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Design of Monitoring System for Photovoltaics Performance Verification Plant in Project Las Nubes

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Licentiate in Mechatronics Engineering

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Los miembros de este Tribunal dan fe de que el presente trabajo de graduación ha sido aprobado y cumple con las normas establecidas por la Carrera de Ingeniería Mecatrónica

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Declaro que el presente Proyecto de Graduación ha sido realizado enteramente por mi persona, utilizando y aplicando literatura referente al tema e introduciendo conocimientos propios.

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Cartago, Junio de 2015

Hugo Andrés Sánchez Ortiz

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Resumen (Spanish)

El presente informe describe el proceso de diseño de un sistema de monitoreo para una Planta de Verificación Fotovoltaica que pretende ser implementada en el Proyecto Las Nubes, proyecto desarrollado por el autor de esta tesis con la ayuda de Sustainable Energy Initiative (Iniciativa de Energía Sostenible) y el proyecto Las Nubes, que operan bajo la coordinación de la Facultad de Estudios Ambientales de la Universidad de York, en Toronto Canadá. La zona tropical cuenta con excelentes condiciones para la utilización de la energía solar fotovoltaica. Sin embargo, toda la información técnica dada por los fabricantes es obtenida bajo pruebas de laboratorio, bajo condiciones ideales. El verdadero comportamiento de un módulo fotovoltaico puede diferir mucho de este comportamiento previsto, y para El Trópico, se desconoce dicho comportamiento. Esta información es de mucha utilidad al usuario final para poder estimar el tiempo de retorno de la inversión para los distintos módulos fotovoltaicos. Por esta razón, fue desarrollado un sistema de monitoreo que será implementado en esta clase de estudios, de acuerdo a lo establecido por las normas IEC 61724 y IEC 61853. El sistema permite recolectar información sobre la salida de potencia del módulo fotovoltaico y envía la información a un equipo de cómputo, para realizar análisis más detallado.

El entregable final es un prototipo funcional que servirá para realizar futuros estudios. Y en un trabajo adicional se diseñó una estructura de montaje para la Planta de Verificación Fotovoltaica.

Palabras clave: Mediciones de campo, rendimiento fotovoltaico, fotovoltaico, energía solar.

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Abstract

The present report describes the design of a monitoring system for the Photovoltaics Performance Verification that will implemented in Project Las Nubes, developed by the author of this thesis within the Sustainable Energy Initiative and Project Las Nubes inside the Faculty of Environmental Studies of York University based in Toronto, Canada. Tropical zone has a good conditions for the implementation of photovoltaic energy. However, all the information provided by the manufacturer is obtained under ideals conditions. But the final energy yield of a photovoltaic module has a different behavior under real conditions and the actual performance of photovoltaic cells is unknown at tropical latitudes. This information really meets the requirements of the end user who wants to estimate the pay-back time of his investment for different module types. For this reason was development a monitoring system that will be implemented in this kind of studies following the standards IEC 61724 and IEC 61853. The hardware can collect the information of the output power and the environmental conditions of the PV module and send the information to the computer for future analysis. The final deliverable is a testing model that is going to be used for further studies. An additional work will be developed designing and a preliminary mounting structure for the Performance Verification Plant.

Keywords- Outdoor Measurements, Performance, Photovoltaics, Solar Energy.

Dedication

To Marcelino Sánchez Tencio and María de la Cruz Ortiz Castillo, the first engineers that I knew, who planning, designed and implemented a great project, our family.

To Pablo and Randall, I hope always be a good example for you. I also expect great things from you. Dream, the limit is not in the sky

//

A Marcelino Sánchez Tencio y María de la Cruz Ortiz Castillo, los primeros ingenieros que he conocido. Quienes planearon, diseñaron e implementan un grandioso proyecto, nuestra familia.

A Pablo y Randall, espero siempre servirles de ejemplo. Espero también grandes cosas de ustedes. Sueñen, el límite no está en el cielo.

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Thanks to all my friends, who were my right hand in this years in the university and always will be. For all the study´s nights, and not study nights. Always I take you in my heart.

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Thanks to Eng. Carlos Meza Benavides, PhD; for help me like tutor in the development of this project. And Eng. Sergio Morales and Eng. Javier Perez, who were the reviewers of the present job.

And finally, thanks God for let me write this lines and guide me in this way.

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Chapter 1 Introduction

This chapter aims to give a general overview of the project, its context, the problem and how it is going to be addressed to the main objectives.

1.1. Context of the project

During the last years, the energy sector has been influenced by new trends in its search for alternative solutions in generation sources. [1] This search tries to improve the environmental impact generated by this activity. Solar energy is one of those energy sources has grown exponentially in recent years, as it is shown in Figure 1-1. And this is the energy source that this project will be focus, with emphasis in photovoltaics energy.

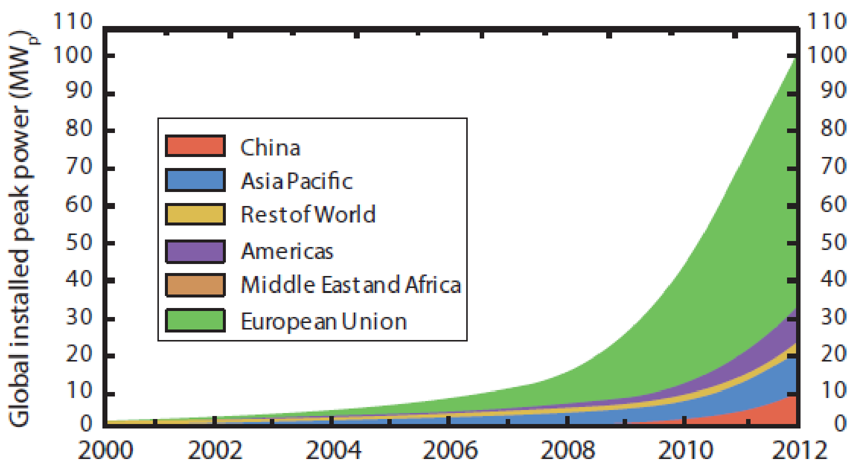


Figure 1-1. The global installed photovoltaic capacity *[2]*

Costa Rica is not an exception in this upward growth. The most recent estimation, as a result of the "*Plan Piloto de Generación Distribuida ICE*", indicates the capacity in Costa Rica approaches to 11 MW [3]. In the next few years, solar energy has a lot of opportunities for further increase, but depends on the approval of regulations [4]. At present, the most important regulation in process is *POASEN*. [5]. To do a more professional work in this area, it is necessary to create methods for generating a reliable information about the real behavior of photovoltaics (forward call like PV) modules under conditions in Costa Rica.

To determine the PV performance, it is necessary to complement the datasheet information obtained with the statement of electrical performance under Standard Test Conditions (STC) [6]. STC determining V-I curve and electrical output characteristics under the next conditions, which will be explained in next section (Irradiance 1000 W/m2, Air Mass 1.5 global and operation temperature of 25°C). This test provides the information that is found on the manufacturer datasheets. The main problem of these measurements is that none provided real information about the real energy yield of a PV module, because the data is obtained in simulation laboratories. In addition, a PV module has no-lineal characteristics that depends, in no-lineal form, on environmental variables like temperature and irradiation. These variables in real conditions are not constant, as they are in the STC tests. [7].

A real outdoor measurement meets the requirements of the end user and helps them to estimate the payback time of this investment. Also, helps to know which technology has potentially the highest energy yield (kW/Wp), based in standard IEC 61724 and IEC 61853, and predicts for how many years the module will produce energy.

For these reasons, the Faculty of Environmental Studies of York University in Toronto Canada, under the coordination of Sustainable Energy Initiative [8] and Project Las Nubes [9] want to development a Photovoltaics Performance Verification Plant (PVPV) at the location of conservation area Las Nubes, in Santa Elena de Peréz Zeledón, Costa Rica. The location of the project is illustrated in figure 1-2.

