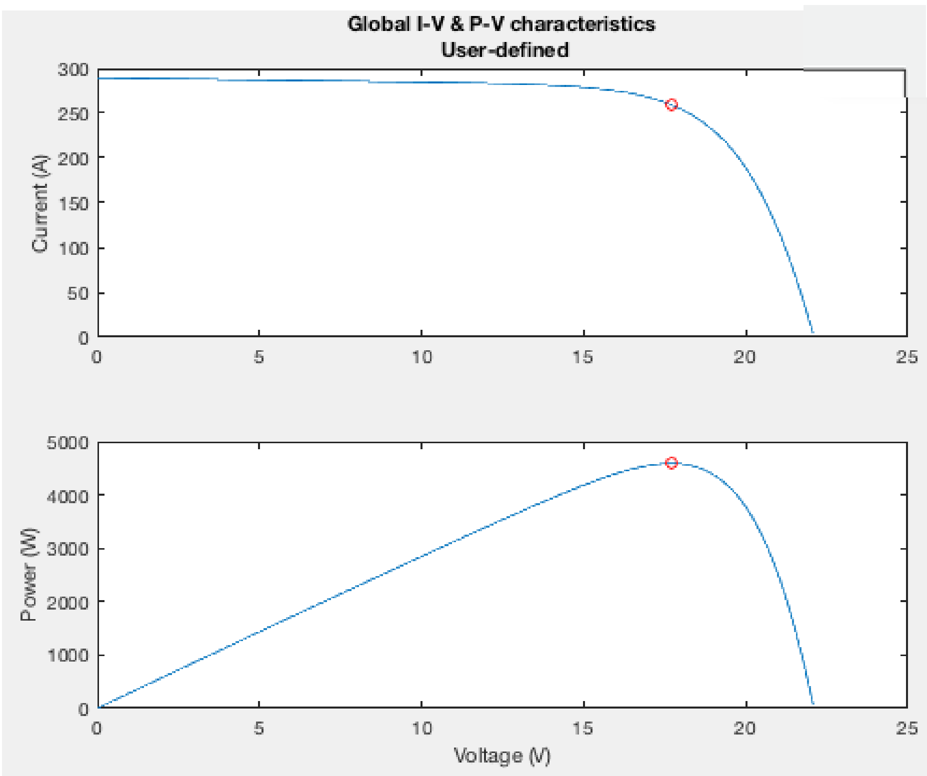


Figure 3.12 - Panel 2-36 calibration model plot.

Figure 3.11 and 3.12 show the model and results of the 2-36 calibration module representation to validate the thirty-five panels in the string. This block will allow for the simulation to represent the whole string and show the cell temperature increase effects on the entire string of panels.

3.4 PHYSICAL TESTING SITE AND EQUIPMENT

The Townsville RSL Stadium Solar Farm has approximately 1,800 PV panels. It is not feasible to test every PV panel, therefore practical testing was restricted to thirty-six panels. The location is indicated by the orange oval in figure 3.13. There were thirty-six panels selected as this is the number of panels in a single string. The PV panels are 135W Kyocera KD135GH-2PU – High efficiency multi-crystal photovoltaic module. All conclusions are therefore based on the assumption that the results of the testing and equipment of these panels may not be applicable to other PV panel models commercially available (Data sheet in appendix A3).

Figure 3.13 - RSL Stadium Solar Farm, scanned area in orange (Kyocera, 2012).

Figure 3.14 - Physical scanned area first roof tier, (orange area from figure 3.13).

3.5 SAFETY - PHYSICAL TESTING

Safety is a critical consideration with every task, safety in design, safety in work practice and safety in the life cycle. The detailed risk assessment can be found in Appendix A4. Medium level risks identified include working at heights. At five storeys tall, a fall from the roof at the RSL Stadium could be fatal. This risk was reduced by wearing appropriate equipment including, a tested harness and always ensuring one connection point was maintained to an approved attachment point, suitable to provided fall restraint loads.

Other medium risks present are test equipment use. Working around these live DC electrical parts are mitigated due to the technician being a qualified electrician and using this experience to identify possible risk sources and limit the exposure to these sources.

All vehicle driving is medium risk but is reduced by conscious adherence to driving appropriately, obeying road rules and driving to the conditions. In general, working outdoors also poses a medium risk. All medium risks were reduced to low once the control measures were implemented. This allowed the physical testing to be performed safely. A detailed risk assessment and control measures is attached (Appendix A4).

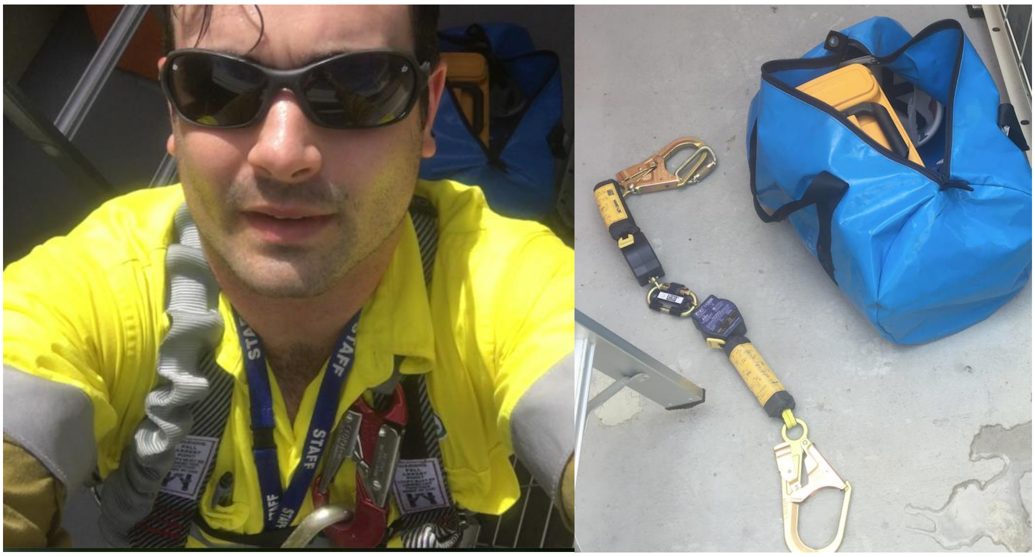


Figure 3.15 - Glen Adcock wearing harness onsite (left) and associated attachment gear (right).

3.6 PHYSICAL TESTING

The Physical testing was performed at RSL Stadium Solar Farm, Townsville, Australia. The testing was conducted using a hand held Fluke 25Ti thermal camera. Scans were performed on thirty-six 135W panels representing one string, with the aim to detect any panels with thermal variations or “hot spots”. When an abnormality was detected, a detailed thermal scan was completed. Infrared images were captured of the area to allow temperature increases to be measured and recorded.

The major constraints associated with testing and using a thermal camera, that it can only be completed under certain conditions. Most importantly for quality results there is a need for a continuous light source. Sources available are either the sun or an artificial source. For this method testing, using the sun was the most practical source despite the disadvantage of it being an uncontrollable source.

4 CHAPTER FOUR: RESULTS

4.1 SIMULATION RESULTS

Table 4.1 shows the MATLAB/Simscape results for the main thirty-six panel model in figure 3.2. Table 4.1 shows the output reduction for the thirty-six panel string as each cell or panel temperature is increased to the maximum panel operating temperature of 90°C. Panel 1 being the five section variable panel and panel 2-36 being the thirty-five panel string block representation. Table 4.1 calculations are based on the model output data performed at 1000w/m^2. This irradiance is the standard manufacturers irradiance value for panel output rating.

Table 4.1 - Simulated results at panel rating 1000w/m^2.

Total String Panel Configuration @1000w/ m^2 Irradiance								
Panel 2-36 (°C)	Panel 1(°C)					Output (Watts)	Output Reduction %	Loss Watts
	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5-36			
25	25	25	25	25	25	4860.30	0.000	0.000
25	38	25	25	25	25	4859.80	0.010	0.500
25	51	25	25	25	25	4859.30	0.021	1.000
25	64	25	25	25	25	4858.70	0.033	1.600
25	77	25	25	25	25	4858.20	0.043	2.100
25	90	25	25	25	25	4857.60	0.056	2.700
25	90	38	25	25	25	4857.00	0.068	3.300
25	90	51	25	25	25	4856.30	0.082	4.000
25	90	64	25	25	25	4855.70	0.095	4.600
25	90	77	25	25	25	4855.00	0.109	5.300
25	90	90	25	25	25	4854.20	0.126	6.100
25	90	90	38	25	25	4853.50	0.140	6.800
25	90	90	51	25	25	4852.70	0.156	7.600
25	90	90	64	25	25	4851.90	0.173	8.400
25	90	90	77	25	25	4851.10	0.189	9.200
25	90	90	90	25	25	4850.20	0.208	10.100
25	90	90	90	38	25	4849.30	0.226	11.000
25	90	90	90	51	25	4848.60	0.241	11.700
25	90	90	90	64	25	4847.40	0.265	12.900
25	90	90	90	77	25	4846.40	0.286	13.900
25	90	90	90	90	25	4845.40	0.307	14.900
25	90	90	90	90	38	4796.20	1.319	64.100
25	90	90	90	90	51	4685.70	3.592	174.600
25	90	90	90	90	64	4513.10	7.144	347.200
25	90	90	90	90	77	4291.60	11.701	568.700
25	90	90	90	90	90	4037.10	16.937	823.200
38	90	90	90	90	90	3931.70	19.106	928.600
51	90	90	90	90	90	3345.90	31.159	1514.400
64	90	90	90	90	90	2863.10	41.092	1997.200
77	90	90	90	90	90	2320.20	52.262	2540.100
90	90	90	90	90	90	1757.10	63.848	3103.200

From table 4.1 the effects of increasing cell temperature on the entire panel/s is evident. There is less than 1% string output reduction when four cells are operating at 90%. The major impact is when the operating temperature is above 60°C for the single panel. At this temperature there is almost a 17% reduction on the string output. When a single panel is operating at 90°C, and all other panels in the string are operating at 25°C.

4.2 PHYSICAL TESTING RESULTS

The physical infrared thermal scans were completed on 20th August 2016 at Townsville RSL Stadium between 12.30-2pm. These panels were selected after analysis of factors including access, attachment point locations and risk assessment. Figure 4.1 below shows the access, attachment points and identification of the thirty-six panels scanned. Each panel was identified using a numbered yellow post-it note to allow photo identification.

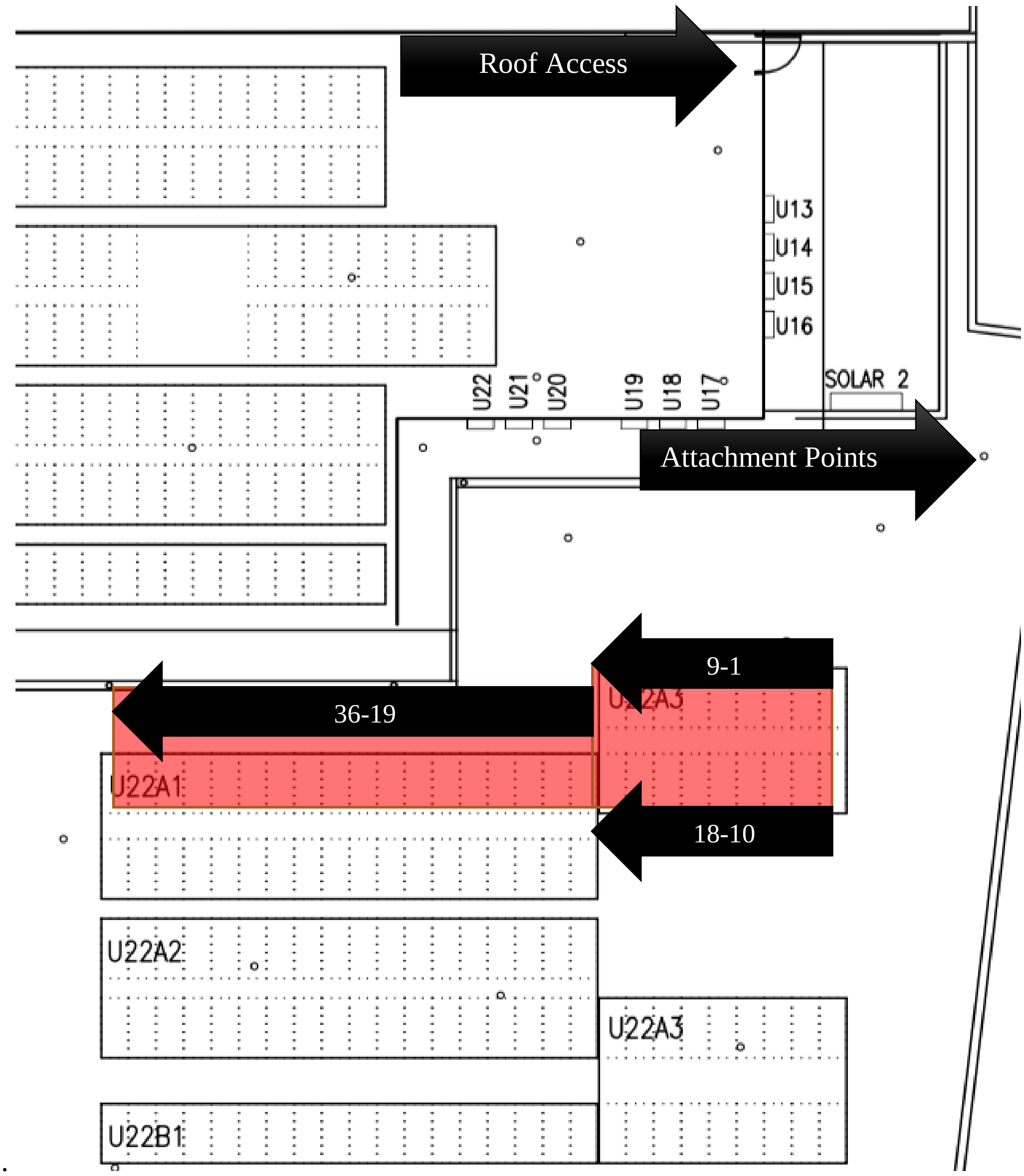


Figure 4.1 - Zoom of layout (Red) indicating the 36 panels scanned, access and attachment points (Appendix B full size).

4.3 TESTING PERIOD TEMPERATURE

The temperature at RSL Stadium during physical testing is detailed in table 4.2. Throughout the 1.5 hour period which physical testing was conducted, the temperature remained within the band of 24-26°C. There were no rain events recorded during this period.

Table 4.2 - Temperature at RSL Stadium during physical testing (Weatherzone, 2016).

Timestamp	Wind Direction	Wind Speed (km/h)	Temperature (°C)	Dew Point (°C)	Relative Humidity (%)
11:50:00 am	ENE	19	25	16.9	60
12:00:00 pm	E	18	24.4	16.8	63
12:10:00 pm	ESE	19	24	16.5	63
12:20:00 pm	NE	22	24.4	16.8	62
12:30:00 pm	ENE	18	25.5	16.6	58
12:40:00 pm	E	24	26.3	16.8	56
12:50:00 pm	ENE	22	25.5	16.8	58
1:00:00 pm	E	20	24.5	16.9	63
1:10:00 pm	NE	20	24.4	16.9	63
1:20:00 pm	NE	17	25.4	16.8	59
1:30:00 pm	NE	20	25.1	16.7	60
1:40:00 pm	E	20	25.3	16.7	59
1:50:00 pm	NE	19	25.4	17	59
2:00:00 pm	ENE	20	25.6	17.2	60
2:10:00 pm	NE	26	25.8	17.7	61
2:20:00 pm	ENE	22	24.8	18	66
2:30:00 pm	ENE	24	24.8	17.8	65

4.4 INFRARED THERMAL CAMERA ISSUES

All physical thermal camera shots are not in sync. Fluke Ti25 infrared thermal camera has two separate cameras; one for the thermograph and one for the standard image when the image is captured on an angle. This overlay of the two images will not line up, which is evidenced in the figure 4.3. Figure 4.4 shows the manually edited image to provide thermal and physical details aligned.

Figure 4.2 - Fluke Ti25 infrared thermal camera showing the top visual camera (blue) and bottom infrared lens (red) (Fluke, 2010).

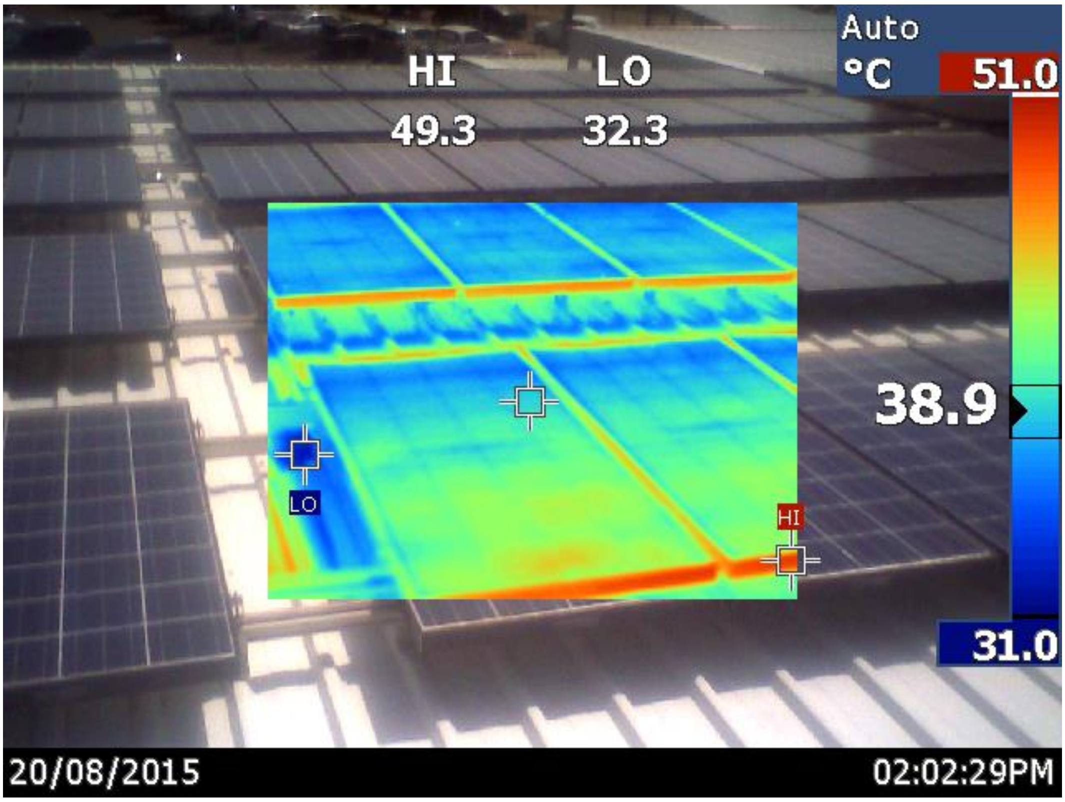


Figure 4.3 - The infrared image and photo image are out of sync.

