UNIVERSIDAD DE CANTABRIA
ESCUELA POLITECNICA DE INGENIERÍA DE MINAS Y ENERGIAS

Productivity analysis of a photovoltaic plant in Namibia

GRADO EN INGERÍA DE LOS RECURSOS ENERGÉTICOS

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Keywords: Solar energy, photovoltaic, irradiance, productivity analysis, management, Namibia, SCADA.

This project main objective is to analyse and compare the differences that have occur during a one-year period between the estimations done by AEE Power Ventures "*an international EPC contractor and Power Developer specialized in the energy industry and focused on developing countries"* and Arup *"an independent firm of designers, planners, engineers, consultants and technical specialists"*, prior to the construction and commissioning of the Rosh Pinah solar photovoltaic power plant and the actual results that have been gather during this one-year period. As well as getting to know how a solar photovoltaic power plant works, how it is managed and to acquire the basic knowledge needed to do so.

In order to do so, we have had access to a web client application provided by Inaccess "*a company that designs and develops state-of-the-art products and solutions focusing on digital infrastructure management"*, based on SCADA software, that allows to control and supervise processes remotely and has given us the information directly from the power plant in real time as it also saves the past days information from which we can then compare and analyse.

The project is divided into two parts. Firstly, the global view of solar energy and the theoretical concept of the photovoltaic technology, focused on the energy situation around the world, especially in Africa and Namibia. Secondly in the Rosh Pinah solar photovoltaic power plant in Namibia, where it will develop the following topics:

- Site information
- Introduction to data analysis – SCADA
- Meteorological information
- Monthly analysis
- Daily analysis
- Monthly energy yield
- Average annual performance
- Comparative optimal vs bad day
- Inverters
- Pyranometers

After all the information gathered through the first year of production has been analysed and compared with the estimations done prior to construction and commissioning of the photovoltaic solar power plant, we will be able to come up with some conclusions, trying to give some solutions to any problem that we can detect and try to solve.

Resumen

Análisis de productividad de una planta fotovoltaica en Namibia

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Palabras clave: Energía solar, fotovoltaica, irradiación, análisis de productividad, gestión, Namibia, SCADA.

El objetivo principal de este proyecto es analizar y comparar las diferencias que han ocurrido durante un año entre las estimaciones realizadas por AEE Power Ventures "un contratista internacional de EPC y desarrollador de energía especializado en la industria energética y enfocado en países en desarrollo" y Arup " una firma independiente de diseñadores, planificadores, ingenieros, consultores y especialistas técnicos ", antes de la construcción y puesta en marcha de la planta de energía solar fotovoltaica Rosh Pinah y los resultados reales que se han reunido durante este período de tiempo de un año. Además de conocer cómo funciona una planta de energía solar fotovoltaica, cómo se gestiona y adquirir los conocimientos básicos necesarios para hacerlo.

Para ello, hemos tenido acceso a una aplicación web provista por Inaccess "*una empresa que diseña y desarrolla productos y soluciones de última generación centrados en la gestión de la infraestructura digital*", basada en el software SCADA, que permite controlar y supervisar los procesos industriales de forma remota, la cual nos ha dado la información directamente de la planta en tiempo real, y que a su vez iba guardando la información de los días pasados, a partir de la cual hemos podido analizarla y compararla.

El proyecto está dividido en dos partes. En primer lugar, la visión global de la energía solar y el concepto teórico de la tecnología fotovoltaica, centrada en la situación energética en todo el mundo, especialmente en África y Namibia. En segundo lugar, la planta de energía solar fotovoltaica Rosh Pinah en Namibia, donde se desarrollará los siguientes temas:

-Información del lugar

- Introducción al análisis de datos - SCADA
- Información meteorológica
- Análisis mensual
- Análisis diario
- Rendimiento energético mensual
- Rendimiento anual promedio
- Comparativa día óptimo contra día malo
- Inversores

- Piranómetros

Una vez que se haya analizado toda la información recopilada durante el primer año de producción y comparada con las estimaciones realizadas antes de la construcción y puesta en marcha de la planta de energía solar fotovoltaica, podremos llegar a algunas conclusiones, tratando de dar algunas soluciones a cualquier problema que podamos detectar e intentar resolver.

Glossary of Terms.

A	Area (m^2)
AM	Air-Mass-ratio
C	Thermal capacitance ($J \cdot K^{-1}$)
C_p	Power coefficient
C_r	Concentration ratio
D	Distance (m)
δ	Declination
E	Energy (J)
EMF	Electromotive force (V)
F	Force (N)
G	Solar irradiance (W/m^2)
$G_{0\lambda}$	Solar constant ($\cong$1367 Wm^{-2})
G_b, G_d, G_h	Irradiance (beam, diffuse, on horizontal)
GW	Gigawatts
H	Enthalpy (J)
I	Electric current (A)
I_{sc}	Short-circuit current
M	Mass (Kg)
MW	Megawatts
N_O	Avogadro number
nm	Nanometer
P	Power (W)
P’	Power per unit length
PS	Photosystem
PPC	Power Plant Controller
T	Temperature
V	Volume (m^3)
V_{oc}	Open circuit voltage
W	Watt
Wp	Watt peak

1. Introduction

Since the beginning of the times the Sun has provided us with light and heat, necessary to support live as we know it. But it was not until the 19th century when the photovoltaic effect was discovered and studied, ever since then there has been a remarkable advance in this field up until now a day where we have solar photovoltaic plants that generate power and provide us with electricity.

Photovoltaic energy is a type of renewable energy, consisting in the generation of electricity due to complex reactions in an atomic level that ends up generating electricity. Ever since the discovery of the photovoltaic effect we have been studying and improving ways to produce energy in this manner, thanks to dedicated research worldwide in this field, the efficiency of photovoltaic has continued to increase while production costs have dropped.

For the past several years, energy and electricity consumption has increased drastically, and so the ways to produce energy have changed from conventional carbon, oil and natural gas, that are directly connected to CO_2 emissions and pollution, to other cleaner sources such as renewables or nuclear.

During 2017 global energy demand increased by 2,1% compared with previous 0,9% from 2016 and 0,9% on average over the previous five years. Such growth was especially remarkable for the solar photovoltaic (PV), since the world added more capacity from PV than from any other energy source.

In Africa, 588 million people (nearly 48% of the population) lack access to electricity, with the majority of those living in sub-Saharan Africa. Having in mind that Africa receives more hours of bright sunshine than any other continent on Earth and with the abovementioned problem, this leads us to the conclusion that the continent of Africa has an enormous potential for solar photovoltaic production.

So far South Africa is leading the solar photovoltaic capacity, followed by Algeria, Ghana, and Morocco, as many others. In our case of study, Namibia has plans to construct 500 megawatts of photovoltaic capacity in years to come, this makes clear that solar energy in Africa is the present and future on energy.

2. Purpose and Scope

The purpose and scope of this study is to analyse the difference between the foresight data that was considered during the construction and commissioning of the solar photovoltaic power plant, located near the city of Rosh Pinah in Namibia, and the actual data that has been generated and collected during a one-year period.

The main objective of this project is the productivity analysis of Rosh Pinah solar photovoltaic power plant, a polycrystalline based solar cells plant with a 315 Wp in conditions of 21ºC and 1000 W/m^2 in direct solar radiation, that has a nominal capacity of 5,67 MW. As well as getting to know how a photovoltaic power plant works, how it is managed and to acquire the basic knowledge needed to do so.

This analysis is possible thanks to the information that has been provided by AEE-Power Ventures, an international Engineering, Procurement and Construction (EPC) Contractor and Power Developer specialized in the energy industry and focused on developing countries. Through a SCADA platform runned by Inaccess servers that its integrated in the solar PV plant, allowing to control and manage the plant in real time. This has allowed us to get the real information form the plant and compare it with the estimations done prior to the construction and commissioning.

The expectation from this project is to understand better solar energy, and to inquire deeply into the photovoltaic technology, as well as to put in perspective what is the global situation with photovoltaic, emphasizing in Africa's and Namibia's situation and potential. Followed up by the real case scenario that we have, in which the main goal is to compare the overall productivity. In order to do so we will need to analyse different aspects, such as meteorological information, irradiance and others, related to the generation of electricity through PV cells.

3. State of the art

3.1. Solar Radiation

The Sun is a star whose surface is at an average temperature of approximately 6000 ºK, at a distance of 150 million kilometres from Earth. Due to complex reactions, that produce a loss of mass, this star, the Sun, provides us with light and heat, necessary to support live as we know it. Thus energy, coming from the Sun, it is exported throughout what is called solar radiation. "Solar radiation reaches the Earth´s surface at a maximum flux density of about 1.0 kWm^{-2} in a wavelength band between 0.3 and 2.5 μm. This is called *short wave radiation* and includes the visible spectrum" [1]

In *Figure 1* solar radiation spectrum is shown. If we take a look at it, we can observe that 43% of the total energy emitted by the Sun is found in the visual part of the spectrum.

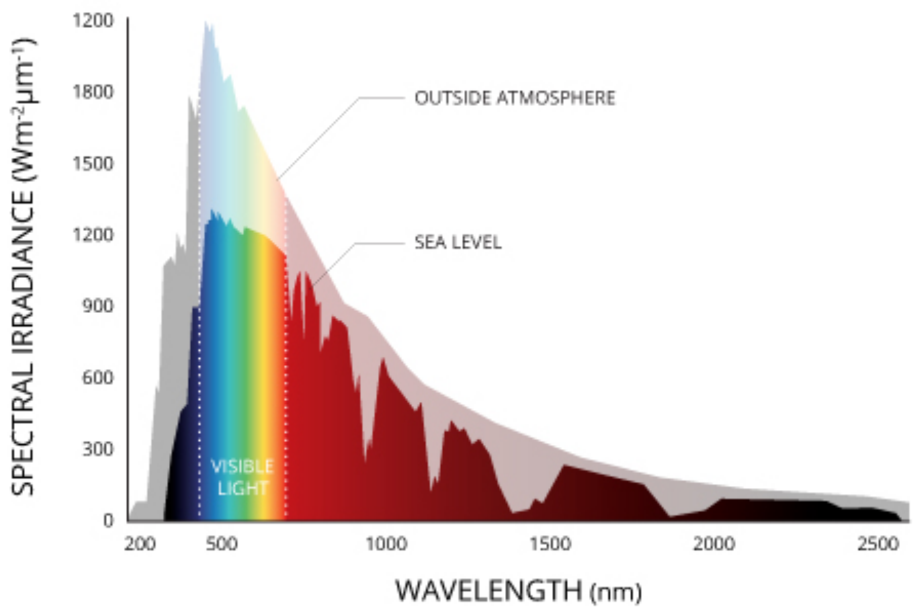


Figure 1 – Spectral distribution of solar irradiance, outside the atmosphere and at sea level. The total area equals $G_{0\lambda}$. (data source: Gueymard 2004).

"The solar spectrum can be divided into three main regions:

1. Ultraviolet region (λ < 400 nm) ≅ 5% of the irradiance
2. Visible region (400 nm < λ < 700 nm) ≅ 43% of the irradiance
3. Infrared region (λ > 700 nm) ≅ 52% of the irradiance."

"The proportions given above are received at Earth´s surface with the Sun incident at about a 45º angle."[1]

The area beneath this curve is the solar radiation constant G_o = 1367 $W \cdot m^{-2}$.

Ultraviolet radiations are very energetic, but also, they are few, since only 7% of the total radiations belong to this kind of radiation. The contrary occurs with the infrared radiations, that are more abundant (43% from total) but much less energetic that the previous ones.

Solar radiation outside the atmosphere has an approximate value of 1352 W/m^2, measured on a perpendicular area to its propagation direction. This value is known as *solar constant* and it is slightly different from the value we receive in the Earth's surface. This reduction of energy received by the sun is justified due to its obligatory crossing of the atmosphere, produced mainly by three factors, which are the following:

- Atmospheric gases (nitrogen, oxygen, ozone, etc.)
- Water vapour
- Dust

The combination of these elements is the reason why in Earth's surface, and at sea level we only receive 1000 W/m^2. Value that it is only achieved when the day is clear, and the air is "transparent ". Also, this value depends on the location of the point we want to measure, since geometric factors such as latitude also affect the amount of energy that reaches a certain point on Earth's surface.

Considering the random fact of the clear days and covered during the period on a year, we see the necessity of obtaining statistics data of different radiations on different seasons of a year (summer, winter, autumn and spring) and the different location of a solar power plant in order to get more accurate approximation of production.

3.2. Geometry Earth and Sun[2]

There are two movements that affect the Earth and Sun relation. These movements have to be considered since they affect directly to the irradiance.

The first, and probably more obvious movement, is called Earth´s <u>rotation movement</u>. The illustration below represents the spinning of the Earth on its axis, which defines the north (N) and south (S) poles. The axis of the poles is perpendicular to the earth's equatorial plane.

One rotation occurs every twenty-four hours and it's called *mean solar day*. The rotation is responsible for the daily cycles of day and night. During the night period, solar radiation is none, since the surface of the earth is in the opposite side from the Sun. This meaning that during this period there is no production of electricity due to solar radiation.

A point (P) on the earth´s surface is determined by its *latitude* (ϕ) and *longitude* (ψ). Latitude is positive for points north of the equator and negative for those that are south, whereas with longitude, by international agreement, is measured positive eastwards from Greenwich, England.

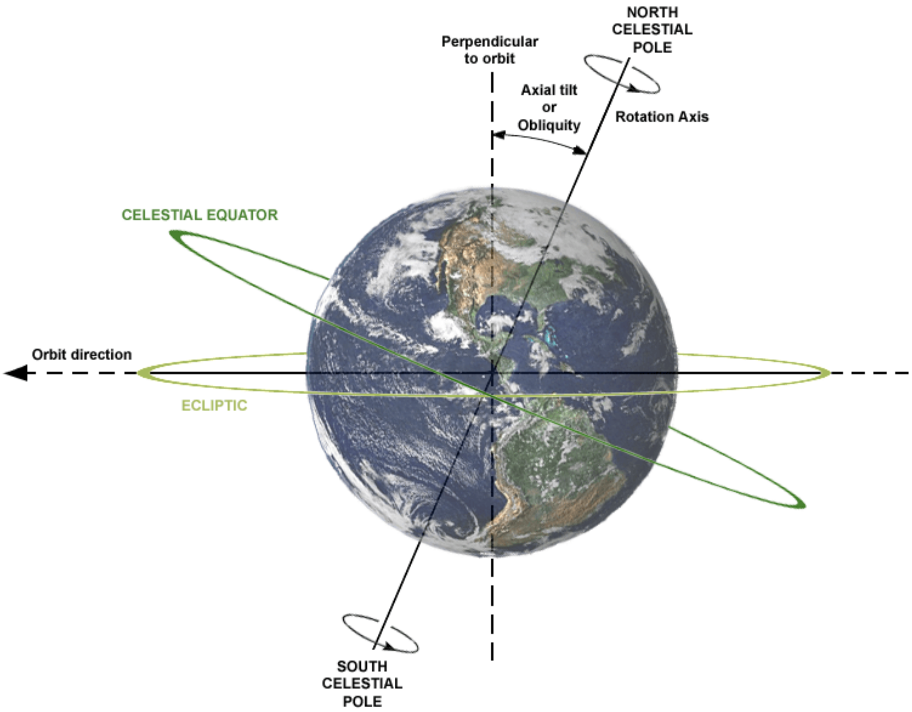


Figure 3 - Earth's rotation movement

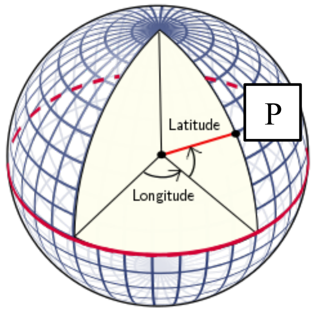


Figure 2 – A point P on Earth's surface

"The *hour angle* ω at P is the angle through which the Earth has rotated since solar noon. Since the Earth rotates at 360º every 24h, meaning that 360º/24h = $15ºh^{-1}$ is Earths speed of rotation. The hour angle is given by

$$\omega = (15ºh^{-1})\ (t_{solar} - 12h) = (15ºh^{-1})\ (t_{zone} - 12h) + \omega_{eq} + (\psi - \psi_{zone})$$

where t_{solar} and t_{zone} are respectively the local solar and civil times, ψ_{zone} is the longitude where the Sun is overhead when t_{zone} is noon. ω is positive in the evening and negative in the morning. The small correction term ω_{eq} is called the equation of time; it never exceeds 15 minutes and can be neglected for most purposes. It occurs due to the Earth's elliptical orbit around the Sun means that there are not exactly 24 h between successive solar noons, although the average interval is 24h.

Earth's orbits around the Sun once per year, while the direction of its axis remains fixed in space, at an angle δ_o = 23.45º away from the normal to the plane of revolution.

When determining solar insolation, cloud coverage, solar declination angle, zenith angle and hour angle are necessary variables to consider. Units used to measure solar insolation are generally $kWh/m^2/day$, this represents the amount of daily solar energy striking a square meter of earth's surface.

This difference between the angle of the Earth and the Sun's direction is called declination δ, relating the seasonal changes.

$$\delta = \delta o \cdot \sin\left(\frac{360° \cdot (284 + n)}{365}\right)$$

Where n is the day of the year.

The hours that occur between sunrise and sunset N is:

$$N = \frac{2}{15} \cdot cos^{-1}(-tan\,\phi \cdot \tan\delta)$$

Where ϕ is the latitude.
The daily insolation H is a function of the latitude ϕ, and the declination δ of the Sun and is the total energy per unit area received in one day from the sun:

$$H = \int_{t=0h}^{t=24h} G\,dt$$

This value varies with latitude and season. Its seasonal variation arises from three main factors:

- Variation of the length of the day.
- Orientation of receiving surface.
- Variation in atmospheric absorption.

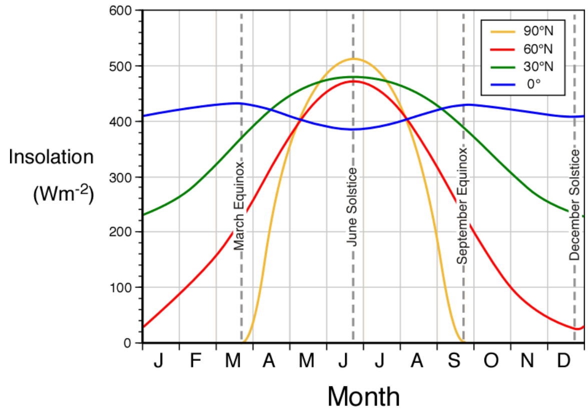


Figure 4 - Variation with season and latitude of H

The hour angle, h, of a point on the earth's surface is defined as the angle through which the earth would turn to bring the meridian of the point directly under the sun.

The hour angle at local solar noon is zero, with each 360/24 or 15º of longitude equivalent to 1h, afternoon hours being designated as positive. Expressed symbolically, the hour angle in degrees is:

h=±0,25*(number of minutes from local solar noon)

where the plus sign applies to afternoon hours and the minus sign to the morning hours.

3.3. Theoretical concepts of PV cells[3]

Matter is made from atoms, which at the same time are constituted by two well differentiated parts: the core, with a positive charge, and the electrons, that spin around the core in different energy orbits; with its negative electric charge, that compensates the charge in the core, and in this way, forming a completely neutral and stabilized (form an electrical point of view) element.

The last orbit of an atom is commonly known as *valence shell*, which has the capability of interconnect with similar elements, creating a crystal network.

We could divide these elements in three categories, such as:

- Conductors: This kind of elements have a valence shell that is not very attached to the core, that allows these electrons from the valence shell to move easily inside the crystal network in response to an external force.

- Semiconductors: The electrons placed in the valence shell of these type of elements are more attached to the core than the previous ones, but still it is enough to apply a bit of energy so that they behave as the conductors, freeing the most external electrons.
- Insulators: They have a very stable structure, which is difficult to change, since its valence shell electros are very attached to the core element and the energy needed to break the connexion would be extremely big.

The elements used in photovoltaic cells are semiconductors, due to the fact that the energy that bounds the valence shell electrons to the core is similar to the energy carried by the photons that are part of the sun light. When the sun light incises on the semiconductor, thus photons give the valence shell electrons the enough amount energy needed in order to escape the attraction that the core produces in these electrons.

The space left by the electron has a positive charge, the same as the electron but of opposite sign. These spaces also move, since the electron that has left the empty space moves to other near gaps, creating a movement due to the lack of the electrons. This process, of the electrons occupying the spaces it is also known as *recombination*.

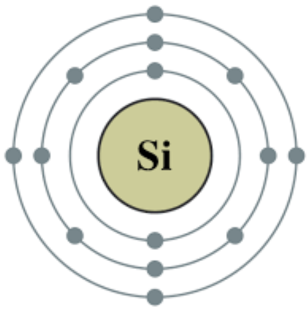


Figure 5 - Silicon atom structure

These free electrons and the spaces that are created in the place where there is light, tend to blur towards the dark areas, by doing so, they lose their activity. Although, since they both move with the same direction, it happens to not create an electrical impulse, and sooner or later they recombine re-storying the broken bond. Furthermore, if in the area, or near, where these pairs of electrons and spaces have been created an electric field is created inside the semiconductor, this electric field would make the electrons and the spaces go on opposite directions, which would consequently, create and electric current in the same direction as the electric field.

There are several ways of creating an electric field of this kind, inside a semiconductor element, but all of them are based in the same principle of potential contact and affinity that different solids have for electrons.

In conventional photovoltaic cells this electric field is acquired from the union of two regions of a silicon crystal that have a different chemical treatment each.

One of the so-called regions, denominated region n, has been altered (un-purified), with phosphorus. The phosphide has one more valence shell electron, five. So, in this way the region un-purified with phosphor shows an affinity for the lower silicon electrons.

The other region, so called region p, has been altered with boron. The boron only has three [3] valence shell electrons, one less than the silicon. For this reason, the silicon altered with boron, has an affinity for the electrons from a superior valence shell of pure silicon. In this way, the p-n union, that is created in this way shows a potential difference V_c that make the electrons from the n side have less energy than those on the p side. Consequently, a magnetic field that goes from the n region to the p, tends to “throw” the electrons to the n part and the holes to the p side.

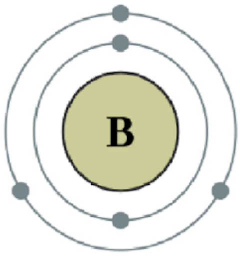


Figure 6 – Boros atom structure

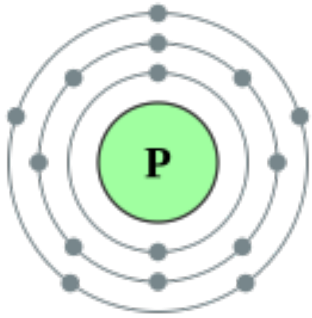


Figure 7 – Phosphoro atom structure

The physical makeup of a photovoltaic cell of traditional monocrystalline silicon starts with an ingot of altered silicon with boron, that is sliced into a 0.3mm thickness, and even less nowadays. Once this cutting is concluded, one of the sides of the monocrystalline is strongly doped with phosphor by applying thru diffusion, in a gassified high temperature atmosphere rich of its one component (phosphor). In this way the phosphor penetrates the silicon, deeper than the boron that was contained previously, up to a maximum depth of 0.3 microns. On top of that layer, a conductive metallic rack is placed, and in the opposite side of the cell, a continuous layer. They both serve to a common goal, to facilitate the electrical contact between the two regions.

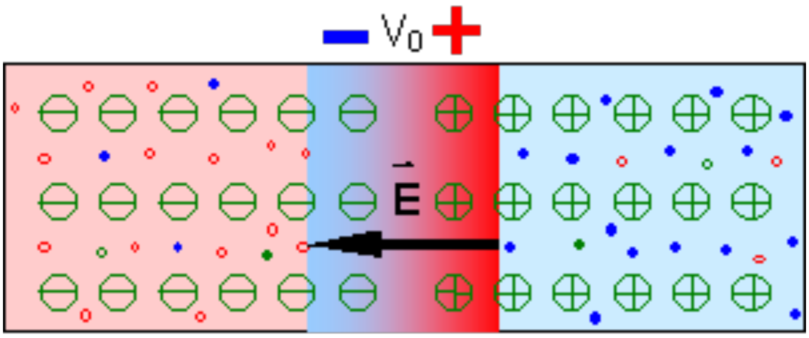


Figure 8 – Movement of electrons trough a boron-phosphoron cell

When photons incise in the superior layer of the cell, some bonds are broken, creating in this way electron-hole pairs.

If this generation is produced at a distance smaller than what is known as *diffusion length,* sooner or later these transmitters will be separated due to the intense magnetic field that exists in the union. This will make the electron move towards the n side and the hole to the p side, and in consequence creating a current from the n side to the p side.

If the *diffusion length* is very small, then in a short path, the electron and the hole will recombine and the luminous energy that was absorbed in order to create the pair will be recuperated as heat, which is not what we wish.

Like this, the electrons that have been absorbed in the back side of the solar cell will have fewer possibilities of make it to the union, if the *diffusion length* is not big enough. In order for the diffusion length to make it to the value that we desire, it is necessary that both structurally and constitutionally, the silicon crystal is of great pureness; this meaning that the crystal has to be monocrystalline and that it must have an infinite number of imperfections different from the ones that have been created (boron and phosphor). This is due to the fact that the imperfections, as the structural damages, catalyse with great efficiency the process of recombination of the pair electron-hole in its way to the p-n union.

The electric current produced, since its used in a useful work, develops a tension fall that makes the p area to be negative. Since this area is the one with less potential energy of electrons, the effect of the outside load is to reduce the potential of the p zone, that is, to make smaller the magnetic field separator that appears in the union.

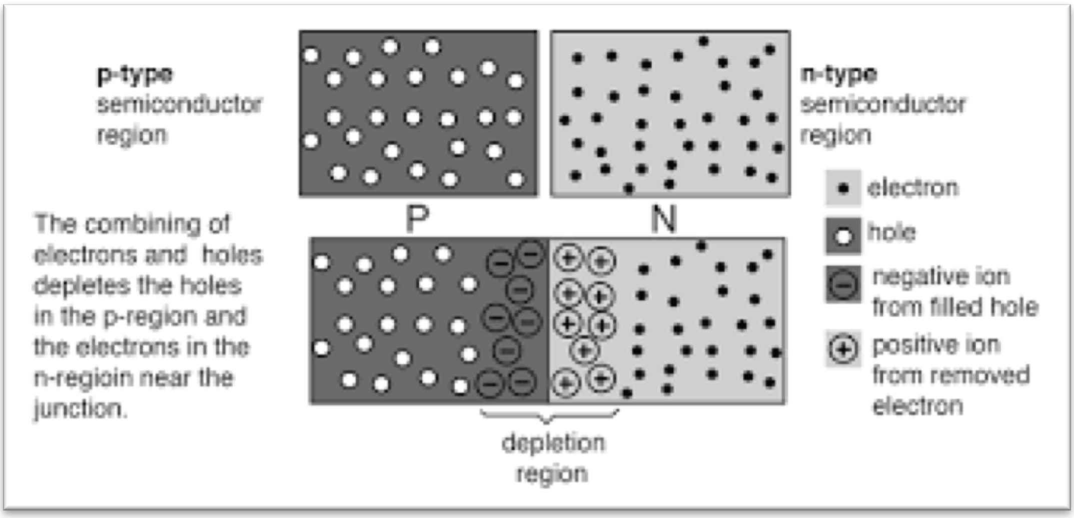


Figure 9 - P-N type cells

The given current for each photovoltaic cell for a given luminosity changes in such way as the loss of tension does in the exterior, as it is shown in the next picture.