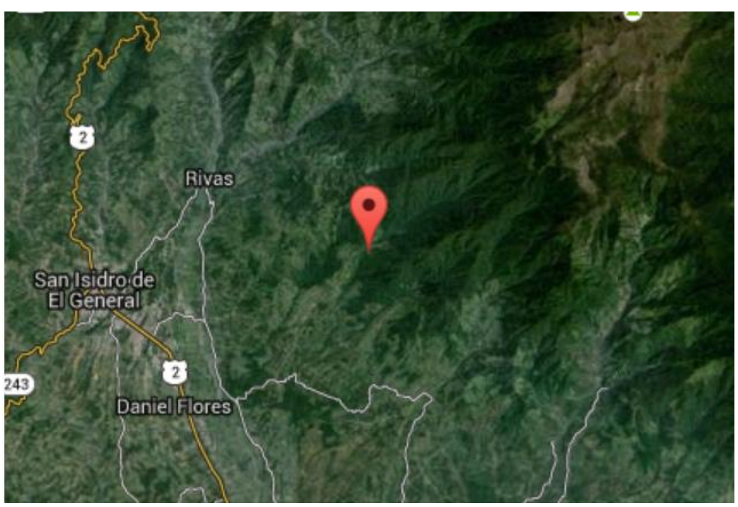


Figure 1-2 Location of Project Las Nubes *[9]*

This proposal is inspired at the PVPV development at Kortright Center of Conservation located at Vaughan, Ontario Canada, a 12 km from the university [10] [11]. This project is under the program of *Sustainable Technologies Evaluation Program*. Since 2012, PVPV works, among many other functions, in characterizing the behavior of 20 PV modules, which are available in the local market.

It is also important to mention that the literature has a lot of sources about this kind of the PV Performance, but all the data are located in latitudes away from the Tropical Zone(23°N-23°S) and thus from Costa Rica. Costa Rica is located in a special zone on the Earth, where the Sun irradiation arrives perpendicular to the surface. In addition, Costa Rica has a very high irradiation ranging from 1700 to 2100 W/m^2/year and a lot of opportunities to harness the solar resource. [12]

To collect this data some system of monitoring is necessary. For this reason York University wants to development this system. There is no research background in the development of this monitoring system at York University. And this is the main topic of the present thesis.

The project of this thesis took place in the Sustainable Energy Initiative, located in York University, Toronto Canada. Under the supervision of Jose Etcheverry PhD and Felipe Montoya Greenback PhD with the support of *Lassonde School of Engineering* located at the same university.

1.2. Problem Synthesis

It is required to develop a monitoring system for the Performance Verification Photovoltaics Plant in project Las Nubes.

1.3. Solution Approach

The solution is intended to be found with the use of concurrent design methodology [13]. Figure 1.2 illustrates this concept.

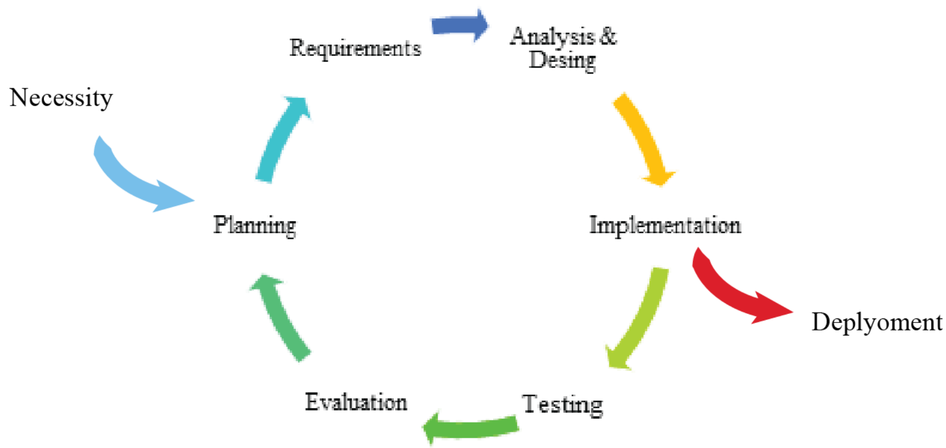


Figure 1-3 Iterative method in concurrent design

For the implementation, it is important to understand that the final product can always be improved until it meets all the requirements and needs. In this case, the problem to solve does not a preliminary background or prototype in the university, which involves developing the methodology of the searching solution from the beginning.

According to the requirements that, will be analyzed in the next section, it is necessary to solve little problems and then join all the parts into a general solution following the process known as *bottom up.* A general solution has been presented in Figure 1-4.

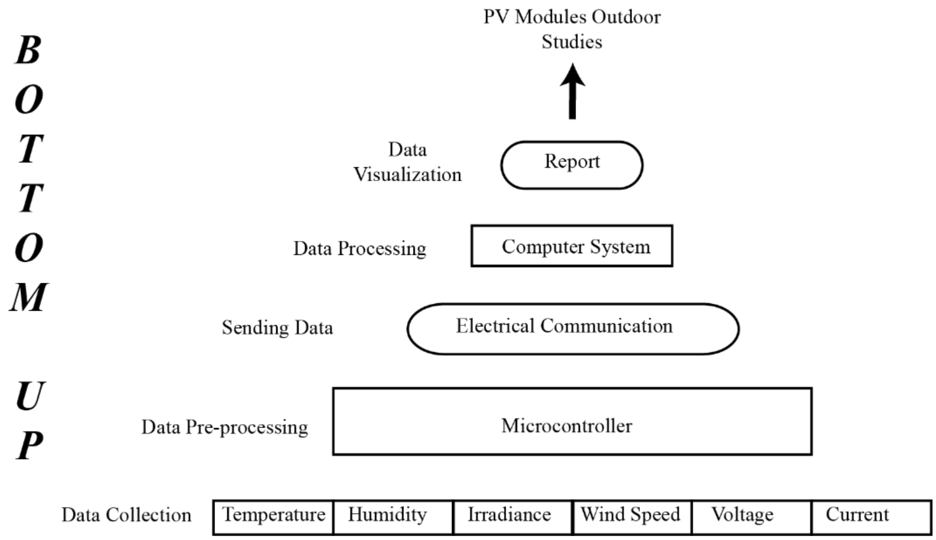


Figure 1-4. Overview of the solution

According to the last figure, some sub-systems to be designed are:

Data Collection: The basis of the PV outdoor measurements is the acquisition of data appropriate for further processing. This process involves the selection of the sensor according to the nature and need to be sensed value.

Data Pre-processing: Later data acquisition process is necessary to order the information received and prepare that for the next stage. In this step, the most important point is the operation of a microcontroller.

Sending Data: Since measurements are made outside, where very robust equipment cannot be placed, it is recommend to send the information to a data center, where the information can be process and stored.

Computer System: In this point, the solution need to tabulate the information. It is important to process the information according to the standards and desired results.

Data Visualization: Finally, the visualization of the process data is the key to further assess the performance verification of the PV modules.

1.4. Objectives

1.4.1. General Objective

Design a monitoring system for Photovoltaics Performance Verification Plant, to be installed in project Las Nubes, which can obtain the necessary parameters for the evaluation of PV modules.

1.4.2. Specific Objectives

a) Design an electronic system for acquisition, processing and display data needed to study the performance of solar panels deployed in a Photovoltaics Performance Verification Plant.
b) Assembly the subsystem in a testing model, for field testing.
c) Design the mechanical structure for mounting the solar panels to be measured.
d) Formulate a methodology for the implementation of the system in a Photovoltaics Performance Verification Plant at Las Nubes.

Chapter 2 Literature Review

This chapter aims to show all the theoretical implications of this project also it serves as a starting point for the conception of the solution. The fundamentals of PV modules are introduced with the objective to having a better understanding of the characterization process and also, the state of art in outdoor measurements for a PV performance verification plant.

2.1 General Aspects about Solar Photovoltaic Energy

Solar Photovoltaics Energy has a long history in the development of its technology, since the discovery of the photoelectric effect by Alexandre Becquerel in 1839. For this project, it is necessary to explore the basics of this technology, focused on solar cells and modules, which are the main part of a PV system.

2.1.1 Photovoltaics Fundaments

Photovoltaics (PV) is the technology that generates direct current (DC), electrical power measurement in Watts (W) from semiconductors when they are illuminated by photons [14]. Solar cells are formed by semiconductors materials which have typical characteristics in the electron structure in the valence band. When the cell is excited by light, in this case from the Sun, the energy exceeds a bandgap energy and some electrons are free to move to the conduction band. In this process, the solar cells produce electricity [2]. Figure 2-1 illustrates the solar cell model.