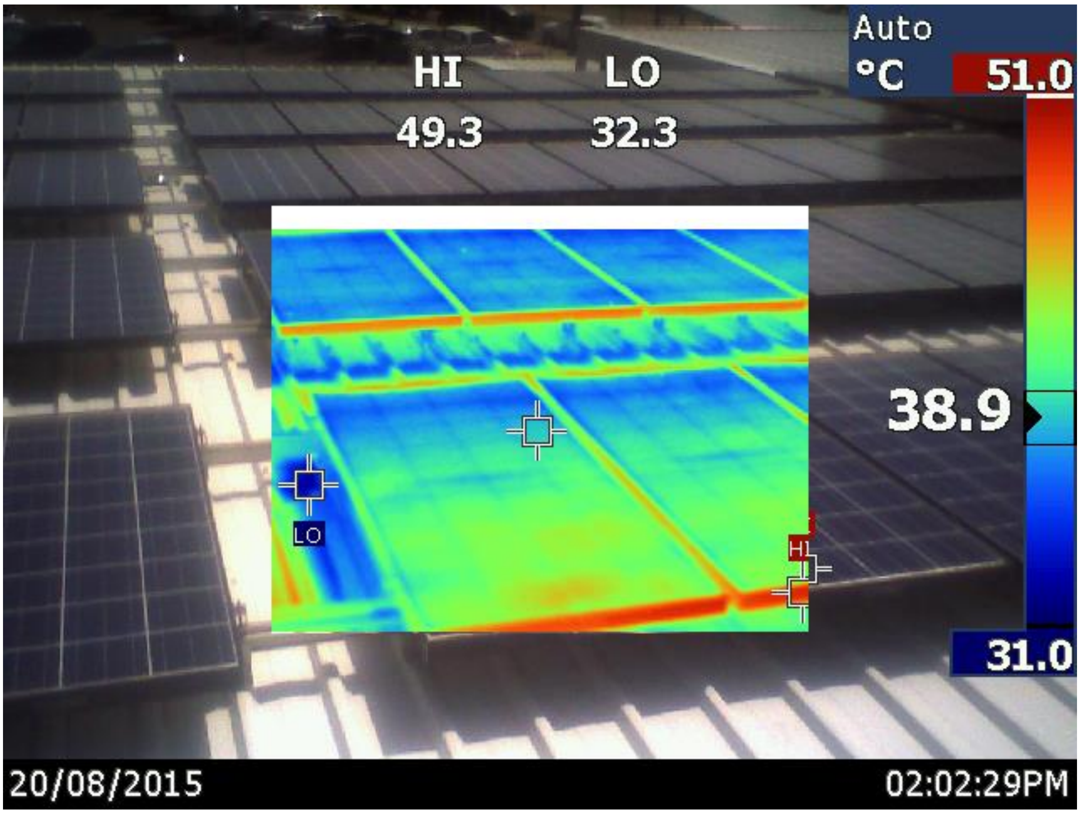


Figure 4.4 - Infrared imaged has been lowered to sync with photo image.

All infrared images will be manually aligned to allow for accurate visual representation.

4.5 DIRT/INGRESS EFFECT

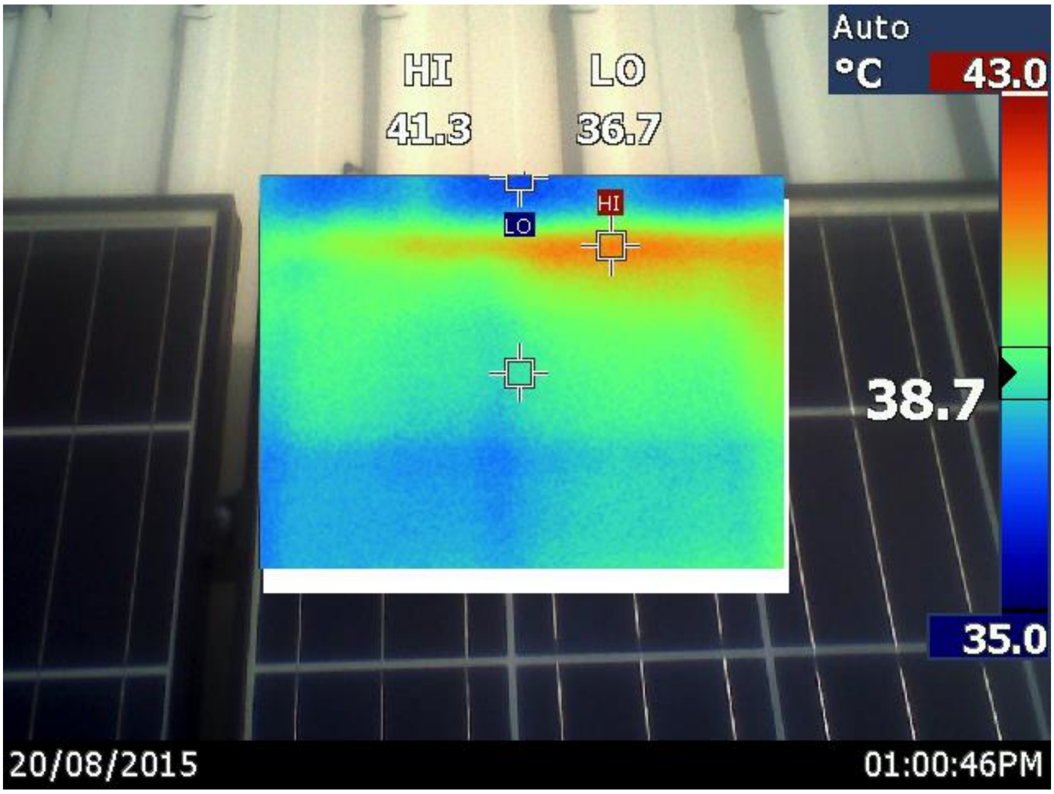


Figure 4.5 - Effects of ingress and dirt on array.

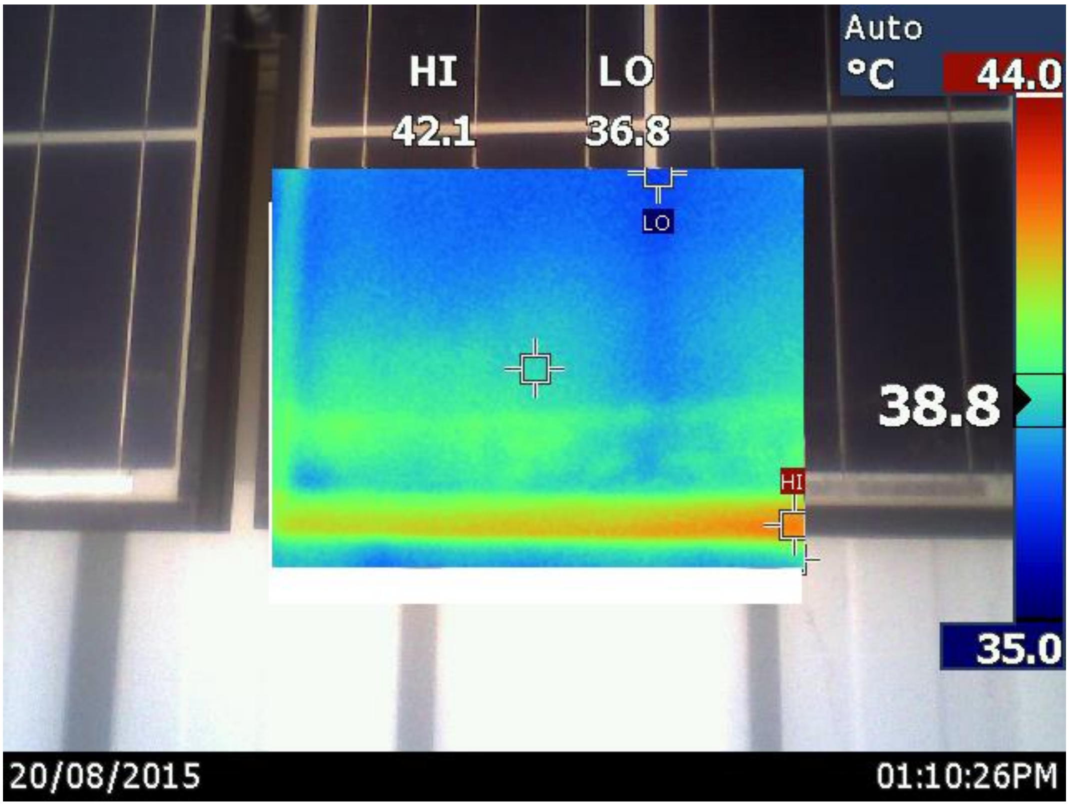


Figure 4.6 - Panel temperature lowered from 41.3 - 36.8°C after cleaning.

Figures 4.5 and 4.6 display before and after infrared images, which is caused by ingress, build up on the bottom side of the slope of the panel. There was only a small 4.5°C increase caused by this dirt/ingress.

Due to the low megapixel camera on the infrared thermal camera matching still photos were also taken to provide greater detail. Figure 4.7 below shows the dirt and ingress.

Figure 4.7 - Ingress and dirt on panel before cleaning causing heating.

4.6 CELL HOT SPOT DETECTION

All the following cell failures are assumed to be approximately 36°C for healthy panel temperature at normal operation. Hot spots will be any temperature increase above this value. This assumption is validated by the infrared images in figure 4.8 to 4.21.

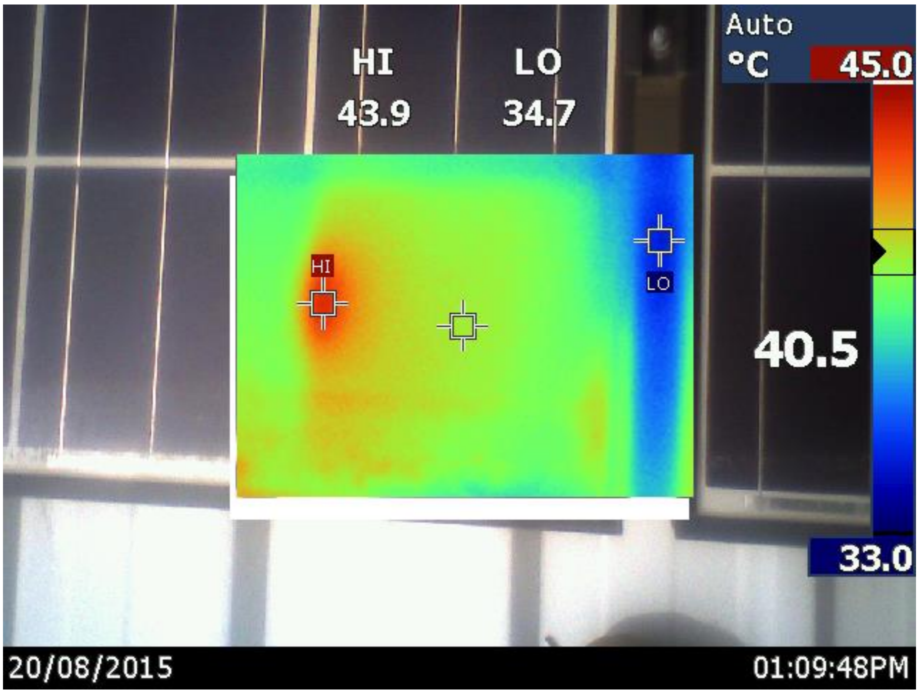


Figure 4.8 - Early cell failure signs 8°C hot spot approximately, less than 10% cell coverage.

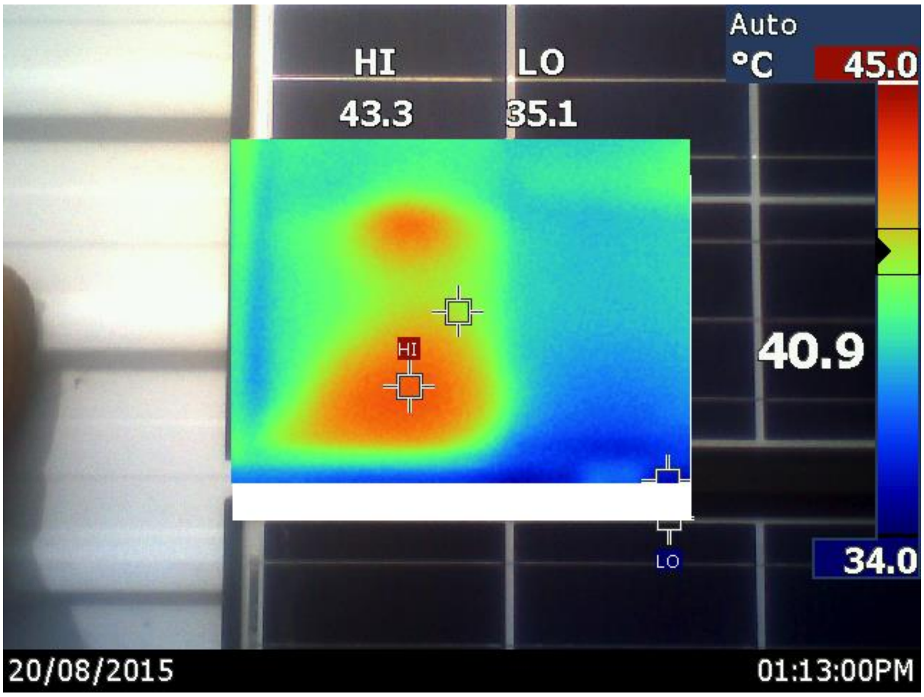


Figure 4.9 - 1st major cell failure detection 7.3°C hot spot, approximately 40% cell coverage.

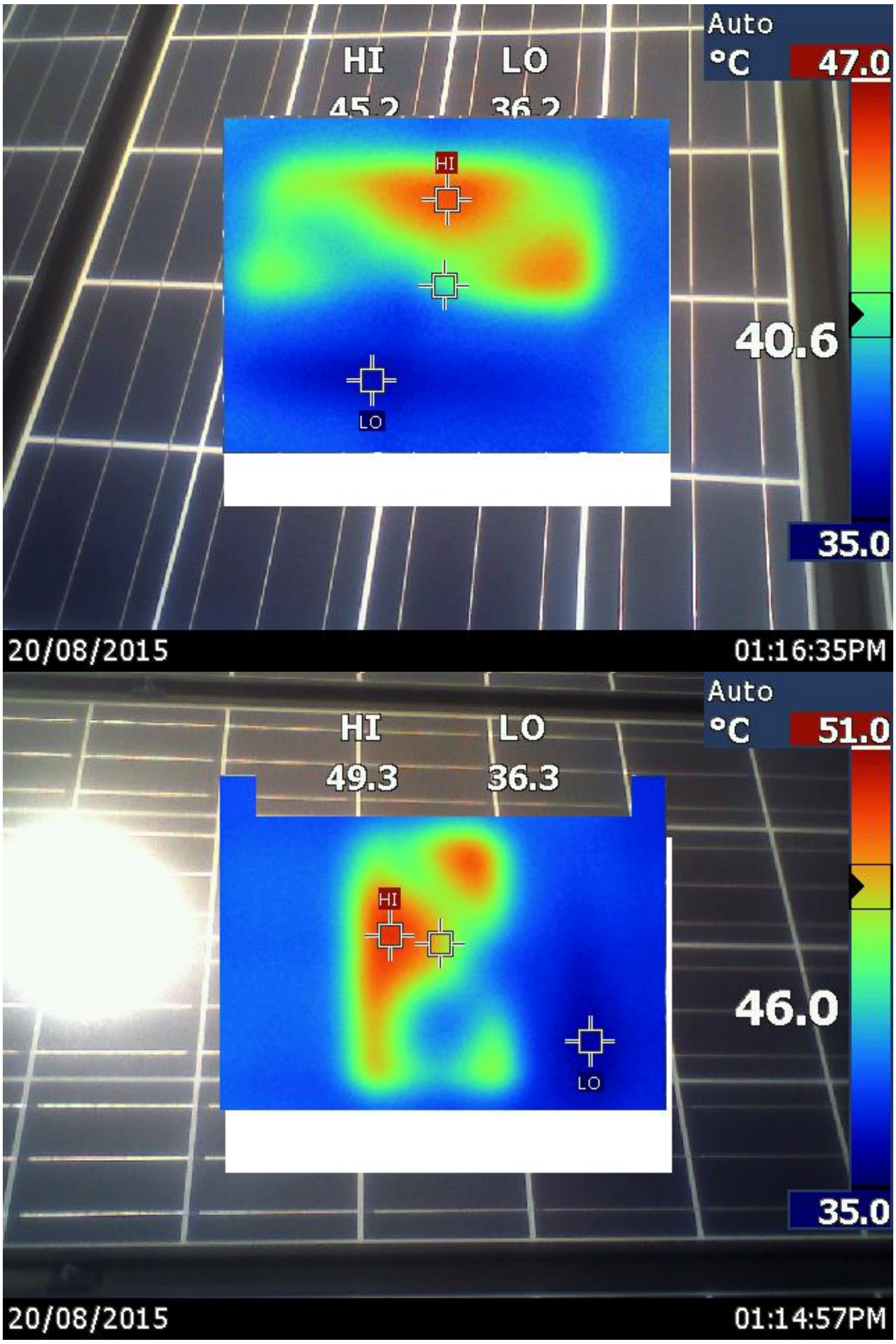


Figure 4.10 - Two images of the 2nd detection dual cell failures – 13.3°C max hot spot, approximately 50% cell coverage.