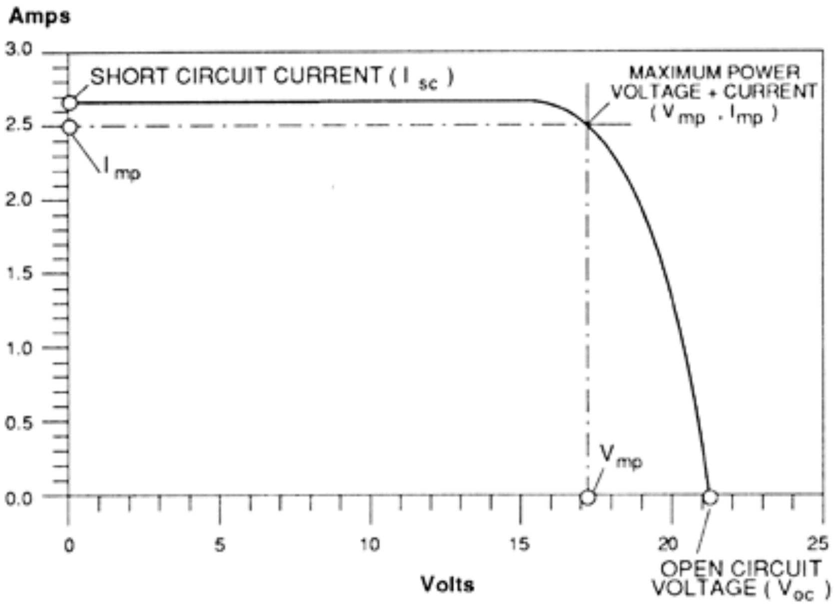


Figure 10 - Amplitude -Voltage relation

3.4. Photovoltaic Cells[3]

Photovoltaic cells convert solar radiation into electrical energy in the form of direct current. Photoelectric cells are an indispensable element for this type of renewable energy.

There are different types of photoelectric cells depending on the nature and characteristics of the materials used. The most common type is the crystalline silicon cell (Si). This material is cut into very thin disc-shaped, monocrystalline or polycrystalline sheets, depending on the manufacturing process of the silicon bar.

The first crystalline cell that was manufactured in the industrial field was of pure monocrystalline silicon. These types of solar cells have a good energy efficiency, but they cost more than other types. For this reason, they currently have a moderate level of implementation.

3.4.1. Types of photovoltaic cells

Monocrystalline solar cells usually have a square shape, with rounded corners. Formerly they had a circular shape. Due to the growth process of the monocrystalline silicon crystal having a cylindrical shape.

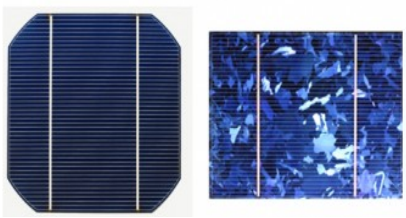


Figure 11 - Monocrystalline vs Polycrystalline cells

In the manufacturing process of polycrystalline silicon, the silicon is allowed to solidify slowly in a rectangular mould and a rectangular solid with many crystals is obtained, which has the result of the polycrystalline cells. This type of cells have lower yield than monocrystalline but have a strong implantation since they have a lower economic cost.

With less implementation, we can find in the market photovoltaic panels called "**thin layer**". These are not manufactured with individual cells, but in the form of continuous bands in which a thin layer of amorphous silicon (a-Si), 1 or 2 microns thick, is deposited on an appropriate substrate (glass or synthetic resins), making a continuous panel that does not need interior interconnections.

An important characteristic of these cells is that the photons that do not collide with any electron, passes through them thanks to their small thickness, which makes it possible to design panels with different layers superimposed and which are called tandem (two layers) or triple union (three layers).

The cells with **amorphous silicon** have a yield of approximately half that of the crystalline cells, and therefore, in the manufacture of thin-film cells are beginning to use other types of semiconductors, essentially the selenium of copper and indium (CIS) or cadmium telluride (CdTe).

As innovative technologies in the manufacture of photovoltaic cells, we will highlight the so-called "HIT cells" (Heterojunction with Intrinsic Thin Layer). This term refers to a technique based on the superposition of semiconductor layers of different "gap" such as amorphous silicon combined with crystalline silicon cells or cadmium tellurium, etc.

This improves the energy efficiency of the solar cells and broadens the usable solar radiation spectrum, since each of the semiconductors is especially sensitive to some of the bands of the electromagnetic spectrum.

3.4.2. Solar concentration systems

Another line of work for the technological innovation developed in recent years is the so-called solar concentration technique.

This technology is based on the concentration of solar radiation on a small surface (the photovoltaic cell) by means of an optical concentrator. For example, through a Fresnel lens (magnifying effect) or a reflector, such as a simple mirror with which a significant increase in the incident solar radiation can be achieved and, consequently, a greater energy efficiency of the system. This technique is also known as a solar oven.

In any case, the concentration systems have the disadvantage that they take advantage of almost only direct solar radiation. Therefore, with the concentration panels it is essential to use precise tracking systems.

Currently, the market offers some photovoltaic panels with point Fresnel concentrator systems and other parabolic trough concentrators integrated in the same panel, which can increase the radiation incident in the cell up to 500 times, thus increasing production significantly energy per cell surface unit.

3.5. Global solar energy scenario

During 2017 global energy demand increased by 2,1% compared with previous 0,9% from 2016 and 0,9% on average over the previous five years. Globally speaking, Asia concentrated more than 40% of its growth on energy demand, mainly China and India. It is also interesting to highlight that there was a notable growth in Southeast Asia (8% from global demand) and Africa (6%) although per capita use in these regions are still below average.

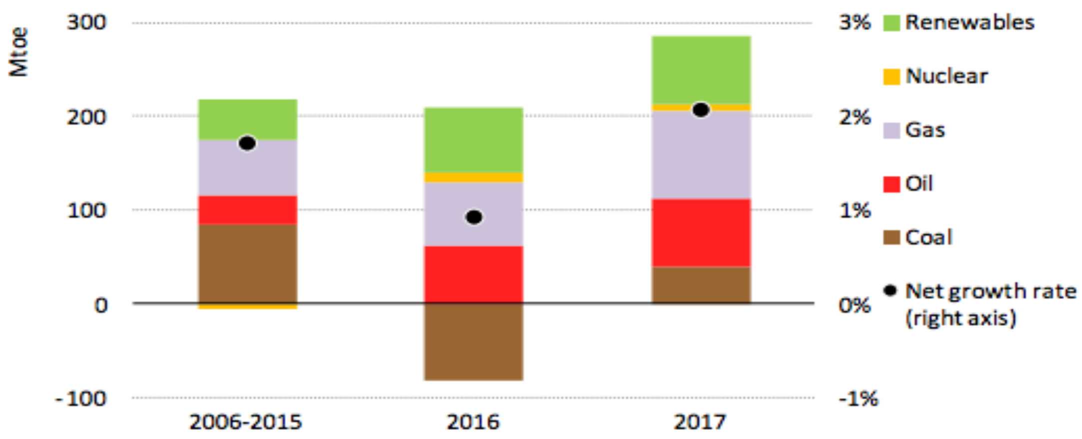


Figure 12 - Average annual growth in energy demand by fuel. ***Source: IEA Global Energy & CO2 Status Report 2017***

Such growth was especially remarkable for the solar photovoltaics (PV), since the world added more capacity from PV than from any other energy source. “Globally at least 98 GW_{dc} of solar PV capacity was installed (on and off-grid), increasing total capacity by nearly one-third, for a cumulative total of approximately 402 GW.”

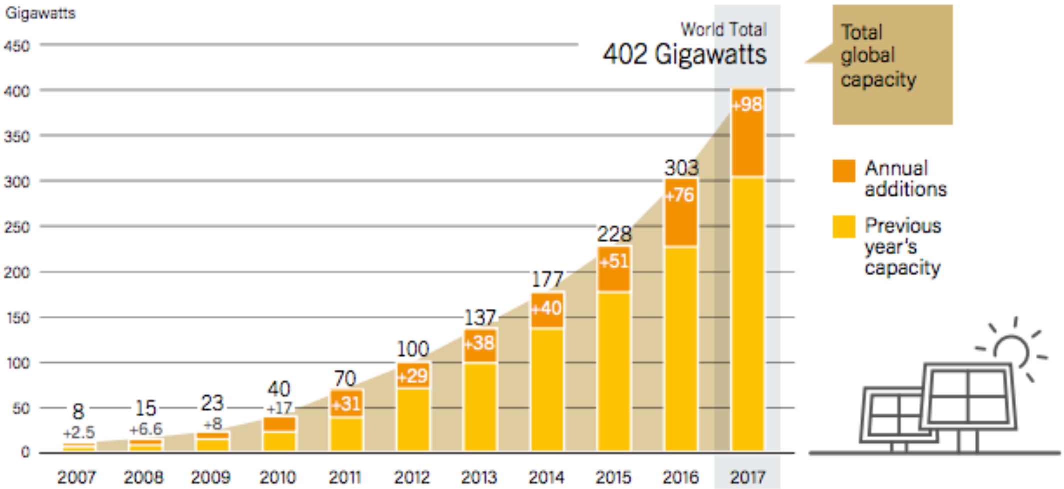


Figure 13 - Solar PV Global capacity and Annual Additions 2007-2017 **Source: RNE21**

3.6. Leading Countries

The 84% of newly installed capacity took place in the top five markets – China, the United States, India, Japan and Turkey; followed by Germany, Australia, the Republic of Korea, the United Kingdom and Brazil.

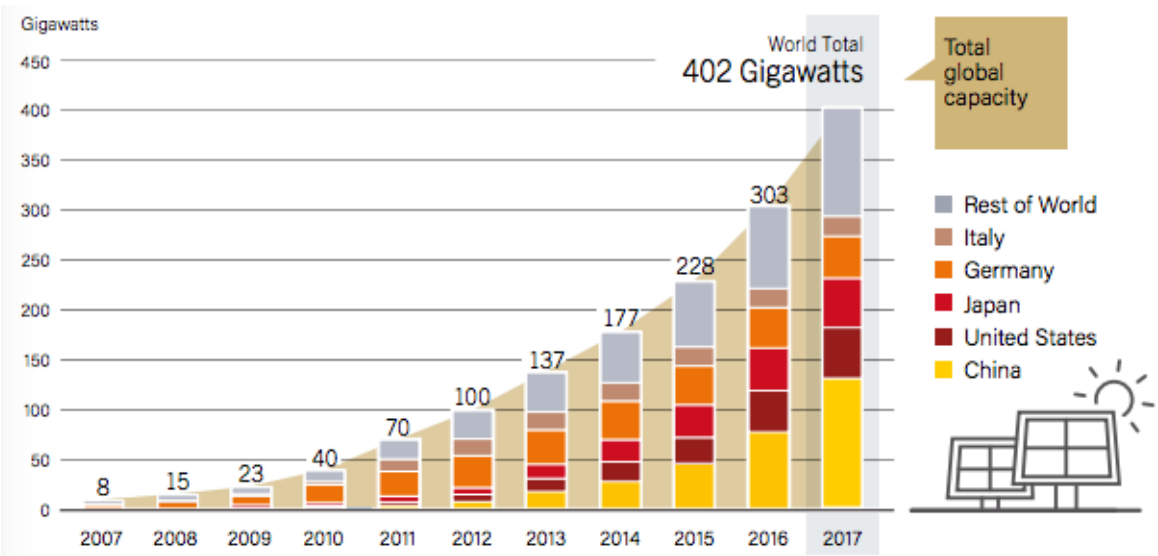


Figure 14 - Solar PV Global Capacity, by country or region 2007-2017. **Source: RNE21**

“Global energy demand increased by 2,1% in 2017, compared with 0,9% the previous year and 0,9% on average over the previous five years. More than 40% of the growth in 2017 was driven by China and India; 72% of the rise was met by fossil fuels, a quarter by renewables and the remainder by nuclear.”

3.7. Global overview energy in Africa

As the RNE21 Global report states**,** In Africa, 588 million people (nearly 48% of the population) lack access to electricity, with the majority of those living in sub-Saharan Africa. An estimated 26 million people in the region gained access to electricity annually between 2012 and 2016, with progress made in electricity access outpacing population growth between 2014 and 2016. However, progress has been slow compared to other regions, as shown in the following figure 15.

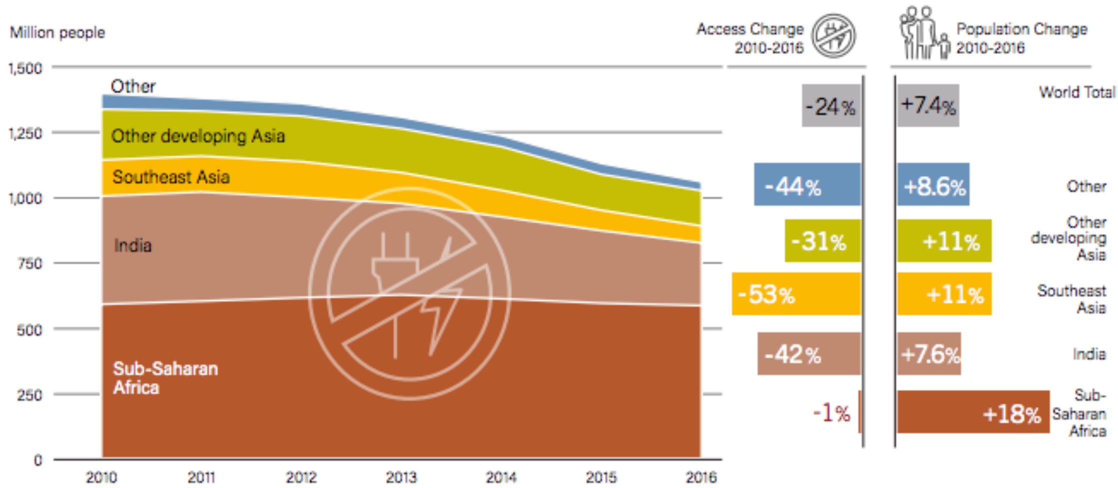


Figure 15 - Population without access to electricity, by region or country 2010-2016. ***Source: REN21***

In some 24 countries in the sub-Saharan region, more than 90% of the population still relied on traditional biomass, coal or kerosene for cooking purposes.

As seen Africa has a great potential to energy production from renewable sources, and know-a-days there are many efforts being done to promote these resources in what generation and of power and electricity concerning the sustainable development scenario, by this scenario we refer to the IEA concept “an integrated way to achieve a range of energy-related goals crucial for sustainable economic development: climate stabilisation, cleaner air and universal access to modern energy, while also reducing energy security risks”.

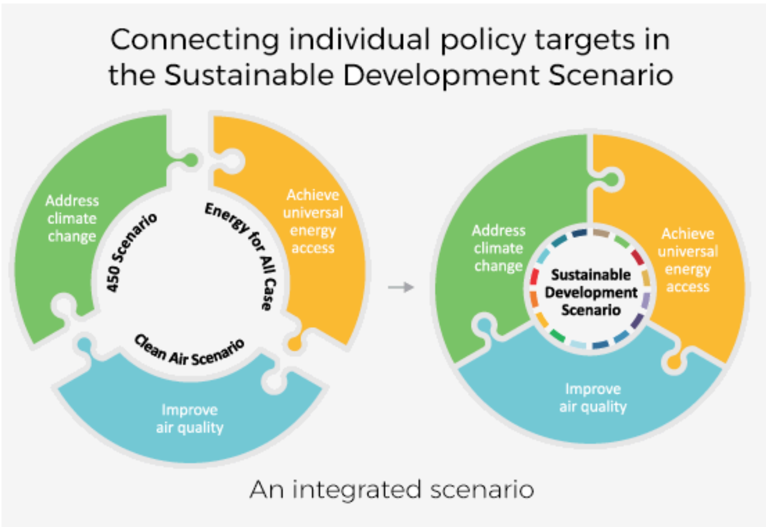


Figure 16 - Sustainable development scenario

3.8. Global aspects of Namibia

Namibia, officially the Republic of Namibia, is a country in southern Africa whose western border is the Atlantic Ocean. It shares land borders with Zambia and Angola to the north, Botswana to the east and South Africa to the south and east. Its capital and largest city is Windhoek, and it is a member state of the United Nations (UN), the Southern African Development Community (SADC), the African Union (AU), and the Commonwealth of Nations.

Namibia, the driest country in Sub-Saharan Africa has a population of 2.6 million people. Agriculture, herding, tourism and the mining industry – including mining for gem diamonds, uranium, gold, silver, and base metals – form the basis of its economy. The large, arid Namib Desert has resulted in Namibia being overall one of the least densely populated countries in the world.

In terms on energy production and electricity generation the following illustrations are shown in order to get an idea on the current (data available until 2015) situation that the country is in right know and some estimations in what the country expects to achieve.

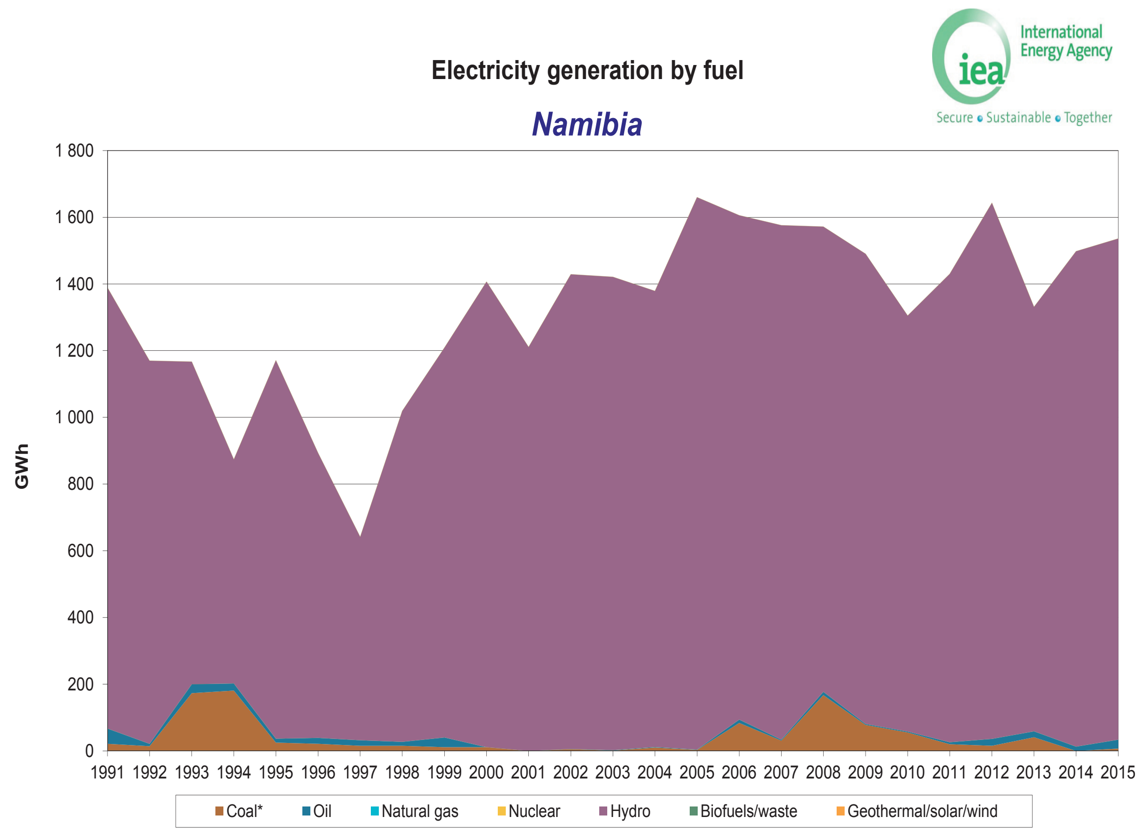


Figure 17 - Electricity generation in Namibia by fuel. Source: IEA

Here, in the previous Figure 17, we can see a display of the electricity generation in Namibia by fuel up until the year 2015. We can appreciate that the majority of the electricity was generated by a renewable source (Hydroelectric power), but also, we see that the rest of the electricity production comes from non-renewable sources such as oil, natural gas and coal, there are no other renewable sources of electricity production in the country.

Next, we have will see figure 18 where energy production is shown. As it is seen, even though in the earlier illustration we saw that electricity was mainly generated by hydropower, we can now see that energy is mainly produced by biofuels/waste. This is because the country is in an early stage of development and no infrastructure to provide electricity is yet exists, so the population rely on old-fashioned methods (mainly burning waste) to produce energy for living (cooking, heat... etc)

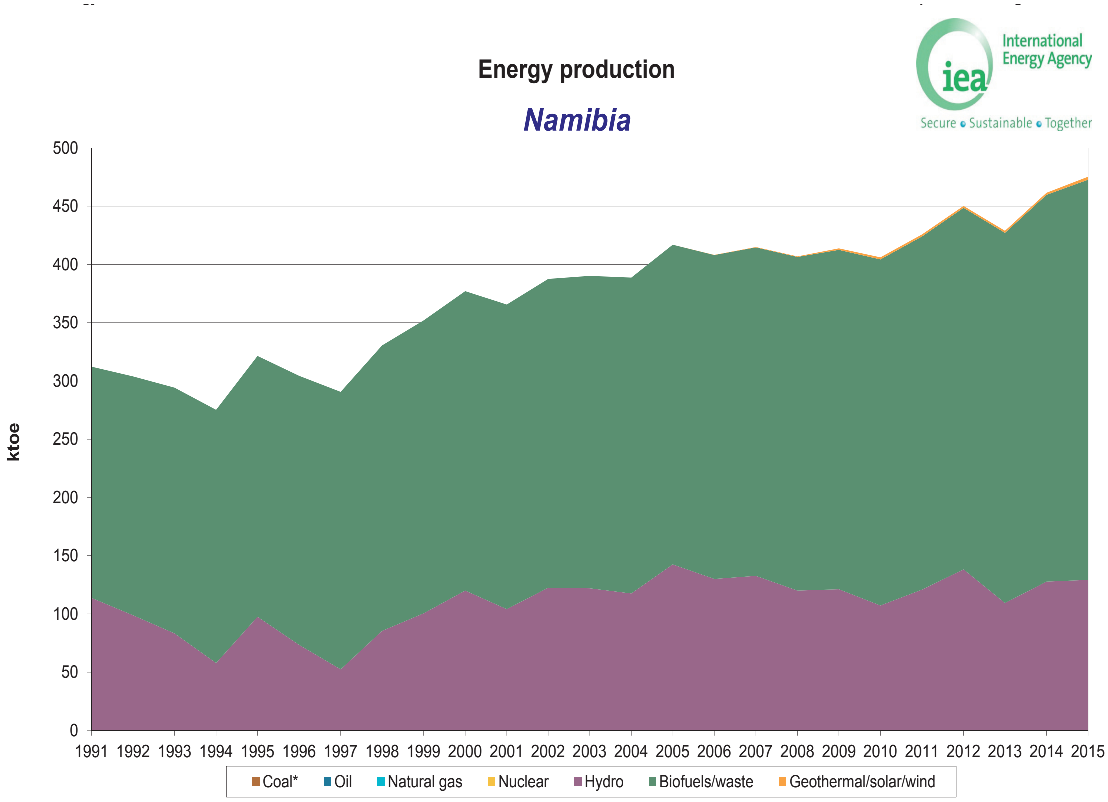


Figure 18 - Share of total primary energy supply 1991-2015. ***Source: IEA***

3.9. Namibia´s Solar Energy

Although up until 2015 there has not been any solar PV electricity generation, there are currently been develop several plans and strategies to change this and some PV power plant has already been constructed, like the one that brings us to this study, as we shall see in further pages.

There is however, information regarding the solar radiation and the potential that Africa and this country, Namibia, particular have.

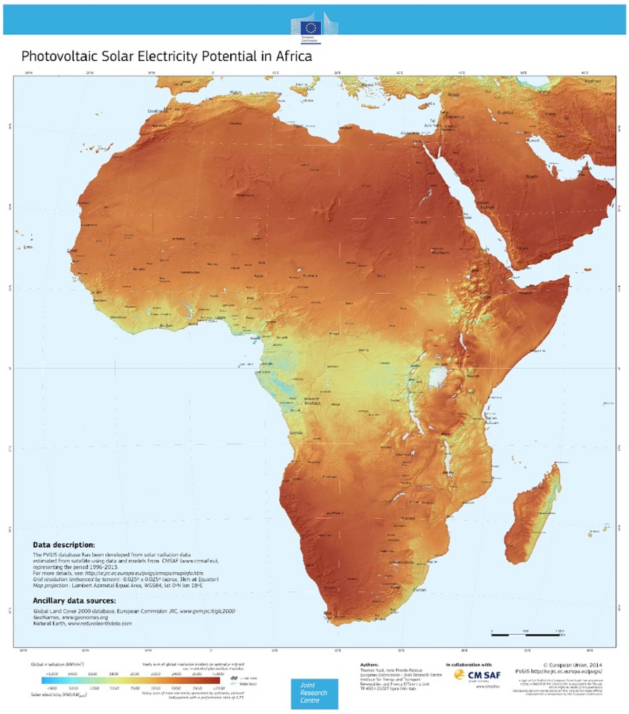


Figure 19 - Africa's photovoltaic solar electricity potential. Source: PVGIS

In this figure 19 we can appreciate the photovoltaic solar electricity potential in Africa; this information has been gathered through PVGIS – Photovoltaic Geographical Information System.

Whereas in illustration 10, we have the global irradiation and solar electricity potential in Namibia, in which we will be entering in more detail further on.

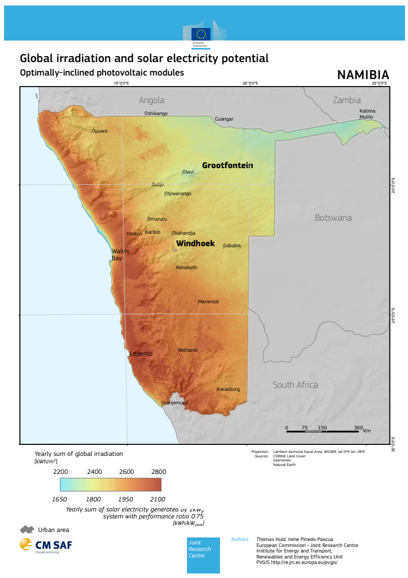


Figure 20 - GHI information from Namibia. Source: PVGIS

4. Productivity analysis[4,5]

4.1. Introduction

Arup, an independent firm of designers, planners, engineers, consultants and technical specialists, was appointed by AEE Power Ventures, an international EPC contractor and Power Developer specialized in the energy industry and focused on developing countries, to provide technical advisory services with respect to the 5 MW Rosh Pinah Solar Park project developed in Namibia by AEE Power Ventures during the year 2017.