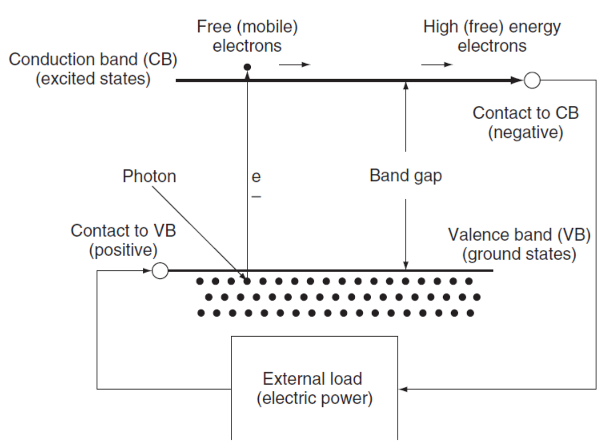


Figure 2-1. Solar cell model *[14]*

Solar cells are the basic units on PV systems. A set of solar cells connected is called a PV module. A PV module is the best known component of the PV systems. The variety of fabrication technologies is large and has different sizes and electrical values according to the manufacturer strategy and the application required. However it is possible to join up the technologies in three main groups. Each group is categorized according to the materials and junction techniques applied. Also, each group can be located in a historic line based on the time of onset. For more details about each technology, refer to [2] [14] [15]. Figure 2-2 shows a general schematic of this classification.

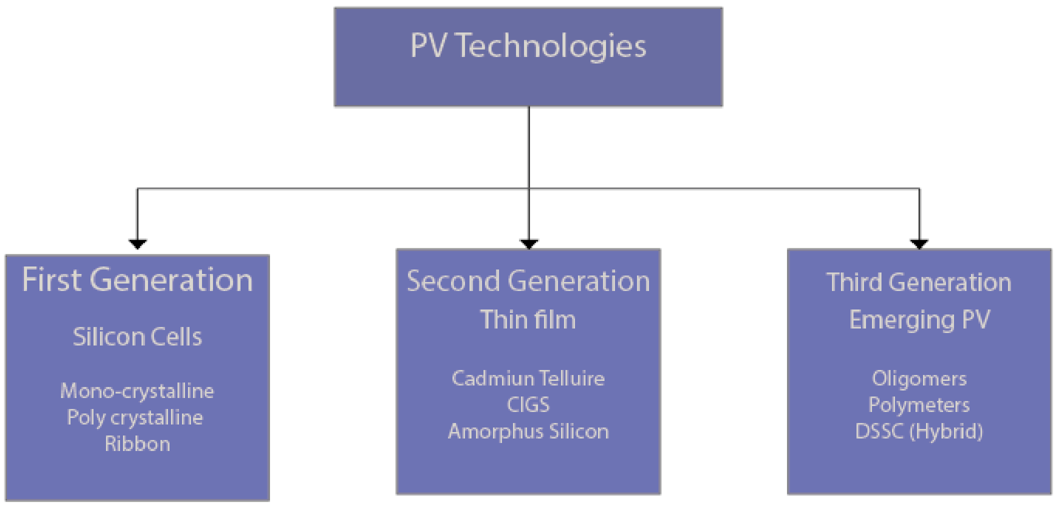


Figure 2-2 PV Technologies

Nevertheless, it is possible to define a general anatomy for a PV module. The PV modules are made by connecting numerous cells in series, parallel or series/parallel configuration [16]. A general description is a model of layers, where traditional started with the *back sheet*, there is the general support of the structure. Later, the PV cell is covered by an *encapsulated sheet.* And finally, all the layers are covered by a *glass layer*, which protect all the materials inside. A good selection of these components is necessary to obtain a good performance of a PV module. Figure 2-3 shows a general PV module anatomy.

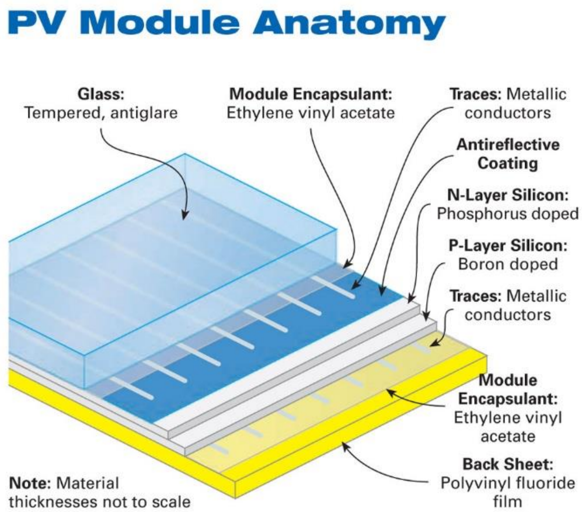


Figure 2-3 A PV module general anatomy *[16]*

2.1.2 Solar Cells Parameters

Solar cells have electrical parameters that allow to describe the performance of the cell operation. Characterization between technologies can be different. [17] However, the following characteristics can be found in all the manufacturer datasheets. It is necessary to explain, the following mathematical expressions are obtained for the ideal model.

Short circuit current density (J_{sc}): The short circuit current (I_{sc}) is the current flowing in the external circuit when the solar cell is a short circuited. This parameter depend of the area of the solar cell. For this reason, is commonly used the term *short circuit current density*, in order to remove the dependence of the area [2]. The short circuit current density depends on the photon flux density incent in the solar cell. Also, the Short Circuit current density is related with the optical properties of the solar cell like absorption and reflection process. J_{sc} can be expressed in the equation (2-1):

$$J_{sc} = qG(L_n + L_p)$$

(2-1)

Where G is the generation rate and L_n and L_p are the electron and hole diffusion lengths respectively. For crystalline silicon solar cells under and AM[1] 1,5 spectrum a maximum possible current above 42,7 mA/cm^2 [18].

Open Circuit Voltage (V_{oc}): The open voltage circuit is the voltage at no current flows through the external circuit. There is the maximum voltage that a solar cell can deliver. The equation (2-2) describes the V_{oc} and it can be found by setting the net current equal to zero:

$$V_{oc} = \frac{kT}{e} \ln\left(\frac{J_{sc}}{J_0} + 1\right)$$

(2-2)

This equation shows that V_{oc} depends of the photo-generated current density and the light generated current. The V_{oc} for commercial silicon high performance cells exceeds the 700 mV under the standard of AM 1.5. [18]. But normally this value is around 600mV.

Fill factor (FF): This parameter indicates the maximum power of solar cells. There is the ratio between the maximum power from the solar cell and the product of the *Open circuit voltage* and *short circuit current density*. Equation (2-3) illustrates this relationship:

$$FF = \frac{J_{mp}V_{mp}}{J_{sc}V_{oc}}$$

(2-3)

It is necessary to observe that product $J_{mp}V_{mp}$ is the maximum power of the solar cell (P_{max}). Figure 2-4 shows a typical electrical curve for PV panels. In this curve is possible to see that the relation between I_{sc} and the V_{oc} has a decrease in the maximum power point (*Mpp*) because the values of Isc and V_{oc} are not obtained in real operation with electrical load. For this result, at *Mpp* it is possible to derivate to values I_{mpp} and V_{mpp} which are the *maximum power point current* and *voltage* respectively. The most common control strategies for a PV system is to try to keep the operation of the PV panel at this point. [19]

[1] AM: Air Mass

Fill factor equation demonstrates the importance of the ideality factor. There is the measure of the junction quality and the type of recombination in a solar cell. Assuming that the solar cell behaves as an ideal diode, equation (2-3) can be re-written as (2-4):

$$FF = \frac{V_{oc} - \ln(V_{oc} + 0{,}72)}{V_{oc} + 1}$$

(2-4)

With these parameters, it is possible to obtain the characteristic curve which describes the behavior of solar cells. In this curve, it is possible to analyses the different losses and the performance of the solar cell depending on the conditions which are obtained [20].Figure 2-4 shows a typical I-V curve.