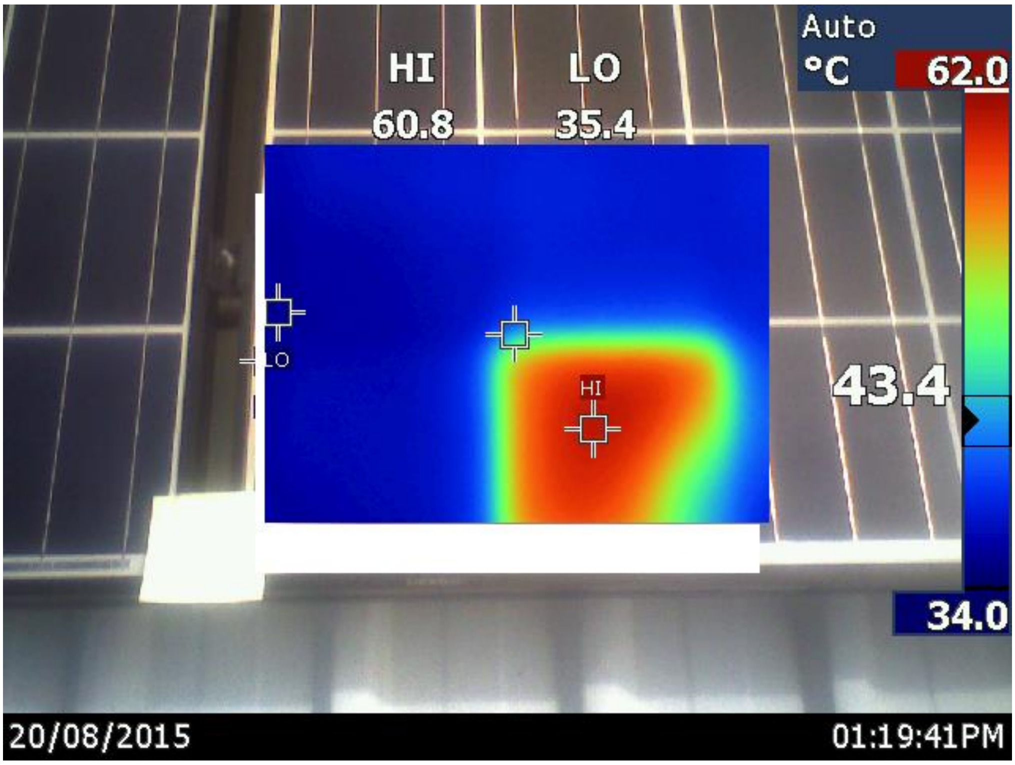


Figure 4.11 - 3rd detection – 24.8°C max hot spot 90% cell coverage.

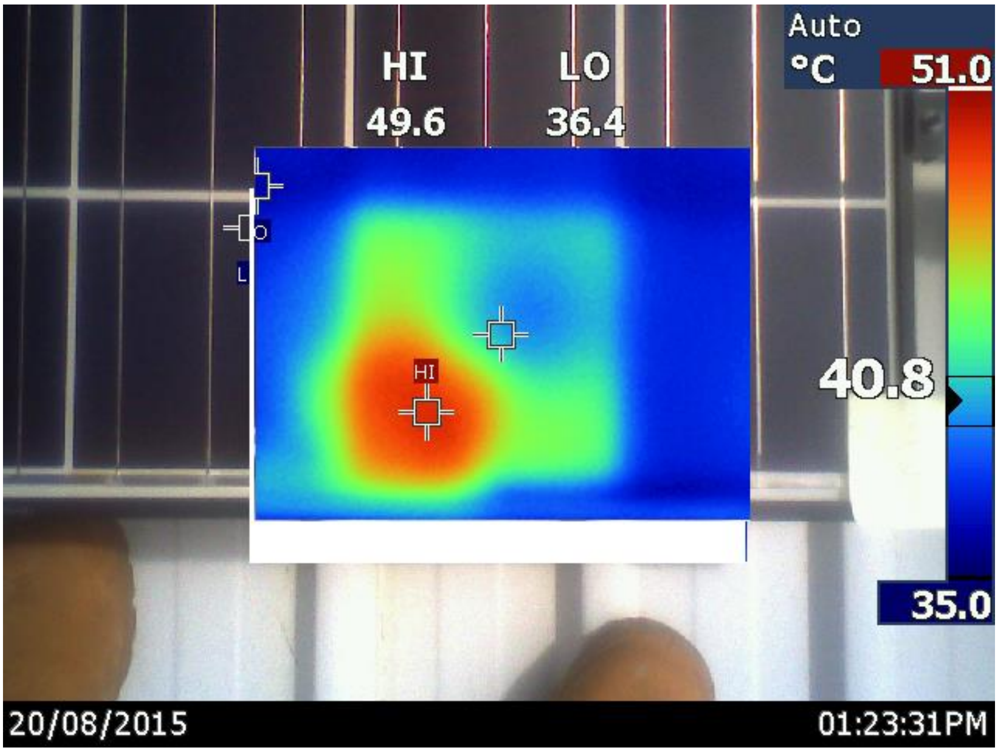


Figure 4.12 - 4th detection 13.6°C hot spot 40% cell coverage.

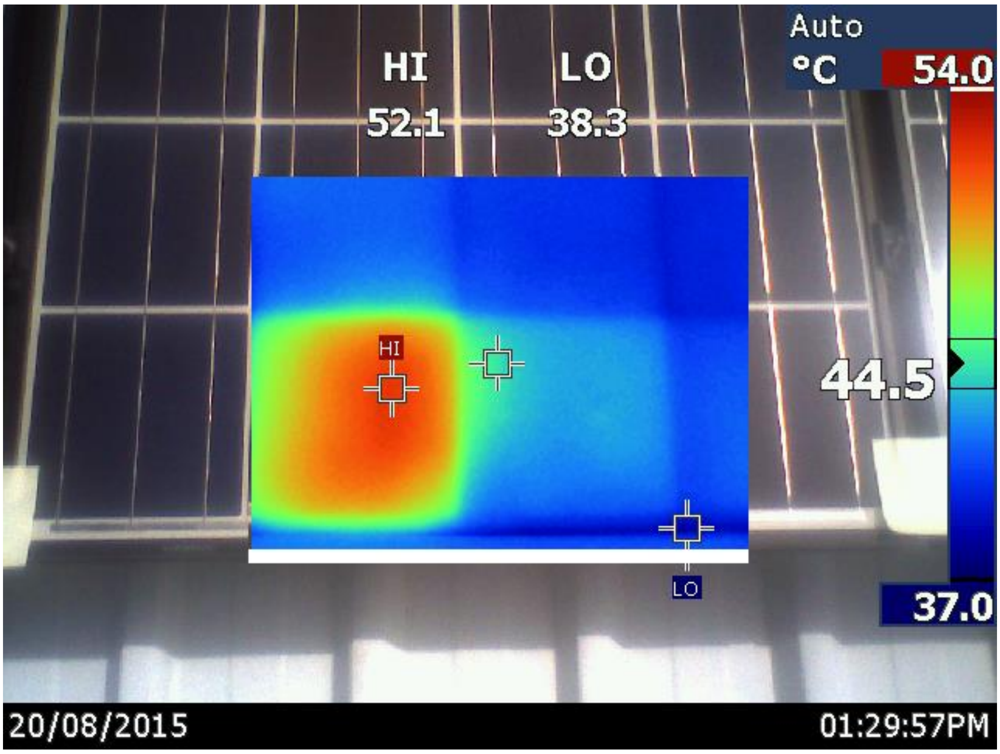


Figure 4.13 - 5th detection 16°C hot spot approximately 95% cell coverage.

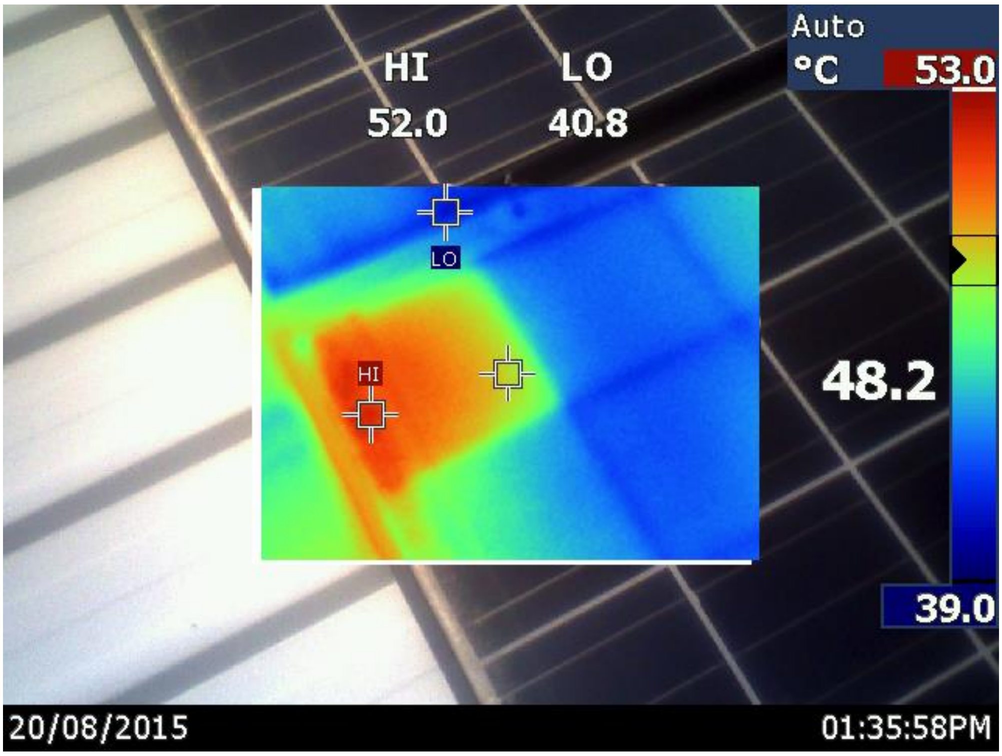


Figure 4.14 - 6th detection - 16°C hot spot approximately 95% cell coverage.

4.7 HOT SPOT DISTANCE DETECTION

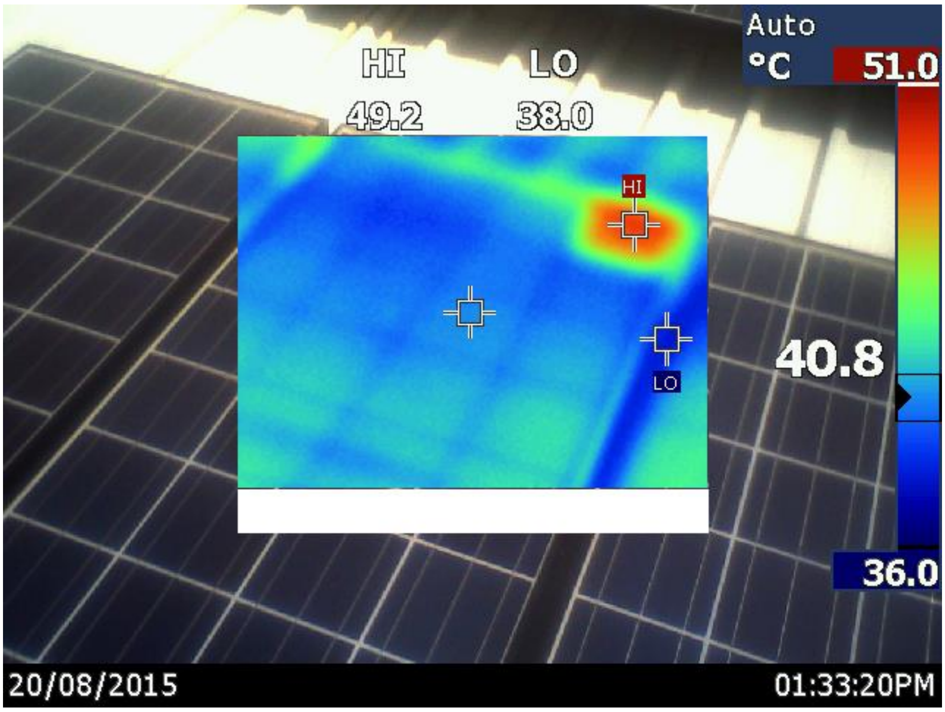


Figure 4.15 - Same 6th detection from distance hot spot stands out.

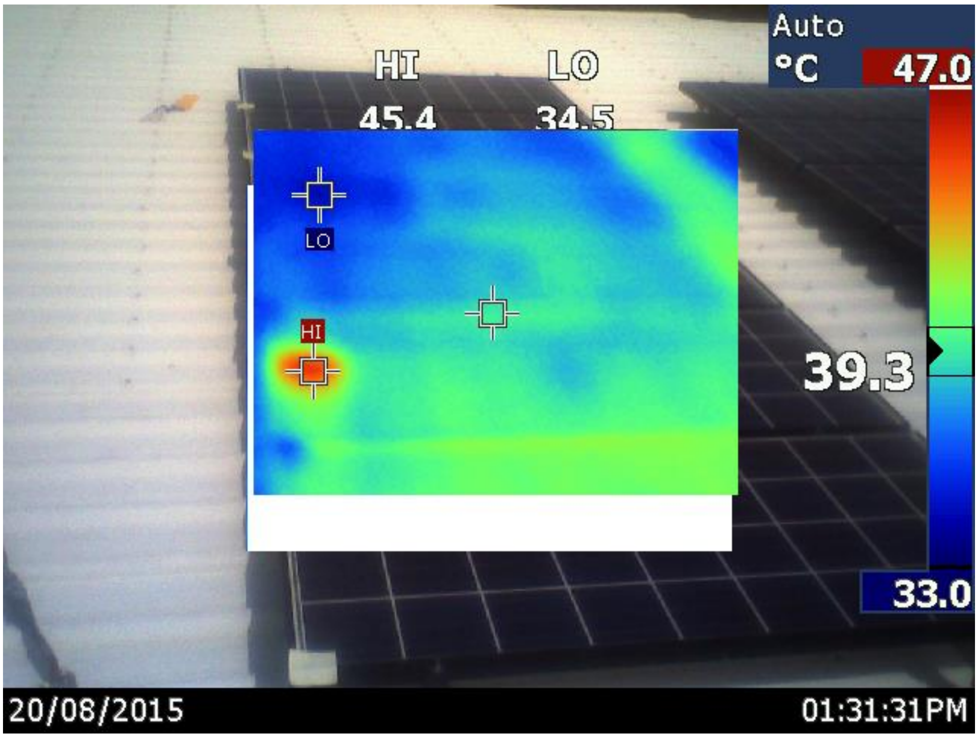


Figure 4.16 - 4th detection from distance hot spot stands out.

Figures 4.15 and 4.16 show how noticeable the hot spots are even at 3-5 meters away, this will support the chances for effective thermography with the a UAV. Effectively once a technician was experienced they could quickly sweep the PV panels and only have to perform a detailed scan once detection is triggered. This would provide a great time efficiency. No hot spots detected indicated any degradation signs to the naked eye.

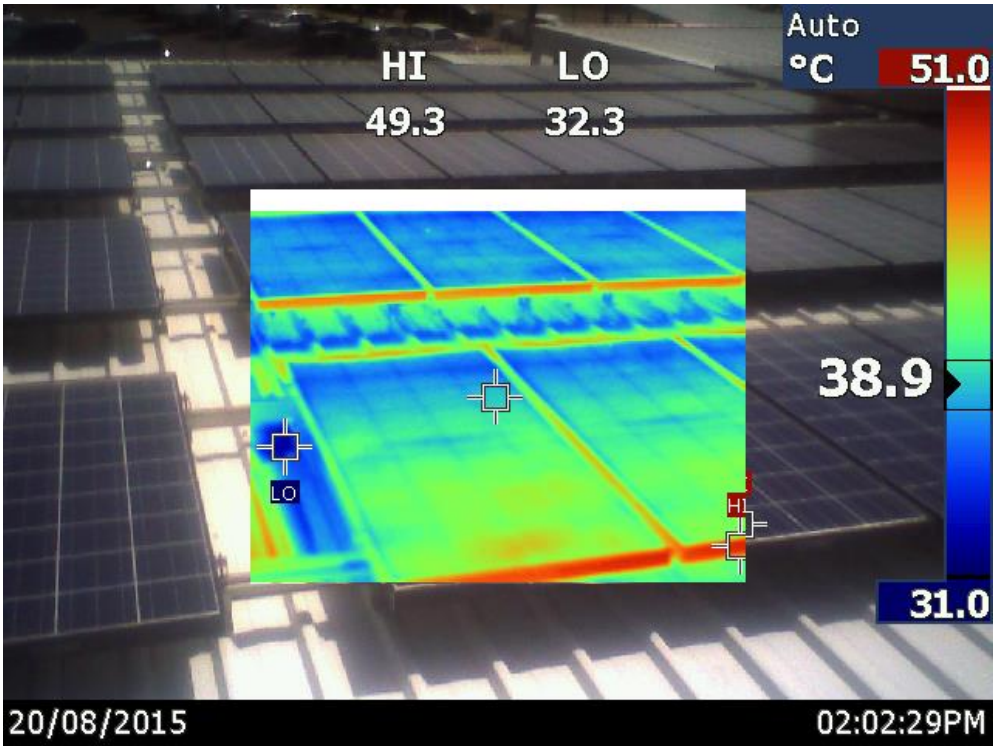


Figure 4.17 - Healthy panels from a distance, no visual signs of hot spots.