AEE Power Ventures has developed a 5,67 MW solar PV plant near the town of Rosh Pinah, in the Karas Region of Namibia and is currently interested in analysing the difference between the results that were taken into consideration during the construction and development of the project and the real data obtained during the first year of operation of the power plant.

Rosh Pinah is a PV plant with single-axis tracking panels as shown in appendix NA001-5RP-D-S005-2 TRACKER DETAILS, of 315 Wp and that in optimal conditions of 21 ºC no cloud cover, no dust etc. receives 1000 W/m with a cadence of ±5w.This power plant consists of 18 000 panels, 150 inverters .The panels work from 12V DC to 400V AC and from there connection to the grid, emitting at 30 KV more details are giving in the following table 1.

Table 1- PV system design characteristics. *Source: Rosh Pinah PV LTA Draft*

		AEE
Modules		
Manufacturer		Hanwha Solarone
Model		P6-PC-1-315
Nominal Rated Power (STC)	[Wp]	315
Power Tolerance	[%]	0,4
Module Efficiency at STC	[%]	16,11
Temperature Power Coefficient	[%/ªC]	-0,41
Inverters		
Manufacturer		ABB S.p. A
Model		PRO-33.0-TL-OUTD-SX-400
Nominal Rated AC Power	[kW]	33
System Characteristics		
Nominal Capacity (DC)	[MWdc]	5,67
Inverter Capacity (AC)	[Mwac]	4,95
DC /AC Ratio		1,15
Quantity of PV Modules		18 000

Quantity of Inverters		150
Modules per String		20
PV System Type		Tracking
Shading Limit Angle (at Maximum Tilt)	[º]	22,9
Tracking Angle Range	[º]	-55 / 55
Backtracking controls		Yes
Pitch (row separation, centre to centre]	[m]	5

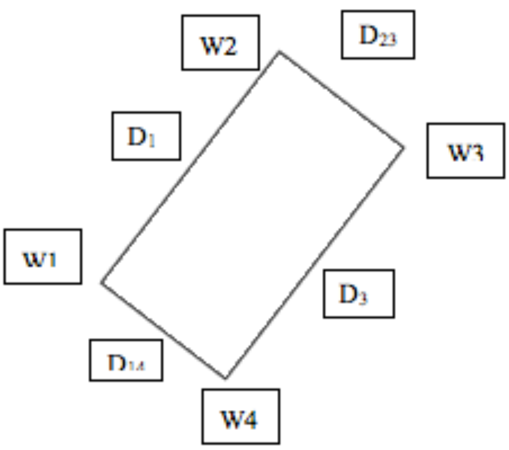
4.2. Site

As shown in the appendix 2 NA001-5RP-D-C003-1 SITUATION the facility is located in Southern Namibia, in the Karas region, approximately 20 Km from the border with South Africa. Its geographical coordinates are 27º 57’ 54’’ South and 16º 45’ 36’’ East.

The proposed facility’s footprint and proximity to nearby town of Rosh Pinah can be seen in the appendixes 3 & 4 NA001-5RP-D-C005-2 SITE COORDINATES LAYOUT and NA001-5RP-D-C004-2 LOCATION.

In order to calculate the footprint of the overall area affected by the plant, by knowing the coordinates of the vertexes given in appendix 2 NA001-5RP-D-C005-2 SITE COORDINATES LAYOUT we can easily calculate the area involved as follows:

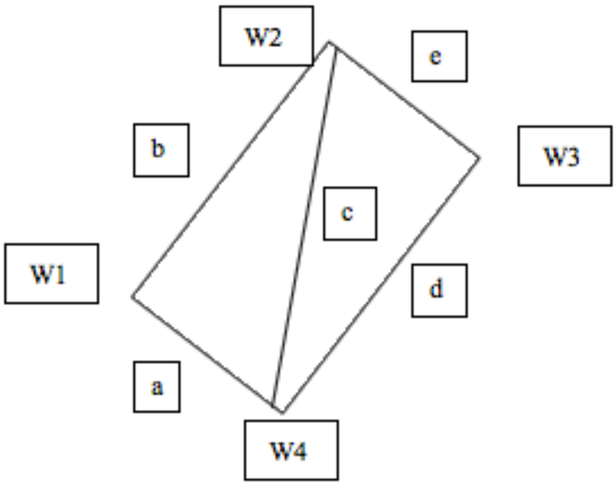
In order of obtaining the overall development footprint, taking the appendix 2 NA001-5RP-D-C005-2 SITE COORDINATES LAYOUT. Since we know the coordinates for every vertex we will use Heron’s formula method:



Point	Coord. X	Coord. Y
W1	26378,24	662583,71
W2	26079,45	662112,36
W3	25742,69	662555,16
W4	26401,04	663031,82

And knowing that, D=$\sqrt{\Delta x^2 + \Delta y^2}$ we then calculate:

Distances	Value (m)
D_{12}=	558,0737286
D_{23}=	556,3084914
D_{34}=	812,7911651
D_{14}=	448,6896612
D_{24}=	974,0774198



So we have that:

And because what we wish to

calculate is the total area. We calculate the

two separate perimeters of W1W2W4 and

W2W3W4 triangles:

$P_1=\frac{a+b+c}{2}$; $P_2=\frac{c+d+e}{2}$

Perimeter	Value (m)
P1=	990,4204048
P2=	1 171,588538

By knowing this we can then proceed to calculate the surfaces

$S_1= \sqrt{P \cdot (P-a) \cdot (P-b) \cdot (P-c)}$

$S_2=\sqrt{P \cdot (P-c) \cdot (P-d) \cdot (P-e)}$

Surface	Value (m^2)
S_1=	61 572,00345
S_2=	226 018,7008

Like this, we have that the total area occupied by the photovoltaic plant is of **287 590,7043 m^2.**

However, if we go to appendix 5 NA001-5RP-D-C009-3 INTERNAL ROADS. GENERAL LAYOUT we know that only *PVpl*= 483*239, 5= 115 678, 5 m^2 is utilized for photovoltaic panels and supporting structures of the plant.

In the following table, there is more general information about the power plant:

Table 2 - General Information Rosh Pinah SPV plant

Name	Rosh Pinah
Status	100
Country	Namibia
Number of TCPs	5
Type of plant	Grid-connected
Altitude	418
Recording period	15 min
Time zone	Africa/ Windhoek
City	Rosh Pinah
Grid connected	Yes
Plant installer	AEE Power
AC Load	Yes
Longitude	16,73º
Latitude	-27,98º
Typical use	Power station
Sun tracker	No
Plant designer	AEE Power
Type of Project	Production
Installation Date	12-07-2017

4.3. Introduction to data analysis

Now we shall begin to deepen in our particular case of study. The following information, tables and graphs represent a first approach made by AEE Power and Arup as an estimation done during the development and construction of the photovoltaic power plant.

Also, we will have the real information gathered during the time period that goes from September 2017 until August 2018 (12 months) that we will be analysing and comparing with the estimations done by both parts previous operating start date of the plant.

This information has been gathered through a SCADA based program by Inaccess, "*a company that designs and develops state-of-the-art products and solutions focusing on digital infrastructure management*". SCADA is a software that allows to control and supervise processes remotely, stands for *"Supervisory Control And Data Acquisition"*.

Inaccess PPC controls the output of the PV plant at the Point of Common Coupling (PCC) using the plant inverters, meters, statcom, capacitors, circuit breakers... providing near real-time capabilities of control and monitoring to the grid and plant operator, since it has a distortion of 30 seconds and records all the information provided in a range of 15 minutes.

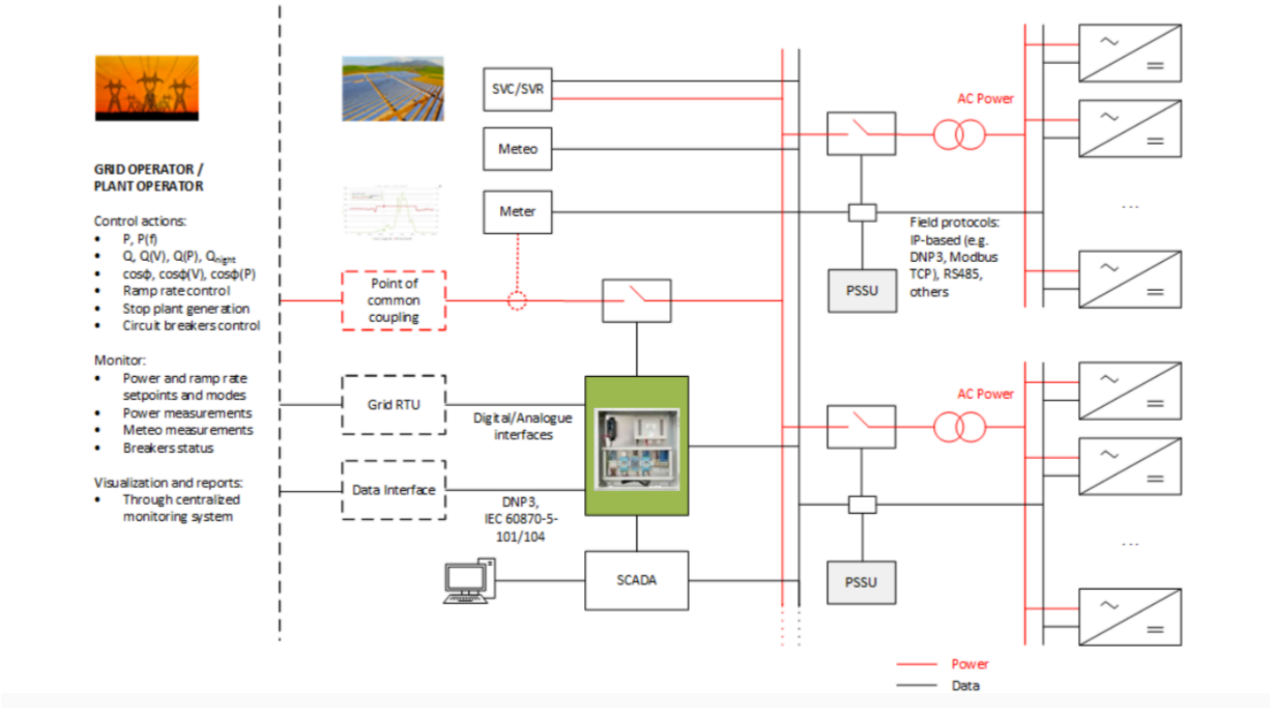


Figure 21 - Inaccess power plant controller. ***Source: Inaccess PPC Operating Manual v2.7***

All of the information is shown and saved in through the Inaccess platform whose way of operating is shown in figure 21. This platform has a web client application from which the grid and plant operator can access the power plant in real-time in order to control and monitor the situation of the plant.

In figure 22 we see what the actual web client application looks like. In such illustration, we appreciate the application with the fleet manager selected from the Fleet menu, in this case we only have our site, Rosh Pinah, but in the case that more PV sites where available they would appear in a list in order for the user to select one.

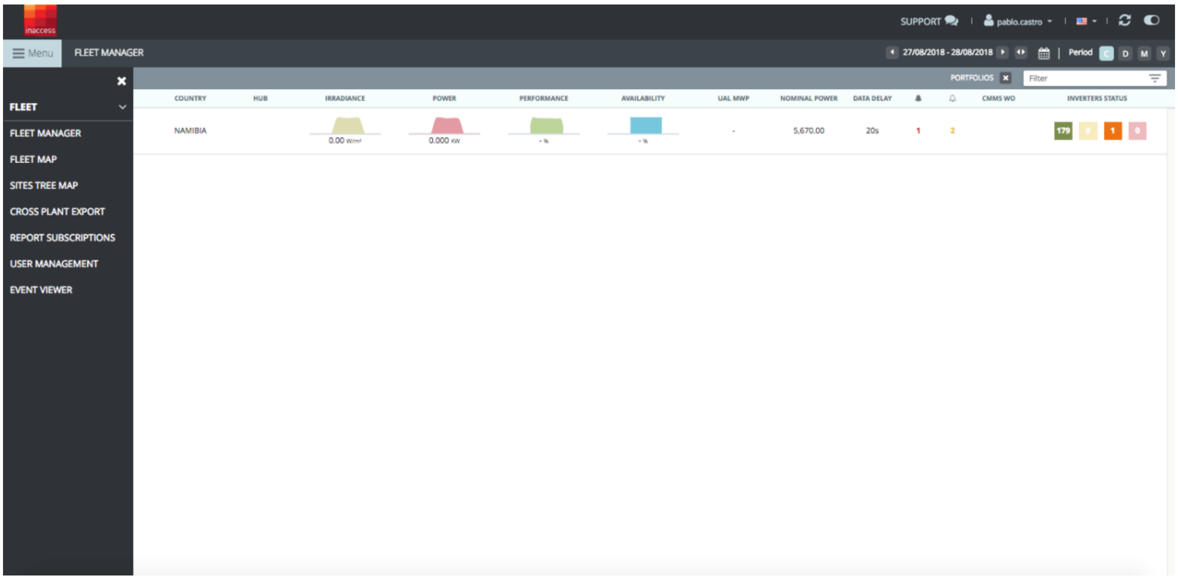


Figure 22 - The "Fleet" page ***Source: Inaccess web application***

Once we have selected a site, the site menu appears with several options to select. In figure 23 the overview page is selected, this page gives an explanatory overview of the site, that include the key functional parameters in numerical, graphical and lists formats. From here we can directly export graphs and information in .csv or .xlsx format.

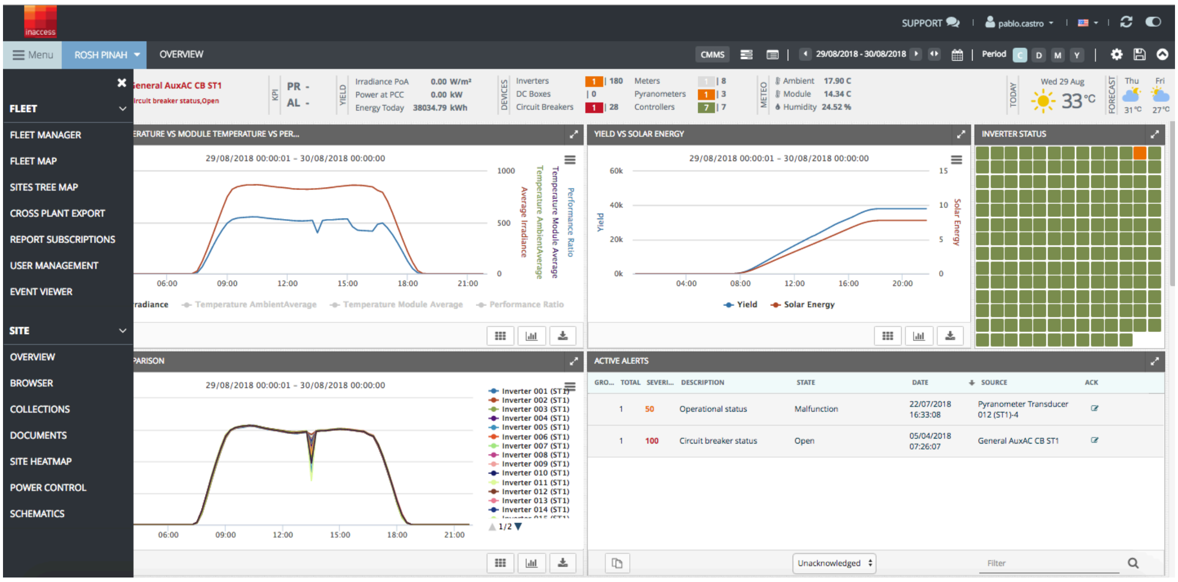


Figure 23– The "Overview" page *Source: Inaccess web application*

Inside the site we can change between several "pages", in the above-mentioned figure 23 we saw the overview page. Another important page is the browser, that "*offers a plethora of supplementary features that serve the provision of advanced monitoring techniques. Furthermore, it gives the opportunity to select the events of interest for further inspection and the definition of monitoring parameter groups for further analysis".* As shown in figure

24, this part of the web client application shows the content area as a tree tab at the left, which can be expanded to show the hierarchy of the equipment at site. This is useful in case you want to follow a warning up to its main cause.

Also, in this mode, you can select several parameters to plot, and export the ones of interest for each case, as shown in the bottom part of figure 24.

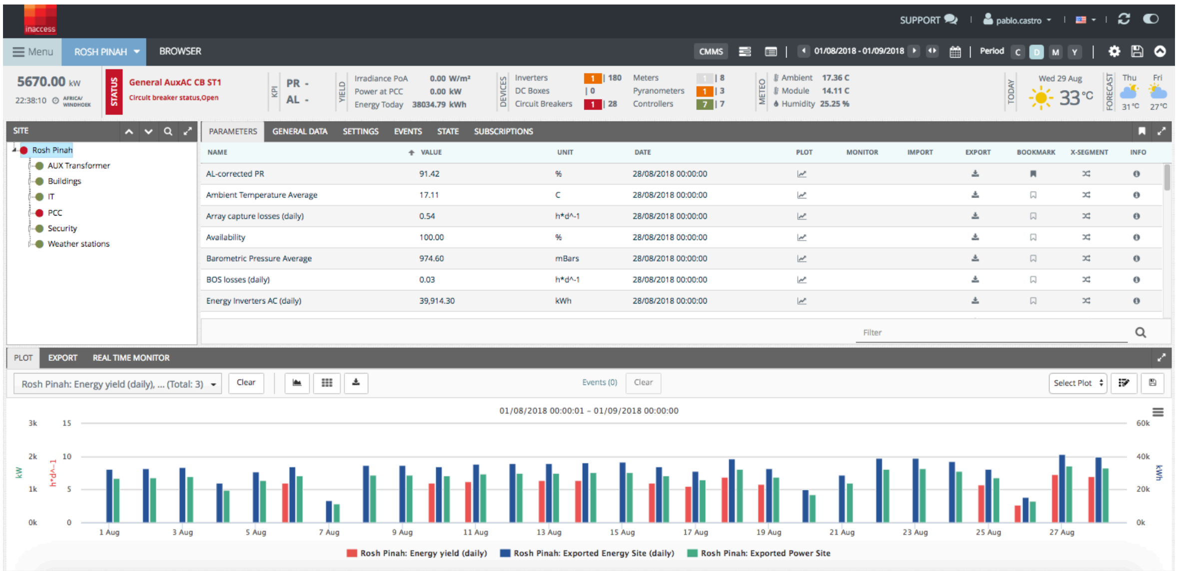


Figure 24-The "Browser" page. ***Source Inaccess web application.***

Another of the main pages from the web client application, in figure 25 we have the cross-plant export page that *“enables the fast collection and download of one or more data parameters of interest, from one or more supported PV plant sites.”* As we can see in figure 25, only one site is selected but several parameters. You can export all at once (152 parameters) or select what you wish to study with more precision.

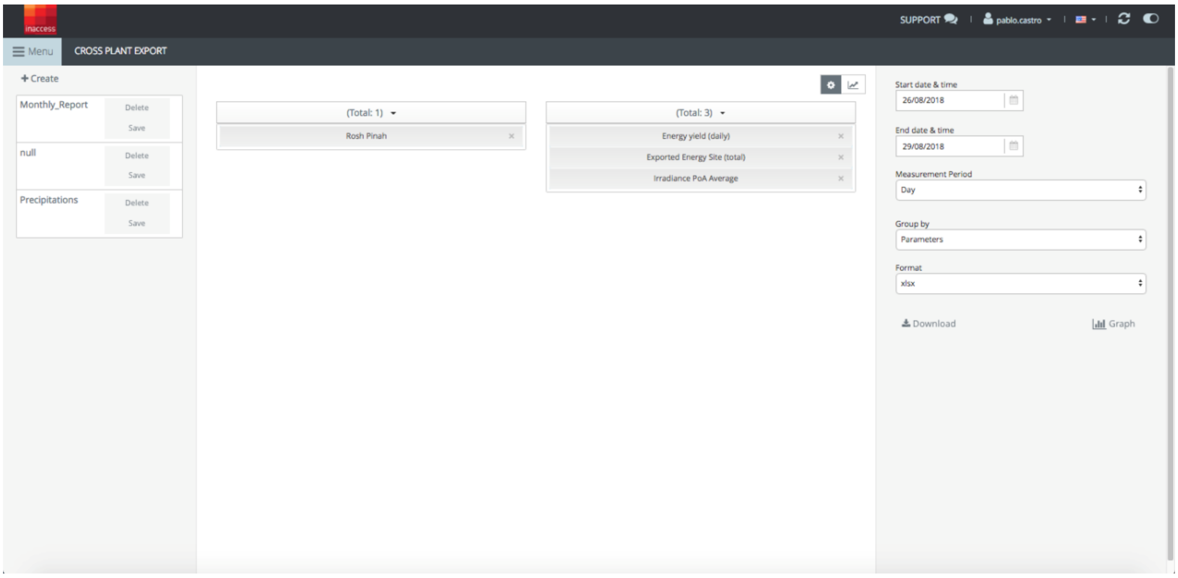


Figure 25-The "Cross Plant Export" Page ***Source: Inaccess web application***

Finally, to summarize with the web client application, in figure 26 we have the power control page that gives you the possibility to view in real time parameter related to the power control in order to detect any malfunction and to know the measurements of several control services as well as to see every 15 min, 1h or 24h a monitoring graph that shows active and reactive power, voltage, frequency and power factor values.

Although it must be taken into consideration that this page does not allow to select a certain date in order to download the information. Here you can only download the data that you have been monitoring in real time for a period of time (that you have been watching).

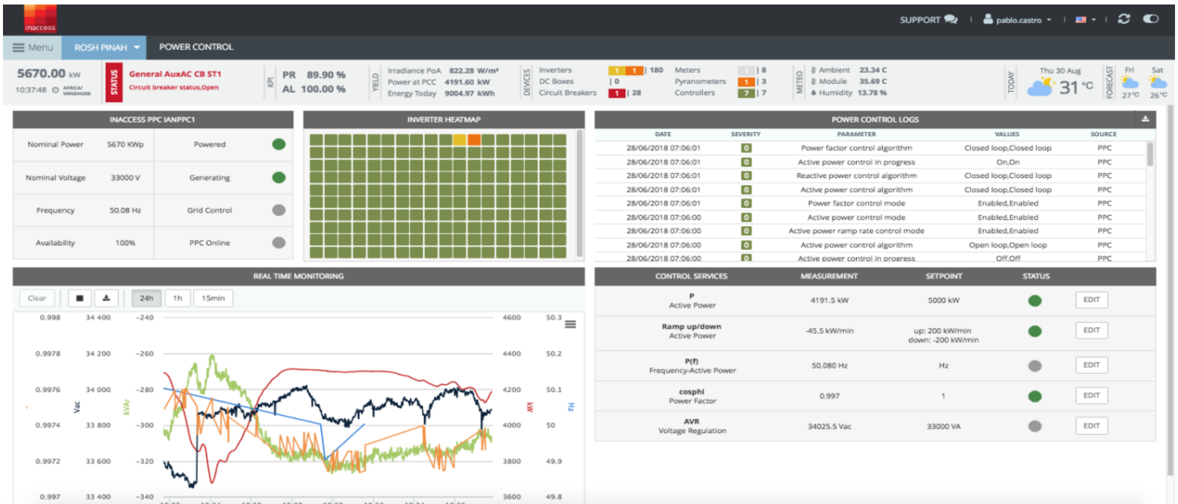


Figure 26 - The "Power Control" Page ***Source: Inaccess web application***

4.4. Meteorological data analysis

To begin with our case of study, and now that we know where we will be obtaining our information from. First, we need to understand that meteorological data is very important for yield analysis, since such analysis will be carried out in following sections, we will start with the study that was carried out prior to the construction of Rosh Pinah solar power plant, made by AEE, Arup and other companies.

The before mentioned study compares different values from global horizontal irradiation (GHI) measured in kWh·m^{-2} during a one-year period. In table 3 we have the information relative to how the different companies obtained there GHI information.

Table 3 - Comparison of meteorological data available. Source Rosh Pinah PV LTA _ Draft

Weather data source	Measurement method	Period of data
Meteonorm V6	Interpolation of five to six nearest weather stations. When there are no weather stations nearby, satellite data is used	Radiation: 1986-2005 Temperature: 2000-2009
SolarGIS	Interpolation of six nearest weather stations	1994-2015
NASA	Satellite	1983-2005
PVGIS-SAF	Satellite	1998-2005 & 2006-2010
PVGIS-Helioclim	Satellite	1985-2004

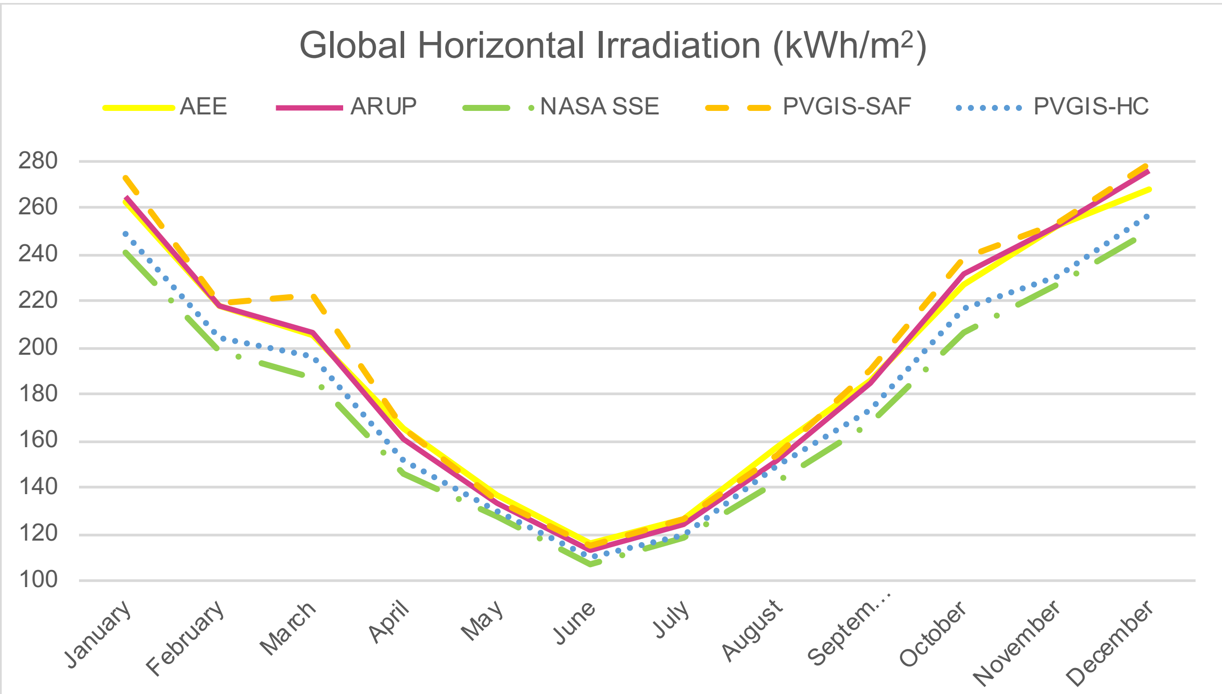
Considering what we just mentioned on the previous table, it is understood that the study takes the data from Meteonorm as the one on which to base the study.