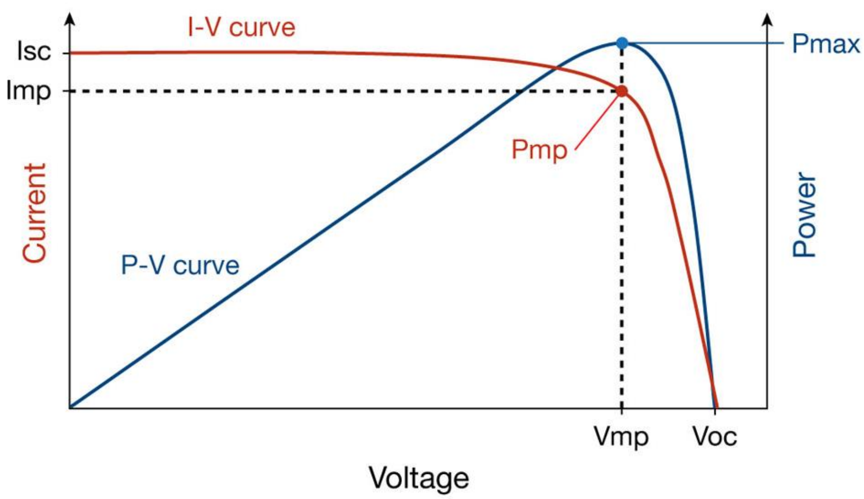


Figure 2-4 Characteristic Curve PV cell *[21]*

Conversion efficiency (η): This is also an important parameter in solar cells. Unlike the fill factor, this parameter compares the ratio between the maximal general power and the incident power. For a standard of AM 1,5 the irradiance value is P_{in} = 1000 W/m^2. The equation (2-5) expresses this parameter, and it is common to multiply per 100 to express it in a percentage.

$$\eta = \frac{P_{max}}{P_{in}} = \frac{J_{mp}V_{mp}}{P_{in}} = \frac{J_{sc}V_{oc}FF}{P_{in}}$$

(2-5)

A comparison of the conversion efficiency is performed, regardless of the production technology [7]. Most of the technologies efficiency lies in the range of 15% & 20%, but most recent developments reach up to 45% as shown in figure 2-5.

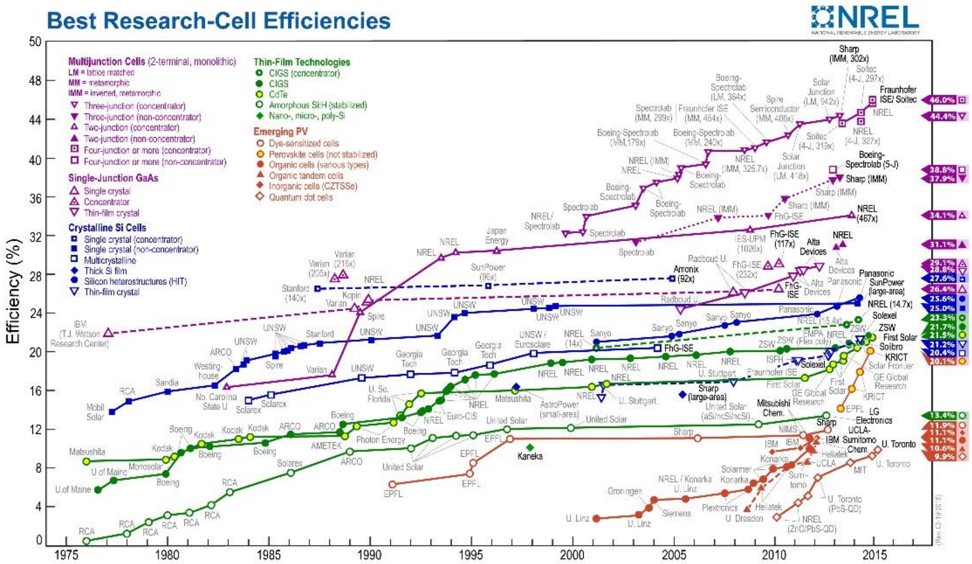


Figure 2-5. Conversion Efficiency in different PV technologies *[22]*

2.1.3 External variables involved in PV generation

Like was discussed in the last section, PV technologies have a non-linear behavior and this behaviour depends nonlinearly of environmental variables and this will be discussed in this section. Also each photovoltaic technology responds in a different way under these conditions [14, 17, 23]. On this point, it is not possible to ensure that one specific PV module has the same performance always.

Spectral Response (SR (λ)): the short current circuit in a PV cell is directly proportional to the irradiation, although, all the irradiation is not constant and all the wavelengths contribute to the short circuit current. In this way, this parameter can be defined like (2-6):

$$I_{sc} = \int_{\lambda} SR_{ext}(\lambda) f(\lambda) d\lambda$$

(2-6)

The internal spectral response in a PV cell gives an indication of which sources of recombination are affecting the cell performance. [14]. Figure 2-6 illustrates how the spectral response it is not linear model and how it changes according to different wavelengths.

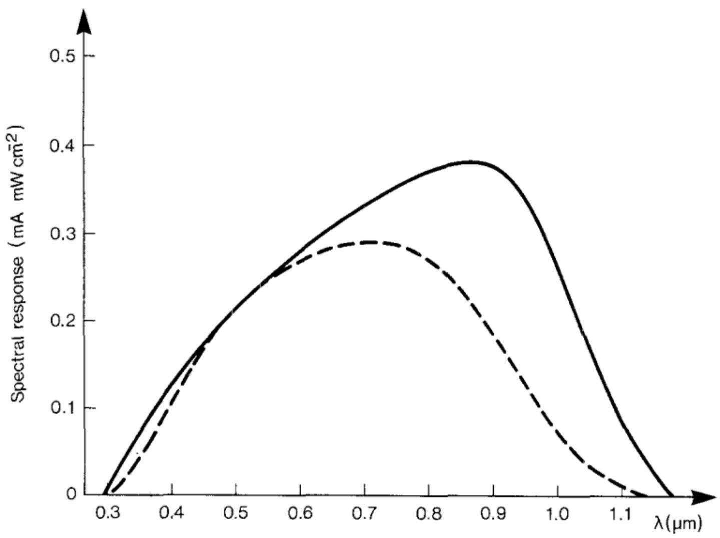


Figure 2-6 Spectral Response of the silicon solar cell before and after irradiation *[24]*

Also figure 2-6 shows two important things. The first one is how the spectral response changes according to the different wavelengths present in line, and this relation is not linear. The second one that is an important thing to see is the degradation in the solar cells. This effect is important in the long-term. The dashed line is the curve after irradiation simulation and indicates how a simple silicon solar cell losses the capacity to generate power. This phenomena is explained with more detail on [2, 14, 17, 24, 25]

Temperature: in the past section, it was possible to see how the temperature is involved on the PV cell parameters. I_{sc} and V_{oc} are direct related with temperature in the module, as were seen in equations (2-2), (2-3) and derived expressions. But there is also an equally large number of correlations expressing the temperature dependence of the PV electrical efficiency (η) [26]. For a *current short circuit*, an increase of the temperature represents an increase of this value. On the other hand, an increase of temperature represents a decrease in *open circuit voltage* and in *fill factor* too. This effect can be describe mathematically as equation (2-7).

$$\eta = \eta_{T_{ref}}[1 - \beta_{ref}(T_c - T_{ref} + \gamma \log G_T)$$

(2-7)

In which $\eta_{T_{ref}}$ is the module efficiency at the reference temperature, T_{ref} and standard radiation flux (1000 W/m^2); β_{ref} is the temperature coefficient and γ is the solar radiation coefficient. These values are given by the manufacturer.

Another important value of PV cells is the *Nominal Operating Cell Temperature (NOCT)*, which represents the temperature of the module in more real conditions (irradiance: 800 W/m^2, Air Temperature: 20°C, Wind velocity: 1 m/s). This value is obtained as the temperature reached by open circuit cells under the last conditions [2].

Also, this effect can be explained in a thermodynamic point of view [2]. In this point of view, the solar cell is modelling like a heat engine and with this model it is possible to obtain a good approximation for losses by thermal dissipation. But in this analysis, the I_{sc} and V_{oc} can be written as a function of the temperature in equation (2-8).

$$I_{sc} = \frac{G_T}{G_{T0}} I_{sc_0}[1 + \alpha(T_c - T_0)]$$

$$V_{oc} = V_{OC_0}[1 + \beta(G_{T_0})(T_c - T_0)]\left[1 + \delta(T_c)\ln\left(\frac{G_T}{G_{T_0}}\right)\right]$$

(2-8)

It is necessary to mention that the mounting system has an important role in real applications to try to minimize this effect. In this case, the designer has to consider this losses for a better performance in the real applications [26, 27].