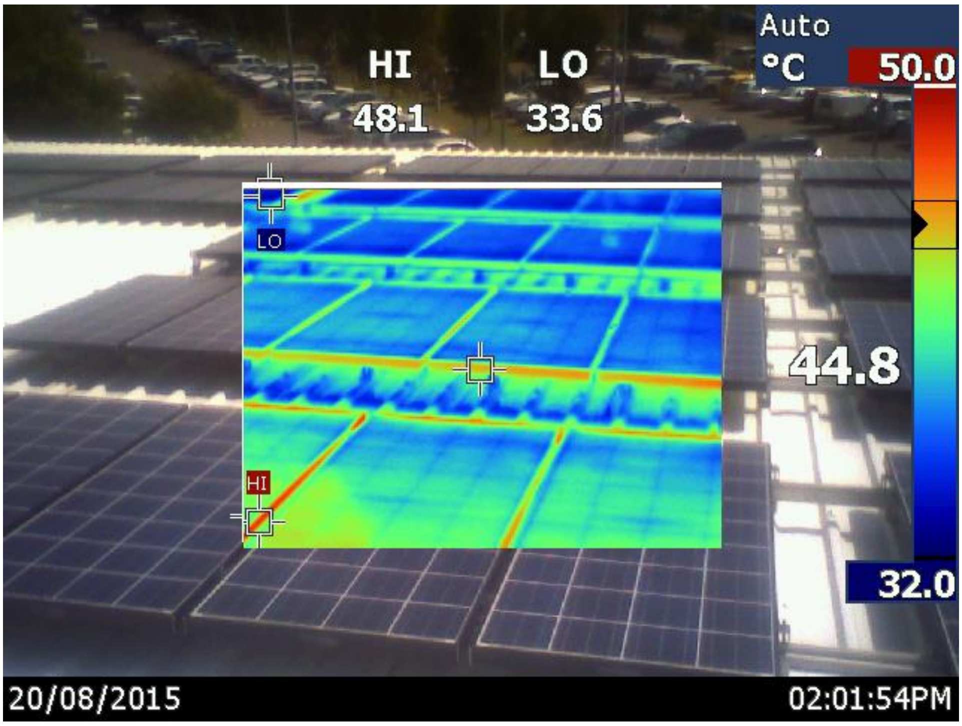


Figure 4.18 - Healthy panels from a distance, no major visual signs of hot spots.

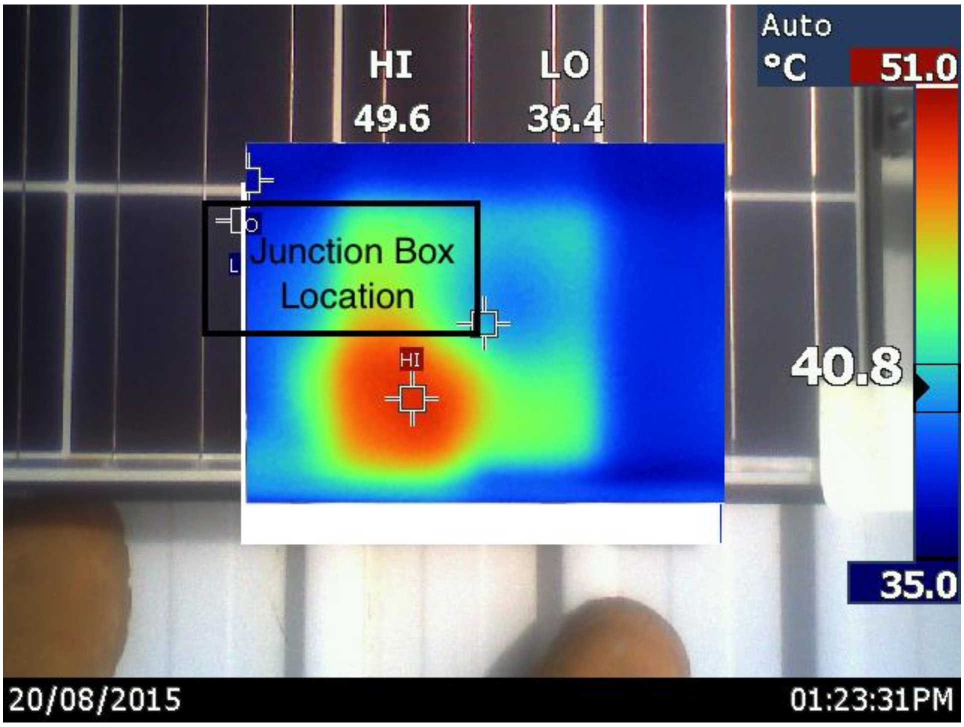


Figure 4.19 - Junction box indication, to confirm heating was not coming from junction box area.

Figure 4.20 - Junction box located between 2nd and 3rd cell on 1st row.

Figure 4.19 and 4.20 provide certainty that none of the heating originated from the junction box. The junction box position has been drawn overlaying figure 4.19 to provide a visual representation of position, showing no correlation with any of the hot cells detected.

4.8 INFRARED CAMERA IMAGE RESOLUTION

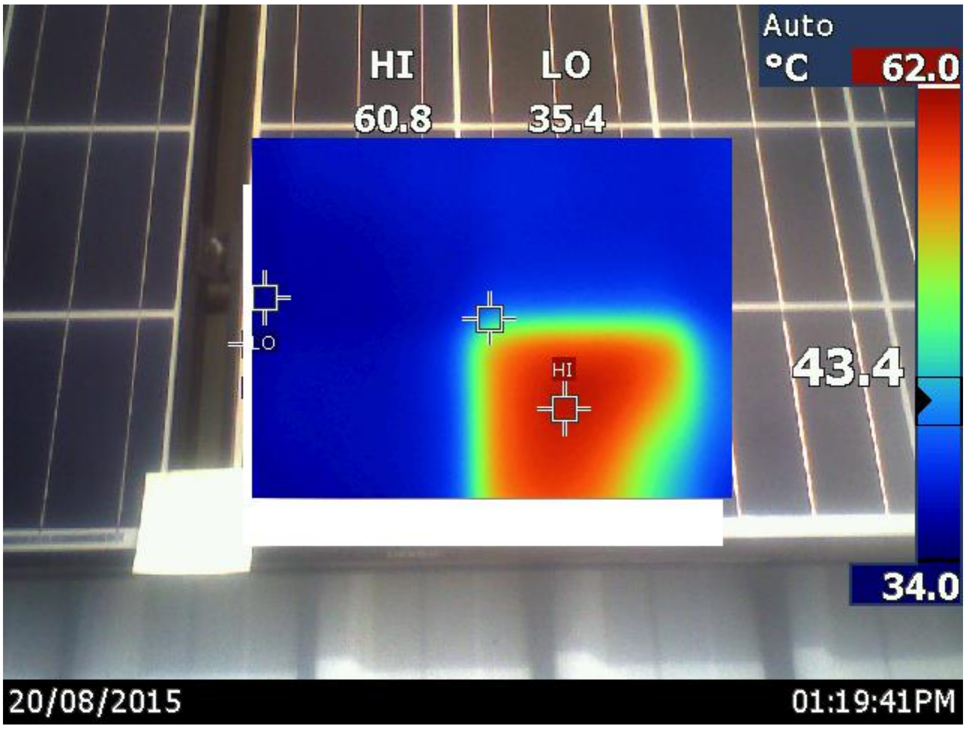


Figure 4.21 - Cell identification, yellow post-it note not legible due to poor thermography picture quality.

Figure 4.22 - 2nd picture taken of yellow post-it note showing panel 4 and foot indicating hot cell from figure 4.21.

Due to the lower quality of the Fluke Ti25 thermal thermograph image, a second picture was captured at cell failure locations. The hot cell was indicated by the shoe in figure 4.22. This allowed identification of which panel corresponded to each hot spot cells thermography images to be identified offsite at a later time.

4.9 PHYSICAL TESTING SUMMARY

Physical testing was successful using the Fluke Ti25 infrared thermal camera as shown in table 4.3. Multiple hot spots were detected, with six out of thirty-six panels having hot spots or 16.6%.. Identifying the failure rate of the thirty-six panels at a cell value, seven failed cells, thirty-six arrays multiplied by thirty-six cells per array, calculated to a cell failure rate of 0.54%. However with only a thirty-six panel sample size; out of the eighteen-hundred panels installed at the solar farm it is unsure if this is a true indication of the whole solar farms failure rates.

Table 4.3 - Infrared thermograph detection results.

Detection Number	Number of Cells and Coverage %	Temperature	Rise
1	1 x 40%	43.3	7.3
2	2 x 50%	49.3	13.3
3	1 x 90%	60.8	24.8
4	1 x 40%	49.6	13.6
5	1 x 95%	52.1	16.1
6	1 x 95%	52.0	16.0

$$Cell\ Failure\ Rate = \left(\frac{7\ cell}{(36\ cells\ x\ 36\ panels}\right) \text{x}\ 100$$

$$= 0.54\ \%$$

An issue during the physical testing was the low resolution of the Fluke Ti25 infrared thermal camera. The image also had sync issues between the infrared and photo image, which was identified and a second camera was used to capture faulted cell location.

4.10 RESULTS SUMMARY

The simulation was successful in confirming that increased panel temperature will result in reduced output. The physical testing was also successful in detecting hot spots, with no hot spots being visible to the naked eye. The dirty arrays temperature increase was heated to 42°C with the hottest cell temperature measured at 60.8°C, equating to almost a 25°C temperature rise. In total seven hot spots were found which was a successful confirmation that infrared thermography is a viable option for detection. However a more effective identification and scanning process would be required for large scale scanning. This is due to the time consuming use of hand held device.

5 CHAPTER FIVE: BENEFITS ANALYSIS

5.1 CONDITION MONITORING

Condition monitoring of PV arrays is crucial in assuring the systems are operating at peak power output. Even though a typical solar farm does not have a large number of moving parts, they are subject to various fault conditions (identified in chapter two). As previously highlighted in earlier chapters it can be difficult to detect all faults with the naked eye. Detection of faulty conditions is very important as they can otherwise turn into safety issues. As previously shown, particular fault conditions cause increase heating, which culminates into an increased fire risk and premature panel degradation. The regular monitoring of assets would also improve reliability as detections can be monitored and will provide confidence in current asset condition. However condition monitoring does come at a cost. This cost being labour to perform physical testing, as well as the equipment required for testing and maintaining.

Condition monitoring should be performed at multiple stages of the life cycle. Manufacturers could perform thermographs before shipping as evidence and to provide quality assurance. Thermographs could again be performed, once arrays are unpacked from delivery, to provide assurance that no damage has been caused during transportation. Another stage that thermographs could be performed is after installation to ensure no damage is caused during installation. Finally, routine scans which would be completed anywhere from three months to a number of years (depending on the site's importance, value and size). This testing period would be dependent on testing cost, replacement cost, wages and project lifetime payback periods.

All this monitoring data will be valuable in identifying which components of the life cycle are contributing most to the degradation of the asset. This would mean possibly implementing better control measures to minimise these impacts and improve the lifespan of the asset.

5.2 REVENUE IMPACTS

The main aim of condition monitoring is to maximise revenue and improve safety. Monitoring will need to be supported by a guideline for when remedial actions are feasible. All calculations are based on RSL Stadiums estimated output from Kyocera of 500MWh per year. For our example calculations we are assuming all 1,800 panels at the solar farm experience the same percentage reductions. The revenue rate will be calculated from the current 6.35c/kWh regional feed in tariff and the very generous solar bonus 44c/kWh, to provide the minimum and maximum examples.

Calculation for 348kW RSL Stadium

$$(Solar\ Farm\ Output) = \quad 500{,}000kWh\ per\ year\ (\text{Kyocera}, 2012)$$

	Minimum	Maximum
$\$ =$	$500{,}000\ x\ 6.35c$	$500{,}000\ x\ 44c$
$\$ =$	$31{,}750$	$220{,}000$

For a 135W Single Panel

$\frac{Solar\ Farm\ Output}{No.Panel} =$	$\frac{31{,}750}{1800}$	$\frac{220{,}0000}{1800}$
$(\$\ per\ 135W\ Panel\ per\ year) =$	17.63	122.22

Current replacement cost of 135W Kyocera Panel $369 (Wholesale Solar, 2016)

$Payback\ years =$	$\frac{369}{17.63}$	$\frac{369}{122.22}$
$Payback\ years =$	22.46	3.24

String Calculations

$No.of\ strings =$		$\frac{1800}{36} = 50$
$Average\ \$\ per\ string =$	$\frac{31{,}750}{50}$	$\frac{220{,}000}{50}$
$Average\ \$\ per\ string =$	635	$4{,}400$

From the results the 44c/kWh has the best return and payback periods.

5.2.1 Simulated Revenue Impacts – Theoretical

Using the above calculations for annual profit, the per string data was calculated to show the impacts. Table 5.1 shows revenue impacts for a single string. If these percentages are extrapolated to the entire solar farms fifty strings, using table 5.1, the 6th result from the bottom is one panel failing at 90°C, it will experience a $745 x 50 = $37,261 loss in revenue per year at 44c/kWh and $5,377 at 6.35c/kWh.

Table 5.1 - Annual lost revenue per string for 6.35c/kWh and 44c/kWh at various cell temperatures.

Total String Panel Configuration @1000w/m^2 Irradiance								
Panel 2-36 (°C)	Panel 1 (°C)							
	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5-36	Output Reduction %	Yearly $ Loss 6.35c	Yearly $ Loss 44c
25	25	25	25	25	25	0.00	0.00	0.00
25	38	25	25	25	25	0.01	0.06	0.44
25	51	25	25	25	25	0.02	0.13	0.92
25	64	25	25	25	25	0.03	0.21	1.45
25	77	25	25	25	25	0.04	0.27	1.89
25	90	25	25	25	25	0.06	0.36	2.46
25	90	38	25	25	25	0.07	0.43	2.99
25	90	51	25	25	25	0.08	0.52	3.61
25	90	64	25	25	25	0.10	0.60	4.18
25	90	77	25	25	25	0.11	0.69	4.80
25	90	90	25	25	25	0.13	0.80	5.54
25	90	90	38	25	25	0.14	0.89	6.16
25	90	90	51	25	25	0.16	0.99	6.86
25	90	90	64	25	25	0.17	1.10	7.61
25	90	90	77	25	25	0.19	1.20	8.32
25	90	90	90	25	25	0.21	1.32	9.15
25	90	90	90	38	25	0.23	1.44	9.94
25	90	90	90	51	25	0.24	1.53	10.60
25	90	90	90	64	25	0.27	1.68	11.66
25	90	90	90	77	25	0.29	1.82	12.58
25	90	90	90	90	25	0.31	1.95	13.51
25	90	90	90	90	38	1.32	8.38	58.04
25	90	90	90	90	51	3.59	22.81	158.05
25	90	90	90	90	64	7.14	45.36	314.34
25	90	90	90	90	77	11.70	74.30	514.84
25	90	90	90	90	90	16.94	107.55	745.23
38	90	90	90	90	90	19.11	121.32	840.66
51	90	90	90	90	90	31.16	197.86	1371.00
64	90	90	90	90	90	41.09	260.93	1808.05
77	90	90	90	90	90	52.26	331.86	2299.53
90	90	90	90	90	90	63.85	405.43	2809.31

5.2.2 Simulated Revenue Impacts – Physical Results

Using the temperatures measured from the physical testing, these temperature were input back into the simulation to provide estimated impacts. The greatest impact simulated was the dirt/ingress issue. The results were extrapolated to the other 50 strings (whole site), assuming no self-cleaning such as rain, wind etc. occurred throughout the year to provide for worst case scenario.

This resulted in a reduction of the strings output by 6.56% or 463.8W. Table 5.2 and 5.3 both show losses and revenue impacts for a single string estimated to $288.76 per string loss. If these results are extrapolated to the entire solar farm, would precipitate per annum revenue losses of approximately $14,438 at 44c/kWh and $2,084 at 6.35c/kWh. The seven failed cells detected from the thermography results were simulated and calculated to 0.1% reduction in output and a 7.1W loss, calculated to be a $4.42 per string. If this reduction was assumed to be present on all strings the annual revenue lost would be $221 per annum reduction at 44c/kWh. The extrapolation may be an imprecise assumption, however it is used as a guide for indication purposes only. Below are tables of all the measured temperatures, which have been simulated to allow for real world estimated reductions to be calculated.

Table 5.2 - RSL Stadium average irradiance, physical infrared thermography results simulation data, per string.

Total String Panel Configuration @1600w/m^2 Irradiance								
Panel 2-36 (°C)	Panel 1 (°C)					Output (Watts)	Output Reduction %	Loss Watts
	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5-36			
25	25	25	25	25	25	7918.80	0.000	0.000
36	36	36	36	36	36	7067.20	10.754	851.600
36	42	36	36	36	36	7066.90	0.004	0.300
36	42	42	36	36	36	7066.50	0.010	0.700
36	42	42	42	36	36	7066.10	0.016	1.100
36	44	36	36	36	36	7066.70	0.007	0.500
36	50	36	36	36	36	7066.40	0.011	0.800
36	60	36	36	36	36	7065.70	0.021	1.500
36	50	50	36	36	36	7065.50	0.024	1.700
36	50	61	52	52	37	7060.10	0.100	7.100
42	42	42	42	42	42	6603.40	6.563	463.800

Table 5.3 - Simulated revenue lost from physical scans, data from table 5.2 data.