As seen in this table 3 Arup's study, that is based on SolarGIS has the values that a more alike to the ones considered by AEE Power Ventures, based in Meteonorm. From here we can see why for the following cases of study, the other companies will be neglected.

Table 4 - Global Horizontal Irradiance (kWh/m2). *Source Rosh Pinah PV LTA _ Draft*

Period	AEE	ARUP		Further Comparisons					
	Meteonorm V6.1 (kWh·m^2)	SolarGIS (kWh·m^2)	Diff (%)	NASA SSE (kWh·m^2)	Diff (%)	PVGIS-SAF (kWh·m^2)	Diff (%)	PVGIS-HC (kWh·m^2)	Diff (%)
Jan	263	265	-0,8%	241	8,4%	273	-3,8%	249	5,3%
Feb	218	218	0,0%	198	9,2%	219	-0,5%	204	6,4%
Mar	205	207	-1,0%	187	8,8%	222	-8,3%	196	4,4%
Apr	165	161	2,4%	146	11,5%	165	0,0%	152	7,9%
May	137	133	2,9%	127	7,3%	134	2,2%	130	5,1%
Jun	116	113	2,6%	107	7,8%	115	0,9%	110	5,2%
Jul	126	124	1,6%	118	6,3%	126	0,0%	120	4,8%
Aug	157	152	3,2%	142	9,6%	154	1,9%	149	5,1%
Sept	186	185	0,5%	168	9,7%	190	-2,2%	173	7,0%
Oct	227	232	-2,2%	206	9,3%	239	-5,3%	217	4,4%
Nov	252	252	0,0%	227	9,9%	254	-0,8%	231	8,3%
Dec	268	276	-3,0%	250	6,7%	279	-4,1%	257	4,1%
Total	**2320**	**2318**	**0,1%**	**2117**	**8,8%**	**2370**	**-2,2%**	**2188**	**5,7%**

The information from table 4 is represented in graph 1, in order to get a clearer view of the overall information from different sources that was taken into consideration in the earlier stages of the construction and development of Rosh Pinah solar PV power plant site.



Graph 1 - Global horizontal irradiation. ***Source: Rosh Pinah PV LTA _Draft 7***

With this results in mind we will now compare the two main sources of data with the real values gather throughout the year of study with the Inaccess web client platform. Such values are presented in the following table 5.

Table 5 - GHI differences

Period	Real data (Inaccess) (kWh·m^2	AEE Estimated (kWh·m^2)	Arup Estimated (kWh·m^2)	Difference AEE (kWh·m^2)	Difference Arup (kWh·m^2)	Diff AEE (%)	Diff Arup (%)
Sept'17	190,25	186	185	4,25	5,25	2,2%	2,76%
Oct'17	304,84	227	232	77,84	72,84	25,5%	23,89%
Nov'17	462,59	252	252	210,59	210,59	45,5%	45,52%
Dec'17	640,50	268	276	372,50	364,50	58,2%	56,91%
Jan'18	494,26	263	265	231,26	229,26	46,8%	46,38%
Feb'18	343,63	218	218	125,63	125,63	36,6%	36,56%
Mar'18	271,72	205	207	66,72	64,72	24,6%	23,82%
Apr'18	206,64	165	161	41,64	45,64	20,1%	22,08%
May'18	165,70	137	133	28,70	32,70	17,3%	19,74%
Jun'18	135,57	116	113	19,57	22,57	14,4%	16,65%
Jul'18	150,01	126	124	24,01	26,01	16,0%	17,34%
Aug'18	164,92	157	152	7,92	12,92	4,8%	7,84%
Total	3530,62	2320	2318	1210,62	1212,62	34,29%	34,35%

Table 5 compares the differences occurred during the one-year period analysis, as a result we have that measurements of GHI made by AEE where 0,06% more precise than the ones made by Arup, not a really significant percentage to take into consideration translated into a 2 kWh/m^2 difference between both companies.

Also, we see that December 2017 was the month where both sources had a bigger difference with the real GHI, followed by January 2018 and November 2017.

It is fair to say that the real global horizontal irradiance has exceeded the estimations in almost a 35%.

4.4.1. Temperature analysis

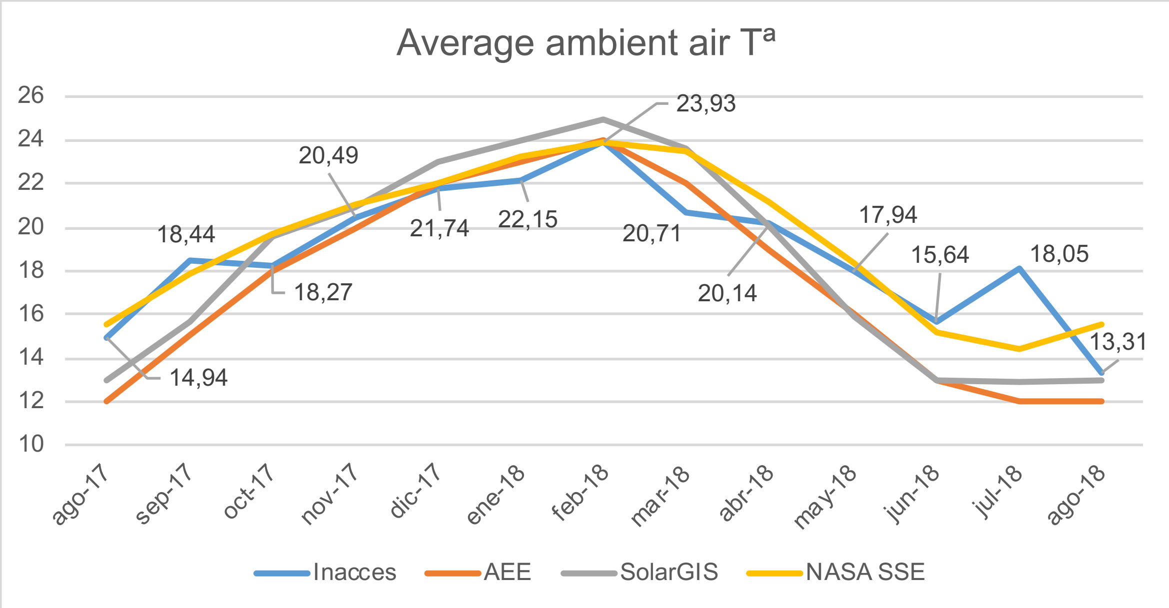
Continuing with the meteorological data analysis, now we shall study the temperature differences that have occurred throughout the year.

In the following table 6, we have the real average monthly temperatures, given by Inaccess, for the period considered compared with some of the previous estimations done by other sources.

Table 6 - Average monthly ambient temperatures comparison between data used in the FESR and two other sources Source: Rosh Pinah PV LTA _Draft 7 & Inaccess web client application.

	Real Data (ºC)	Estimated (ºC)			Difference (ºC)		
Period	**Inaccess**	**AEE**	**SolarGIS**	**NASA SSE**	**AEE**	**SolarGis**	**NASE SSE**
Aug-17	14,94	12	13,01	15,5	2,94	1,93	0,56
Sept-17	18,44	15	15,67	17,8	3,44	2,77	0,64
Oct-17	18,27	18	19,6	19,7	0,27	1,33	1,43
Nov-17	20,49	20	20,88	21,0	0,49	0,39	0,51
Dec-17	21,74	22	23,06	22,0	0,26	1,32	0,26
Jan-18	22,15	23	24,03	23,3	0,85	1,88	1,15
Feb-18	23,93	24	24,95	23,9	0,07	1,02	0,03
Mar-18	20,71	22	23,6	23,5	1,29	2,89	2,79
Apr-18	20,14	19	20,02	21,2	1,14	0,12	1,06
May-18	17,94	16	15,94	18,4	1,94	2,00	0,46
Jun-18	15,64	13	12,96	15,2	2,64	2,68	0,44
Jul-18	18,05	12	12,89	14,4	6,05	5,16	3,65
Aug-18	13,31	12	13,01	15,5	1,31	0,30	2,19

From Table 6 we can now represent its values, as shown in the following graph 2 where we can see in a clearer way the comparison between all the information estimated and the actual values obtained.



Graph 2 – Temperature analysis

From graph 2 and table 6, we can conclude the following:

Major differences occur during August - September 2017 and June-July 2018, having a remarkable peak on July 2018 with a difference of over 6 ºC between Inaccess and AEE Power and over 5ºC with SolarGIS. The minor differences take place between the months of October 2017 and February 2018, being this last one the one with a smaller difference with the estimated values AEE 0,07; SolarGIS 1,02 & NASA SS 0,03.

Also, we can assure that SolarGIS has the higher differences between the estimated values and the real value given by Inaccess, since if we sum up the overall differences it is the one that deviates more, 23,785 ºC in total, followed by AEE Power with a difference of 22,683 ºC and NASA SS has the smallest deviation with a value of 15,165ºC in total.

We must take into consideration that the temperature is directly connected with the efficiency of the photovoltaic cell, since the efficiency of the photovoltaic cell depends on the temperature at which they are operating.

“When a PV cell is exposed to higher temperatures, I_{sc} increases slightly, while V_{oc} decreases more significantly, and the overall effect is the reduction in efficiency.

As a result, higher temperatures decrease the maximum power output P_{max}.

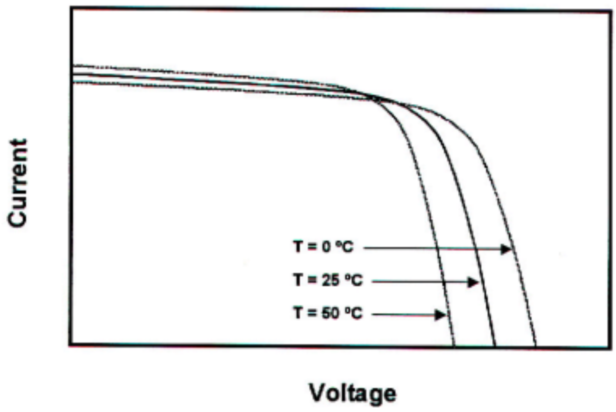


Figure 27 – Effect of temperature in the efficiency on photovoltaic cells

As temperature increases, the band gap energy decreases, because the crystal lattice expands, and the interatomic bonds are weakened. Therefore, less energy is needed to free an electron and move it to the conduction band."3

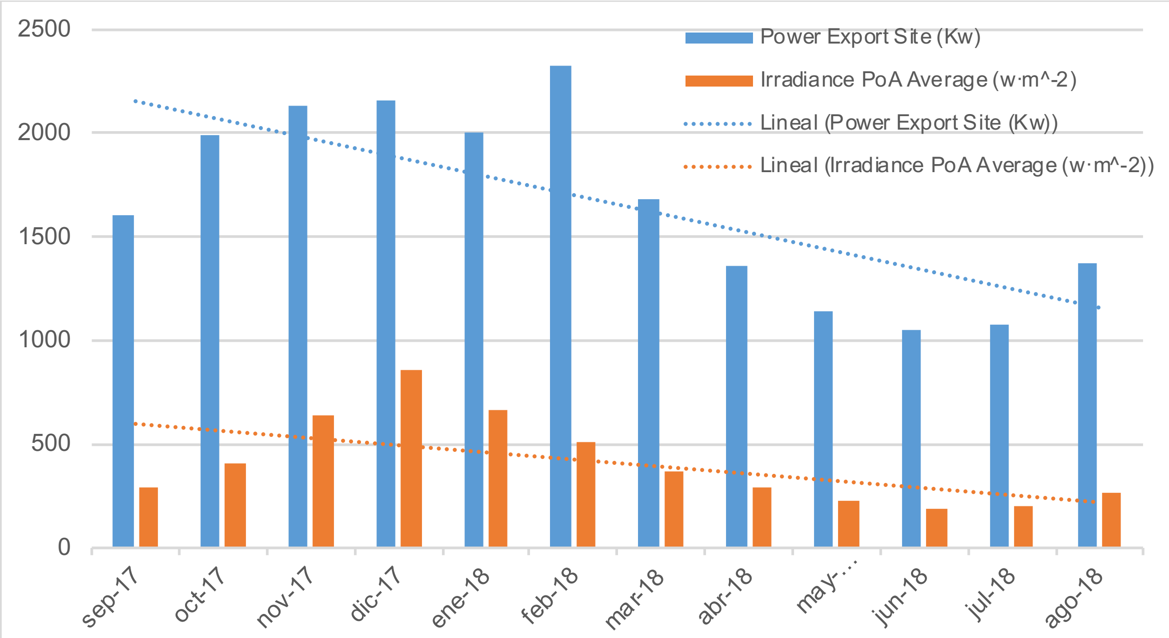
4.5. Monthly analysis

During the period of study (September 2017 – August 2018), the following average monthly values where obtained as shown in Table 7.

Table 7 -Monthly average values. *Source: Inaccess web client application*

Period	Power Export Site (Kw)	Irradiance PoA Average (W·m^2)	Average ambient air temperature (ºC)	Module Temperature Average (ºC)	Raw PR (%)
Sept-17	1602,68	294,16	18,44	21,08	87,83%
Oct-17	1987,05	409,73	18,27	23,31	84,23%
Nov-17	2127,93	642,49	20,49	32,14	82,04%
Dec-17	2164,15	860,88	21,74	39,38	80,52%
Jan-18	2009,15	664,33	22,15	34,51	79,10%
Feb-18	2325,27	511,35	23,93	31,35	78,90%
Mar-18	1677,63	365,21	20,71	25,35	81,02%
Apr-18	1357,33	286,50	20,14	27,09	83,54%
May-18	1136,87	222,72	17,94	24,22	88,71%
Jun-18	1056,02	194,79	15,64	16,97	95,42%
Jul-18	1081,46	201,62	18,05	19,29	94,61%
Aug-18	1370,84	259,87	13,31	15,69	92,74%

Table 7 represents the average values by month, these values are calculated from the averages of every day during each month, that also have the average values of the hours from each day of the month. This meaning that to analyse deeply the information, we should go to a smaller detail table (week, day...) as we will be doing further in the study.



Graph 3 - Monthly average Power - Irradiance values ***Source: Inaccess web client application***

Taking into consideration table 7 and graph 3, we can extrapolate that the months that have produced more power are the ones that have a higher irradiance, this is obvious since they are directly connected one on other. Also, these months are the period corresponding to summer season, when there is more irradiance due to the position and inclination of the Earth and Sun.

Although as we see February 2018, is the month with higher value of Power export and has an irradiance value lower than the following three months. This could have its explanation from the temperature value, as shown in the following table 8 that shows how the temperature both from the ambient temperature and from the modules affect the overall efficiency (PR). In order to clarify this event, an as stated before, we should go into more detailed values rather than averages.

Table 8 - Monthly average values in ascendant order

Period	Power Export Site (Kw)	Irradiance PoA Average (w·m^2)	Average ambient air temperature (ºC)	Module Temperature Average (ºC)	Raw PR (%)
Feb-18	2325,27	511,35	23,93	31,35	78,90%
Dec-17	2164,15	860,88	21,74	39,38	80,52%
Nov-17	2127,93	642,49	20,49	32,14	82,04%
Jan-18	2009,15	664,33	22,15	34,51	79,10%
Oct-17	1987,05	409,73	18,27	23,31	84,23%
Mar-18	1677,63	365,21	20,71	25,35	81,02%
Sept-17	1602,68	294,16	18,44	21,08	87,83%
Apr-18	1357,33	286,50	20,14	27,09	83,54%
Aug-18	1370,84	259,87	13,31	15,69	92,74
May-18	1136,87	222,72	17,94	24,22	88,71%
Jul-18	1081,46	201,62	18,05	19,29	94,61%
Jun-18	1056,02	194,79	15,64	16,97	95,42%

Table 8 is organized to show the first the months that have a greater power export value. Here we can see that the during the summer season in the south hemisphere we have the bigger power export values and during the winter season the lowest, as it would be expected. The lowest power value is attributed to June 2018 and the highest to February 2018.

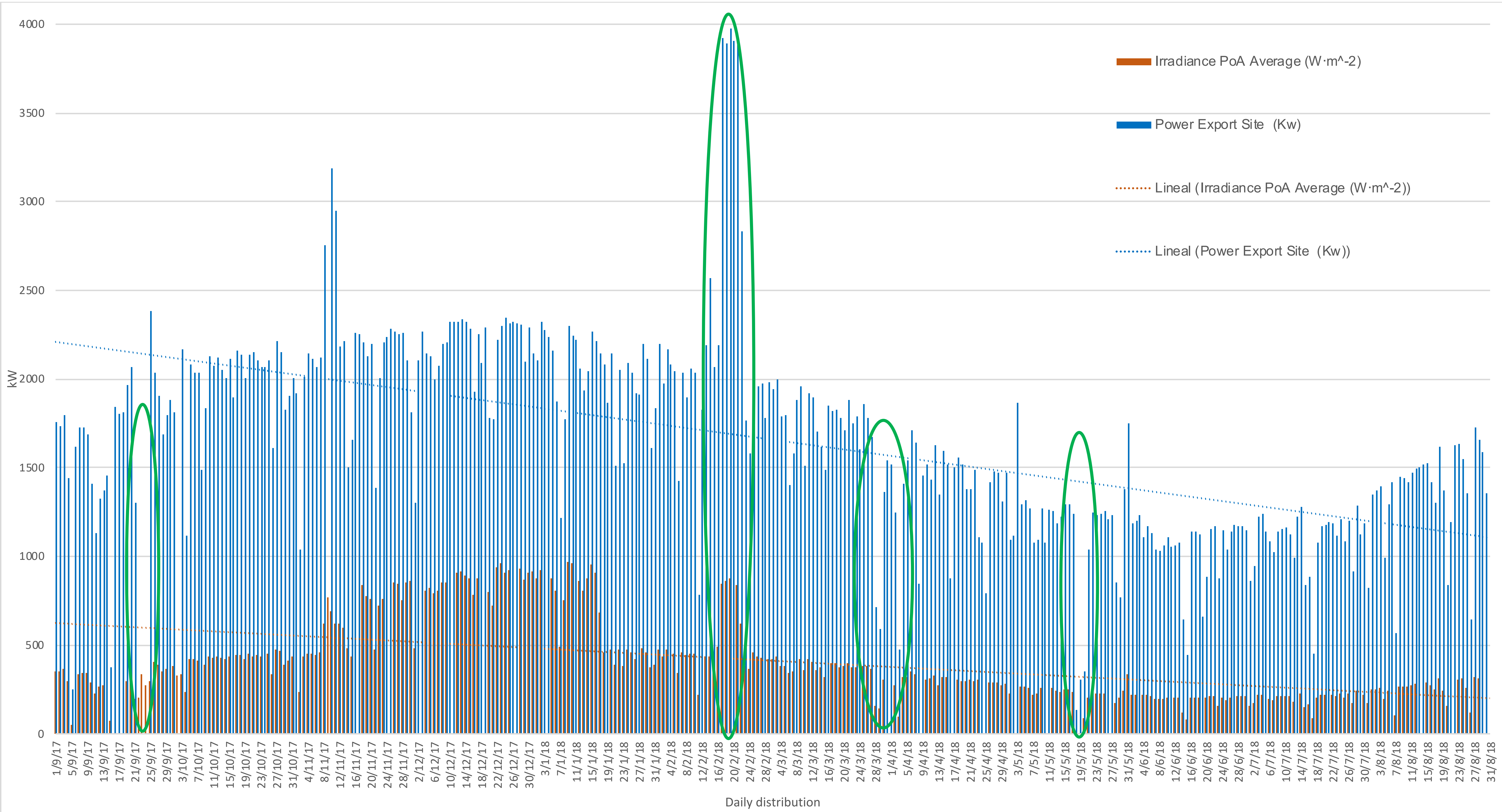
4.6. Daily analysis

In this part we shall compare the results obtained through each month by days. To do so, we first gather all the information produced during each month (daily); we obtain this information from the Inaccess web client application. Such values are averaged from every day analysis, all we need to do is compile it in one unique file in order to compare and study the overall period of one-year, or more if we had more information and we would wish to do so.

Table 9 shows the average information of January 2018, that would give the average value showed in table 7. By doing this with every month is how we obtain the values for graph 4, since representing the tables for every 12 months would take a lot of space.

Table 9 - January 2018

Day	Power Export Site (Kw)	Irradiance PoA Average (W·m^-2)	Ambient Temperature Average (ºC)	Module Temperature Average (ºC)	Raw PR (%)
1/1/18	2103,56	872,88	20,24	36,11	78,46%
2/1/18	2319,88	923,77	23,20	38,46	80,23%
3/1/18	2275,79	936,76	28,37	46,66	79,10%
4/1/18	2238,41	919,09	27,68	47,30	79,30%
5/1/18	2159,74	873,32	23,83	43,87	80,53%
6/1/18	1876,17	803,37	22,02	40,04	77,53%
7/1/18	1219,92	490,15	20,53	32,57	86,00%
8/1/18	1773,99	754,47	20,07	33,83	81,25%
9/1/18	2300,08	966,93	21,19	38,61	78,97%
10/1/18	2243,28	958,17	26,86	46,29	79,24%
11/1/18	2222,50	929,62	23,75	43,78	80,89%
12/1/18	2059,16	858,61	20,39	39,61	81,21%
13/1/18	1936,39	809,13	21,54	37,74	81,04%
14/1/18	2041,25	878,64	22,08	39,26	78,67%
15/1/18	2268,78	956,24	21,87	38,53	80,33%
16/1/18	2210,54	905,30	21,50	40,43	81,06%
17/1/18	2141,68	680,09	21,19	34,60	80,79%
18/1/18	2079,74	456,81	21,32	28,37	80,31%
19/1/18	1865,90	409,61	21,55	28,06	80,35%
20/1/18	2146,69	475,27	22,47	29,96	79,67%
21/1/18	1512,99	387,52	21,78	27,26	68,87%
22/1/18	2052,73	477,54	21,93	28,46	75,81%
23/1/18	1522,73	379,06	21,94	28,07	70,86%
24/1/18	2086,08	473,48	22,39	28,79	77,72%
25/1/18	2038,35	460,27	20,79	27,61	78,12%
26/1/18	1922,46	421,21	19,35	25,94	80,50%
27/1/18	1913,44	426,37	20,48	26,71	79,15%
28/1/18	2196,15	484,82	22,41	29,25	79,90%
29/1/18	2111,15	459,39	21,14	28,29	81,06%
30/1/18	1611,72	377,44	21,42	27,86	75,32%
31/1/18	1832,36	388,95	21,36	27,42	79,78%



Graph 4 - Daily average power & irradiance values. ***Source: Inaccess web client application***

Graph 4 represents all the average daily values from the period considered (September 2017 – August 2018) in which we can appreciate several days that have unusual readings highlighted in the green circles, in which we will focus next.

As a continuation, we will now see some of the peculiarities exhibited in graph 4. To begin with, we will see the period of time that goes from 16/09/2017 to 24/09/2017 in the following table 10.

Table 10 - September peculiarities *Source: Inaccess web client application*

Day	Power Export Site (Kw)	Irradiance PoA Average (W·m^-2)	Ambient Temperature Average (ºC)	Module Temperature Average (ºC)	Raw PR (%)
16/9/17	1840,19	-	16,98	-	-
17/9/17	1801,97	-	21,73	-	-
18/9/17	1811,81	-	22,24	-	95,88%
19/9/17	1967,96	297,31	15,78	21,25	87,43%
20/9/17	2063,53	285,71	25,22	24,93	85,88%
21/9/17	1301,23	196,42	19,42	21,25	87,28%
22/9/17	-	200,78	-	17,33	88,14%
23/9/17	-	331,67	-	21,88	-
24/9/17	-	273,57	-	22,21	-

From table 10 we can see that some values have not been measured or saved. It is likely to be a problem with the Inaccess web client application rather than from the plant itself, since for example the first three days we have a value in the power export site column and we know for sure that these values must come with an irradiance value associated.

In the case of 23/09/2017 and 24/09/2017 it is unclear whether it is a problem from the Inaccess application, or from the power plant, since the only values given could easily mean that both, that the was a problem within the plant that stopped the power from being exported or produced, or there is a problem with the information shown in Inaccess. For further details and if we would wish to clarify the problem, more information than the one of we dispose would be required.

The next two peculiarities that we encounter is take place on the 2/10/2017 and on the 9/11/2017, that present a similar problem as the ones mentioned above.

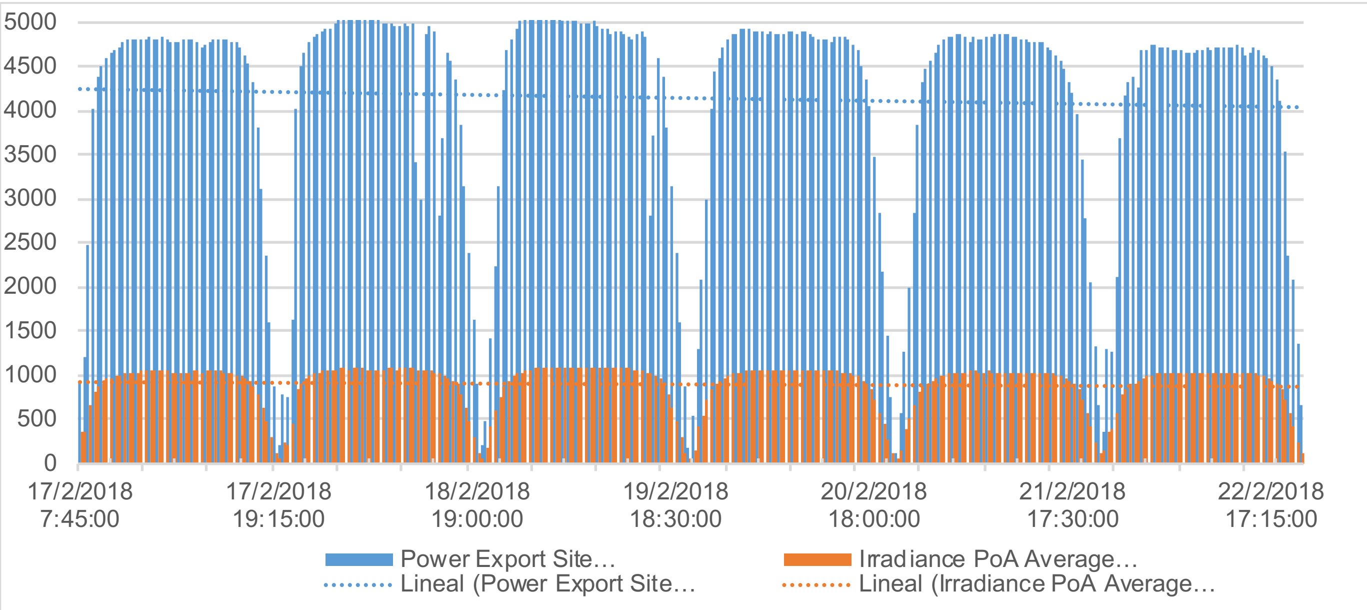
Following with the peculiarities, we reach the next set of days that have unusual readings, considering the average. Such period of days goes from the 17/02/2018 to the 22/02/2018, as shown in the following Table 11.