In this way, according the *National Renewable Energy Laboratories (NREL)* of United States of America [28], it is established a set of rules for the coefficient correction of Performance Ratio. The Performance ratio will be explain in next sections. The coefficient correction of the Performance Ratio is given by equation

$$Y_{fcorr} = \frac{E}{\sum[P_0 \left(\frac{G_{POA_i}}{G_{STC}}\right)\left(1 - \frac{\partial}{100}\left(T_{cell\_typ\_avg} - T_{cell\_i}\right)\right)]}$$

(2-9)

Where:

The summations are over a defined period of time (days, weeks, months, years)

Y_{fcorr} = corrected performance ratio (unitless)

EN = measured electrical generation (kW)

P_0= summation of installed modules power rating from flash test data (kW)

GPOA = measured plane of array (POA) irradiance (kW/m2)

i = a given point in time

GSTC = irradiance at standard test conditions (STC) (1,000 W/m2)

Tcell = cell temperature computed from measured meteorological data (°C)

Tcell_typ_avg = average cell temperature computed from one year of weather data using the project weather file (°C)

δ = temperature coefficient for power (%/°C, negative in sign) that corresponds to the installed modules.

Equation (2-9) is very useful in the analysis of the results of test the PV panels. This coefficient can give a real idea of the behavior of the PV panel production. In this line, it is important to take account in all the test that can be doing to check the performance. These performance measurements and their principal characteristics are shown in the next section.

2.2 Performance Measures for Photovoltaics Modules

For the causes than affect the operation of PV modules is necessary to determine the real efficiency of PV modules. Because this parameter is very important to make decisions in common applications, taking into account the balance between the economic investment and how much energy can be produced by a system. Also, due to the large number of existing technologies it is a good way to characterize all the technologies under the same analysis.

In this section, the different forms to measure the parameters of PV modules will be discussed. Basically, it can be divided into two main branches: indoor and outdoor measures. It is important to mention, that the variety of the measure depends of the nature of the study desired.

2.2.1 Standard Test Conditions (STC)

Standard Test Conditions (STC) is a first approximation to the performance of a PV module. This is the most common test in the PV market. All the commercial PV panels have to be this standard with the results shown in the datasheet and the tag behind the modules by the manufacturer [29]

STC approaches the PV module performance to normal conditions under laboratory simulator, which can produce similar environmental conditions. In this case, the operating temperature is 25°C and the illumination is provided in a short flash equivalent to 1 sun intensity at 1000 W/m^2, and an air mass of 1,5 is assumed. Under these conditions, one proceeds to measure the current-voltage characteristic of an electrical load. Figure 2-7 shows a STC simulator designed by Spired Corporation.

Figure 2-7 Spi-Sun Simulator Photovoltaic Module Testing *[30]*

STC is developed according to the standard *IEC 60904-1: Photovoltaics devices-Part 1: Measurements of photovoltaic current-voltage characteristics for current-voltage characterization*, *IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules-Design qualification and type approval* and *IEC 61646: Thin-film terrestrial photovoltaic (PV) modules* for a module performance at STC and other standards if a more detailed test is required. Also, the majority of the reports are prepared according with the standard *ISO 17025*.

Even though this test is world-renowned, and all the manufacturers provide this information, STC is a simulation under ideal conditions. Real conditions could be different for this conditions and these will be reflected in indicators like *effective sun hours.* [23, 29]. For this reason recent standards find to describe in best way the true performance of the PV modules under real conditions. In addition, these check points change according to the geographical location of the project. The next part presents this kind of testing.

2.2.2 Normal Operation Cell Temperature (NOCT) Test

As was mentioned in the previous section, the STC represented the ideal case. But in the real operation, the PV modules operate at higher temperatures and with less irradiation [31]. The

NOTC is designed for finding the expected operating temperature of the PV module under more real conditions. For this test, the following parameters are used: Irradiance on cell surface: 800 W/m^2, Air Temperature: 20°C, Wind Velocity: 1 m/s and mounting: open back side. Also, the manufacturers of PV modules provide this information in the datasheet of the product.

As was discussed in section 2.1.3, it is possible to note a remarkable difference between the performance of a PV module under NOTC conditions and STC. This difference is illustrated in Figure 2-8.

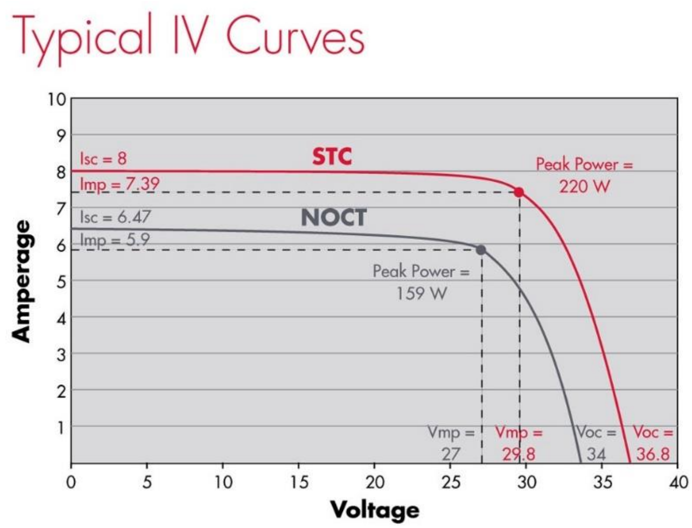


Figure 2-8. Comparison between STC and NOTC PV module Performance *[32]*

The best performance of PV panel is better for values low values of NOCT. A lower NOCT of a PV module will be a better response to the different values of irradiation. Otherwise with larger value [33].The best module operation point at a NOTC of 33°C, the worst at 57°C and the typical module at 48°C respectively [18]. An approximate mathematical expression for calculating the cell temperature in all moments is given by (2-10).

$$T_{cell} = T_{air} + \frac{NOTC - 20}{800} * G_M$$

(2-10)

Where G_m is the solar irradiance and T_{air} is the air temperature.

It is important to mention the role that the racking system can have help on the efficiency of a PV system. For example, in a roof integrated mounting system, a rear surface work infinite rear thermal resistance because it cannot exchange heating with the environment. For this reason, another similar value called *Installed Nominal Operating Conditions Temperature (INOCT)* is defined, and includes the effect of the mounting configuration. This value is determined experimentally and the results can be found in the literature [2, 18, 29].

2.2.3 Outdoor evaluated performance parameters

Although the tests mentioned above are internationally recognized and used, they may not be sufficient for a true characterization of a PV module. The real energy yield is difficult to predict just with datasheet declarations, which are obtained in laboratory tests. In summary, the datasheet declaration includes open circuit voltage V_{oc}, short circuit current I_{sc}, MPP voltage V_{mpp}, MPP current I_{mpp}, maximum power P_{mpp}, efficiency η and temperature coefficients [23].

In fact, none of this information really meets the requirements for the real behavior of a PV system in some specifically geographical location. This real behavior it is useful for the end user in order to determine some economics aspects about the implementation of one of these systems.

For this reason, there is another kind of measurement, which has a real performance analysis of a PV module in the field. There are called outdoor measurements. This test evaluates three principal parameters: the *final energy yield*, the *reference yield* and the *performance ratio* (*PR*). The standard *IEC 61724* [34] defines these three parameters. A detailed definition is found in [35] and these definitions are presented in the following lines.