Total String Panel Configuration @1600w/m^2 Irradiance								
Panel 2-36 (°C)	Panel 1 (°C)					Output Reduction %	Yearly $ Loss 6.35c	Yearly $ Loss 44c
	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5-36			
36	36	36	36	36	36	0.000	0.00	0.00
36	42	36	36	36	36	0.004	0.03	0.19
36	42	42	36	36	36	0.010	0.06	0.44
36	42	42	42	36	36	0.016	0.10	0.68
36	44	36	36	36	36	0.007	0.04	0.31
36	50	36	36	36	36	0.011	0.07	0.50
36	60	36	36	36	36	0.021	0.13	0.93
36	50	50	36	36	36	0.024	0.15	1.06
36	50	61	52	52	37	0.100	0.64	4.42
42	42	42	42	42	42	6.563	41.67	288.76

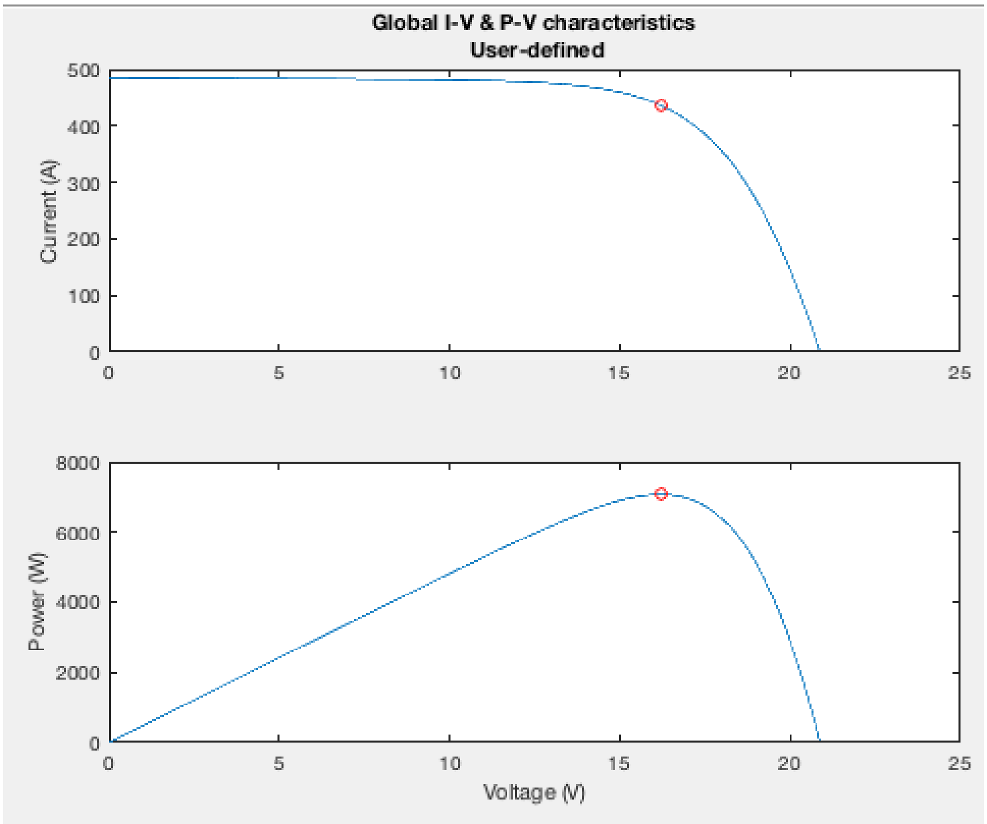


Figure 5.1 - Total output curves at 61°C hottest single cell model.

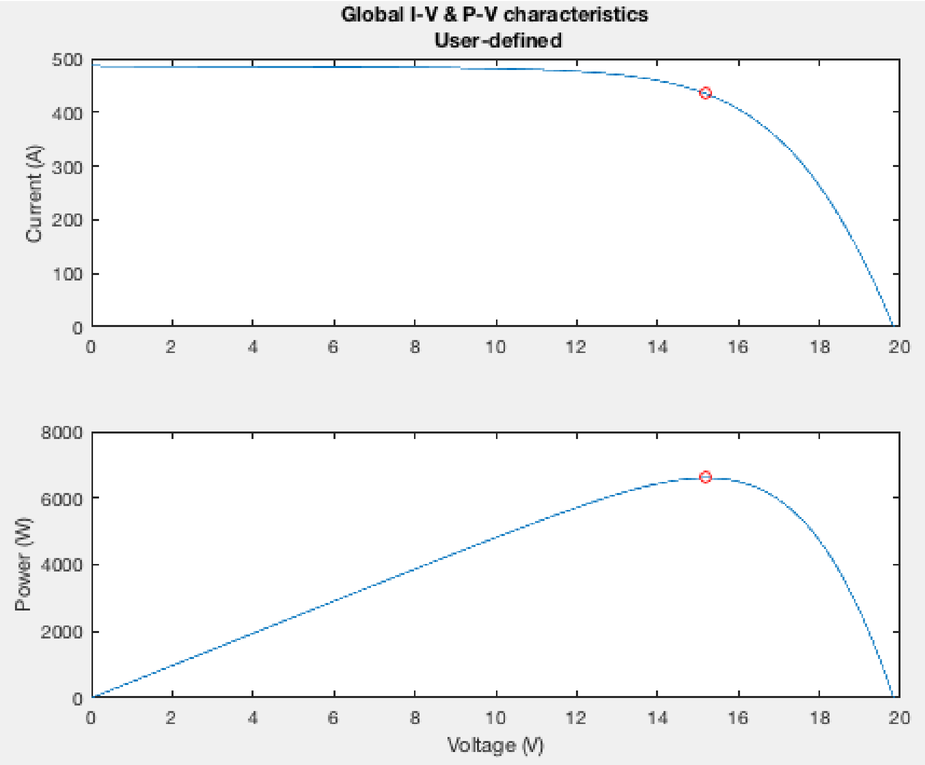


Figure 5.2 - Total output of 36 x dirty panels @ 42°C.

Figures 5.1 and 5.2 curves show how the increase in panel temperature effects only the overall output. The V-I curve will continue to move the knee point left which will reduce the area under the curve, which is the output.

5.3 OUTCOMES AND CONSEQUENCES

This research project has successfully demonstrated the possibility to detect degradation within a PV array. Therefore this method may have a real world application to analyse solar farms and determine when a PV array/s should be replaced or maintained. This would be most effective if integrated into a maintenance etc. cleaning and a condition monitoring service, which could ultimately become a viable business opportunity.

This service would involve regular scans or visits to a customer's PV panel systems in order to identify which panels need replacing or to determine if panel cleaning is necessary. Such a service would require continual integrity, as it would be easy to take shortcuts to expediate the physical testing or provide false scans to save costs or justify further services. There is potential for many unethical opportunities to arise for technicians. For example as solar panel company might give a bonus if a certain number of panels fail each year or generate pressure to pass equipment to reduce the quantity of warranty claims. These are just a few examples of failing engineering principles; integrity and competence. Poor leadership could occur where a technician is recommending the above actions to staff. This is not promoting sustainability as it would be a waste of valuable non-renewable resources.

If the project method was developed into a service, it would require a more competent testing method (then used) to identify failed cells and panels. Due to the testing being data hungry, data records must be precise in identification as a large solar farm would have thousands of panels and it would be unethical to replace a healthy array due to poor record keeping. This would transfer into leadership requirements in addition to the reputation of engineers to provide a trustworthy practice. It also links into the sustainability of the project as you are identifying a requirement to spend more money and replace assets, which is a use of resources.

Major health and safety benefits are also present with the condition monitoring of assets aspects. Detection of hot cells will provide increased site safety and cleaning would provide an opportunity for faults to be detected, before they cause an accident.

The method could also be implemented throughout many stages of the life cycle to help identify which stage of the process is causing the damage. There are multiple opportunities for the array to become damaged at manufacturing, transportation, installation and operation. By using this method, data can also be provided to improve the life cycle of PV arrays, and to allow detection of which section/s cause or contribute to degradation of the panels.

Appropriate consideration should be taken as to the impacts of the entire life cycle of the PV array. Although there are benefits in using solar energy rather than unsustainable resources such as fossil fuels, there are also disadvantages to be considered. For example in using numerous energy and resources to manufacture, transport and install etc. The solar industry still is yet to have a holistic analysis into the impacts of equipment recycling. PV arrays, invertor’s and associated equipment still need a total life cycle assessment. From the so called ‘birth’ with the mining of all the required resources, right through to ‘death’ with total recycling to get a true gauge on the impacts of PV. Such analysis would also allow comparison to other renewable options.

6 CHAPTER SIX: CONCLUSION

6.1 ACHIEVEMENT OF PROJECT

Overall the project was a success, with simulations and research showing that increasing the panel temperature above 25°C will decrease the rated output of PV arrays. Due to student version software limitations, it was not possible to provide full thirty-six cell and thirty-six panel simulation resolution. Despite this the condensed simulation did provide a good indication on the possible impacts that a single cell and panel increase temperature can have on the entire strings output. Single cell failures simulated results had minimal impact the strings output. However the extrapolated dirty cells simulation did indicate more significant impacts on the overall string output performance.

This indicates development potential of a service which would provide routine quality control solar panel testing. The use of infrared thermal camera was successful with physical hot spot detection, however alternative methods could be further investigated to provide secondary correlation based on performance data.

In the field, large scale commercial implementation with UAV would be the only feasible option. UAV physical scanning would also increase safety for employees, as it requires less to no time working at heights. With elimination being the first control measure in safety reduction hierarchy. Other issues present with physical testing was asset identification, as using post-it notes would not be effective in large scale scans. Further work is needed in this area, possible solutions include GPS tagging linked with automated software, to help the large data problem.

The simulations showed that a single panel failure at 90°C would cause 17% reduction in total thirty-six panel string output, which is a major financial impact. Due to the scanned site only being installed four years prior, the site is still in early life stages. This could be why physical testing didn't detect any total panel failures

Other key simulation findings were that approximately a 20°C temperature increase above 25°C will reduce a single panels output by 20%. This reduction is the twenty-five year output guarantee for most PV panels. Overall this method should be used in conjunction with cleaning and monitoring services to provide justification for cleaning and to allow for detection of failed cells to maximise the systems output and safety.

6.2 PROJECT RESEARCH CONTRIBUTION

1) Proof of concept that an infrared thermal camera can be used to detect PV panel cells degradation processes;
2) Initial MATLAB/Simscape model that similarly predicts this thermal footprint due to internal cell or connection damage;
3) Cost benefit model indication of the best and worst case magnitude of lost electricity revenue for a large PV array due to panel cell degradation .

6.3 FURTHER RESEARCH

Further work which may help provide more resolution on this topic:

- More analysis can be done to compare the effects of temperature on different PV array types, manufacturing etc. which may prove beneficial in location asset selections.
- How to calculate when replacement of panel/s is viable, including estimated monitoring periods to allow business viability and/or when the price reduction of panels will allow this in the future.
- More precise simulation could be performed with full MATLAB software. Simulation only being performed with irradiance and temperature. Variable resistance increase could be investigated to show link to temperature and output reduction and energy wasted to create the internal heating was ignored.
- Total site scan would also provide a more accurate result on site performance as the total site results were extrapolated to provide an indication of impacts.
- Also 100% cell temperature saturation and separation was assumed which is another cascading dynamic worth investigating.
- UAV implementation is required to make this method practical for business use. This would also link into implementation of analysis software to automatically detect abnormalities on panels during the UAV scan, (recording and identifying this with location data references).

REFERENCES

Acta Universatis Upaliensis Uppsala, 2008, Modelling and Degradation Characteristics of Thin-film CIGS Solar Cells

ASRDH, Australian Solar Radiation Data Handbook 4th Edition, 2006, Australian Solar Energy Society, http://www.exemplary.com.au/download/ASRDH_cover_contents.pdf

Bagavathiappan S, Lahiri B.B, Saravanan T, Philip J, Jayakumar T, 2012 , Infrared thermography for condition monitoring – A review

Bloomberg, New Energy Report 2015, viewed on the 11th August 2016, http://www.bloomberg.com/news/articles/2016-06-13/we-ve-almost-reached-peak-fossil-fuels-for-electricity

BOM Australian Government, Daily Global Solar Exposure at Mt Stuart Radar Site, viewed on the 21st August 2016, http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=193&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=032120

BOM, Solar Radiation Definitions, June 2012, viewed on the 23rd August 2016, http://www.bom.gov.au/climate/austmaps/solar-radiation-glossary.shtml

Bruno Andò, Salvatore Baglio, Antonio Pistorio, Giuseppe Marco Tina, and Cristina Ventura, August 2015, Smart Monitoring of Photovoltaic Systems at Panel Level

Christian Schuss, Kimmo Leppänen, Kari Remes, Juha Saarela, Tapio Fabritius, Bernd Eichberger, and Timo Rahkonen, 2016, Detecting Defects in Photovoltaic Cells and Panels and Evaluating the Impact on Output Performances

CISRO, Australian Gridded Climate Data - Solar Exposure, 20 August 2016, viewed on the 21st August 2016, http://rs-data1-mel.csiro.au/thredds/godiva2/godiva2.html?server=http://rs-data1-#mel.csiro.au/thredds/wms/bawap/rad/day/2016/bom-rad_day-20160801-20160831.nc

Cleaner Cars from Cradle to Grave, 2015, viewed on the 10th July 2016, http://www.ucsusa.org/clean-vehicles/electric-vehicles/life-cycle-ev-emissions#V4Gv5leIu-8

DC Circuit Theory, Electronic Tutorials, 2016, viewed on the 30th Mary 2016, http://www.electronics-tutorials.ws/dccircuits/dcp_1.html

DC Electrical Power, viewed on the 27th May 2016, http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elepow.html

Dominique Bonkoungou, Zacharie Koalaga, Donatien Njomo, 2013, Modelling and Simulation of photovoltaic module considering single -diode equivalent circuit model in MATLAB

Dustin Mulvaney, 2014, Solar Energy Isn't Always as Green as You Think, viewed on the 9th June 2016, http://spectrum.ieee.org/green-tech/solar/solar-energy-isnt-always-as-green-as-you-think

Ekren Orhan, Ekren Banu Yetkin, 2011, Size Optimization of a Solar-wind Hybrid Energy System Using Two Simulation Based optimization Techniques, China, Shaghai

Encyclopaedia Britannica, 2016, viewed on the 9th June 2016, http://www.britannica.com/biography/Alessandro-Volta

Ergon Energy, 2012, Townsville RSL Stadium PV Array System. Drawing No.1019577-00 Ver 0C, received from Dean Condon – Innovation Engineer on 11th March 2016

Ergon Energy, 2016, Daily / Task Risk Management Plan (Safety, Environment, Cultural Heritage) Form CS000501F115 Ver 8

Fluke, 2010, User Manual for Ti9, Ti10, Ti25, TiRx, TiR and TiR1 Thermal Imagers, viewed on 20th June 2016, https://www.instrumentation2000.com/pdf/fluke-ti9-manual.pdf

Gil Knier, Nasa Science – How do photovoltaics work?, viewed on the 3rd June 2016, http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

Global Sustainable Energy Solutions, 2015 Micro fractures in Solar Modules: Causes, Detection and Consequences

ILijun Qin,Xiao Lu, Matlab/Simulink-Based Research on Maximum Power Point Tracking of Photovoltaic Generation, 2012

John H. Wohlgemuth, Michael D. Kempe, 2010, Equating Damp Heat Testing with Field Failures of PV Modules

Jordan C, Kurtz, S Photovoltaic Degradation Rates, 2012, National Renewable Energy Laboratory, viewed on the 20th July 2016, http://www.nrel.gov/docs/fy12osti/51664.pdf

Krismadinata, Nasrudin Abd, Rahim, Hew Wooi Ping, Jeyraj Selvaraj, 2012, Photovoltaic module modelling using Simulink/MATLAB

Kyocera KD135GH-2PU High efficiency multicrystal photovoltaic module Datasheet, 2010, viewed on the 11th July 2016, www.kyocerasolar.de

Kyocera Solar Limited Warranty for Kyocera Photovoltaic Modules, 2016, viewed on 14th August 2016, www.kyocerasolar.eu/index/products/download/English.-cps-13016-files-6246-File.cpsdownload.tmp/1_English_Warranty%20PV%20Modules_since%2001_08_2016_KKM-SE-00001-08.pdf

Kyocera, Residential Success Stories, 2012, viewed on the 14th August 2016, http://www.kyocerasolar.com.au/australia/success-stories/?id=19)

Marco Paggi, Mauro Corrado, Maria Alejandra Rodriguez , March 2013, A multi-physics and multi-scale numerical approach to microcracking and power-loss in photovoltaic modules

Mathworks, 2016, PV Array, viewed on the 23rd August 2016, 20http://au.mathworks.com/help/physmod/sps/powersys/ref/pvarray.html

NASA, Do Variation in the Solar Cycle Affect out Climate system, January 2009, viewed on the 22nd August 2016, http://www.giss.nasa.gov/research/briefs/rind_03/

Odden, J.O, .C.Lommasson C, Tayyib, M , Vedde, J, Buseth & Triestad, K. 2014, Results on performance and ageing of solar modules based on ElkemSolar Silicon(ESS™) from installations at various locations

Pan Rong, Joseph Kuitche, Govindasamy Tamizhmani, 2011, UniversityDegradation Analysis of Solar Photovoltaic Modules: Influence of Environmental Factor.

PV Education, Solar Cell Efficiency Records, viewed on the 31st August 2016, http://www.pveducation.org/pvcdrom/appendices/solar-cell-efficiency-results2

Savitha P, Shashikala M, Puttabuddhi K, March 2014, Modelling of Photovoltaic Cell/Module under Environmental Disturbances using MATLAB/Simulink

Shockly Willian, Queisser Hans, 1960, Detailed Balance Limit of Efficiency of p-n Junction Solar Cells. Shockley Transistor, Unit of Clevile Transistor, Palo Alto, California

SMA Solar Technology AG, 2016, viewed on the 10th August 2016, http://www.sma-australia.com.au/products/monitoring-control.html, http://files.sma.de/dl/18414/SSM-21-DEN1516-V21.pdf

Solar Central, Solar Efficiency Limits, viewed on the 31st August 2016, http://www.solarcellcentral.com/limits_page.html

SOLARGIS, iMaps Solar Irradiance, 2016, viewed on the 22nd August 2016, http://solargis.info/imaps/

Solary Energy, viewed on the 11th July 2016, http://www.inforse.org/europe/dieret/Solar/solar.html

Sunny Tripower SMA, 2011, viewed on the 11th July 2016, www.SMA-Solar.com

Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi, 20.02.2012, MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell

Thekaekara, M. P., 1976, "Solar Radiation Measurement: Techniques and Instrumentation," Solar Energy 18(4), 309.