Table 11 - February peculiarities *Source: Inaccess web client application*

Day	Power Export Site (Kw)	Irradiance PoA Average (W·m^-2)	Ambient Temperature Average (ºC)	Module Temperature Average (ºC)	Raw PR (%)
17/2/18	3919,95	847,88	25,74	40,74	81,54%
18/2/18	3888,02	860,17	22,84	37,47	79,72%
19/2/18	3974,46	874,73	24,21	38,17	80,14%
20/2/18	3902,75	841,63	26,10	38,77	81,79%
21/2/18	3900,67	841,01	25,51	40,12	81,80%
22/2/18	2832,52	618,13	24,55	35,97	80,82%

Table 11 shows the period of time mentioned before, but this time instead of presenting a problem with no data or misreading, we encounter higher values than what we have seen so far. Being the average from the power export site value of the whole year around 1625 kW, this also affects the irradiance values, that nearly double the average 405 w·m^2 of the period considered.

The values shown in the above table call our attention, so we go deeper in the values of these days, from which we get the following graph 5.



Graph 5 - February peculiarities

As we can appreciate in the graph 5 we have values near the nominal power of the PV plant (5670 kW) this is the reason of why the values shown on Table 11 are so high even being average values.

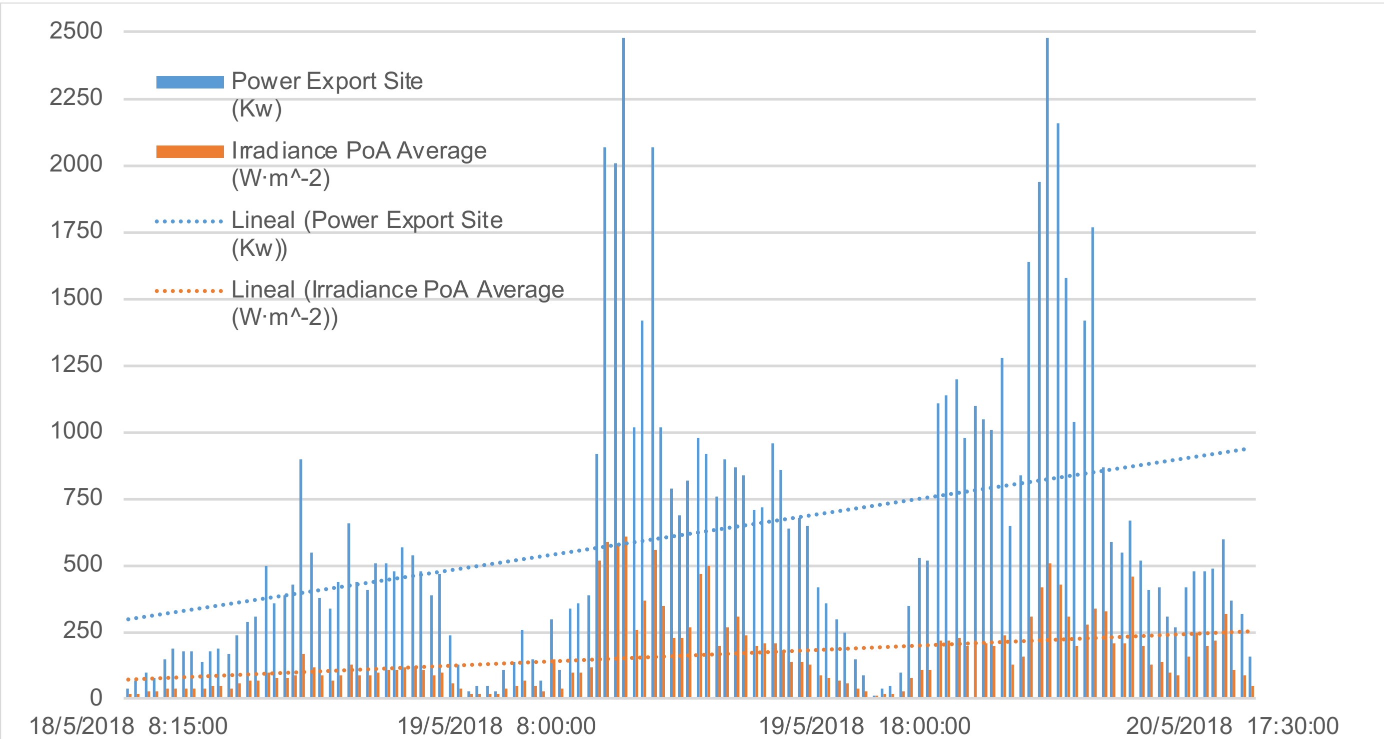
But not only anomalies occur with high values, low values also have happened during the one-year period.

Such is the case that follows. Between the 18th and 20th of May 2018, we have the opposite case from our previous one as shown in the table 12.

Table 12 - Peculiarities occurred in May.

Day	Power Export Site (Kw)	Irradiance PoA Average ($W \cdot m^2$)	Ambient Temperature Average (ºC)	Module Temperature Average (ºC)	Raw PR (%)
18/5/18	131,25	28,06	18,09	22,33	82,59%
19/5/18	307,40	90,98	16,50	22,15	59,62%
20/5/18	351,98	87,13	15,23	21,01	71,25%

As in the previous case, but now with Table 12 data, we are going to see if we find an explanation for these results. For this, we go to the Inaccess application and gather the information from this three-day period, every 15 minutes. The result is the following graph 6.



Graph 6 - May peculiarities

Graph 6 gives us a clear vision on why these values are so low in the average overall graph 4 that we saw previously. We can observe that within these three days the tendency line value does not go over the 1625 kW value mentioned earlier.

Same case scenario occurs within the days 15 and 17 of July 2018, although in this occasion the values are a bit higher that the ones we have just analysed, around 730 kW power exported.

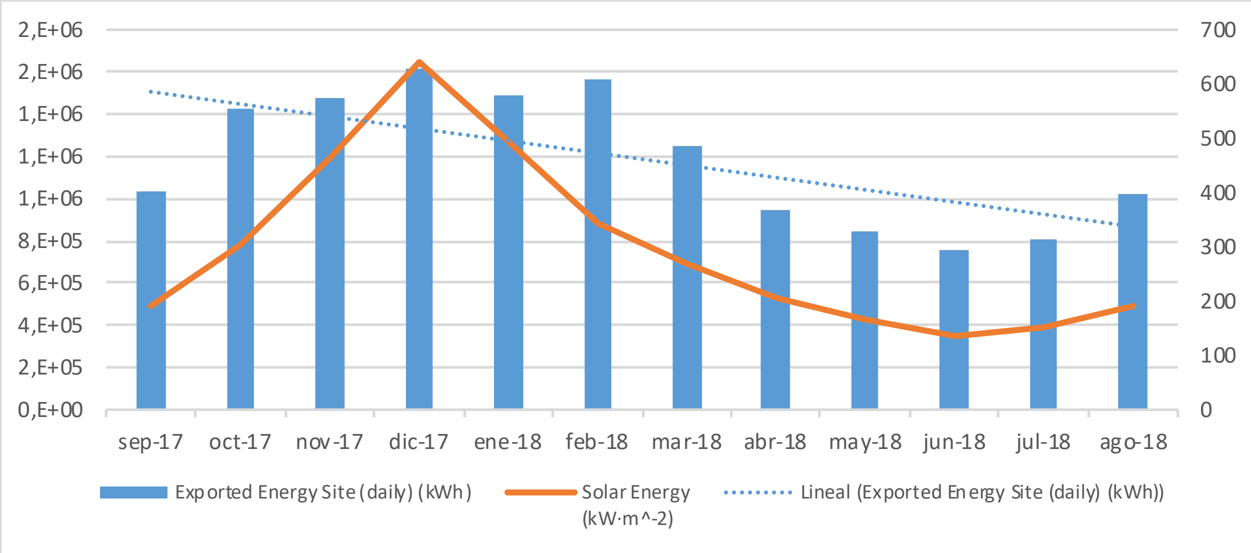
4.7. Monthly energy yield distribution

First, we need to know how the solar energy (kw·m^{-2}) and power exported (kW) by the site have been occurring through the period of analysis, for this the following table 13 and graph 7 are shown:

Table 13 - Energy exported & solar energy distribution. Source: Inaccess web client application

Period	Exported Energy Site (daily) (kWh)	Solar Energy (kW·m-^{2})
Sept-17	1.036.738,50	190,25
Oct-17	1.430.674,87	304,84
Nov-17	1.481.040,12	462,59
Dec-17	1.610.124,59	640,50
Jan-18	1.494.807,22	494,26
Feb-18	1.562.583,93	343,63
Mar-18	1.248.153,91	271,72
Apr-18	951.404,09	206,64
May-18	845.827,86	165,70
Jun-18	760.335,49	135,57
Jul-18	804.603,75	150,01
Aug-18	1.019.901,42	193,34

After all the information has been collected and put together into the previous table 13 and in order to see how Energy exported from the site (MW) and solar energy (kW·m^{2}) are related we have the following graph 7.



Graph 7 – Energy exported & solar energy monthly distribution

Having solar energy, one-year information distributed by months, we can compare the estimations done by AEE and Arup with the real information obtained from Inaccess web client platform.

In the study done prior to the construction and commissioning of the Rosh Pinah PV power plant, the following P50 values where drafted:

To assess the solar resource or energy yield potential of a site, we model the solar resource/energy yield using best available information and methods. P50 refers to, as SolarGIS states "P50 is essentially a statistical level of confidence suggesting that we expect that the predicted solar resource/energy yield may be exceeded with 50% probability. This also means that with at same probability the expectation may not be achieved. The resulting estimate is the P50 estimate, or in other words, the "best estimate".

Table 14 - Estimated total energy yield for a one-year period

P50 values	AEE Estimated (MWh)	Arup Estimated (MWh)
	14.378	13.643

With these values a percentage is calculated for every particularly month, taking into consideration different aspects as meteorological conditions, the equipment and system losses and the modelling uncertainties that give generic values for a specific month, no matter what year, as shown in the following table 15.

Table 15 - Generic year. Monthly energy yield distribution Source: Rosh Pinah PV LTA _Draft

Period	AEE Estimated (% of total)	Arup Estimated (% of total)
January	11%	11%
February	9%	9%
March	9%	9%
April	7%	7%
May	6%	6%
June	6%	5%
July	6%	6%
August	7%	7%
September	8%	8%
October	10%	10%
November	10%	10%
December	11%	11%

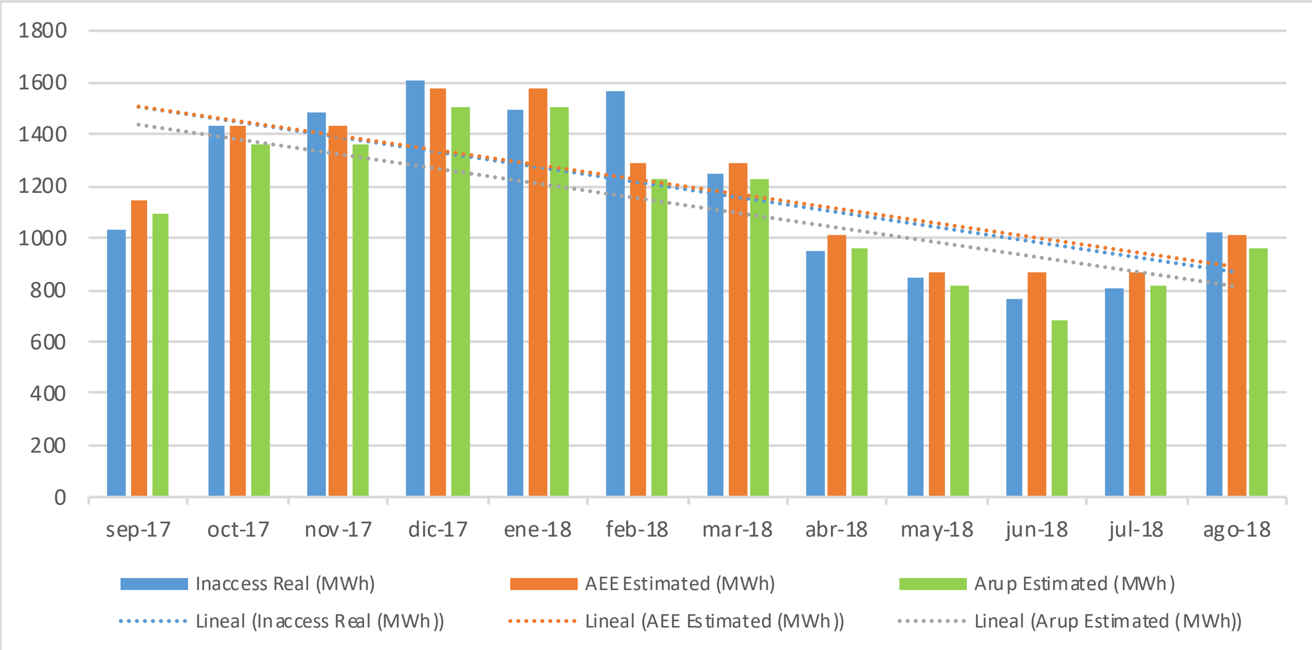
With the information from table 14 and table 15, we now calculate the real percentage distribution that has occurred in the period of our study. For this, we first get the value of the total exported energy from the site, that is equal to 14 246 195,7424 Wh/yr. With this total value, and the average value from every month given by the average value of every day. We can then calculate the percentage by assuming the 100% is the number mentioned before (14.246,2 MW), in order to know the corresponding percentage for every real month.

By doing so and comparing the calculated values with the ones we have from the study done prior to construction of the PV plant we obtain the following table 16 and graph 8:

Table 16 - Monthly energy yield distribution. Source: Inaccess web client application

Period	Inaccess Real (MWh)	AEE Estimated (MWh)	Arup Estimated (MWh)	Inaccess Real (%)	AEE Estimated (% of total)	Arup Estimated (% of total)
Sept-17	1036,74	1150,24	1091,44	7,3%	8%	8%
Oct-17	1430,67	1437,8	1364,3	10,0%	10%	10%
Nov-17	1481,04	1437,8	1364,3	10,4%	10%	10%
Dec-17	1610,12	1581,58	1500,73	11,3%	11%	11%
Jan-18	1494,81	1581,58	1500,73	10,5%	11%	11%
Feb-18	1562,58	1294,02	1227,87	11,0%	9%	9%
Mar-18	1248,15	1294,02	1227,87	8,8%	9%	9%
Apr-18	951,40	1006,46	955,01	6,7%	7%	7%
May-18	845,83	862,68	818,58	5,9%	6%	6%

Jun-18	760,34	862,68	682,15	5,3%	6%	5%
Jul-18	804,60	862,68	818,58	5,6%	6%	6%
Aug-18	1019,90	1006,46	955,01	7,2%	7%	7%
Total	14246,20	14378	13507	100%	100%	99%



Graph 8 - Monthly energy yield distribution

From which we can deduce the following:

Table 17 - Differences between estimations and results.

Period	Difference AEE (MW)	Difference AEE (%)	Difference Arup (MW)	Difference Arup (%)
Sept-17	113,50	0,79%	54,70	0,40%
Oct-17	7,13	0,05%	66,37	0,49%
Nov-17	43,24	0,30%	116,74	0,86%
Dec-17	28,54	0,20%	109,39	0,80%
Jan-18	86,77	0,60%	5,92	0,04%
Feb-18	268,56	1,87%	334,71	2,45%
Mar-18	45,87	0,32%	20,28	0,15%
Apr-18	55,06	0,38%	3,61	0,03%
May-18	16,85	0,12%	27,25	0,20%
Jun-18	102,34	0,71%	78,19	0,57%
Jul-18	58,08	0,40%	13,98	0,10%
Aug-18	13,44	0,09%	64,89	0,48%

Total	131,80	5,84%	739,63	6,57%

- Differences between the estimations with the real data is much higher in the case of Arup, as shown it has a total difference of 739,63 MWh whereas AEE has 131,80 MWh. This meaning that from the initial estimation value, Arup has a 6,57% deviation and AEE has a 5,84%. Also shown by the tendency lines in graph 7, we can appreciate such deviation.
- The month that has a higher discrepancy is February 2018 where both sources estimated a 9% from the total and it turned out to be an 11%, this turning into a 1,87% and a 2,45% deviation respectively.
- The most accurate estimation done by each of the companies are: October 2017 in the case of AEE Power Ventures, with a deviation of 7,13MWh (0,05%) and April 2018 for Arup with a deviation of 3,61MWh (0,03%)

4.8. Average annual performance analysis

In table 18 we have a comparison of the average annual performance estimated by Arup and AEE Power Ventures.

Table 18 - Average annual performance estimations *Source: Rosh Pinah PV LTA _Draft*

		AEE	Arup
Total energy injected in to the grid	[MWh/yr.]	14 378	13 743
Specific energy injected into the grid	[kWh/kWp/yr]	2 536	2 414
Performance Ratio	[%]	80,8%	78,1%

The above shown results are the estimations, with losses, of the annual output expected production values from the solar PV Rosh Pinah power plant, having taken into consideration that the 100% production would be 17 794,55 MWh and 17 493,27 MWh, respectively AEE and Arup.

And since from previous calculations we know that the real total energy injected in to the grid in the period of one year, has been 14 246,20 [MWh]. We can now compare whether the estimations where near to reality or not.

In order to calculate the *Performance Ratio (PR)* we need to know that:

$$PR = \frac{Annual\ reading\ of\ plant\ output\ in\ kWh}{Calculated,\ nominal\ plant\ output\ in\ kWh}\ [\%]$$

By applying this formula to our case of study, we obtain the following:

$$PR_{AEE} = \frac{14\,246{,}20}{17\,794{,}55} \cdot 100 = 80{,}05\%$$

$$PR_{Arup} = \frac{14\,246{,}20}{17\,493{,}27} \cdot 100 = 81{,}441\%$$

This leads us to the conclusion that AEE was closer than Arup in their estimations since the overall difference is smaller 0,75% < 3,34%. Although we could highlight that the overall PR estimation done by AEE is higher than the real PR obtained in that case and that Arup stays 3,34% lower than the real value.

4.9. Comparative: Optimal day vs bad days

Next, we shall see the difference between the data obtained in a day where the power plant is working in near to nominal conditions and the information that we can get on a bad day.

To begin with, we are going to analyse the 3rd of August 2018, in the following table 19 and fig. 28 we see the results of such day.

Table 19 - 3rd August 2018 Information

Time	Power Export Site (kW)	Irradiance PoA Average ($W \cdot m^{-2}$)	Ambient Temperature Average (ºC)	Module Temperature Average (ºC)	Raw PR (%)
08:00:00	171,88	44,54	9,40	5,45	68,06%
09:00:00	2642,77	454,87	12,61	17,41	102,47%
10:00:00	4006,34	725,50	12,35	21,26	97,39%
11:00:00	4014,07	725,82	11,88	22,48	97,54%
12:00:00	3893,12	702,16	13,79	22,93	97,79%
13:00:00	3799,30	686,23	15,97	23,84	97,65%
14:00:00	3768,67	695,27	17,57	28,30	95,60%
15:00:00	3848,61	713,11	18,58	29,92	95,18%
16:00:00	3943,45	733,78	19,04	29,57	94,78%
17:00:00	2866,71	519,80	18,16	24,43	97,27%
18:00:00	433,73	106,21	16,59	16,61	72,02%
18:15:00	90,21	34,09	16,15	15,07	46,67%

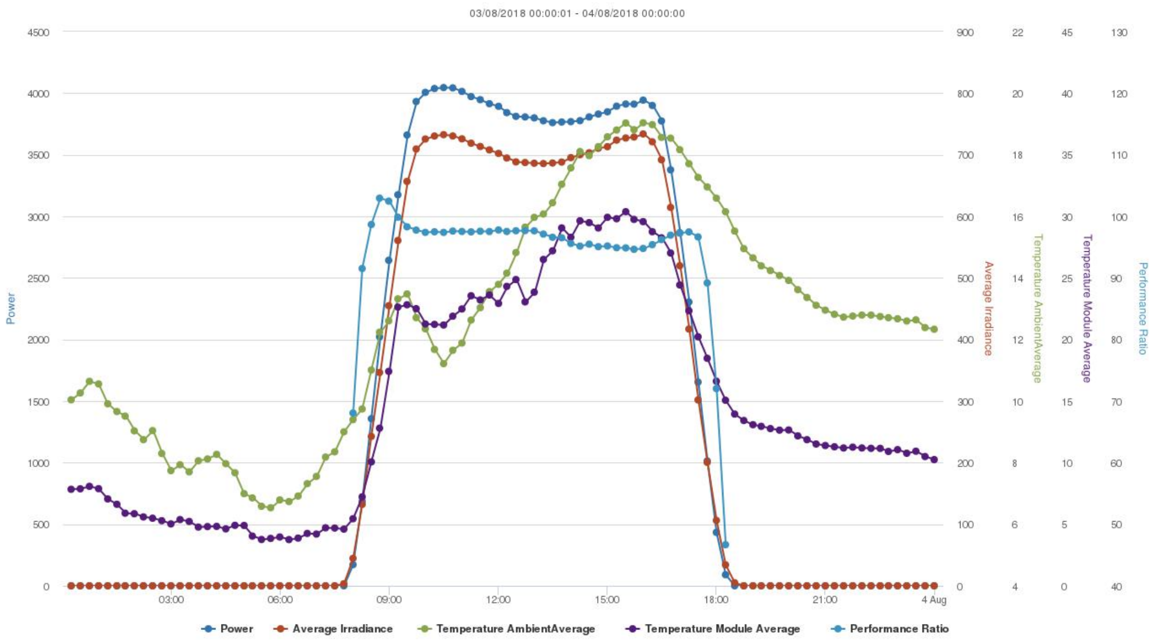


Figure 28 - 3rd of August 2018

If we compare these results with other day in which the irradiation was not as good, meaning that the power export was not as good either, we shall see major differences. For example, the following day, the 4rd of August 2018 as shown in the following table 20 and figure 29, gives us an idea of the differences that can occur in only 24 hours.

Table 20 - 4rd August 2018. Information

Time	Power Export Site (kW)	Irradiance PoA Average ($W·m^{-2}$)	Ambient Temperature Average (ºC)	Module Temperature Average (ºC)	Raw PR (%)
08:00:00	219,31	54,83	11,77	10,22	70,54%
09:00:00	2650,11	453,49	13,09	17,36	103,07%
10:00:00	3894,65	712,89	14,10	24,77	96,35%
11:00:00	4255,92	790,48	15,36	28,23	94,96%
12:00:00	3742,49	735,00	16,21	27,91	89,80%
13:00:00	1850,62	407,00	16,78	26,44	80,19%
14:00:00	2802,66	612,48	17,59	28,52	80,70%
15:00:00	1239,34	282,28	18,31	27,61	77,43%
16:00:00	880,20	172,78	17,92	20,46	89,85%
17:00:00	1203,08	229,41	17,16	18,88	92,49%
18:00:00	407,24	99,69	16,33	17,15	72,05%
18:15:00	60,10	21,40	15,86	15,06	49,52%

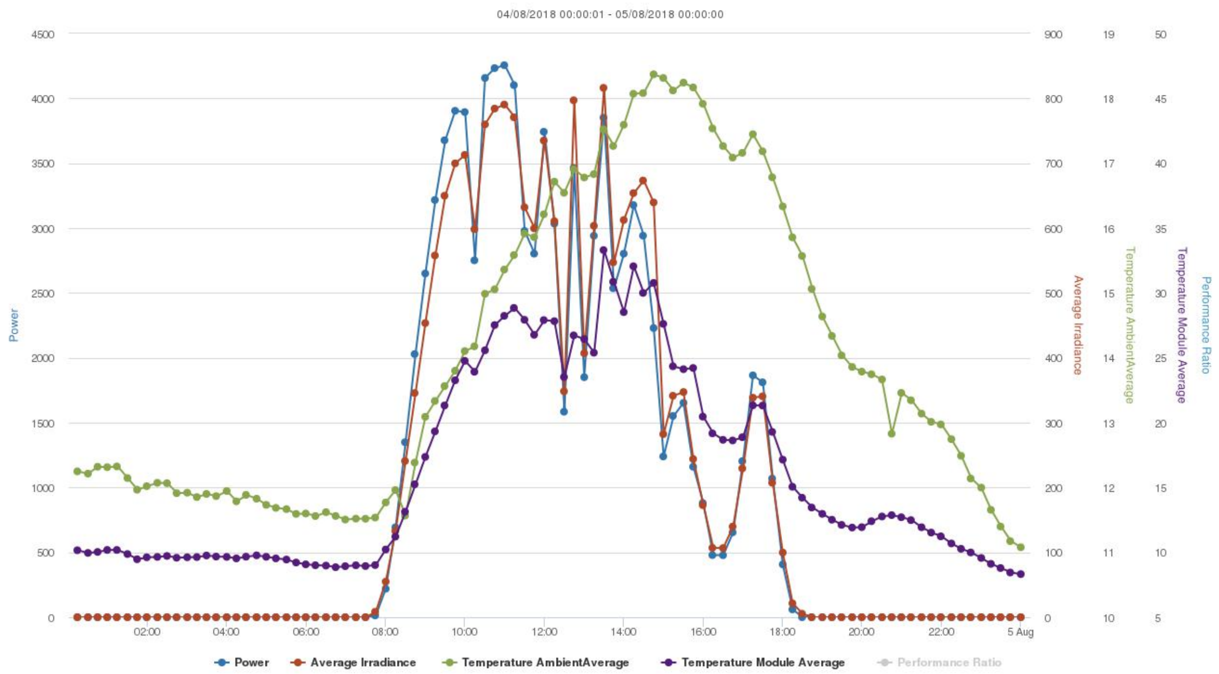


Figure 29 - 4rd August 2018

As we can see, the values are much more disorganized with peaks and valleys during the day period. This is due mainly to the meteorological conditions during that day, since this day was a cloudy day, and the average air temperature was not as low, the module temperature was quite low especially from 14:00 to 16:00 hours, this affects the power exported ultimately.

In order to expose other examples of “bad days” the following figures are exhibit, representing the days July 23rd, 2018 in figure 30.