Final energy yield (Y_f): is the net energy output E divided by the nameplate d.c power P_0 of the installed PV array. It represents the number of hours that the PV array would need to operate at its rated power to provide the same energy. The units are hours or kWh/kW, with the latter preferred by the authors because it describes the quantities used to derive this parameter. For this reason, the energy yield is used for comparing the energy produced for a different sizes. The final energy yield is given by equation (2-11)

$$Y_f = \frac{E}{P_0}$$

(2-11)

Reference yield (Y_r): is the total in plane irradiance H divided by the PV´s reference irradiance G under STC (1000W/m^2). This reference yield defines the solar radiation resource for the PV system. It is a function of the location, orientation of the array and time-time weather variability. The equation (2-12) describes this parameter and its unit is hours.

$$Y_r = \frac{H}{G}$$

(2-12)

Performance Ratio (PR): is defined as the ratio between Yf and Yr, as expressed in (2-13). This parameter is used as an useful way to quantify the overall effect of losses on the rated output due to PV module temperature, spectrum, module mismatch and other loses such as optical reflection, soiling and downtime failures.

$$PR = \frac{Y_f}{Y_r}$$

(2-13)

And alternative way to obtain the performance ratio is defined with a new parameter, the *outdoor efficiency* ($\eta_{outdoor}$) [35] that is defined by equation (2-13).

$$\eta_{outdoor} = \frac{E}{H * A}$$

(2-13)

Where E is the energy output and H is the total plane irradiation (kW/m^2) and A (m^2) is the area of the PV array. With this expression it is possible to calculate the performance ratio given by the equation:

$$PR = \frac{E}{H * A * \eta_{STC}}$$

(2-14)

η_{STC} is the STC efficiency present in datasheet.

Performance ratio values are typically reported on a monthly or yearly basis. Smaller intervals, such as weekly or daily, may be useful for identifying some problems related with components failures. Yearly values may indicate the degradation of the PV module, represented by loses in energy yield in a more efficient way that accelerated ageing test. [36]

The International Electrotechnical Commission (IEC), in the Technical Committee 82 Working Group 2 has been working around fifteen years to create an appropriate power and energy standard (IEC 61853). This standard is composed by four parts describe by [37].

IEC 61853-1Irradiance and temperature performance measurements and power rating, which describes requirements of evaluating PV module performance in term of power (watts) rating over a range of irradiances and temperatures.

IEC 61853-2 Spectral response, incidence angle and module operating temperature measurements, which describes test procedures for measuring the effect of varying angle of incidence and sunlight spectra as well as the estimation of module temperature from irradiance, ambient temperature and wind speed.

IEC 61853-3 Energy rating of PV modules, which describes the calculations for module energy (watts-hours) ratings.

IEC 61853-4 Standard days, which describes the standard time periods and weather conditions that can be used for the energy rating calculations.

2.2.4 Photovoltaic Performance Verification Program (PVPV)

Now, this section will discussed the job realized by the research group in Ontario, Canada, called *The Sustainable Technologies Evaluation Program (STEP)* at *Toronto and Region Conservation Authority (TRCA).* This program was developed to provide the data and analytical tools needed to support broader implementation of sustainable technologies and practices [11]. Its mains objectives are:

- Monitor and evaluate clean water, air and energy technologies;
- Assess barriers and opportunities to implementing technologies;
- Develop tools, guidelines and policies; and
- Promote broader use of effective technologies through research, education and advocacy.

STEP has a special program called the *Photovoltaic Performance Verification Program (PVPV)* that is the premier photovoltaic testing facility and showcase for Ontario clean energy manufacturing, technology and innovation. [38]. *PVPV* works on analyze the performance of Ontario-made PV modules, especially in domestic content modules allowing the user to compare the different technologies, thus helping out to make decisions. Figure 2-9 illustrates the installation of this program.

Figure 2-9 Installation of PVPV at Kortright Center.

2.3 Conclusions

Photovoltaics energy has a large market with a diversity of different technologies available. For this reason, the characterization of these modules is important in the global market, helping to make decisions in economic issues. The PV technologies can be divided into three principal branches according to the material and fabrication processes.

Independent of the PV technology, it is possible to detail the behavior through simple parameters. The *short circuit current* is the current in the electrical load when the PV cell is short circuited and is the maximum current obtained by this cell. The *open circuit voltage* is the voltage in the solar cell when the electrical load is not flow current and this value is the maximum voltage that the panel can give. But these values are not found together in real conditions and for this reason, it is possible to find two new values of current and voltage located at MPP from the I-V curve of the solar cell. With these values the ratio of generation for a PV cell can be defined, called *fill factor.* Another important parameter is the conversion efficiency, which takes into account the irradiation of the cell and the power generated.

To measure this parameter, there are a lot of methodologies. The most famous is called the *STC* and it is the test from which the manufacturers obtain the information printed on datasheets. Due to the environmental conditions on this test it is not possible to ensure the information is for real operating conditions. Because of this, another test *(NOTC)* has also been developed to bring more detailed information of the performance of PV Panels. However, these tests are taken in a special laboratories.

The outdoor measurements give a real value of the behavior of PV modules under standards *IEC 61724* and *IEC 61853.* Three parameters are obtained with this test: *energy yield, reference yield* and *performance ratio.* A lot of information can be obtained from the literature and these are in real conditions. But it is not possible to find information about Costa Rica. For this reason, the design for a monitoring system for a PV performance in project Las Nubes would allow a start with these kind of studies. The results from these studies can also serve to a related research for the rest of the Tropical Zone.

Chapter 3 Requirements

There are several design characteristics that need to be addressed in order to develop a monitoring device that can measure the principal parameters of PV modules. An important aspect of these requirements is the fulfillment of international standards (*National Electrical Code NEC*, *IEC 61724*, *IEC 61853* and others) aiming the device can used in real life. This monitoring system is focused on the outdoor measurements without tracking to obtain the result of the performance ratio [39].

Depending on the necessities of the project, it will divided in two main areas. First the design of the monitoring system and second, the design of structure for mounting the solar panels. For the first area, the deliverable will be a functional prototype and for the second area the deliverable is the set of plans of the structure.

The requirements are divided into two main groups: *functional requirements* that indicates what the prototype has to do and *non-functional requirements*, which indicates how the prototype has to be.

3.1 General characterization of the requirements

For energy yield measurement, it is necessary to monitoring the power generated by the solar panels. Basically it is important to know the current and the voltage of each panel. For the proposal measurement, the current and voltage are to be measured at electrical output. It means, the measurements are in Direct Current. (DC)

To find the maximum values of the current and voltage to be measured, one needs to know first which panels are to be measured. For this reason, it was necessary to know the panels available in the Costa Rican market. Taking into account, the Photovoltaic Performance Verification Plant proceeds to analyze the solar modules available of Costa Rica in a first step.

To get this data, a survey was conducted with the companies that distributes this kind of technology in Costa Rica. Some information is taken directly off the web pages of the companies and for some companies the information was required by email. Then, the electrical parameters are obtained directly from datasheets. The last model in the tables are not available in the Costa Rican market, but will be used in to test the prototype. Tables 3.1, 3.2 and 3.3 shows the principal characteristics obtain for this survey.

Table 3-1 Electrical parameters at SCT for PV modules available in Costa Rica

Manufacter	**Model**	**Cell Type**	**Number of cells**	**Pmax [W]**	**V_{mp} [V]**	**I_{mp} [A]**	**V_{oc} [V]**	**I_{sc} [A]**	**η (%)**
Kyocera	KD255	Polycrystalline	60	255	30,4	8,39	37,6	9,09	15,4
Yingli Solar	YGE 60	Polycrystalline	60	250	30,4	8,32	38,4	8,79	15,3
Canadian Solar	CS6P-250	Polycrystalline	60	250	30,1	8,3	37,2	8,87	15,54
Renesola	Virtus 260w	Polycrystalline	60	260	30,5	8,53	37,6	8,95	16
Sunrise	P660-250	Polycrystalline	60	250	29,9	8,03	37,05	8,63	14,8
Astroenergy	CHSM6610M	Monocrystalline	10	255	30,8	8,31	38,24	8,67	15,5
Jinko	JKM310P-72	Polycrystalline	60	310	37	8,38	45,9	8,96	15,98
ET Solar	P660250	Polycrystalline	60	250	30,3	8,24	37,47	8,76	17
Aleo	S18J250	Monocrystalline	10	250	30,3	8,24	37,5	8,76	15,2
Day	DAY448MC	Polycrystalline	48	165	22,9	7,19	28,60	7,8	15,1