Tsanakas J, Long H, Buerhop C, 2016, Faults and infrared thermography diagnosis in operating c-Si photovoltaic modules: A review of research and future challenges

Ulrich Eitner, Marc Köntges, Rolf Brendel, 2010, Use of digital image correlation technique to determine thermomechanical deformations in photovoltaic laminates: Measurements and accuracy

Viridian Solar, A Guide To Solar Energy, viewed on the 31st August 2016, http://www.viridiansolar.co.uk/Solar_Energy_Guide_5_2.htm

Weatherzone, 2016 sever weather query, Murry Lyons Cres, Annandale, viewed on the 24th August, Data for 20th August, http://stormquery.theweather.com.au/query.jsp

Wholesale Solar, Kyocera 135 KD135GX-LPU, 2016, viewed on the 26th July 2016, http://www.wholesalesolar.com/1121351/kyocera/solar-panels/kyocera-135-kd135gx-lpu-solar-panel

Wlodzimierz Kolodenny, Mariusz Prorok, Tadeusz Zdanowicz, Nicola Pearsall, Ralph Gottschalg, 2008, Applying Modern Informatics Technologies to Monitoring Photovoltaic (PV) Modules and Systems

Yihua Hu, Wenping Cao, Jien Ma, Stephen Finney, David Li, 2013, Identifying PV Module Mismatch Faults by a Thermography - Based Temperature Distribution Analysis

A1: APPENDIX A

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/4112 Research Project

PROJECT SPECIFCATION

FOR:	**Glen Adcock**
TOPIC:	**Electro-Thermal modelling of large PV array degradation for thermography and peak power conditioning monitoring.**
SUPERVISORS	**Dr. Narottam Das** **Andreas Helwig**
ENROLMENT	**ENG4111 – S1 2016 Ex** **ENG4112 – S2 2016 Ex**
PROJECT AIM	**This project will aim to provide a valid method of detecting PV array degradation by using thermography and the effects off this degradation on peak power and when replacement this recommended.**
SPONSORSHIP PROGRAMME	**Project-Das-56**

1. Research background information regarding Photovoltaics and Thermography.
2. Investigate how degradation of the substrate, connections or moisture ingress effects the overall internal resistance or a solar cell and overall panel.
3. Investigate expected thermal properties (Hot Spots) for degraded panels calculated at daily solar peak.
4. Model to predict simulation of solar panel degradation and thermal (Hot Spots).
5. Justify the benefits of condition monitoring for a large PV array.
6. Compile all information (background information, results) into dissertation

As time permits

7. Perform physical thermography scans to detect/measure (Hot Spots)
8. Innovate online monitoring software to detect premature aging of solar cell panels

AGREEED

GA ______ (G.Adcock/Student) 27/ 06 / 2016

______ (Helwig/Supervisor) 27/06/2016

______ (Dr.Narottam/Supervisor) 27/06/16

ENG4111 PROJECT SPECIFICATION VALID AT: 27 JUNE 2016 ISSUED 22/02/16

A2 : THERMAL HAND HELD CAMERA – FLUKE TI25

Figure 0.1 - Picture of Thermal Camera taken by Glen Adcock on 20th June 2016.

Key Data Information (Fluke ,2010)

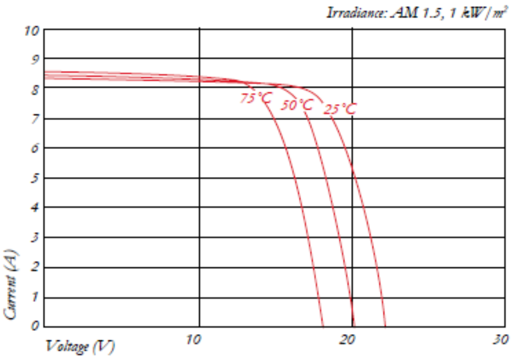
- Temperature Range (not calibrated below -10°C) Ti25 = -20°C to +350°C
- Accuracy Ti25 = ±2°C or 2 % (whichever is greater)
- Spatial Resolution (IFOV)................................... 2.5 mRad
- Image Frequency.. 9 Hz refresh rate
- Detector Type .... 160 X 120 Focal Plane Array
- Infrared Lens Type.. 20 mm EFL, F/0.8 lens
- Thermal Sensitivity (NETD) Ti25= ≤0.1°C at 30°C (100 mK)
- Infrared Spectral Band.. 7.5 μm to 14 μm
- Visual Camera .... 640 x 480 resolution

A3 : RSL STADIUM INFORMATION

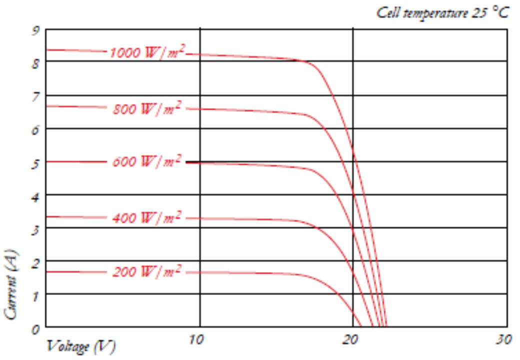
Stadium Panels - Kyocera – 135W Data Sheet

ELECTRICAL CHARACTERISTICS

Current-Voltage characteristics at various cell temperatures



Current-Voltage characteristics at various irradiance levels



ELECTRICAL PERFORMANCE

PV Module Type		KD135GH-2PU
At 1000 W/m² (STC)*		
Maximum Power	[W]	135
Maximum System Voltage	[V]	1000
Maximum Power Voltage	[V]	17.7
Maximum Power Current	[A]	7.63
Open Circuit Voltage (V_{OC})	[V]	22.1
Short Circuit Current (I_{SC})	[A]	8.37
At 800 W/m² (NOCT)**		
Maximum Power	[W]	95
Maximum Power Voltage	[V]	15.7
Maximum Power Current	[A]	6.1
Open Circuit Voltage (V_{OC})	[V]	20
Short Circuit Current (I_{SC})	[A]	6.79
NOCT	[°C]	47.9
Power Tolerance	[%]	+5 / -5
Maximum Reverse Current I_R	[A]	15
Series Fuse Rating	[A]	15
Temperature Coefficient of V_{OC}	[V/°C]	-0.80×10^{-1}
Temperature Coefficient of I_{SC}	[A/°C]	5.02×10^{-3}
Temperature Coefficient of Max. Power	[W/°C]	-6.14×10^{-1}
Reduction of Efficiency (from 1000 W/m² to 200 W/m²)	[%]	5.8

DIMENSIONS

Length	[mm]	1500 (±2.5)
Width	[mm]	668 (±2.5)
Depth / incl. Junction Box	[mm]	46
Weight	[kg]	12.5
Cable	[mm]	(+)840 / (-)840
Connection Type		MC PV-KBT3 / MC PV-KST3
Junction Box	[mm]	100x108x20
IP Code		IP65

GENERAL INFORMATION

Performance Guarantee	10*** / 20 years****
Warranty	5 years

CELLS

Number per Module		36
Cell Technology		polycrystalline
Cell Shape (square)	[mm]	156x156
Cell Bonding		3 busbar

* *Electrical values under standard test conditions (STC): irradiation of 1000 W/m², airmass AM 1.5 and cell temperature of 25 °C*

** *Electrical values under normal operating cell temperature (NOCT): irradiation of 800 W/m², airmass AM 1.5, wind speed of 1m/s and ambient temperature of 20 °C*

*** *10 years on 90 % of the minimally specified power P under standard test conditions (STC)*

**** *20 years on 80 % of the minimally specified power P under standard test conditions (STC)*

Figure 0.2 - Kyocera data sheet electrical characteristics.

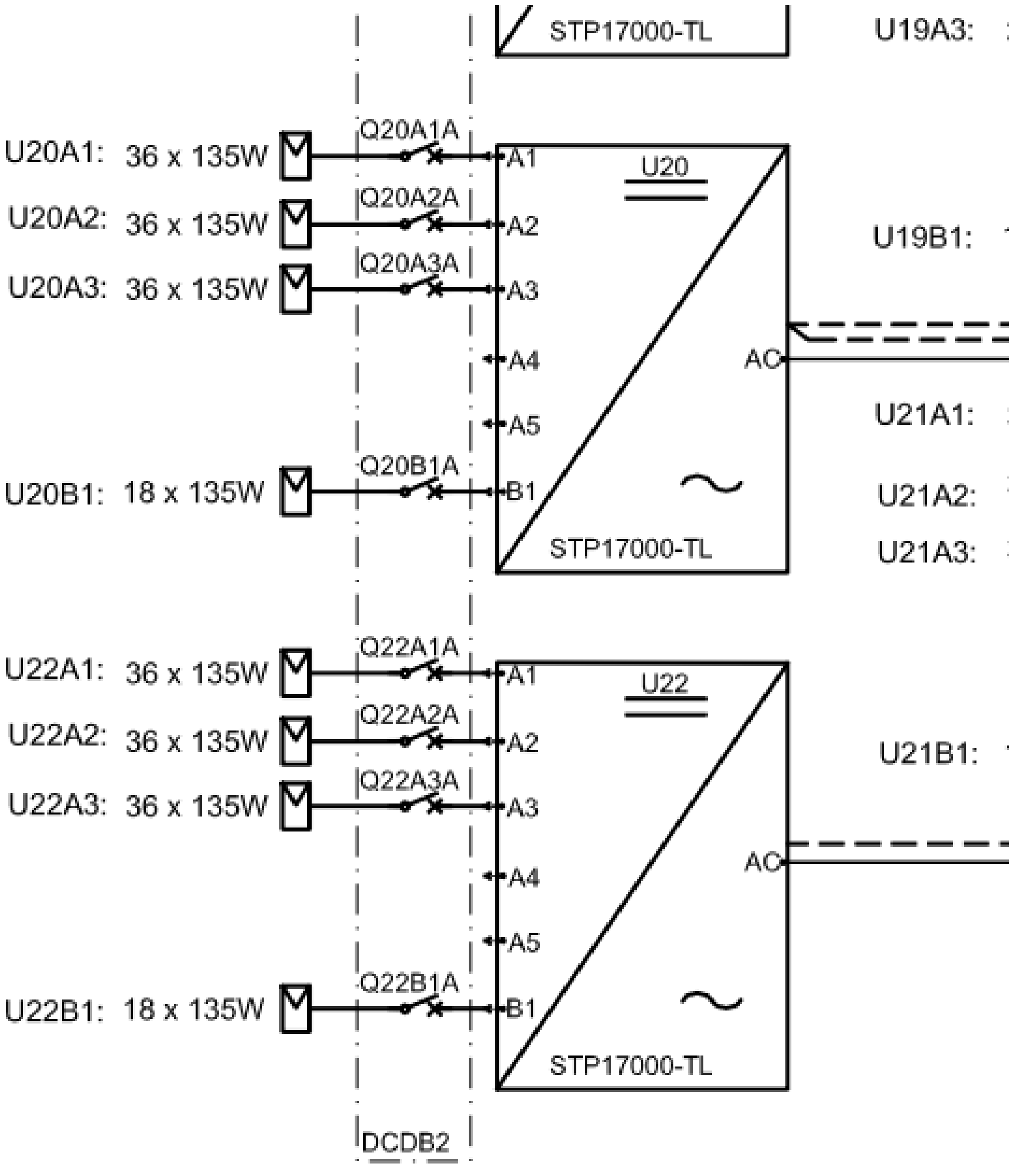


Figure 0.3 - Zoomed section from figure 0.4, Townsville RSL Stadium Solar Farm.

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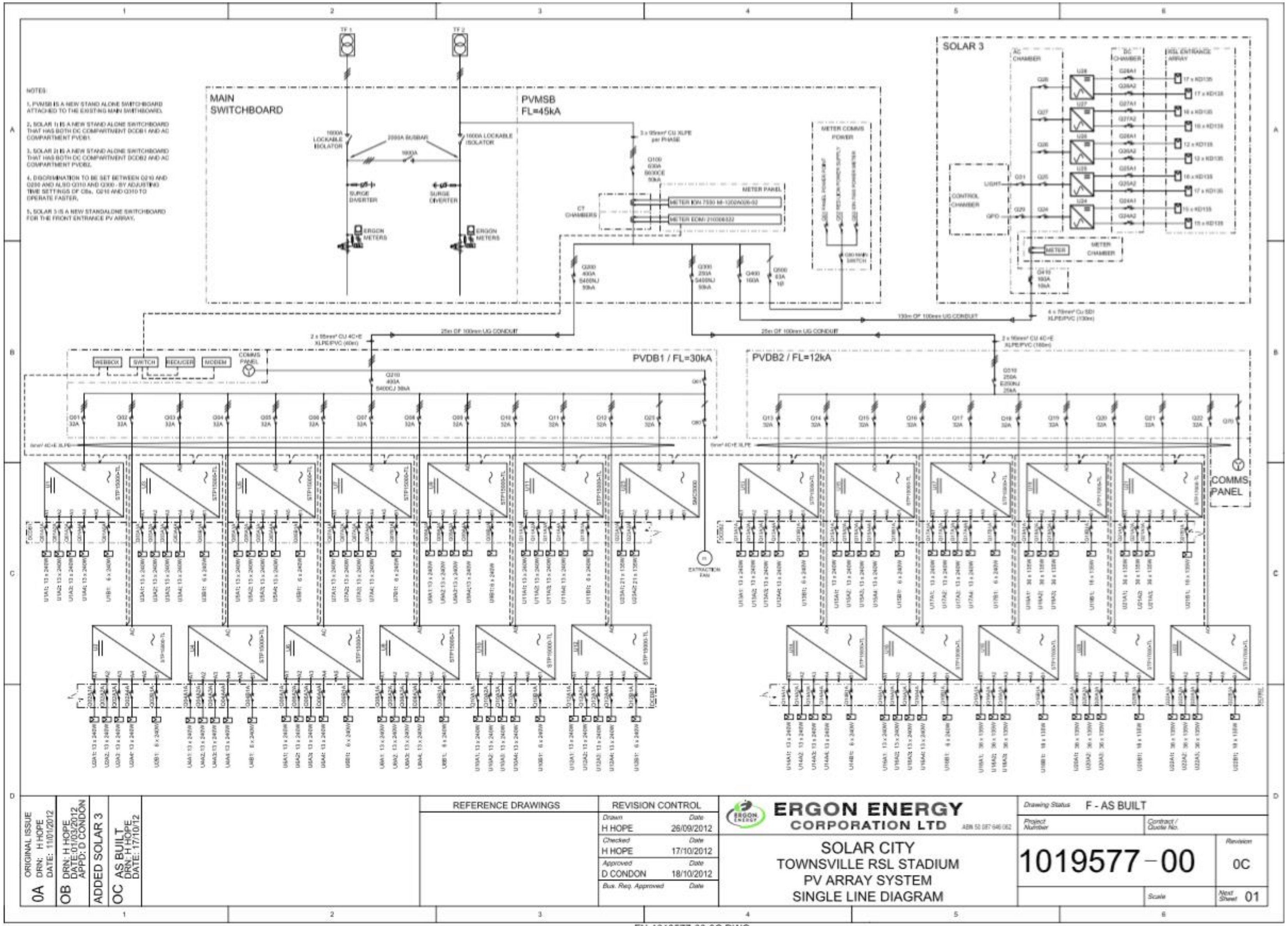

Figure 0.4 - Townsville RSL Stadium Solar Farm single line diagram.

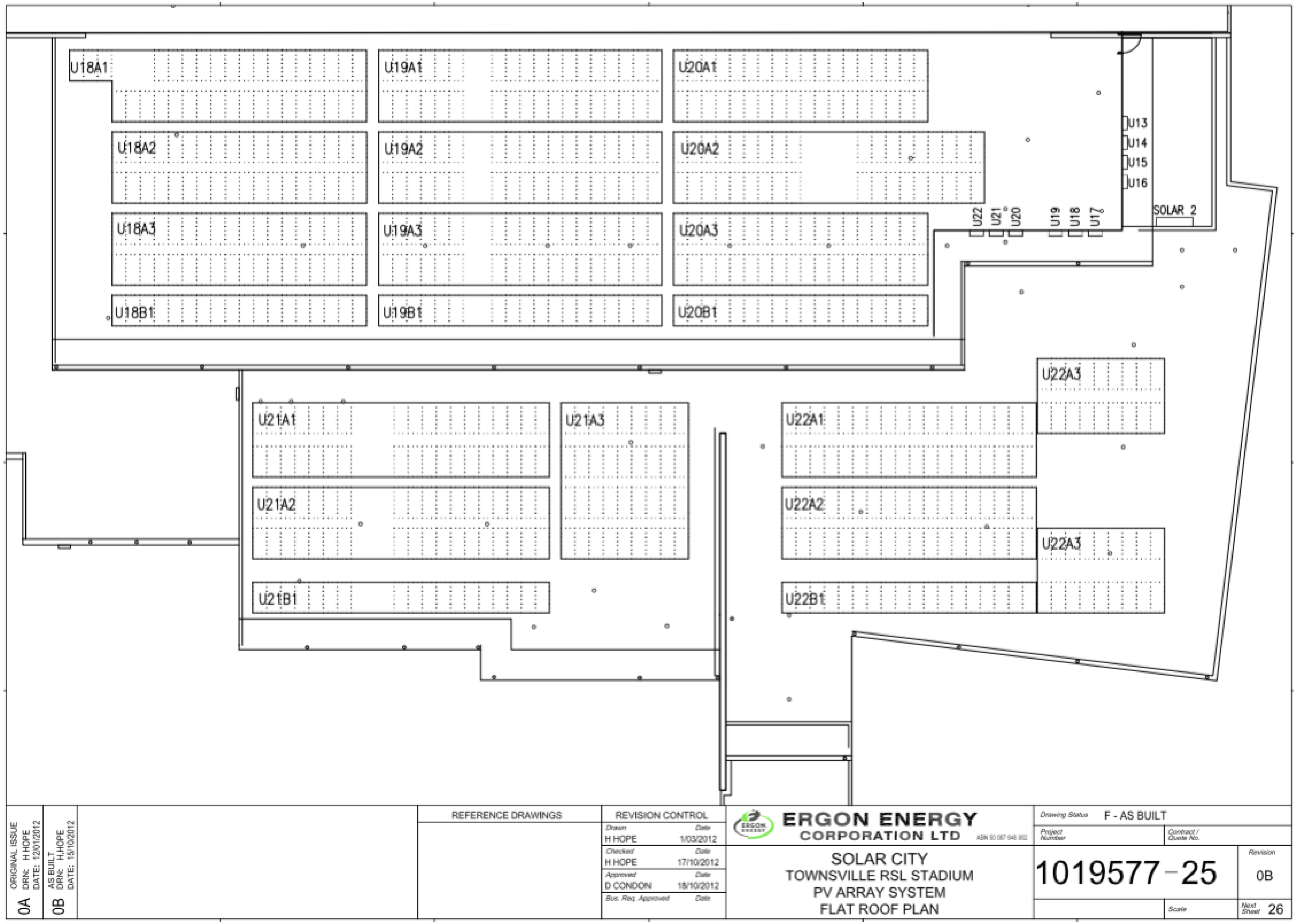

Figure 0.5 - Panel and invertor layout Townsville RSL Stadium flat roof plan.