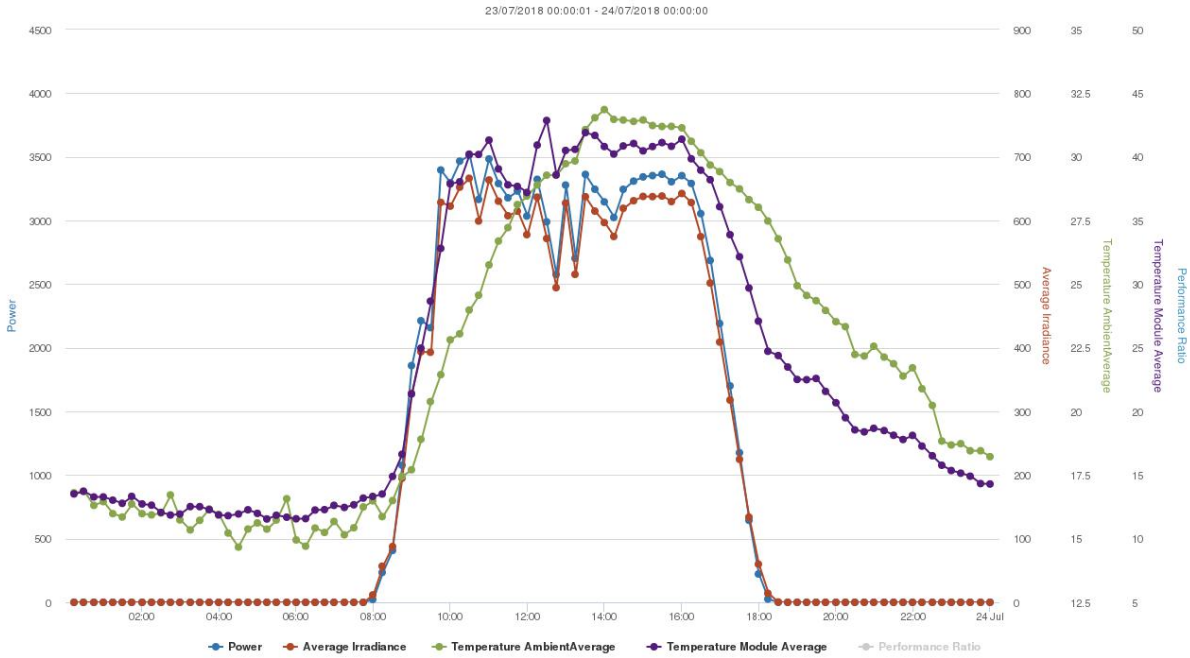


Figure 30 - July 23rd, 2018

Where we can see that although it is not an optimal day, is quite close, meaning that there are no huge changes in what an optimal day looks like, and that the overall power export was of 1113,84 kW. This value is not as far away from the average of that month, being such average value 1081,46 kW.

As for the following figure 31 and figure 32, represent January 21 and March 27, 2018. These days are other possibility that can occur during the year and that we decided to show randomly, with no specific criteria, but show the amount of differences that can happen during a period of time.

If we were to analyse a certain season or a specific month, we could go in to more detail, but since we were interested in the overall of the first year, these alternatives where discarded.

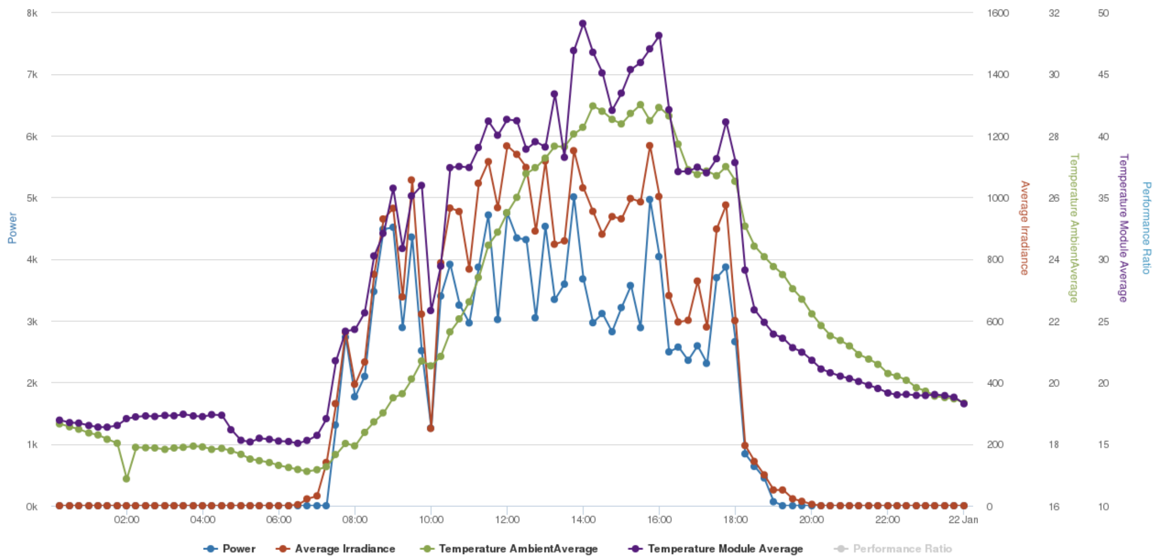


Figure 31 - January 21st, 2018

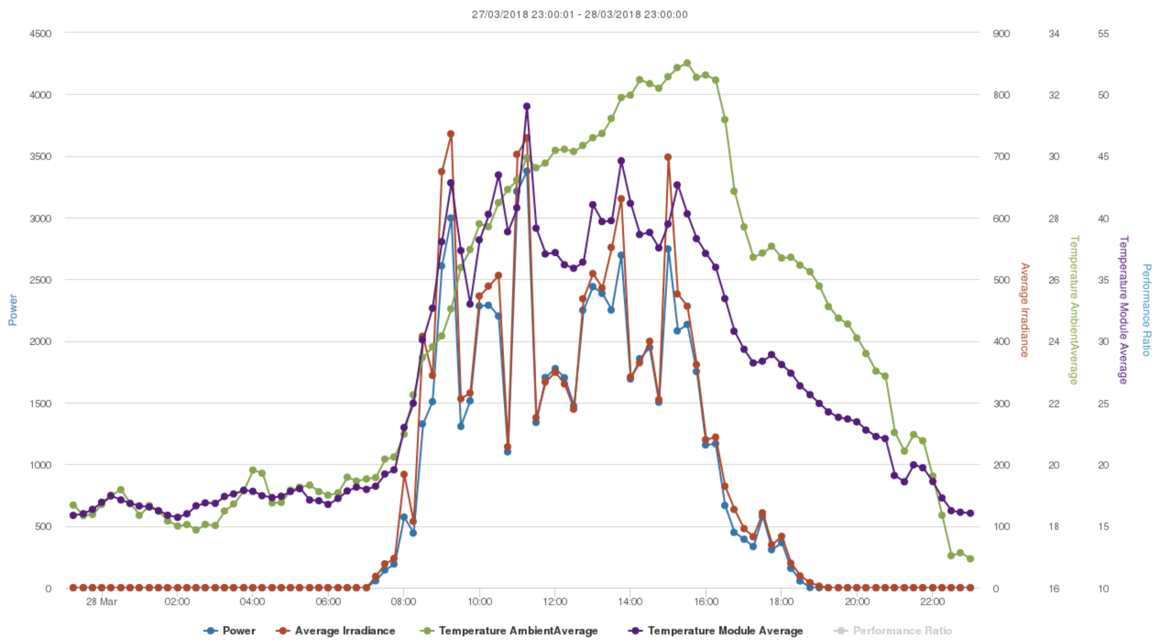


Figure 32 - March 27, 2018

5. Conclusions

This project has shown that the hypothesis considered by AEE Power Ventures have been closer to reality than the one considered by Arup in the overall scenario, although there a few points where Arup was closer to reality.

This could be the results of the estimation method that was taken into consideration by both companies, shown in table 3, where AEE Power Ventures takes their information from Meteonorm V.6 whereas Arup bases its predictions on SolarGIS. The main difference between these two methods is that Meteonorm gathers information from five to six weather stations and when there are no weather stations nearby it uses satellite data whereas SolarGIS only uses the interpolation from the six nearest weather stations, so when information is not available, there is none.

We have also seen that during the elapsed period, there has been four major cases that were worth studying into deeper detail, that are exposed in the daily analysis paragraph when we talk about the peculiarities (green circles in graph 4).

It should be noted that significant differences have occurred in global horizontal irradiance during November 2017 and January 2018, being the biggest difference in December 2017. In what concerns to temperature values the two main difference are 5,5 ºC and 3ºC on July 2018 and September 2017, respectively.

To sum up, the performance ratio, that is a global sign for the overall study also show, that the estimations done by AEE Power Ventures are more precise than Arup's, as we can see in the following table 21 that compares such values, knowing that we have a productivity of 14 426,20 MWh.

Table 21 - Real vs Estimated values

		AEE	Arup
Total energy injected in to the grid	[MWh/yr.]	14 378	13 743
Specific energy injected into the grid	[kWh/kWp/yr]	2 536	2 414
Performance Ratio	[%]	80,8%	78,1%
Real value		80,05%	81,44%
Difference		0,75%	3,34%

6. References

1 1&2. Twidell, John; Weir, Tony. Renewable Energy Resources (2006). Taylor & Francis.

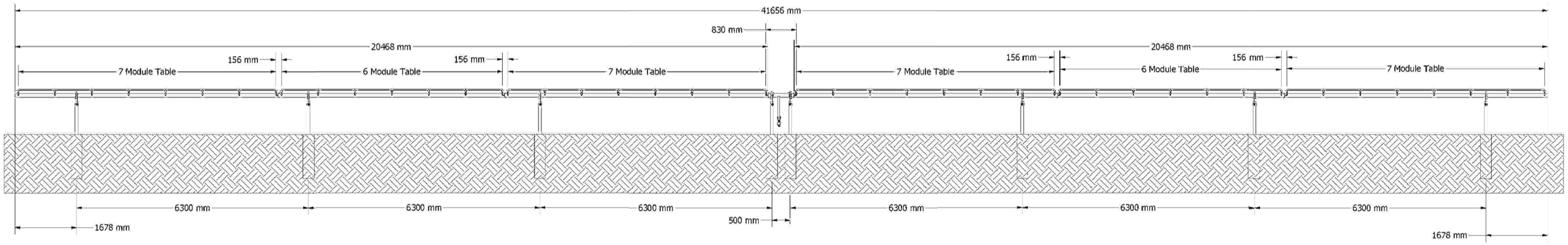
2 PROGENSA (1987-2008) E.Alcor. Instalaciones Solares Fotovoltaicas
PROGENSA (2002-2008). Sistemas de Energía Fotovoltaica – Manual del instalador Colectivo
Annual Report 2017 Nam Power
IEA: Global Installed PV Capacity Leaps to 303 Gigawatts, greentechmedia, Eric Wesoff, April 27, 2017

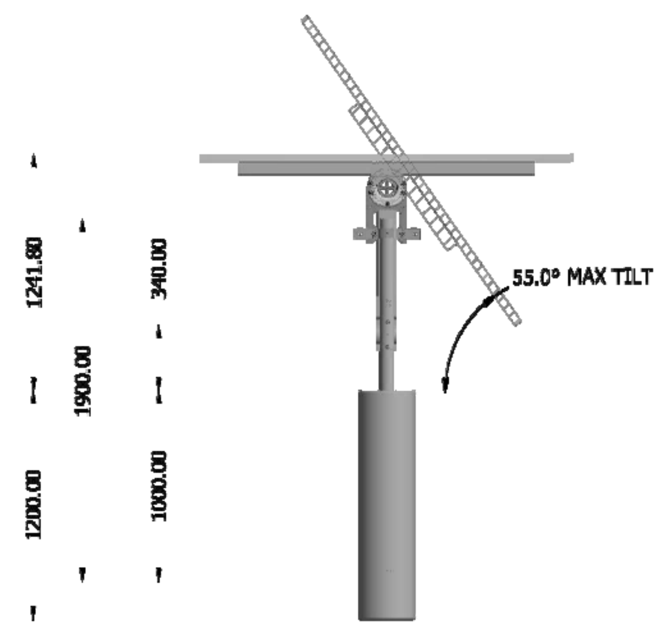
4 Rosh Pinah PV LTA _Draft 7
5 Inaccess PPC Operaing Manual v2.7

3 https://www.homerenergy.com/products/pro/docs/3.11/global_horizontal_irradiance_ghi.html
https://www.eia.gov/
http://www.sunwindenergy.com/namibias-path-to-solar-thermal-future
http://www.fsec.ucf.edu/en/education/k-12/curricula/use/documents/USE_17_IrradianceTemperaturePV.pdf
https://www.campbellsci.eu/blog/pyranometers-need-to-know

7. Appendixes

1 NA001-5RP-D-S005-2 TRACKER DETAILS
2 NA001-5RP-D-C003-1 SITUATION
3 NA001-5RP-D-C005-2 SITE COORDINATES LAYOUT
4 NA001-5RP-D-C004-2 LOCATION
5 NA001-5RP-D-E025-2 COMMUNICATIONS SYSTEM. GENERAL LAYOUT
6 *NA001-5RP-D-C009-3 INTERNAL ROADS. GENERAL LAYOUT*
7 *NA001-5RP-D-E005-2 DC STRING DETAILS*
8 *NA001-5RP-D-E006-3 PV SINGLE LINE DIAGRAM*
9 NA001-5RP-D-S006-1 INVERTER AND SWITCH BOX FIXATION DETAILS I.
10 NA001-5RP-D-S006-1 INVERTER AND SWITCH BOX FIXATION DETAILS II.
11 NA001-5RP-D-S006-1 INVERTER AND SWITCH BOX FIXATION DETAILS III.





NOTES:

1- DIMENSIONS IN MILLIMETERS

REFERENCE DRAWINGS:

- NA001-5RP-D-S003 GENERAL LAYOUT
- NA001-5RP-D-S004 GENERAL LAYOUT WITH TRENCHES
- NA001-5RP-D-S005 TRACKER DETAILS
- NA001-5RP-D-S006 INVERTER AND SWITCH BOX FIXATION DETAILS I
- NA001-5RP-D-S007 INVERTER AND SWITCH BOX FIXATION DETAILS II
- NA001-5RP-D-S008 INVERTER AND SWITCH BOX FIXATION DETAILS III
- NA001-5RP-D-C008 GENERAL LAYOUT. DETAILS
- NA001-5RP-D-C009 INTERNAL ROADS. GENERAL LAYOUT
- NA001-5RP-D-C011 GENERAL TRENCHES LAYOUT
- NA001-5RP-D-C019 FENCE. GENERAL LAYOUT

REV.	DATE	DRAWN	MODIFICATION	APPROVED
2	25/07/17	R. ARRANZ	AS BUILT	–
1	23/03/17	R. ARRANZ	CHANGE TO 180 INVERTERS & UPDATED INFORMATION	–
0	22/02/17	R. ARRANZ	FOR CLIENT APPROVAL	–

ALOE INVESTMENTS 27 (PTY) LTD

PROJECT

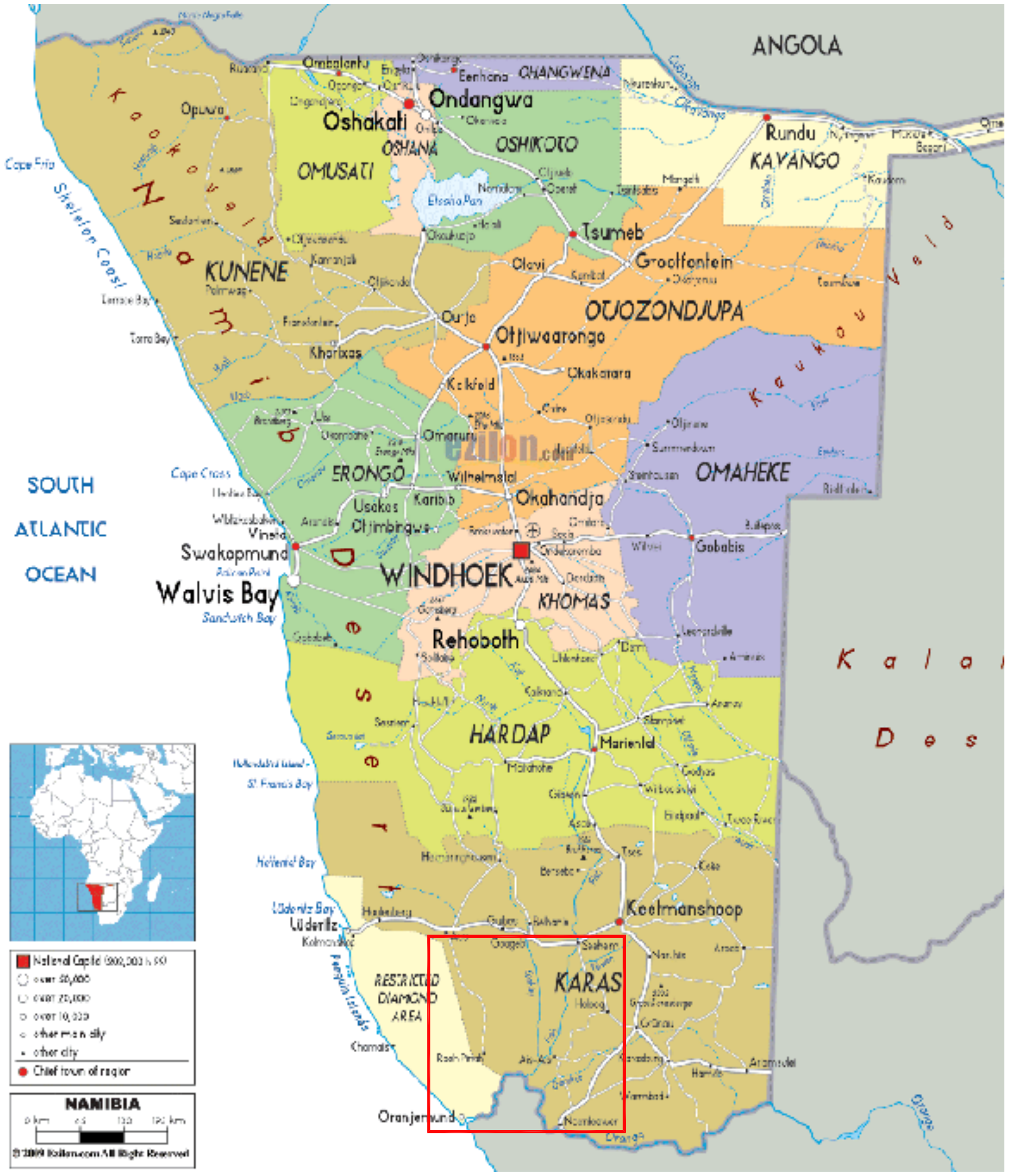
5 MWac ROSH PINAH SOLAR FARM

TITLE

ROSH PINAH PV FARM
TRACKER DETAILS

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
–	NA001-5RP-D-S005-2	NA001-5RP-D-S005-2	1 of 1	A2



REV.	DATE	DRAWN	MODIFICATION	APPROVED
1	25/07/17	R. ARRANZ	AS BUILT	–
0	07/11/16	R. ARRANZ	FOR CLIENT APPROVAL	–

AEE POWER

ALOE INVESTMENTS 27 (PTY) LTD

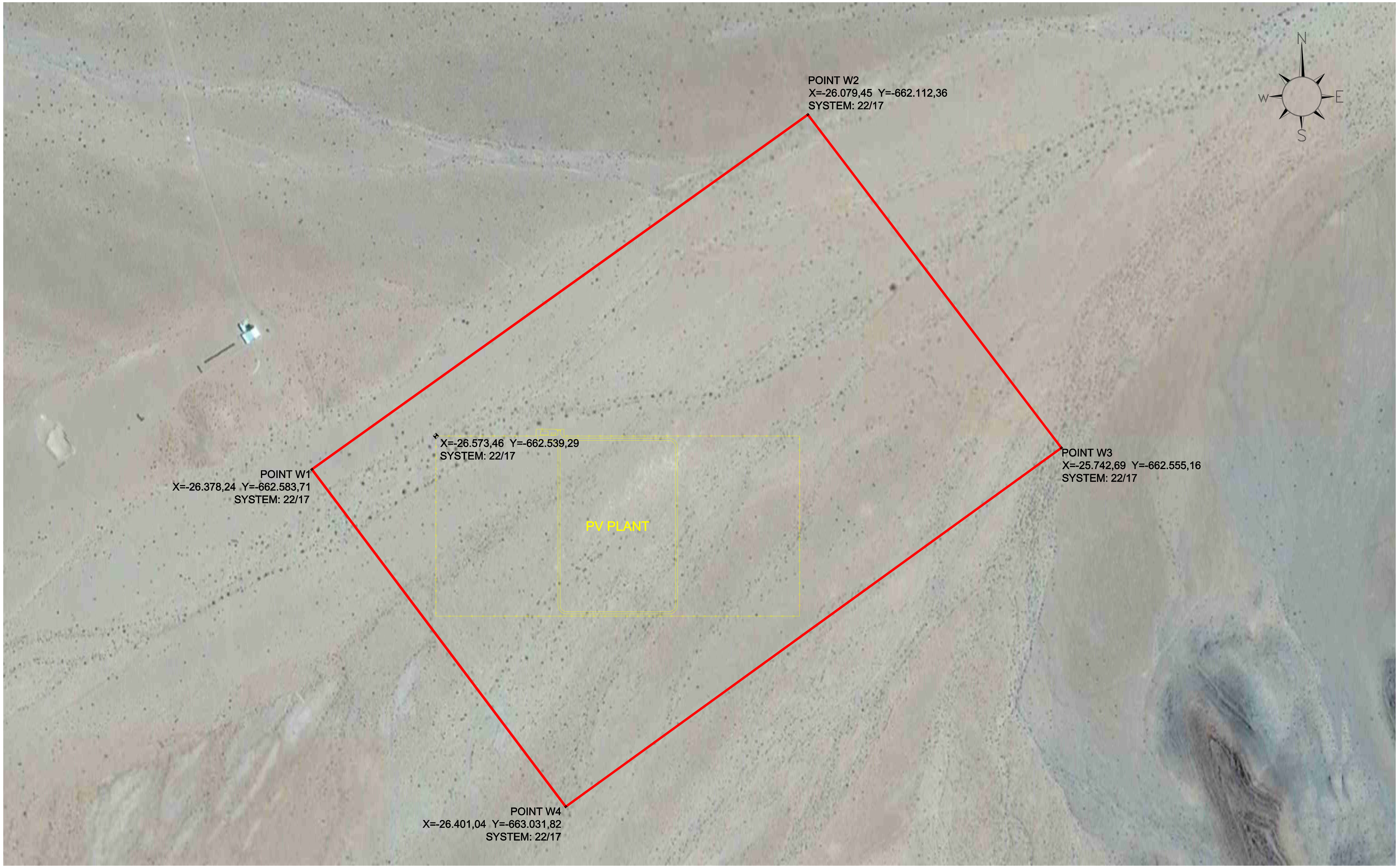
5 MWac ROSH PINAH SOLAR FARM

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

TITLE

ROSH PINAH PV FARM
SITUATION

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
–	NA001-5RP-D-C003-1	NA001-5RP-D-C003-1	1 of 1	A3



REV.	DATE	DRAWN	MODIFICATION	APPROVED
2	25/07/17	R. ARRANZ	AS BUILT	–
1	22/02/17	R. ARRANZ	NEW PLANT LOCATION & UPDATED INFORMATION	–
0	07/11/16	R. ARRANZ	FOR CLIENT APPROVAL	–

AEE POWER

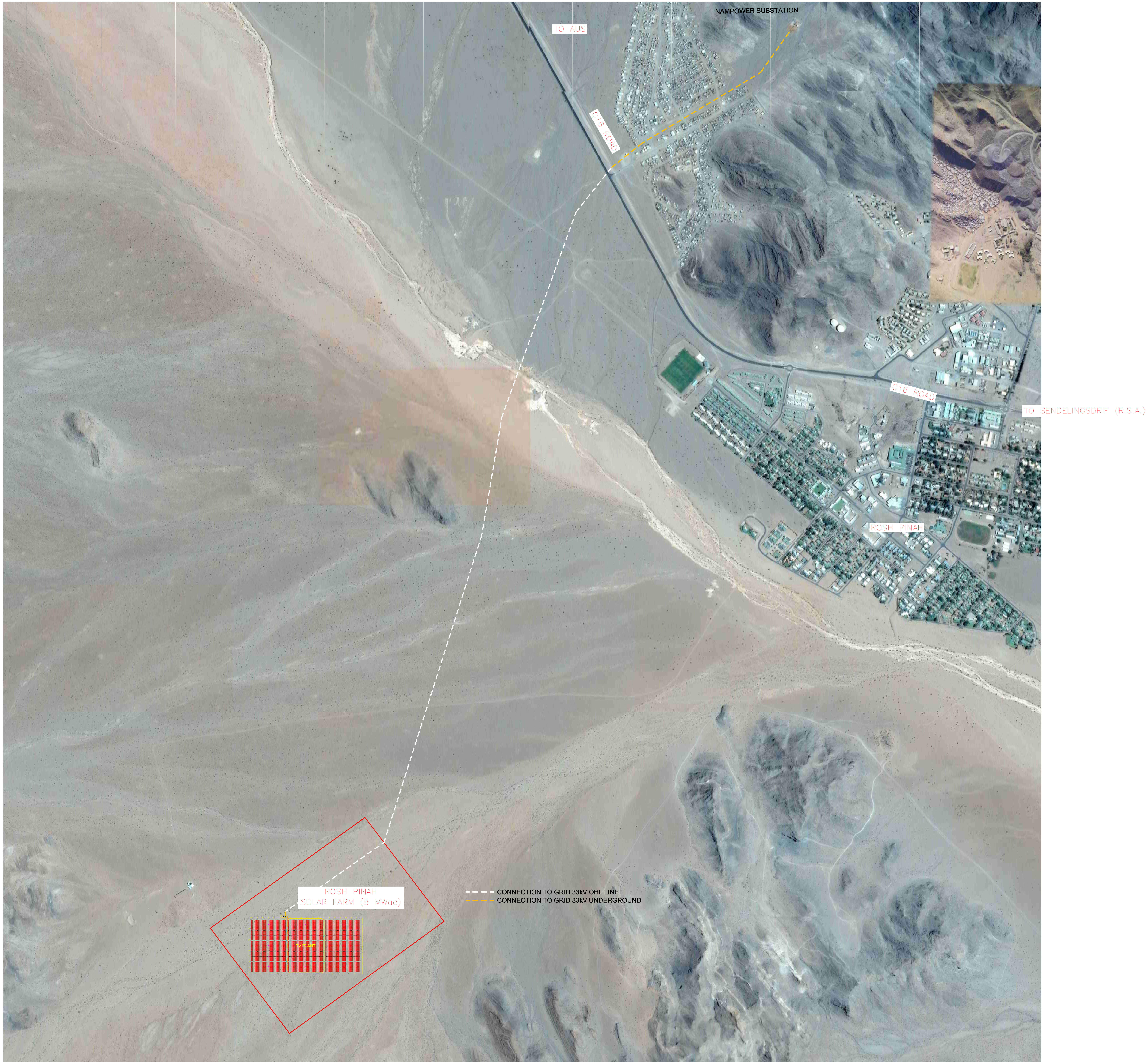
ALOE INVESTMENTS 27 (PTY) LTD

5 MWac ROSH PINAH SOLAR FARM

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

TITLE
ROSH PINAH PV FARM
SITE COORDINATES LAYOUT

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
1/5000	NA001-5RP-D-C005-2	NA001-5RP-D-C005-2	1 of 1	A3



N
E
S
W

NOTES:

1- THE EVACUATION LINE 33kV, FOR REFERENCE ONLY, IS A PART OF ANOTHER PROJECT.
IT SHOULD BE UPDATED IN THE DRAWINGS ONCE IT HAS BEEN CONFIRMED.