Table 3-2 Electrical parameters at NOCT for PV modules available in Costa Rica

Manufacter	**Model**	**Pmax [W]**	**Vmp[V]**	**Imp[A]**	**Voc [V]**	**Isc [A]**	**NOCT [°C]**
Kyocera	KD255	184	27,4	6,72	34,4	7,36	45
Yingli Solar	YGE 60	181,1	28,1	6,7	35,9	7,2	46
Canadian Solar	CS6P-250	181	27,5	6,6	34,2	7,19	45
Renesola	Virtus 260w	193	28,6	6,74	35,2	7,27	45
Sunrise	P660-250	183	29,96	6,12			45
Astroenergy	CHSM6610M	184,8	27,43	6,74	34,8	7,15	47
Jinko	JKM-310P	230	34,4	6,68	42,7	7,26	45
Aleo	S18J250	180	27,83	6,49	34,94	6,96	45
Day	DAY448MC	165	NA	NA	NA	NA	46

Table 3-3 Mechanical parameters for PV modules available in Costa Rica

Manufacter	Model	Length[mm]	Width[m]	Depth[m]	Weight [kg]
Kyocera	KD255	1662	990	46	20
Yingli Solar	YGE 60	1650	990	40	19,1
Canadian Solar	CS6P-250	1638	982	40	18
Renesola	Virtus 260w	1640,84	993,14	40,64	19,04
Sunrise	P660-250	1637	992	40	19,2
Astroenergy	CHSM6610M	1652	994	40	19,5
Jinko	JKM310P-72	1956	992	40	26,5
ET Solar	P660250	1640	992	50	21,56
Aleo	S18J250	1660	990	50	20
DAY	DAY448MC	1307	991	35	17,4

3.2 Monitoring system

The monitoring system is the most important part of the present design and for this system is necessary to take the next requirements into account

3.2.1 Functional requirements

FR1. Current Sensing

According to table 3.1, the maximum current to measure is 9,09A, taking the parameter of the *Short circuit Current* of module Kyocera (KD255) as a reference.

FR2. Voltage Sensing

According to table 3.1, the maximum voltage to measure is 37V. Taking the parameter of the *Open Circuit Voltage* of module Jinko (JKM310P-72) into account.

FR3. Module Temperature Sensing

According to table 3.2, the maximum module temperature to measure is 47°C. Taking the information of module Astroenergy (CHSM6610M) as parameter. It is also important to mention that the sensor has to be added to the panel for efficient measurement.

FR4. Environmental Conditions Sensing

According to *IEC 61724* for optimal measurement, it is necessary to obtain the data of the environmental conditions like: temperature, wind speed and humidity.

FR5 Irradiance Conditions Sensing

According to *IEC 61724,* for optimal measurement, it is necessary to obtain the data of the irradiance in solar modules. This sensor should have the same angle as the PV array.

FR 6. Data acquisition time

According to *IEC 61724* for and optimal measurement it is necessary to obtain the data for the array each minute like maximum sample time.

FR 7. Data transmission

The system should have the capacity to send the data to a bigger computational data system for storage.

3.2.2 Non-functional requirements

NFR 1 Safety

As a system is in direct contact with the human operator, it is necessary to guarantee the system may not endanger human life.

NFR 2 Autonomous Electrical Supply

As the system works in field, a way should be developed to bring autonomous electrical supply to the monitoring system.

NFR 3. Hardware Environmental Protection

As the system works in field, the system must be protected from environmental conditions.

3.3 Mounting structure

3.3.1 Functional requirements

FR 1. Area capacity

The structure must have enough area to place all the panels described in Table 3-1.

FR 1 Load capacity

The structure has the capacity to support without failure, a minimum of three for each panel from Table 3-1.

FR 2 Grounding Capacity

The material structure must have the capacity to be a good grounding material, in accordance with *NEC*

3.3.2 Non-functional requirements

NFR 1. Safety

As a system is in direct contact with the human operator, it is necessary to guarantee the system may not endanger human life. A good selection of the Safety Factor is necessary in the mechanical design.

Chapter 4 Design

The chapter presents the design process for giving a solution to the problem exposed. Also, it shows the important considerations regarding the study and selection of the sensors, the controller, the transmission data system and the design for the software used in this process. In the same way, this chapter shows the design process for the structure for mounting the Photovoltaic Performance Verification Plant.

4.1 General description: Monitoring System

Following the requirements in chapter 3 and the general description of the project, it is possible to create a schematic with the project proposal. One of the objectives of this schematic is the visualization of the comprehensive solution. Figure 4-1 illustrates the general solution.

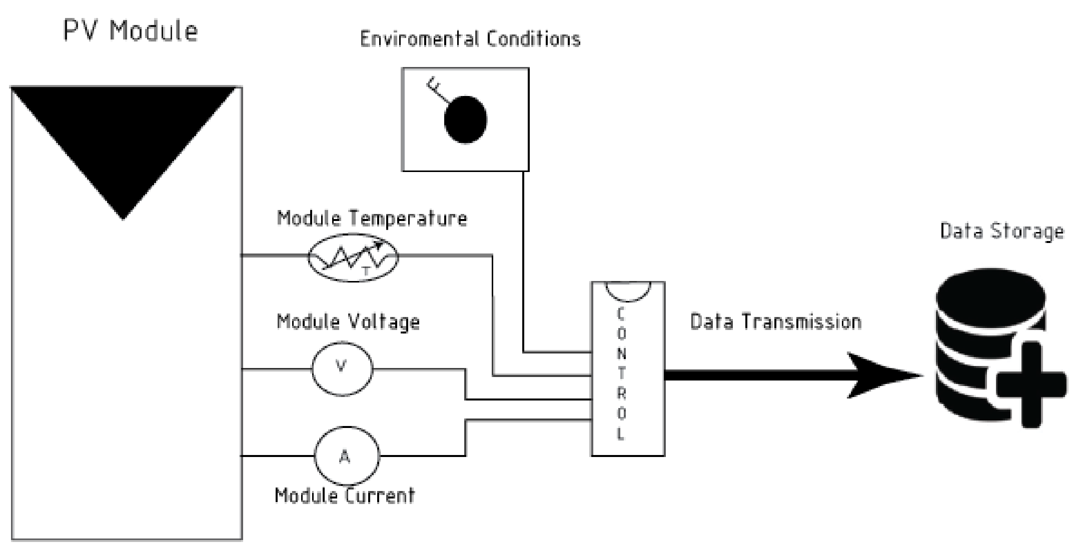


Figure 4-1 General Diagram of Solution

According to the requirements of the Las Nubes Project, in this first stage of the Photovoltaic test will be the energy yield measurement. For this reason the equipment and the procedures are selected according the standard *IEC 61724* and *IEC 61853.*

4.1.1 Data Transmission

For the data transmission it is necessary to define the real application and some considerations about the nature of the place of the measure. There is no location yet for the Photovoltaic Verification Plant, and the project Las Nubes has a lot of open space. For this reason it was decided that the communication is wireless. And in this way to collect data in the field and the send this information to a central PC.

For this proposal, the selection of RF modules will be implemented. The principal advantages the have RF is broader coverage and has the ability to connect a large number of devices. For this reason can be possible to create a network sensor, which the measurements of different PV modules. In next sections will resume this topic.

4.1.2 Data Storage

For the implementation is necessary to storage the data in computer system with increased capacity of storage, since it is required to obtain data per month or years. For this stage of the prototype, this storage system will be a Laptop. The standard IEC 61724, in section 6, provides information about the Data Format. This format is in columns, for this reason an appropriate software to obtain data is EXCEL 2013®. This is a common software that can be found on almost any computer.

The interface process between EXCEL and the communication with RF modules will be realized with Visual Basic 2013® incorporated with Excel. In next section, will work on the development.

4.2 Electronic Equipment selection

This section is related with the process and the detailed of the different equipment for the creation of the prototype.

4.2.1 Controller

The controller was chosen, both to retrieve the signals from the sensors and have the capacity to process the information and then send to a bigger computational system. For each PV module, it is necessary 3 analog inputs (module temperature sensor, current sensor and voltage sensor). And also for this first prototype, has to be the capacity to read the 4 more signals (environmental temperature, environmental humidity, wind speed, sun irradiation). In total was necessary 4 analog inputs to obtain data. In addition the controller, must be capable of communication, using the selected module.

The selected controller, for this first prototype, was *AT mega2560* integrated in an Arduino Mega 2560 Board**.** Table 4.1 presents the main characteristics of this board.