A4 : RISK ASSESSMENT (ERGON ENERGY, 2016) – RSL STADIUM SOLAR FARM

Work Description: Invertor Data Readout, Solar Panel Thermal Scans, Photographs and intrusive testing	**Work Location: Annandale Solar Farm**	**Date:** **N/A**
Perform LV live work justification: ☐ Needed to do the job ☐ Safety Concerns ☐ Wide Spread Outage ■ Not Applicable	**The SPRMP &/or WHS Management Plans reviewed**	☐ Yes ■ Not Applicable
Identify **Safe Work Method Statements** for High Risk Construction Work (Please tick relevant box and implement controls from related SWMS)	**Contractors Licences and SWMS sighted or acquired**	☐ Yes ■ Not Applicable

☐ Work at Heights (Poles & Ladders) ☐ Work at Heights (EWP's) ■ Work at Heights (Roofs & Fascias) ☐ Work at Heights (Scaffold & Guardrails)	☐ Work at Heights (Structures & Towers) ☐ Working on or near Road or Railway ☐ Live Work (LV) ☐ Live Work (HV)	☐ Disturbance of Asbestos (Underground) ☐ Disturbance of Asbestos (Overhead) ☐ Disturbance of Asbestos (Switchboards, Buildings & Switchgear) ☐ Pressurised Gas, Chemical, Fuel Lines	☐ Temporary Support of Poles or Structures ☐ Work on Telecommunication Tower ☐ Movement of Powered Mobile Plant or Vehicles ☐ Contaminated or Flammable Atmosphere	☐ Excavations ☐ Confined Space ☐ Working in or on Water

(A) WORK ACTIVITY: (Tick Yes or add others below)	Relevant to Job **Yes**	**IDENTIFIED ONSITE HAZARDS** (Not addressed by SWMS or standard control measures)	Inherent Level of Risk	**(B) WHAT CONTROLS ARE TO BE APPLIED?**	Residual Level of Risk	**ALLOCATED TO:**
Hand / Power Tool Operation	Yes	Cuts and pinches	M	Gloves and correct operation of device	**L**	All
Working Outdoors		• Solar Radiation	M	1. Regularly apply SPF30+ (or better) sunscreen to unprotected skin surfaces. 2. Rotate tasks / workers to limit exposure, utilise tarpaulins, shade structure and any other available shade. Schedule work during the hours when the solar UVR is less intense. This is usually early in the morning or late in the afternoon.	L	All
Vehicle Driving / Trailer Towing	Yes	Road Conditions, other vehicles	M	Manager Approval, follow all road rules, drive to the conditions	L	Glen A
Test Equipment Use	Yes	DC Hazards'	M	LV Rescue Kit, Qualified Electrician with safety observer.	L	Glen A
Working at Heights	Yes	Falls, Deaths	M	Safety harness maintaining one connection at all times, limit time required on roof and near the edges (check working at heights training completed)	L	All

(A) WORK CTIVITY:	Relevant to Job Yes	IDENTIFIED ONSITE HAZARDS (Not addressed by SWMS or Std Risk Controls)	Inherent Level of Risk	(B) WHAT CONTROLS ARE TO BE APPLIED?	Residual Level of Risk	ALLOCATED TO:

(C) ISOLATION POINT: LOW VOLTAGE
OTHER SYSTEM ISOLATION POINTS: [e.g. Gas or Fuel Isolation]

Op No	Apparatus and Operation (Single Isolation Point)	Time
1		
2		
3		
4		
5		

OTHER SYSTEMS: (e.g. gas, fuels or electrical generator control)

Isolation Point (Max of Three Points)	Isolated & Tagged (Time)	Restored (Time)

Permit to Work (PTW) No.		

LV Switching Sheet No.		Tested & Proved De-energised / Isolated	Name:	Time:	Work Crew advised of Restoration	Name:	Time:

(D) RE-ENERGISING / COMMISSIONING CHECKS:

Test Point(s)	Check Type	Completed By	☑

(E) TRAFFIC MANAGEMENT

ERECT Date/Time/Initial	CHK Date/Time/Initial	CHK Date/Time/Initial	CHK Date/Time/Initial	REMOVE Date/Time/Initial

WORM Diagram/Clause or Contract Plan No.	

(F) PERSON (ON SITE) IN CHARGE OF WORK RESPONSIBILITIES:

Pre-start job briefing conducted.
I understand my responsibilities in regards to implementing and supervising control measures on the work site.
I understand my responsibilities in regards to supervision of all persons on the work site including Apprentices.
I understand I am responsible for ensuring that test requirements are identified assigned and completed.

(G) CREW MEMBER / VISITOR RESPONSIBILITIES:

Attended Pre-start job briefing.
I understand the job and my role.
I understand the standard and other controls for this job.
Act in a manner that contributes to personal and group safety

Crew/Visitor Sign On - REQUIRED FOR EVERY JOB				Crew/Visitor Sign On- REQUIRED FOR EVERY JOB				Crew/Visitor Sign On - REQUIRED FOR EVERY JOB			
ROLE	NAME	SIGNATURE	TIME	ROLE	NAME	SIGNATURE	TIME	ROLE	NAME	SIGNATURE	TIME
PICW	GLEN ADCOCK										
	DEAN CONDON										

(H) LOCKABLE ASSETS: I have confirmed locked and checked prior to leaving the site. (For switching do not list each asset ID. Write down switching sheet number only.)

SWITCHING SHEET NO.		ASSET ID.		ASSET ID.		ASSET ID.		ASSET ID.		SIGNATURE	

Activity	Hazard	Consequences	Control Measures	
Exceed Fatigue Safe Work Hours	• Fatigue • Fitness for safe work	• Personal injury • Injury to other persons • Property damage • Non-compliance with the NHVR exemption notice	1. Complete relevant fatigue risk assessment (personal fatigue calculator) prior to continuing work beyond safe work hours. 2. Implement controls relevant to personal fatigue score. 3. Plan and conduct work wherever possible to occur within the safe work hour limits. 4. Drivers of Fatigue Regulated Heavy Vehicles must comply with the requirements of the Work and Rest Hours Exemption Notice. 5. Team members have attended fatigue training and are assessed competent. 6. Monitor your approach to the maximum work hour limits and communicate early with supervisor. Make alternative arrangements to ensure staff do not exceed the maximum hours. 7. Check that everyone is 'good to go' prior to commencing work and monitor through the job. Advise supervisor if not fit for safe work or if you are concerned about a team member's fitness for safe work.	8. Advise supervisor when you are not feeling well and seek medical advice as appropriate. 9. Advise supervisor if you are taking any medication that may impair your ability to work, drive, and operate machinery, tools or plant. 10. Take all required rest pauses and breaks and schedule additional rest breaks when fatigue is a risk. 11. Consider whether the job or task can be shortened or deferred to normal working hours. 12. Consider deferring safety critical tasks to a time when the likelihood of fatigue is lower. 13. Rotate staff between high fatigue risk tasks e.g. high risk tasks, monotonous or exhausting physical tasks or tasks in environmental extremes such as heat and humidity. 14. Ensure right person is selected for task – i.e. fit for task. 15. Consider implementing a buddy or double check system. 16. Consider alternate transport arrangements for workers to and from an extended job.
Hand Tool Operation	• Loss of control • Misuse • Noise	• Sprain, strain injury • Cuts, abrasions • Tool / equipment damage • Noise nuisance to neighbours • Hearing impairment	1. Competence in tool use. 2. Tool used for intended purpose. 3. Required PPE worn. 4. Consider use of hearing protection . 5. Ensure tools fit for purpose and operated in competent manner. 6. Tools maintained in serviceable condition. 7. Defective tools removed from service, tagged as defective and quarantined.	8. Operation times in accordance with relevant by-laws or landholder / community requirements e.g. limited to normal working hours, where possible. 9. Locate noisy equipment / activities away from sensitive locations or neighbours if possible. 10. Provide supervision and training for new equipment or inexperienced users, e.g. Ellipse Course Code 7087.

Activity	Hazard	Consequences	Control Measures	
Hazardous Manual Task – Risk Factor – Forceful exertions	• *Repetitive force* - using force repeatedly over a period of time to move or support an object • *Sustained force* - occurs when force is applied continually over a period of time. • *High force* – A force that requires great effort and maybe exerted by any part of body. • *Sudden force* – jerky or unexpected movements while handling an item	• Musculoskeletal or soft tissue injury (back injury, strain, sprain, etc.)	1. Use mechanical aids (cranes, loader, backhoe, trolleys, pallet jacks) to assist in lifting and handling items. 2. Make load sizes smaller and lighter. 3. Push rather than pull a load. 4. When moving a load, plan the route, and slow down gradually. Choose a route with the best surface conditions. 5. Use the right tool for the job and ensure the tool is in good working order. 6. Use handles if available to lift loads.	7. Keep heavy work items at waist height. 8. If assistance is required to move or support an item ensure this is planned and coordinated. Personnel should be of similar capabilities, considering body height and build. 9. Ensure there is adequate number of staff for the task. 10. Self-pace work for physically demanding tasks. 11. Replace hand tools with power tools to reduce the level of force required to do the task. 12. Educate and train staff on an ongoing basis.
Hazardous Manual Task – Risk Factor – Awkward or Sustained Posture	• Sustained posture – where part of or the whole body is kept in the same position for a prolonged period. Awkward posture – where any part of the body is in an uncomfortable or unnatural position	• Musculoskeletal or soft tissue injury (back injury, strain, sprain, etc.)	1. Position work to allow a neutral body position where possible. Ideal positioning includes: • Working between waist and shoulder height • Placing the task to the midline of the body to avoid twisting • Position the task within close proximity to the body to avoid overreaching • Allow adequate workspace	2. Rotate work so as to limit the exposure time to any one personnel being in an awkward or sustained position. 3. Move from the sustained / awkward position every 15-30 minutes for a minute or two.
Hazardous Manual Task – Risk Factor – Repetitive movement	• *Repetitive movement* – using the same parts of the body to repeat similar movements over a period of time (such as hammering a nail).	• Musculoskeletal or soft tissue injury (back injury, strain, sprain, etc.)	1. Rotate work to limit exposure time. 2. Ensure tools used for the job are in good working order. 3. Include regular breaks.	
Hazardous Manual Task – Risk Factor - Vibration	• Whole body mechanical vibration and hand arm vibration	• Musculoskeletal or soft tissue injury (back injury, strain, sprain, hand injury etc.)	1. Use mechanical means to minimise manual exposure. 2. Rotate work allocation to limit employee exposure to hand / arm vibration. 3. Required PPE worn, including vibration isolation gloves where required. 4. Provide supervision and training for new equipment or inexperienced users, e.g. Ellipse Course Code 7087.	5. Seek cultural heritage advice if power tool vibration has the potential to disturb registered heritage (i.e. buildings etc.). 6. Take regular rest breaks when driving – a minimum of 15 minutes every 2 hours. 7. Rotate drivers where possible. 8. Operate equipment to the speed recommended by the manufacturer or a speed that reduces vibration.

Activity	Hazard	Consequences	Control Measures	
Hazardous Manual Task – Risk Factor – Duration	• Overuse of particular muscle groups – muscle fatigue	• Musculoskeletal or soft tissue injury (back injury, strain, sprain, etc.)	1. Rotate work to limit exposure time. 2. Take regular breaks every 30 minutes for a minute or two.	
Material Handling	• Loading materials ready for transport • Falling equipment / material during transport • Job site unloading • Spill or release of contaminant	• Personnel / property damage • Damage / injury to personnel or public property or equipment • Environmental Harm	1. Use appropriate methods to load vehicles. 2. Check all loads are correctly secured. 3. Ensure materials handling is carried out by trained personnel with correct equipment and work area guarded. 4. Make sure equipment is in test, suitably rated and visually check equipment is in good condition before use.	5. Make sure appropriate spill kits are available. 6. Make sure product information and emergency response procedures are available.
Panels and Panel Wiring	• Live wiring and components • Stripping brass sheathed cables • Muscle fatigue	• Electric shock • Burns • Supply failures • Cuts • Back injury	1. Wear protective clothing. 2. Erect barriers. 3. Complete Secondary System Isolations. 4. Competent Assistant and LV Rescue Kit required.	5. Use correct stripping technique. 6. Beware of edges of brass tape. 7. Rotate work to limit exposure time. 8. Take regular breaks every 30 minutes for a minute or two.
Power Tool Operation	• Noise • Electrical • Kinetic Energy • Defective Tools • Vibration • Falling objects	• Hearing Impairment • Noise nuisance to neighbours • Electric shock • Sprain, strain injury • Cuts, Abrasions • Tool / equipment damage • Tissue damage • Sprain, strain injury • Cultural Heritage Harm • Serious bodily injury • Plant or property damage	1. Isolate noise source. 2. Reduce noise level at work site, where possible; e.g. shift noise source. 3. Rotate workers to limit noise exposure including schedule rest breaks limiting noise exposure. 4. Select equipment with silencers or noise suppression devices, etc. 5. Use in conjunction with operational Safety Switches. 6. Inspect and maintain portable electrical equipment in serviceable condition and within test date. 7. Portable electrical equipment used, stored and transported in appropriate manner to minimise electrical insulation damage. 8. Protect electrical leads from damage. 9. Provide supervision and training for new equipment or inexperienced users, e.g. Ellipse Course Code 7087.	10. Tools used for intended purpose and operated in competent manner. 11. Defective tools removed from service. 12. Provide supervision and training for new equipment or inexperienced users, e.g. Ellipse Course Code 7087. 13. Use mechanical means to minimise manual exposure. 14. Rotate work allocation to limit employee exposure to hand / arm vibration. 15. Required PPE worn, e.g. Ear muffs or plugs, vibration isolation gloves where required. 16. Seek cultural heritage advice if power tool vibration has the potential to disturb registered heritage (i.e. buildings etc.). 17. Create safe work zones, restrict worker / pedestrian movement within plant operating zone. 18. Implement pedestrian / vehicular traffic controls. 19. Use plant with Falling Object Protective Structure.

Activity	Hazard	Consequences	Control Measures	
Power Tool Operation (hydraulic and compressed air)	• Noise • Vibration • Electricity • Heat • Hydraulic oil operating under pressure • Reciprocating or rotating parts • Pinch points • Flying particles • Condensation	• Personal Injury • Burns • White Knuckle – condition caused by excessive exposure to vibration • Skin penetration of compressed air or hydraulic oil • Hearing damage • Eye injury • Dust inhalation • Equipment damage • Property damage • Minor Environmental damage from oil spill	1. Hydraulic tools compatible with closed / open operating system. 2. Pressure hoses in serviceable condition. 3. Spill kit complete and readily available. 4. Required PPE worn, including safety eye wear e.g. hearing protection, vibration isolation gloves where required and respiratory protection. 5. Compressor and water traps maintained and condensation released on a regular basis. 6. Secure tools to the hose or whip by some positive means such as chain, Minus Clips or flexible catch to prevent accidental disconnection when in use.	7. Securely install and maintain safety clips or retainers on pneumatic impact or percussion tools to prevent attachments from being accidentally expelled. 8. Do not use air supply hoses to hoist or lower tools. 9. Do not exceed manufacturer's recommended operating pressure. 10. Use only approved attachments (e.g. sockets, grinding wheels and bits) on tools. 11. Use only proper tools (e.g. chuck keys, wrench) to change attachments (e.g. sockets, grinding wheels, bits). 12. Do not use compressed air to clean persons. 13. Rotate work allocation to limit employee exposure to hand / arm vibration. 14. Ensure adequate ventilation in and around work area.
Power Tool Operation (Chainsaws)	• Rotating chain • Kick back • Flying debris • Noise • Vibration • Flammable Liquids • Heat	• Serious Bodily Injury • White Knuckle – condition caused by excessive exposure to vibration • Hearing damage • Eye injury • Dust inhalation • Fire/Explosion • Burns from exhaust	1. Use trained, competent and authorised persons to operate powered cutting tools. 2. Maintain tools and equipment in serviceable condition. 3. Create a safe work zone. 4. Required PPE worn: - Safety helmet - Approved Ear Protection/Ear muffs/Ear plugs - Approved Eye Protection/Safety Visor - Safety boots - Reasonably close fitting clothes	- Chaps / Cut-resistant trousers - Close fitting gloves 5. Respiratory protection (as required). 6. Check the effectiveness of chain brake and operating controls. 7. Ensure safety guards and other safety devices are fitted, secure and functioning. 8. Maintain a proper balance and secure footing when operating the chainsaw. 9. Apply chain brake when saw is at rest and when moving around the worksite. 10. Allow hot chainsaws to cool down before refuelling.

Activity	Hazard	Consequences	Control Measures	
Remote and Isolated Work including working unassisted	• Inhospitable environment • Isolation • Failed Communication • Delayed Aid	• Communication difficulties • Difficulty accessing work sites • Serious illness • Personal injury • Short and long term health effects including mental health • Inaccessibility of medical or other aid in the event of an emergency or accident • Being stranded	1. BS001404R150 Remote-Isolated Work. 2. Develop Communication and Emergency Plan including: • Emergency Kit (food, water, first aid kit, PLB); • Journey Plan – destination, estimated time of arrival, estimated time of departure; • Navigational equipment (e.g. GPS); • Communication details and equipment (mobile/satellite phones, UHF / VHF radios); • Emergency contact details and signage; • Emergency action details • Recovery and evacuation plan • Distress equipment as appropriate • Regular line of communication with support group	3. Employees shall be instructed in working in remote and isolated areas and competent in tasks to be performed, including terrain driving (e.g. dirt roads, 4WD tracks, highway driving), use of communication equipment and protocols. 4. Employees shall ensure that they obey property owner instructions (e.g. could be crop dusting in a particular area).
Secondary Systems, Testing or Maintenance	• Electrical	• Electric shock • Fire • Explosion • Serious bodily injury • Plant or property damage • Unintended Operation of Substation Equipment • Compromise Substation Protection	1. Comply with industry HVIA procedures. 2. HV isolation and access performed by competent and authorised persons. 3. Required PPE worn. 4. Test equipment within test date and used by competent persons. 5. Test equipment used by authorised persons (where required). 6. Refer to up to date Substation circuit diagrams, wiring numbers and panel labels to positively identify circuit prior to work commencement.	7. Comply with secondary isolation procedures. 8. Comply with electrical industry codes of practice requirements for work on or near LV systems. These include: • Tape off / barricade adjacent panels • Isolate danger tag circuits • Test before you touch • Don't use exposed leads or terminals • Comply with AS4836 • Use LV mats, covers, barriers and 00 gloves, if required, as determined by a risk assessment • Have LV rescue kit available at work site. 9. Check isolation before commencing work.
Site Access	• Uneven ground • Rural site • Obstacles in work area • Removal of remnant /mature vegetation • Potential cultural heritage items/areas	• Slips, trip and falls • Vehicle roll over • Personal injury • Plant damage • Cultural Heritage Harm	1. Ongoing staff training and education. 2. Ensure access tracks or roads are in good condition for personnel and vehicles. 3. Inspect site before starting work. 4. Remove Access hazards before work starts. 5. Follow cultural heritage discovery process "Find, Stop, Notify, Manage" if identify potential cultural heritage (ES000904R118 Cultural Heritage Pocketbook).	6. Complete and comply with site specific induction. 7. Comply with site signage e.g. exclusion zones, disabling automatic fire protection. 8. Seek cultural heritage advice if ground disturbance is required (access track creation, widening, access modification, mature vegetation removal etc.) in previously undisturbed surface areas ES000906F100 Cultural Heritage Assessment.