REV.	DATE	DRAWN	MODIFICATION	APPROVED
2	25/07/17	R. ARRANZ	AS BUILT	–
1	12/01/17	R. ARRANZ	NEW PLANT LOCATION & UPDATED INFORMATION	–
0	07/11/16	R. ARRANZ	FOR CLIENT APPROVAL	–

ALOE INVESTMENTS 27(PTY)LTD

PROJECT

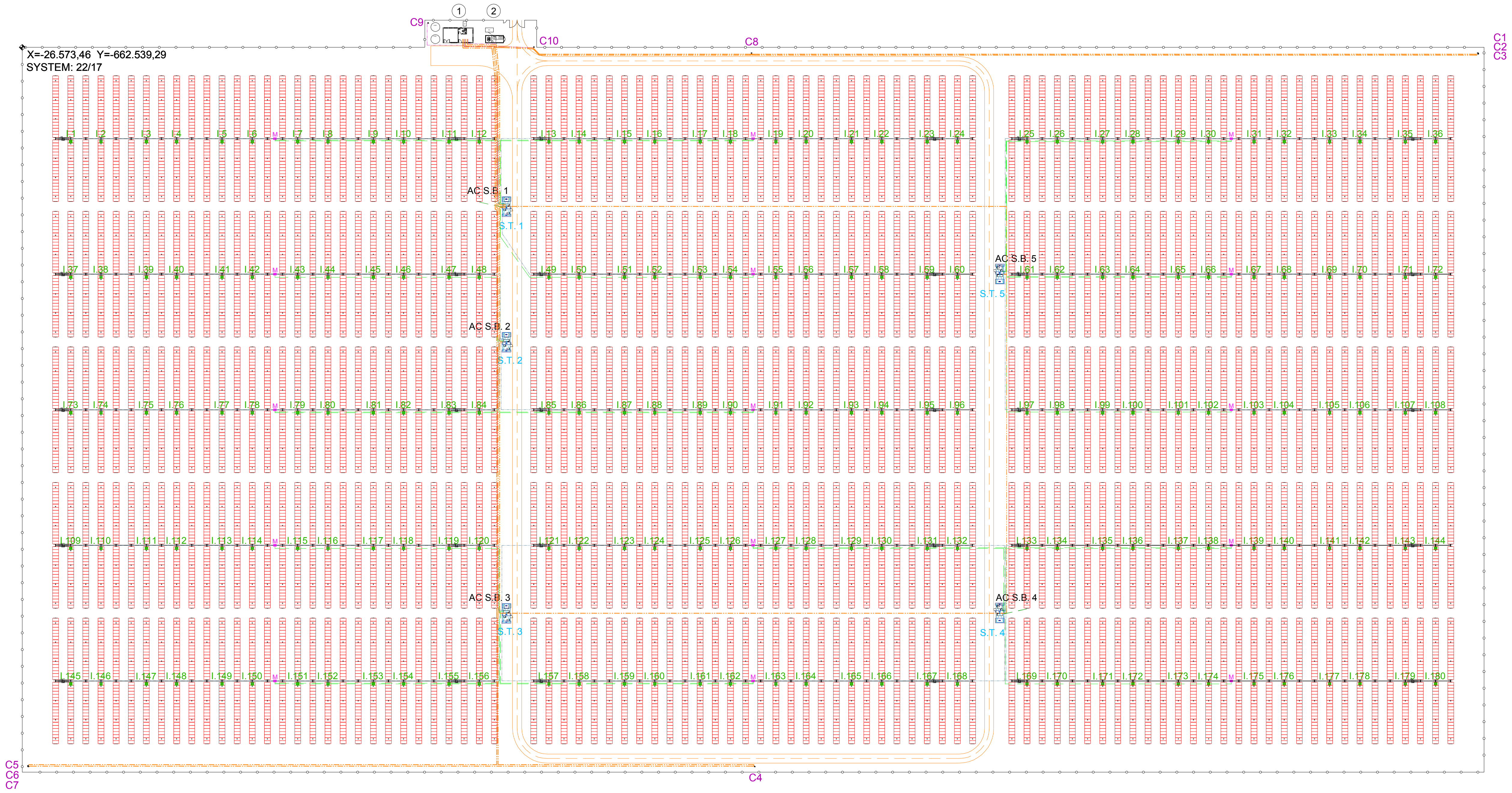
5 MWac ROSH PINAH SOLAR FARM

TITLE

ROSH PINAH PV FARM LOCATION

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

SCALE	CAD–FILE	DRAWING No.	SHEET No.	
–	NA001–5RP–D–C004–2	NA001–5RP–D–C004–2	1 of 1	A1



N
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LEGEND

- SOLAR PANEL 315 Wp
- INVERTER 33 kW
- STATION TRANSFORMER 1.250 kVA 0.4/33 kV
- AC SECONDARY BOX
- 1 CONTROL ROOM / WAREHOUSE / WC
- 2 MAIN SWITCH STATION 33 kV
- C# CCTV DEVICES
- SECURITY FENCE
- ROAD
- M MOTOR CONTROL & PLS BOX
- FIBER OPTIC
- TRACKER COM (RS-485) AND SIGNAL CABLE FROM UPS
- INVERTER COM (RS-485)
- ETHERNET COM (CAT 5E)

PV PLANT DESCRIPTION

MODULES: 18.000
STRINGS: 900
INVERTERS: 180
STATION TRANSFORMER: 5
POWER: 5,67 MWp / 5 MWac

NOTES:

1- FIBER OPTIC RINGS:
RING 1: CONTROL BUILDING-ST1-ST2-ST3-ST4-ST5-CONTROL BUILDING
RING 2: CONTROL BUILDING-CCTV C1C2C3-CCTV C8-CCTV C4-
-CCTV C5C6C7-CONTROL BUILDING
2- ETHERNET CONNECTION CCTV:
CONTROL BUILDING-CCTV C9
CONTROL BUILDING-CCTV C10

REFERENCE DRAWINGS:

- NA001-5RP-D-E007 AC GENERAL LAYOUT
- NA001-5RP-D-E026A ST1 COMMUNICATIONS LAYOUT
- NA001-5RP-D-E026B ST2 COMMUNICATIONS LAYOUT
- NA001-5RP-D-E026C ST3 COMMUNICATIONS LAYOUT
- NA001-5RP-D-E026D ST4 COMMUNICATIONS LAYOUT
- NA001-5RP-D-E026E ST5 COMMUNICATIONS LAYOUT
- NA001-5RP-D-C007 GENERAL LAYOUT
- NA001-5RP-D-C011 GENERAL TRENCHES LAYOUT

REV.	DATE	DRAWN	MODIFICATION	APPROVED
2	25/07/17	R. ARRANZ	AS BUILT	-
1	02/05/17	R. ARRANZ	DIESEL, ST & MSS FOUNDATIONS & UPDATED INFORMATION	-
0	23/03/17	R. ARRANZ	FOR CLIENT APPROVAL	-

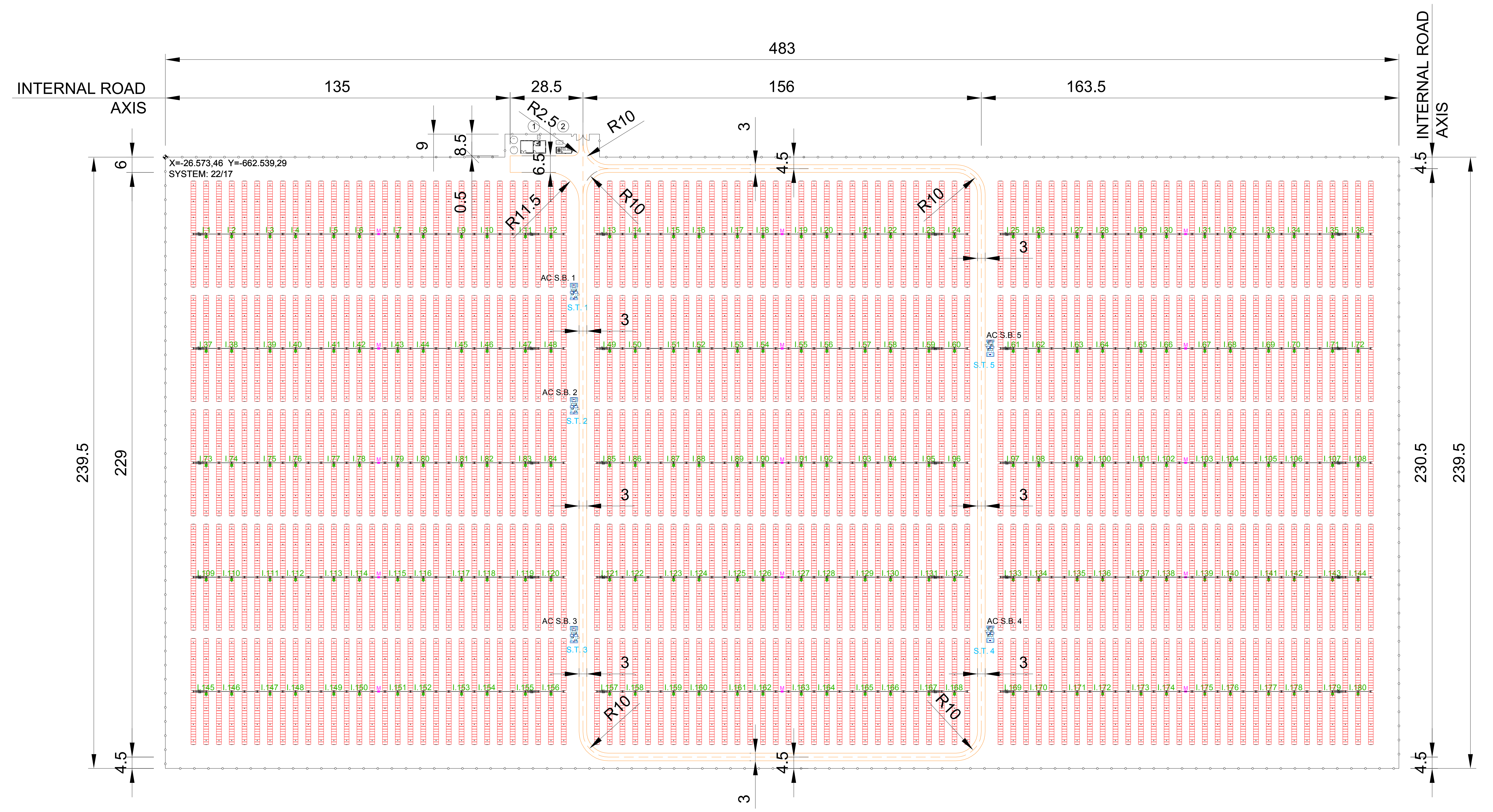
ALDE INVESTMENTS 21 (PTY) LTD

PROJECT
5 MWac ROSH PINAH SOLAR FARM

TITLE
ROSH PINAH PV FARM
COMMUNICATIONS SYSTEM. GENERAL LAYOUT

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
1/1500	NA001-5RP-D-E025-2	NA001-5RP-D-E025-2	1 of 1	A2



LEGEND

- SOLAR PANEL 315 Wp
- INVERTER 33 kW
- STATION TRANSFORMER 1250 kVA 0.4/33 kV
- AC SECONDARY BOX
- 1 CONTROL ROOM / WAREHOUSE / WC
- 2 MAIN SWITCH STATION 33 kV
- SECURITY FENCE
- ROAD

NOTES:

1- DIMENSIONS IN METERS

REFERENCE DRAWINGS:

- NA001-5RP-D-C007 GENERAL LAYOUT
- NA001-5RP-D-C010 INTERNAL ROADS. DETAILS
- NA001-5RP-D-C011 GENERAL TRENCHES LAYOUT
- NA001-5RP-D-C019 FENCE. GENERAL LAYOUT

REV.	DATE	DRAWN	MODIFICATION	APPROVED
3	25/07/17	R. ARRANZ	AS BUILT	–
2	23/03/17	R. ARRANZ	CHANGE TO 180 INVERTERS & UPDATED INFORMATION	–
1	22/02/17	R. ARRANZ	NEW PLANT LOCATION & UPDATED INFORMATION	–
0	07/11/16	R. ARRANZ	FOR CLIENT APPROVAL	–

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

PROJECT

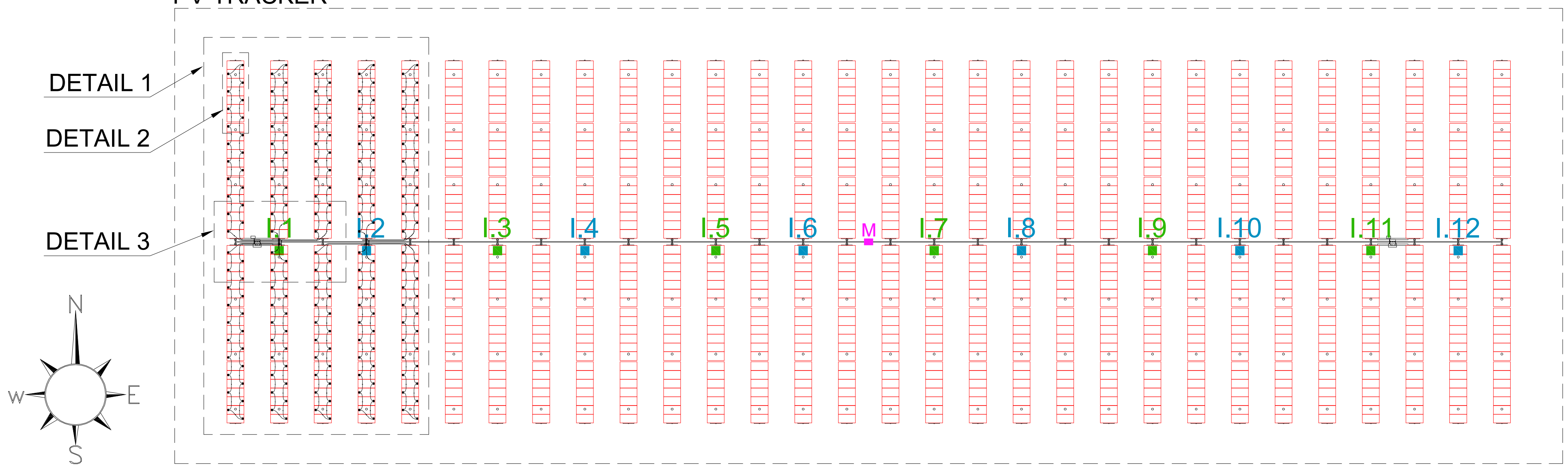
5 MWac ROSH PINAH SOLAR FARM

TITLE

ROSH PINAH PV FARM
INTERNAL ROADS. GENERAL LAYOUT

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
1/1500	NA001-5RP-D-C009-3	NA001-5RP-D-C009-3	1 of 1	A2

PV TRACKER



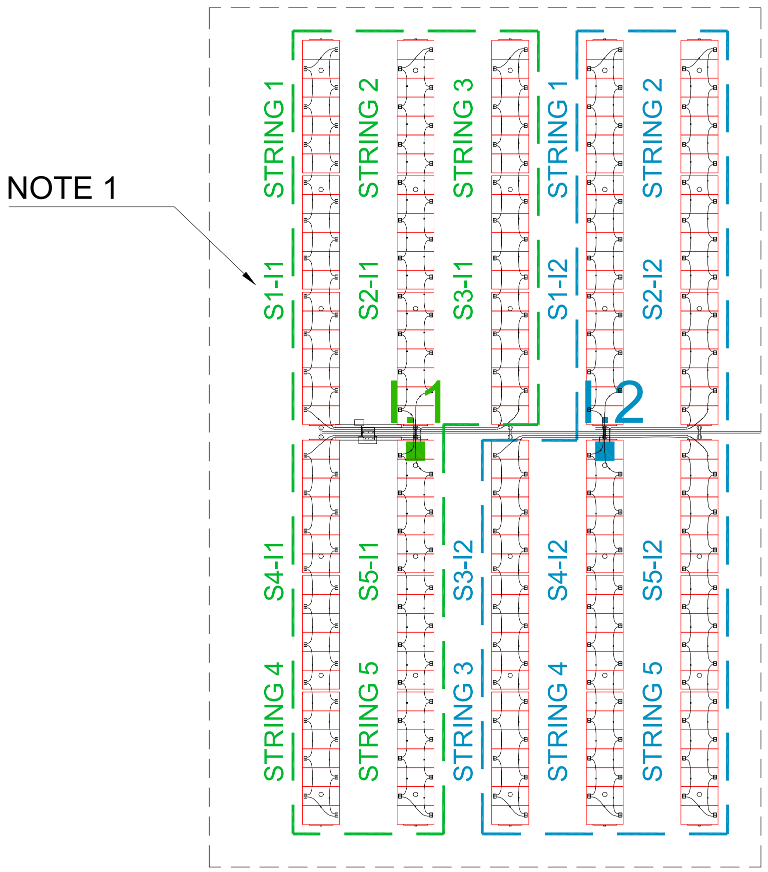
PV PLANT DESCRIPTION

MODULES: 18.000
STRINGS: 900
INVERTERS: 180
STATION TRANSFORMER: 5
POWER: 5,67 MWp / 5 MWac

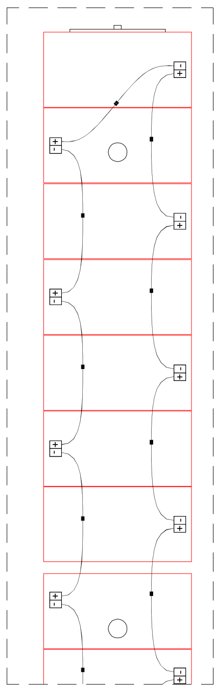
REFERENCE DRAWINGS:

- NA001-5RP-D-E003 DC GENERAL LAYOUT
- NA001-5RP-D-E004 DC DEVICES SPECIFICATION
- NA001-5RP-D-E006 PV SINGLE LINE DIAGRAM

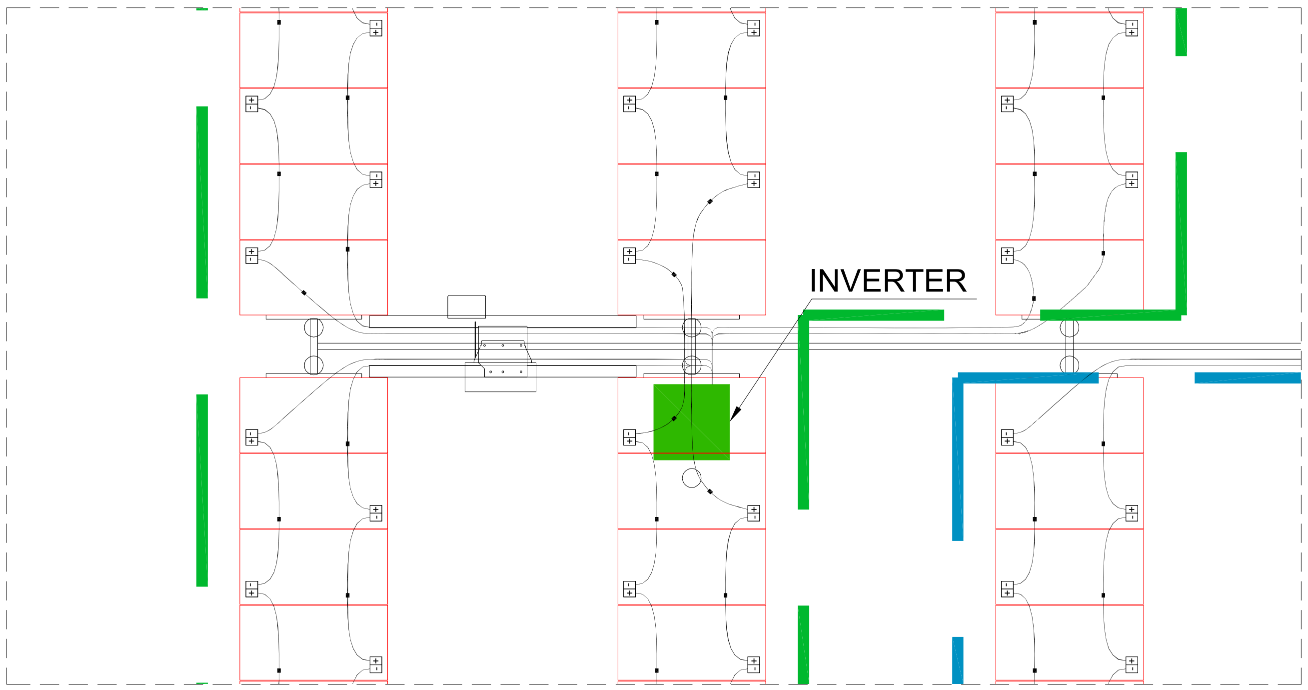
DETAIL 1



DETAIL 2



DETAIL 3



NOTES:

1 - STRING DESIGNATION: S#-I#
- S for string and # for number (1 to 5)
- I for inverter and # for number (1 to 180)

REV.	DATE	DRAWN	MODIFICATION	APPROVED
2	25/07/17	R. ARRANZ	AS BUILT	–
1	23/03/17	R. ARRANZ	CHANGE TO 180 INVERTERS & UPDATED INFO.	–
0	07/11/16	R. ARRANZ	FOR CLIENT APPROVAL	–

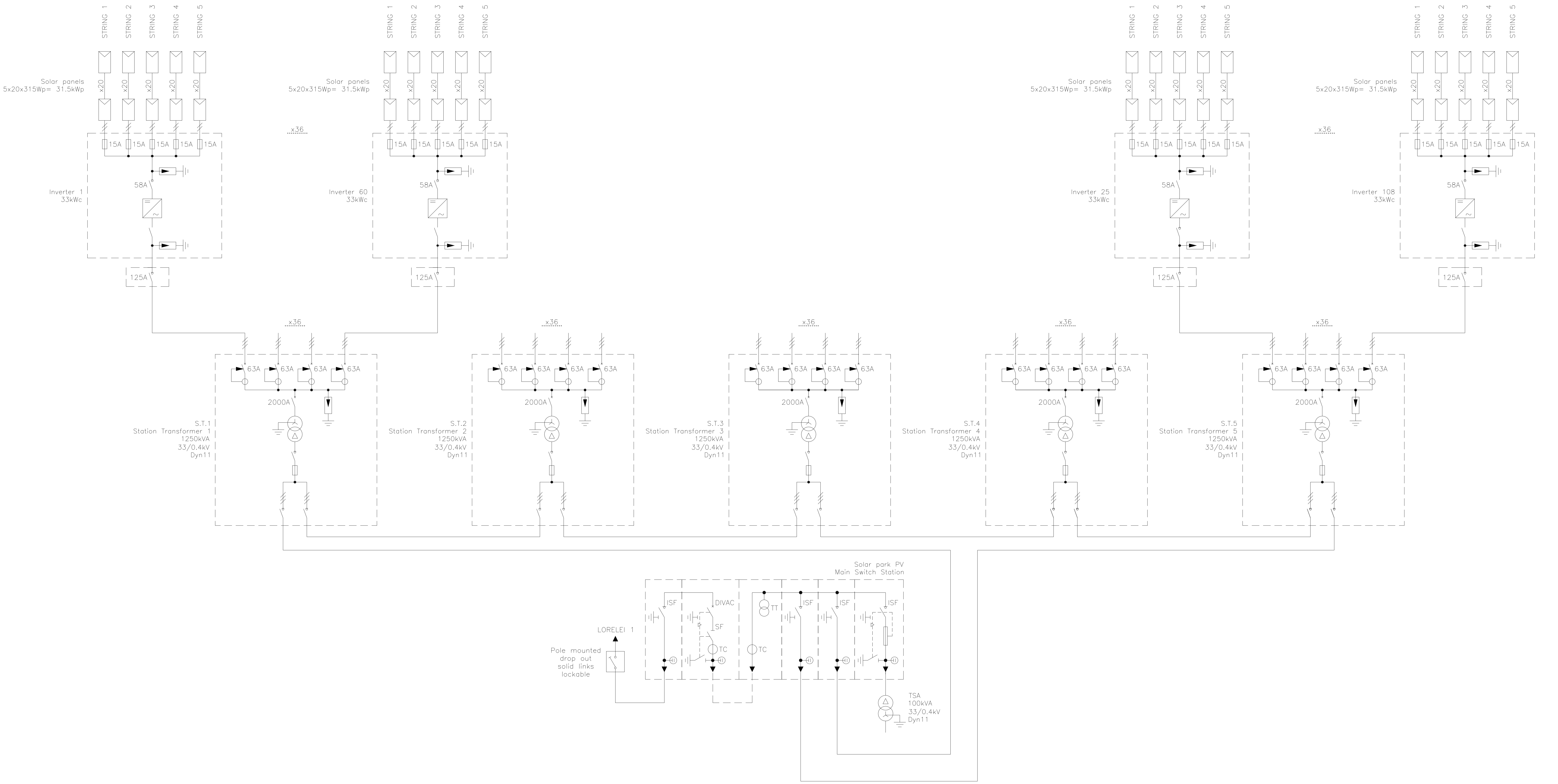
5 MWac ROSH PINAH SOLAR FARM

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

TITLE

ROSH PINAH PV FARM
DC STRING DETAILS

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
–	NA001-5RP-D-E005-2	NA001-5RP-D-E005-2	1 of 1	A3



STATION TRANSFORMER #	INVERTER #	DESCRIPTION
S.T.1	1 To 12	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
	13 To 24	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
	49 To 60	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
S.T.2	37 To 48	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
	73 To 84	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
	85 To 96	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
S.T.3	109 To 126	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
	145 To 162	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
S.T.4	127 To 144	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
	163 To 180	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
S.T.5	25 To 36	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
	61 To 72	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER
	97 To 108	5 STRINGS OF 20 MODULES OF 315 Wp PER INVERTER