Activity	Hazard	Consequences	Control Measures	
Supervision of Apprentices and Trainees	• Electrical • Use of vehicle, plant and equipment	• Electric Shock • Explosion • Fire • Bodily injury	1. Instruct any person supervising apprentices on the job and comply with specific apprentice work restriction requirements. 2. Provide all apprentices working on site with supervision appropriate to type of work performed and competence of apprentice.	3. The Person in Control of the workplace shall be documented on the WH&S Plan and be responsible for ensuring adequate on site supervision of apprentices.
Test Equipment Use	• High voltage Meggers • High current Microhm meters • Equipment supply fault • Power meters • Inadvertent contact with test voltage / current	• Personal injury • Electric shock • Burns	1. Warning signs and barricades to be used. 2. All personnel to remain clear of equipment under test (including remote ends of cables / feeders). 3. Beware of capacitance effect of cables and transformers. 4. Always physically isolate test equipment from input supply source when not in use.	5. Inspect electrical test and measurement equipment before use. 6. Ensure earthing of test equipment and plant being tested is sufficient. 7. Use test currents and voltages as per Australian Standards. 8. Check all connections before use. 9. Ensure all test leads/bridges are removed before commissioning/energising network plant/equipment.
Vehicle Driving and Trailer Towing	• Collision or accident • Load dislodgment • Vehicle overloading • Hitching and unhitching • Vehicle Recovery • Fatigue • Vehicle failure • Driving conditions • Other road users • Weeds • Power Winching	• Serious bodily injury • Plant or property damage • Environmental damage (spread of weeds, damage to sensitive areas) • Non-compliance with NHVR exemption requirements	1. ES000901R171: Operation of Motor Vehicles 2. Standard Work Practice: SV0501. 3. Perform vehicle and trailer pre-start checks daily. 4. Ensure driver is licensed for class of vehicle. 5. Ensure driver is appropriately trained including fatigue training. 6. Familiarise with operation of particular vehicle and trailer. 7. Inspect and maintain vehicle and trailer in serviceable condition. 8. Ensure class of vehicle is suitable to tow trailer 9. Inspect and maintain recovery equipment in serviceable condition. 10. Ensure all winching / recovery equipment used is within load capacities. 11. Load vehicle to within vehicle specifications 12. Secure loads in accordance with BS001404R119 Load Restraint (Field Instruction). 13. Drive defensively, to suit prevailing conditions and the stability of trailer. 14. Drivers of Heavy Vehicles must comply with the requirements of the National Heavy Vehicle Regulators exemption notice.	15. When driving or working always comply with the working hour limits in ES000901R117 Fatigue Guidelines and ES000901R119 Fatigue Risk (Field Instruction). 16. Stay alert and be aware of the symptoms of driver fatigue – do not drive tired. 17. At least every 2 hours take a break of 15 minutes. If possible get out of the vehicle for this break. 18. Take other required rest breaks according to class of vehicle and fatigue management guidelines. 19. Share driving where possible. 20. Communicate regularly with supervisor and advise of arrival at destination. 21. Ensure driving time is included in fatigue working hour limits. 22. Minimise spread of weeds or pests • Plan journeys to drive from clean areas to contaminated areas • Follow clean down procedures • Record any infestations 23. Try to prevent tyre damage and rutting 24. Use tree protectors when power winching

Activity	Hazard	Consequences	Control Measures	
Working (Fatigue, Wellbeing)	• Fatigue • Fitness • Medical condition • Medication	• Personal injury • Injury to other persons • Property damage	1. When driving or working always comply with the working hour limits in ES000901R117 Fatigue Guidelines and ES000901R119 Fatigue Risk (Field Instruction). 2. Plan and conduct work wherever possible to occur within the safe work hour limits. 3. Drivers of Fatigue Regulated Heavy Vehicles must comply with the requirements of the Work and Rest Hours Exemption Notice. 4. Ensure all relevant fatigue training has been attended. 5. Advise supervisor if not fit for safe work or if you are concerned about a team member's fitness for safe work. 6. Advise supervisor when you are not feeling well and seek medical advice as appropriate. 7. Advise supervisor if you are taking any medication that may impair your ability to work, drive, and operate machinery, tools or plant.	8. Discuss fatigue in works planning, toolbox and on the job. Check that everyone is 'good to go'. 9. Take all required rest pauses and breaks and schedule additional rest breaks when fatigue is a risk. 10. Monitor your approach to the safe and maximum work hour thresholds and communicate early with supervisor. 11. Consider whether the job or task can be shortened or deferred to normal working hours. 12. Consider deferring safety critical tasks to a time when the likelihood of fatigue is lower. 13. Rotate staff between high fatigue risk tasks e.g. high risk tasks, monotonous or exhausting physical tasks or tasks in environmental extremes such as heat and humidity. 14. Ensure right person is selected for task – i.e. fit for task 15. Consider implementing a buddy or double check system. 16. Consider alternate transport arrangements for workers to and from an extended job.
Work in Areas Exposed to Unexploded Ordinance	• Disturbance of Unexploded Ordinance	• Serious bodily injury • Hearing Impairment • Tissue Damage • Plant or property damage	1. Do not disturb, touch or move the object. 2. Note the general appearance, dimensions and any visible markings on the object. 3. Safely and clearly mark its location. 4. Inform other workers in the immediate area of the presence of a suspicious object.	5. If possible leave one person at the site to warn others and to secure the object. 6. Note the route to the object. 7. Advise the Superintendent and Site Supervisor as soon as possible. The Superintendent will give the relevant Contractor any directions concerning work. 8. Advise the police as soon as possible and follow their instructions regarding site management and access.
Work in Coastal Regions where Small Copper Conductor is present	• Electrical • Falling Conductor	• Electric Shock • Serious Bodily Injury • Plant or Property Damage	1. In coastal areas where there is small copper conductor (i.e. 064,080) present, extreme care needs to be taken. 2. The conductor in these areas can suffer from annealing and oxidisation caused by the salt air and loading.	3. This causes the conductor to become very brittle and susceptible to failure. 4. Where this is suspected it is recommended that the pole not be disturbed. 5. Follow relevant SWMS/SWPs.
Work on De-energised HV Lines or Apparatus	• Electrical	• Electric Shock • Explosion • Fire	1. Positive identification of equipment to be switched or isolated. 2. Comply with industry HVIA procedures. 3. Establish safe work zone and adhere to Access Permit requirements.	4. HV isolation and access performed by competent persons. 5. Required PPE worn.
Work on De-energised LV Lines or Apparatus	• Electrical	• Electric Shock • Explosion • Fire	1. Comply with electrical industry codes of practice for work on or near LV systems. 2. Positive identification of equipment to be isolated. 3. LV isolation, test and prove de energised, lock and tag out of service. 4. Work crews briefed on isolation method prior to working on isolated LV lines or apparatus.	5. Record of LV isolation points noted on WH&S Plan. 6. LV lines and / or apparatus not isolated from all possible sources of supply, tested and proven de energised must be treated as live. 7. Required PPE worn. 8. Identify adjacent exposed live lines / apparatus and apply control measures.

Activity	Hazard	Consequences	Control Measures	
Work on Non-Ergon Energy Assets	• Identify Asset Owner • Lack of Information • Unfamiliar Equipment • Disturbance to Registered Heritage	• Serious bodily injury • Plant or property damage • Electric shock • Legal and contractual liability • Cultural Heritage Harm	1. Workgroup supervisor to ensure all personnel are aware and competent in identification and operation of non-Ergon Energy Assets before accessing the work site where appropriate. 2. All personnel to receive the appropriate details and instruction in the requirements of the work-site specific to such assets.	3. All personnel to comply with specific work restriction requirements. 4. Appropriate inductions conducted such as Queensland Rail Safety Awareness or Generic Induction to Coal Mining (Surface). 5. Seek cultural heritage advice if asset/premises to be accessed are heritage listed.
Work on Ergon Energy Assets within NSW	• Unfamiliar legislation • Potential cultural heritage items/areas	• Legislative non-compliance• • Cultural Heritage Harm	1. Plan work, comply with Ergon Energy process for all work activities. 2. Undertake as much of ES000906F100 Cultural Heritage Assessment as applicable and contact the relevant Cultural Heritage Officer for advice.	3. All site personnel to obtain appropriate details and instruction on requirements of work-site specifics for such construction or maintenance.
Work on Poles with Bare and Covered Earths attached	• Electrical	• Electric Shock • Explosion • Fire	1. Standard Work Practice SP0217. 2. Required PPE worn. 3. Safe to approach test performed using GLM Mini SWER & Pole Tester or Modiewark.	4. Earth cables to be excavated and located so there is no chance of contact between cable and Power beam Ensure cable clear on opposite side of pole when drilling. 5. No metal equipment to be used to pry cable from pole.
Work on Sloping Location	• Personnel falling • Load dislodgment • Vehicle Instability • Plant / Equipment instability • Erosion and sedimentation	• Serious bodily injury • Plant or property damage • Electric shock • Environmental harm	1. Adorn and affix harnesses where necessary. Negotiate slopes with care to ensure footing and prevent dislodgment of debris. 2. Operator Certification and Authorisation. 3. Comply with manufacturer's operating requirements. 4. Operate lifting plant on stable ground / floor surface. 5. Ensure braking systems are appropriate and operative. 6. Clear debris from path of vehicle / plant on steep sections. 7. Ensure fuel levels are adequate .	8. Where rubber tyred plant or equipment may become unstable or exceed their limit of operation, cease their operation in such locations and only utilise track-operated plant or equipment so as not to exceed their limits of operation. Alternative work processes that reduce exposure to hazard should be sort. 9. Where vehicles may become unstable or exceed their limit of operation, cease their operation in such locations and proceed on foot observing the controls noted above. 10. Do Not operate plant or equipment in such locations without an observer in direct contact with the operator. 11. If required Install sediment fencing / controls around worksite / spoil heaps and monitor erosion control devices regularly. 12. As required Divert storm water / run-off to minimise erosion.

Activity	Hazard	Consequences	Control Measures	
Working in Power Stations	• Rotating plant • Noise and vibration • Hot surfaces, coolants and lubricating oils • Flammable liquids or gases	• Electric shock • Explosion • Fire • Cuts, burns or fractures • Environmental damage (fuel or oil spill) • Hearing loss • Carbon Monoxide poisoning • Dehydration	1. Use of "Permit to Work" system (PTW) including mechanical, fuel and electrical isolation. 2. Allow time for equipment to cool prior to work. 3. PPE – including hearing protection, work gloves.	4. Maintain adequate fluid intake. 5. Provide mechanical ventilation to cool work area.
Working on Substation Equipment including secondary circuitry	• Electrical	• Electric Shock • Burns • Explosion	1. Comply with industry HVIA procedures. 2. Safe work zone established and Access Permit requirements adhered to. 3. HV isolation and access performed by competent persons. 4. Required PPE worn.	5. Comply with electrical industry codes of practice requirements for work on or near LV systems. 6. Positive identification of equipment to be isolated. 7. Positive visual identification of redundant cables along route path prior to cutting and removal. 8. LV isolation, test and prove de energised, lock and tag out of service.
Working on Substation Equipment including secondary circuitry	• Stored energy	• Personal injury / property damage	1. Before working on any device: • Release air or hydraulic pressure • Discharge any springs • Discharge any capacitors, cables, cable sheaths	• Discharge magnetic circuits (i.e. transformer core after DC testing) • Barricade / guard around rotating plant
Working with customers	• Aggressive Customers	• Personal injury	1. Leave the property immediately in a calm and safe manner.	2. Report incident to supervisor once away from immediate perceived danger.
Working Outdoors	• Dog Attacks	• Personal injury	1. Wear close weaved long sleeved shirt (buttoned at wrist), long trousers and covered footwear. 2. Ensure dog or other animals are restrained / locked away. 3. Do not enter property if unsure / not confident. 4. Only use these mechanisms to leave property when dog is unrestrained: • Citronella Spray (refer process CD000302R103) • Dog Dazer (refer to instruction manual)	5. Utilise Dog Management Training: • DO NOT RUN • Stand totally still and freeze • Don't try to make friends • Avoid aggressive behaviour – do not stare • Slowly move away from the dog • If knocked to the ground, roll up into the foetal position and protect head and neck

Activity	Hazard	Consequences	Control Measures	
				• Put up a barrier and leave property slowly
Working Outdoors	• Solar Radiation	• Sunburn • Skin cancer • Eye damage	1. Wear long sleeved shirt (buttoned at wrist), long trousers, broad brim hat and neck protection. 2. Wear eye protection that provides UV protection in accordance with Australian Standards. (Ergon Energy supplied safety eyewear complies with this standard).	3. Regularly apply SPF30+ (or better) sun screen to unprotected skin surfaces. 4. Rotate tasks / workers to limit exposure, utilise tarpaulins, shade structure and any other available shade. 5. Schedule work during the hours when the solar UVR is less intense. This is usually early in the morning or late in the afternoon.
Working in hot conditions	• Heat	• Body fluid loss • Heat related illness	1. Maintain regular intake of cool water and ensure adequate food intake to replenish electrolyte loss with excess sweating. 2. Acclimatisation to work environment. 3. Rotate tasks / workers to limit exposure, utilise tarpaulins, shade structure and any other available shade.	4. Schedule work in the cooler part of the day. This is usually early in the morning or late in the afternoon. 5. Look for signs of heat stress onset. 6. Use wide brim hat / sunscreen / suitable clothing. 7. Provide access to change of clothing if sweating excessively including changing glove liners frequently. 8. Schedule regular breaks.
Working Outdoors	• Cold Weather	• Hypothermia	1. Wear warm clothing 2. Look for signs of hypothermia onset 3. Minimise exposure	4. Rotate tasks / workers to limit exposure 5. Schedule work in the warmer part of the day 6. Schedule regular breaks
Working Outdoors	• Wet Weather	• Skin irritation • Respiratory Infections • Plant, material or property damage	1. Confirm wet weather conditions are suitable before commencing work. 2. Utilise available shelter. 3. Ensure appropriate wet weather attire is provided and worn correctly. 4. Replace wet apparel with warm dry attire after the personnel remove wet items and dry themselves.	5. Movement of personnel, plant and equipment should be reduced to a minimum. 6. Control or cease personnel activity and plant / equipment operation in conditions that increase the likelihood of reduced traction (slips). 7. Provide and maintain adequate drainage facilities 8. Seal and / or cover plant, equipment and materials from exposure to moisture.
Working Outdoors	• High Wind Conditions	• Serious bodily injury • Plant or property damage • Electric shock • Skin irritation	1. Avoid exposure to high wind conditions by providing shelter and / or appropriate apparel. 2. Provide appropriate harnesses and / or guys. 3. Confirm adequate electrical clearance to conductors and electrical apparatus to personnel, equipment, plant and vegetation taking into account their possible movement and stability before entering the vicinity of the work.	4. Inspect vegetation and / or overhanging apparatus for insecure or deteriorated items (branches, slings) that may fall or fail. 5. Wear safety helmet / cap. 6. Avoid any drop zone. 7. Movement of personnel, plant and equipment should be reduced to a minimum. 8. Control or cease personnel activity and plant / equipment operation in conditions that increase the likelihood of instability.
Working Outdoors	• Insects and Ticks	• Bites and stings • Skin irritation • Allergic reaction	1. Wear close weaved long sleeved shirt (buttoned at wrist), long trousers and covered footwear. 2. Check surroundings before commencing work. 3. Identify known tick or insect infested areas.	4. Take note of employees with known allergic reactions and required medication. 5. Apply insect repellent (where applicable). 6. Use Wasp Freeze (as per product instructions).

Activity	Hazard	Consequences	Control Measures	
Working Outdoors	• Snakes and Spiders	• Bites	1. Treat all snakes as dangerous, don't attempt removal of snake ensure a qualified expert is brought in to remove the snake. 2. Keep worksites free of debris (e.g. cardboard, sheet metal) and equipment that may provide shelter for snakes. Cover conduits or other gaps if snakes are suspected. 3. When walking or working in bush areas or areas where snakes may be encountered: • Make noise so snakes are aware of your presence and have a chance to escape; • Take notice of your surroundings and beware of places snakes are likely to be; • Watch where you put your hands and feet; • If you see a snake, stop until it moves away. If that is not possible, step away slowly, keeping the snake in view at all times. Wait for it to move away from the work area; and	• Do not corner a snake. Give it plenty of room to escape. 4. Wear approved protective boots, snake protective leg covers and gloves when working in an environment such as high grass where there are likely to be snakes but you may not be able to see them. 5. Check surroundings and pay attention where hands and feet are placed. 6. Take note of employees with known allergic reactions and required medication. 7. Take care when opening doors or lids of enclosed compartments (e.g. manholes, electrical switchboards). 8. Use a torch for looking in dark areas. 9. Check above your head as well as ledges and corners and crevices on the floor or ground for snakes and spiders before commencing work. 10. Do not put hands or feet in or under logs, rocks, tin, hollows or crevices.
Working Outdoors	• Discovery of Syringes on site	• Needle stick injuries • Contracting blood borne diseases	1. Ensure sharps container, tongs / pliers and / or leather gloves are available on site and / or in vehicle. 2. Take sharps container to the syringe.	3. Do not handle without tongs / pliers and / or protective glove. 4. Place syringe in container needle point first. 5. Dispose of used container at an approved sharps collection point.

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