PV PLANT DESCRIPTION

MODULES: 18.000
STRINGS: 900
INVERTERS: 180
STATION TRANSFORMER: 5
POWER: 5.67 MWp / 5 MWac

REFERENCE DRAWINGS:

- NA001-5RP-D-E003 DC GENERAL LAYOUT
- NA001-5RP-D-E004 DC DEVICES SPECIFICATION
- NA001-5RP-D-E005 DC STRING DETAILS

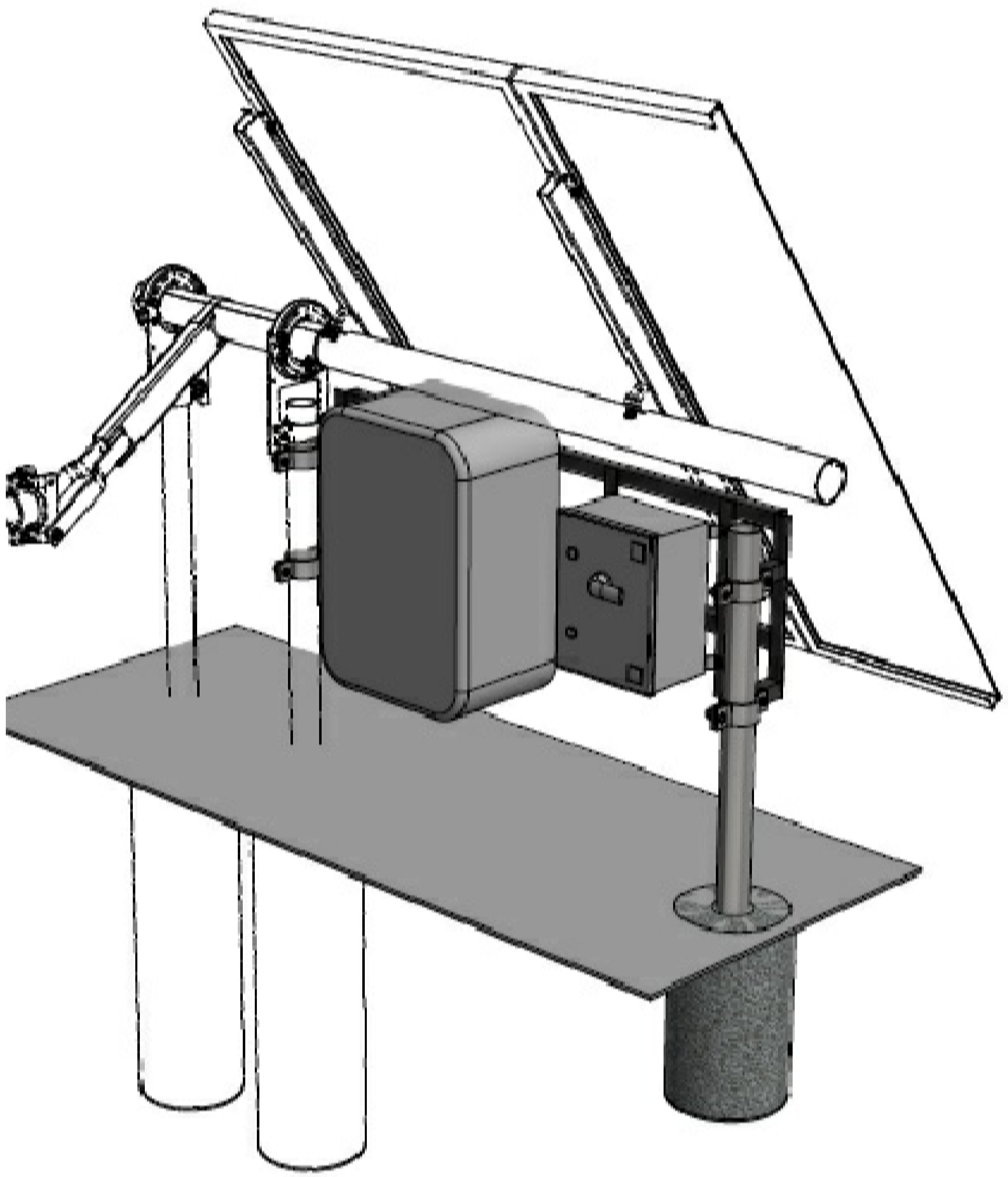
REV.	DATE	DRAWN	MODIFICATION	APPROVED
3	25/07/17	R. ARRANZ	AS BUILT	–
2	23/03/17	R. ARRANZ	CHANGE TO 180 INVERTERS & UPDATED INFORMATION	–
1	22/02/17	R. ARRANZ	NEW PLANT LOCATION & UPDATED INFORMATION	–
0	07/11/16	R. ARRANZ	FOR CLIENT APPROVAL	–

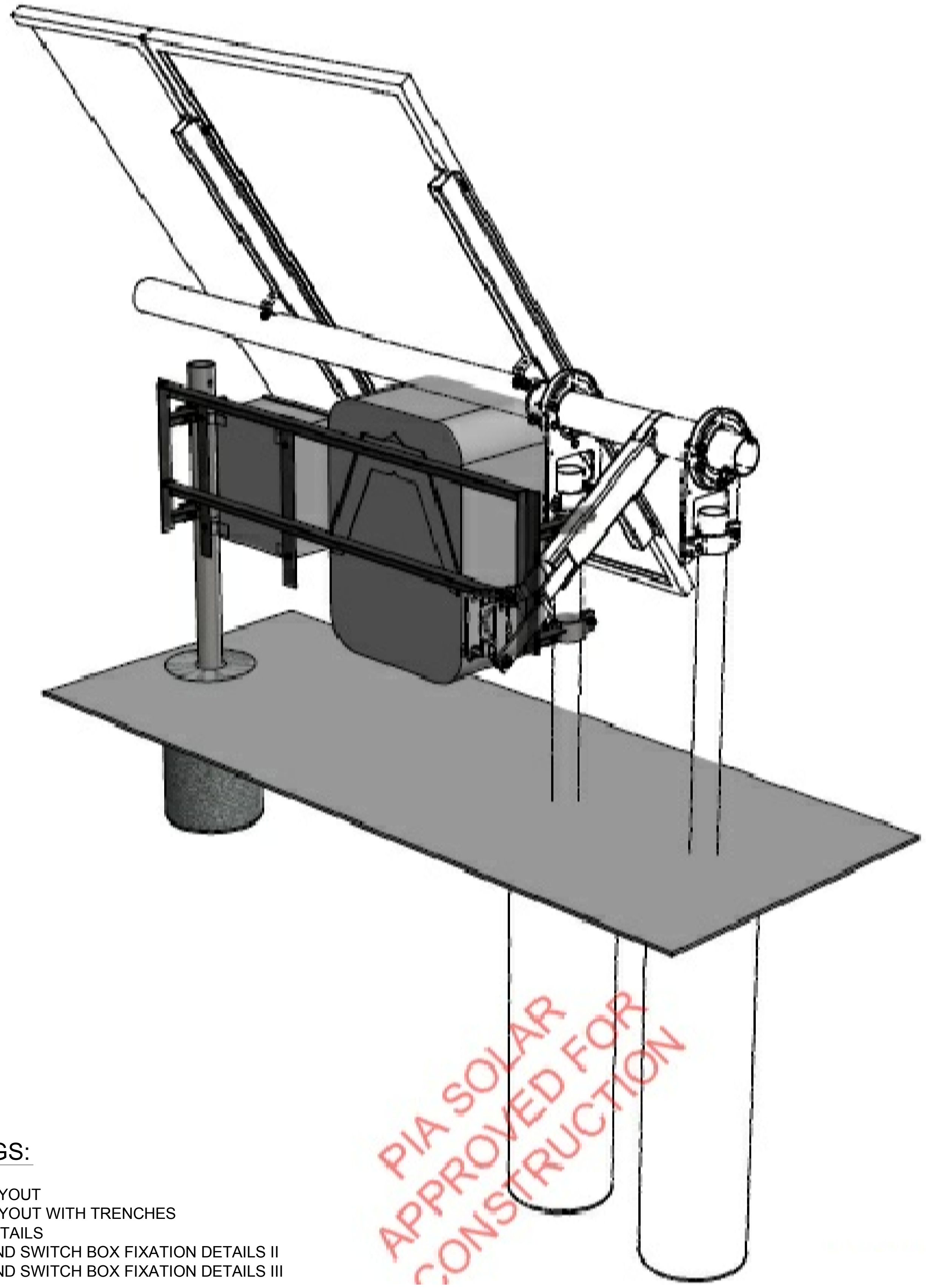
PROJECT
5 MWac ROSH PINAH SOLAR FARM

TITLE
ROSH PINAH PV FARM
PV SINGLE LINE DIAGRAM

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
–	NA001-5RP-D-E006-3	NA001-5RP-D-E006-3	1 of 1	A2





PIA SOLAR
APPROVED FOR
CONSTRUCTION

REFERENCE DRAWINGS:

- NA001-5RP-D-S003 GENERAL LAYOUT
- NA001-5RP-D-S004 GENERAL LAYOUT WITH TRENCHES
- NA001-5RP-D-S005 TRACKER DETAILS
- NA001-5RP-D-S007 INVERTER AND SWITCH BOX FIXATION DETAILS II
- NA001-5RP-D-S008 INVERTER AND SWITCH BOX FIXATION DETAILS III

REV.	DATE	DRAWN	MODIFICATION	APPROVED
1	25/07/17	R. ARRANZ	AS BUILT	–
0	23/03/17	R. ARRANZ	CHANGE TO 180 INVERTERS & UPDATED INFO.	–

AEE POWER

ALOE INVESTMENTS 27(PTY)LTD

5 MWac ROSH PINAH SOLAR FARM

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

TITLE
ROSH PINAH PV FARM
INVERTER AND SWITCH BOX FIXATION DETAILS I

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
–	NA001-5RP-D-S006-1	NA001-5RP-D-S006-1	1 of 1	A3

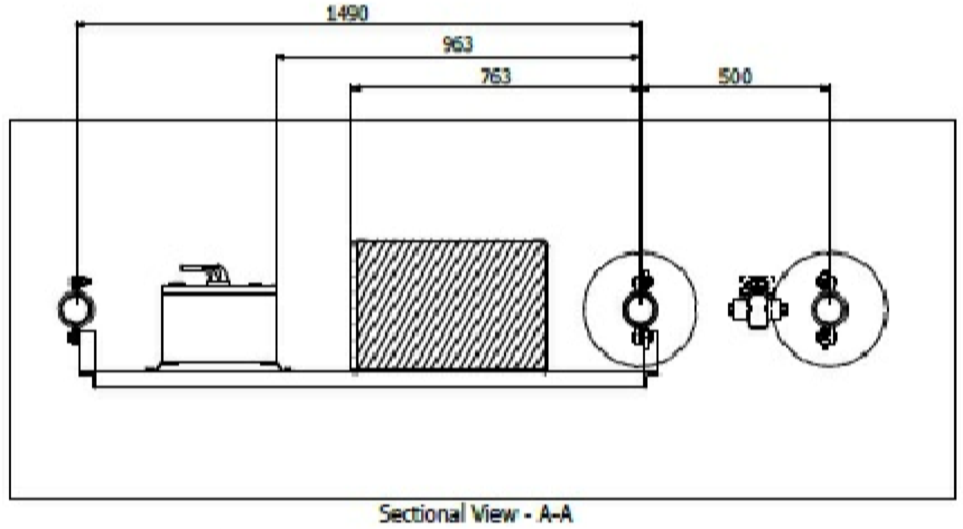
NOTES:

1- DIMENSIONS IN METERS

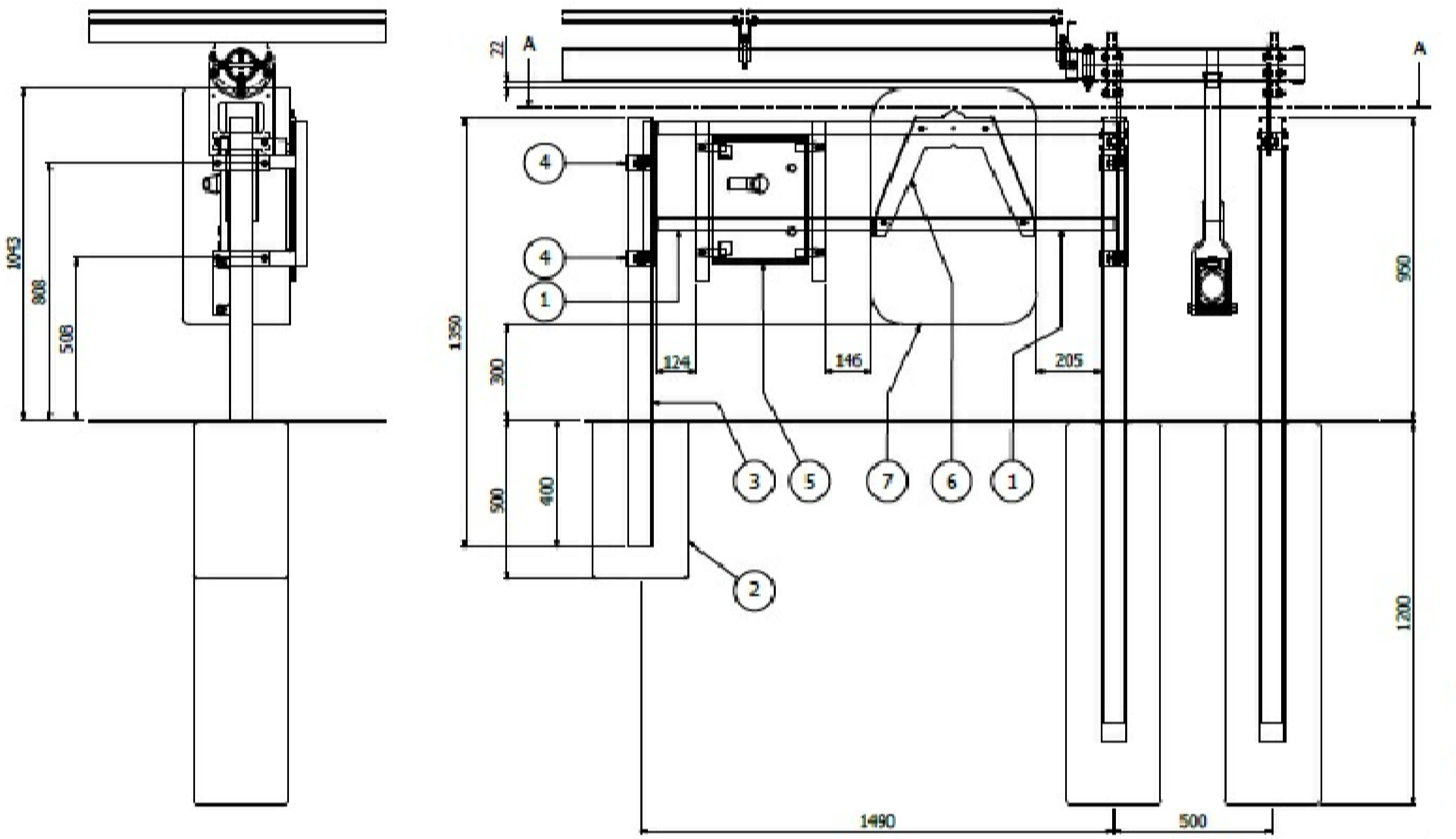
REFERENCE DRAWINGS:

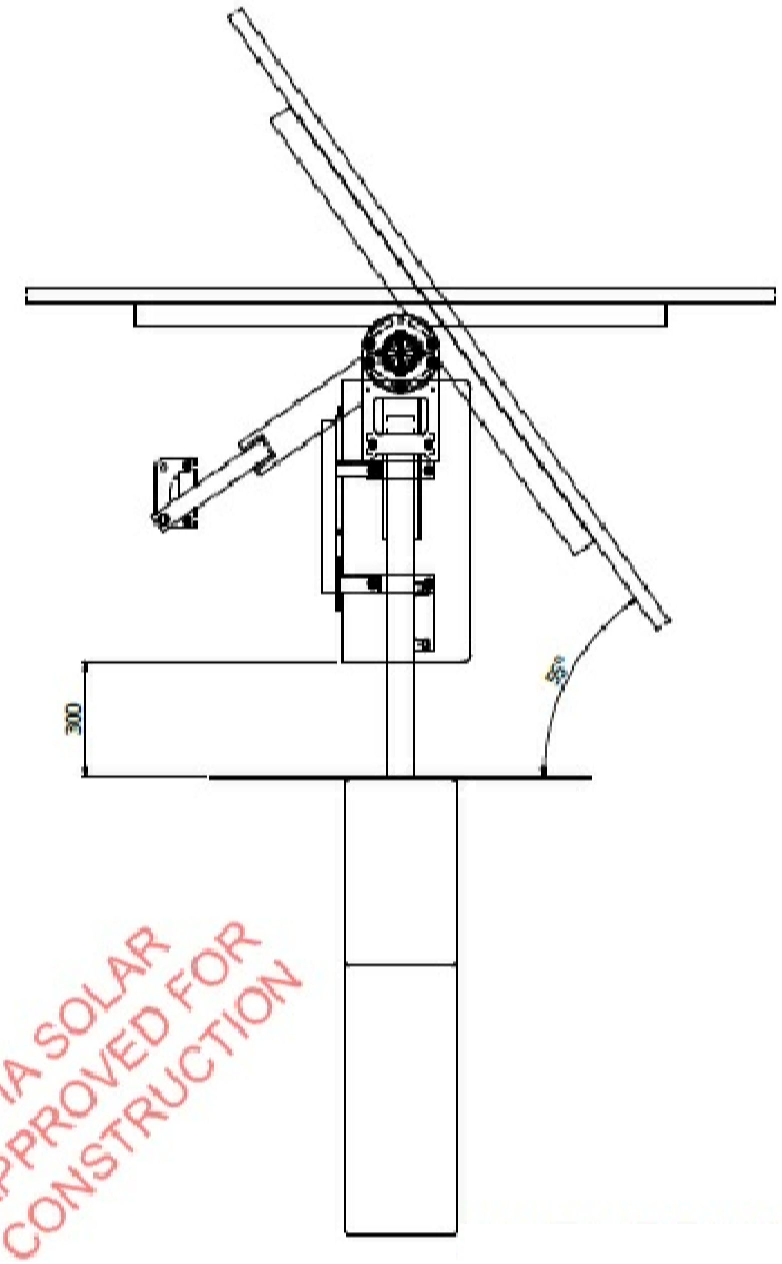
- NA001-5RP-D-S003 GENERAL LAYOUT
- NA001-5RP-D-S004 GENERAL LAYOUT WITH TRENCHES
- NA001-5RP-D-S005 TRACKER DETAILS
- NA001-5RP-D-S007 INVERTER AND SWITCH BOX FIXATION DETAILS II
- NA001-5RP-D-S008 INVERTER AND SWITCH BOX FIXATION DETAILS III

Parts List				
ITEM	QTY	PART NUMBER	REV	DESCRIPTION
1	1	PIA215015	B	Inverter Mounting - Frame - Welded Assembly
2	1	PIA145007	A	Concrete Anchoring for Ø76,20 Post - 500 mm x 300 mm
3	1	PIA142028	A	Anchor Post Ø76,2 mm - 1350 mm x 2,5 mm
4	8	PIA136003	B	Post Brace Clamp Ø76,2mm
5	1	Jucntion Box - Detailed		
6	1	Inverter Backing (A)		
7	1	Inverter - 740x520x300		



Sectional View - A-A





REV.	DATE	DRAWN	MODIFICATION	APPROVED
1	25/07/17	R. ARRANZ	AS BUILT	–
0	23/03/17	R. ARRANZ	CHANGE TO 180 INVERTERS & UPDATED INFO.	–

AEE POWER

ALOE INVESTMENTS 27 (PTY) LTD

5 MWac ROSH PINAH SOLAR FARM

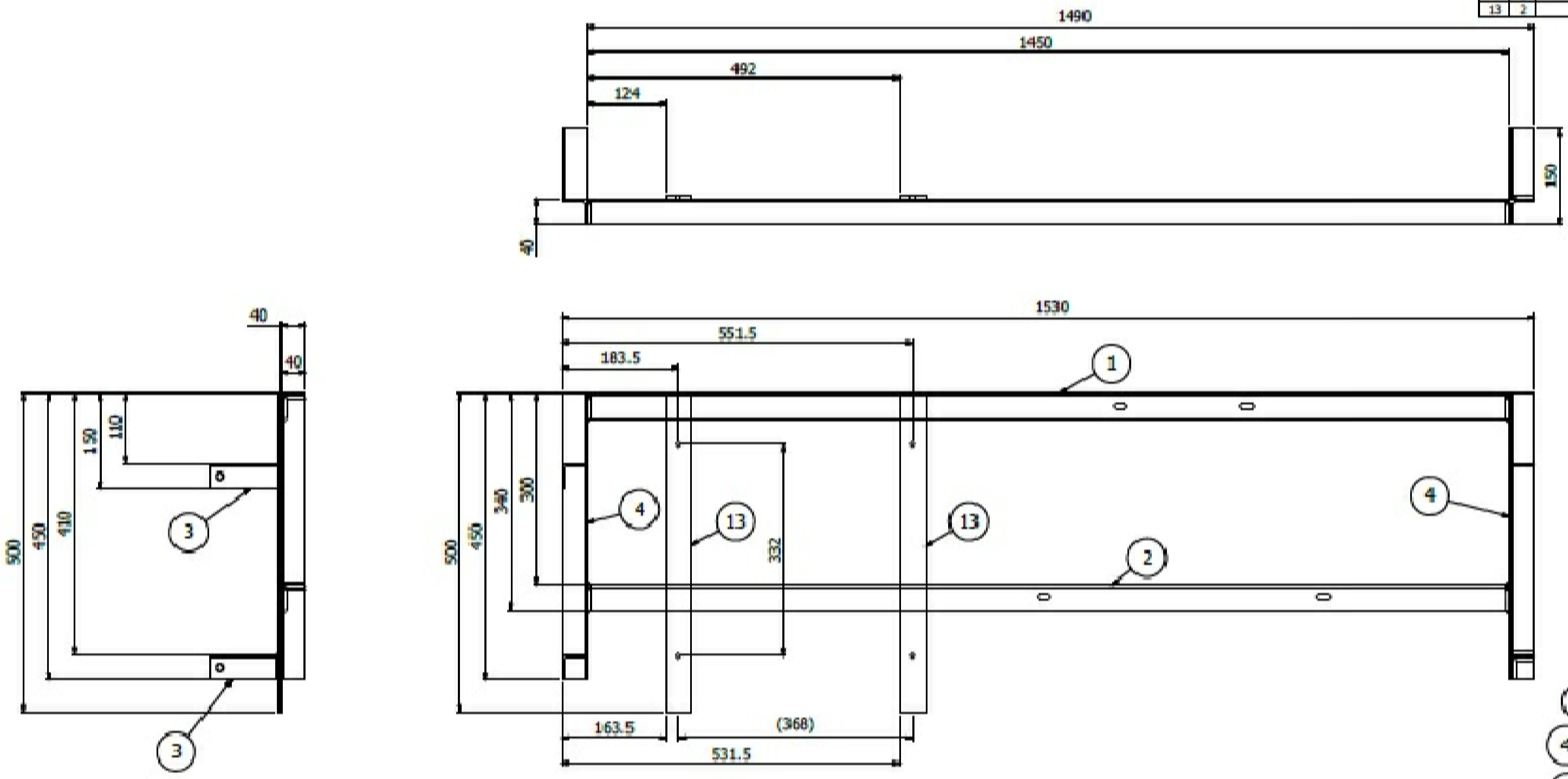
	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

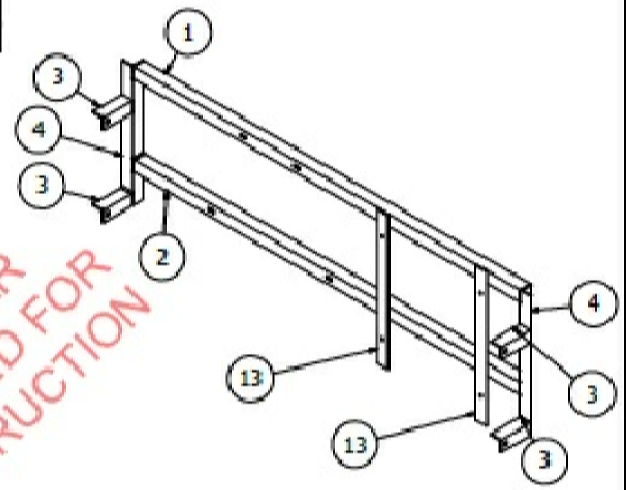
TITLE

ROSH PINAH PV FARM
INVERTER AND SWITCH BOX FIXATION DETAILS II

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
1/20	NA001-5RP-D-S007-1	NA001-5RP-D-S007-1	1 of 1	A3

Parts List					
ITEM	QTY	PART NUMBER	REV	DESCRIPTION	MASS
				OVERALL MASS	10,197 kg
1	1	PIA21-5017	C	Angle Iron 40x40x4x1450 (A)	3,468 kg
2	1	PIA21-5018	C	Angle Iron 40x40x4x1450 (B)	3,468 kg
3	4	PIA21-5019	A	Angle Iron 40x40x4x110 (C)	0,260 kg
4	2	PIA21-5022	A	Angle Iron 40x40x4x450 (E)	1,080 kg
13	2	PIA21-5028	A	Flat Bar 500 mm x 40 mm x 4 mm	0,625 kg





PIA SOLAR
APPROVED FOR
CONSTRUCTION

NOTES:

1- DIMENSIONS IN METERS

REFERENCE DRAWINGS:

- NA001-5RP-D-S003 GENERAL LAYOUT
- NA001-5RP-D-S004 GENERAL LAYOUT WITH TRENCHES
- NA001-5RP-D-S005 TRACKER DETAILS
- NA001-5RP-D-S006 INVERTER AND SWITCH BOX FIXATION DETAILS I
- NA001-5RP-D-S007 INVERTER AND SWITCH BOX FIXATION DETAILS II

REV.	DATE	DRAWN	MODIFICATION	APPROVED
1	25/07/17	R. ARRANZ	AS BUILT	–
0	23/03/17	R. ARRANZ	CHANGE TO 180 INVERTERS & UPDATED INFO.	–

AEE POWER

ALOE INVESTMENTS 27 (PTY) LTD

5 MWac ROSH PINAH SOLAR FARM

	BY	DATE
PREPARED	J.I. VALDES	MARCH 2016
DRAWN	R. ARRANZ	MARCH 2016
CHECKED	J.I. VALDES	MARCH 2016
APPROVED	J.I. VALDES	MARCH 2016

TITLE
ROSH PINAH PV FARM
INVERTER AND SWITCH BOX FIXATION DETAILS III

SCALE	CAD-FILE	DRAWING No.	SHEET No.	
1/10	NA001-5RP-D-S008-1	NA001-5RP-D-S008-1	1 of 1	A3