Table 4-1 Principal feature of Arduino Mega 2560 Board *[40]*

Feature	**Description**
Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

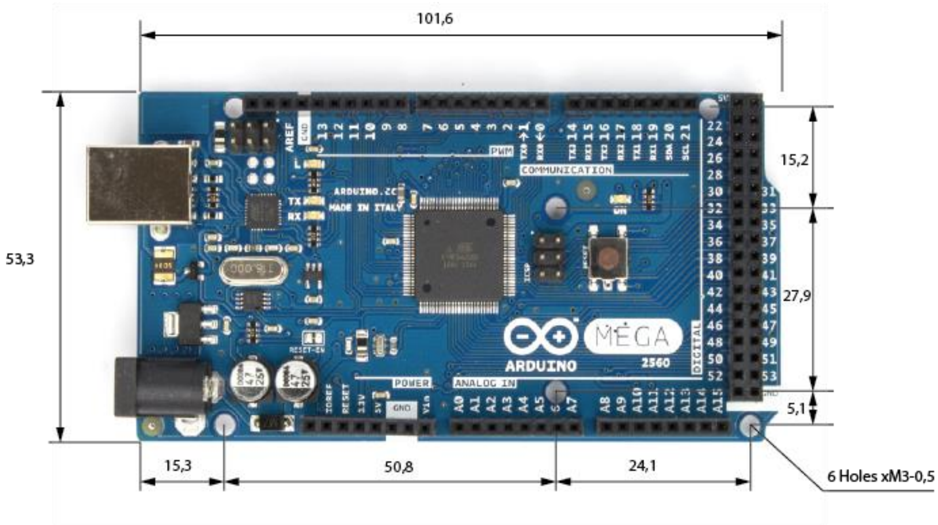


Figure 4-2 Ping mapping and dimensions for Arduino Mega 2560 Board *[40]*

4.2.2 Current Sensor

The current sensing is one of the principal measurements in the system. According to FR1 for monitoring system, the maximum current to measure is 9,09A. This value is taken of the comparison of the different datasheet of PV modules available in the market of Costa Rica. There are a different form to measure current, which will be described below:

Direct form: That consist in passing an electrical current into a *shunt resistance*. It is typical to measure the voltage across the resistance and obtain the value, trough Ohm Law. (4-1)

$$I = \frac{V}{R}$$

(4-1)

An advantages of this method have is easy to interpret, it is not necessary an external power requirement. In the other hand, this kind of measure has the disadvantages of have not electrical isolation, presenting noise, general amplification is required and presents insertion loss resulting in heat.

Indirect Form: For DC current, the other measure method is with a Hall Effect sensor current. This sensor work with a magnetic field that device convert into a voltage output, proportional to the normal magnetic field. This technology are divide into two technologies open loop and close loop. This two technologies are different. More information is found in [41].

The Hall Effect sensor has as advantages the lost cost, provides electrical insolation and is very reliable. On the other hand, has the disadvantages of difficult to understand, requires and external supply and outputs signals for zero current flow.

For this prototype, the sensor selected is the Hall Effect sensor, the integrated circuit ACS712 with part number ACS712ELCTR-20A-T of the manufacturer *Allegro Microsystems*. This is a Hall Effect-Based Linear Current Sensor IC with 2.1 kVRMS Isolation and a Low-Resistance Current Conductor. The output of the device has a positive slope (>$V_{Iout(Q)}$) when an increasing current flows through the primary cooper path. The principal features of this chip are presented in Table 4.2

Table 4-2 Main features of chip ACS712ELCRT-20A-T. *[42]*

Feature	**Description**
Optimized Range, I_p	±20 A
Sensitivity, *Sens (Typ)*	100 mV/A
Supply Voltage (V_{cc})	5V
Supply current (I_{cc})	10 mA
Output Capacitance Load (C_{LOAD})	10 nF
Output Resistance Load (R_{LOAD})	4,7 kΩ
Primary conductor Resistance	1,2 MΩ
Rise time	3,5 µs
Frequency Bandwidth	80 kHz
Nonlinearity	1,5 %
Zero Current Output Voltage	V_{cc} x 0,5

This sensor fulfill with the requirements of current. As it shows on table 4-2, the optimized range is for -20A to 20A. According to Table 3-1 the maximum current to measure is 9,09 A. But with the selection of this sensor can be extend the monitoring system to a bigger PV module and prevent some damages, per overload in the system. Figure 4-3 shows the Pin-out diagram.

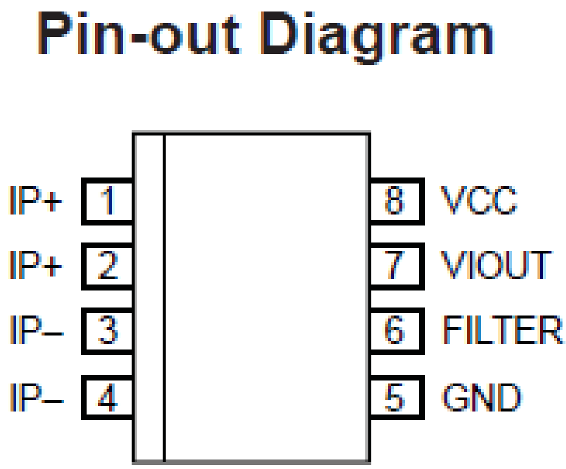


Figure 4-3 Pin out diagram ACS 712 *[42]*

4.2.3 Voltage Sensor

Another important thing in this measure, is the voltage. This voltage, according to *FR 2*, has a maximum value of 37 V in direct current. For this reason the simplest form to measure this parameter is in a direct way. But, the voltage value will damaged the controller. For this reason is necessary the implementation of interface, a voltage divider. This voltage divider provides a proportional value according the input value. Equation 4-2 gives this relation.

$$V_{output} = \frac{R_1}{R_1 + R_2} V_{input}$$

(4-2)

This voltage divider should be relatively small to the channel impedance, but it is necessary to this impedance will be the most higher possible, to improve the signal-to-noise [43]. According to the datasheet of controller AT mega2560, the optimal value for signals with and output of approximately 10 kΩ or less. This value provides that in actual sample, the input resistance is temporarily a lot lower as the sampling capacitor is charged up, making a better measure. For this reason the resistance selected for this proposal for R_2 is 10kΩ and supposed a maximum input of 55 V, with equation 4-2, the resistance for R1 is 1kΩ.

The resistances selected for this proposal are the *High Precision Foil Resistor with TCR S series* of Vishay brand. These resistances are develop with Bulk Metal Foil, the principals features are described in Table 4.3

Table 4-3 Main features High Precision Foil Resistor *[44]*

Feature	**Description**
Power Rating	1 W
Resistance Tolerance	0,005%
Electrostatic discharge	25 kV
Rise time	1 ns
Current noise	0,010µV_{rms}
Voltage coefficient	< 0.1 ppm/V

4.2.4 Module Temperature Sensor

According to *IEC 60904-1* it is necessary to measure the temperature of the module according to Figure 4-4. It is necessary to put the three sensors, obtain data and calculate the average value for special temperature test. For energy yield test, with one sensor located in the middle of the PV module is enough. Other configurations are given for more specific studies.

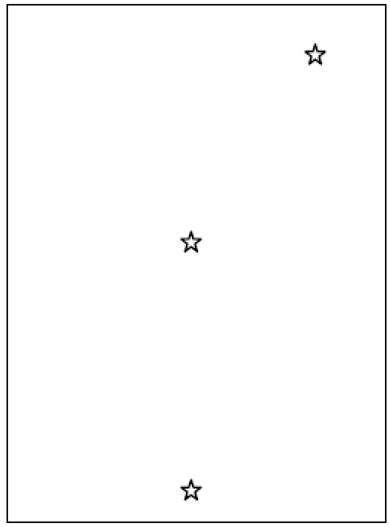


Figure 4-4. Temperature sensor location at PV module *[39]*

The sensor selected for this proposal is the temperature sensor TP-01 type K. The main features are described in table 4-4.

Table 4-4 Main feature PT-01 type K [45]

Feature	**Description**
Coefficient	38,5Ω for 100°C
Capacity	-200 to +350
Electrical Insolation	50 MΩ
Precision	0,4%
Output range	0-50mV
Response time	50 ms

And physical appearance is shown in figure 4-5. [45]

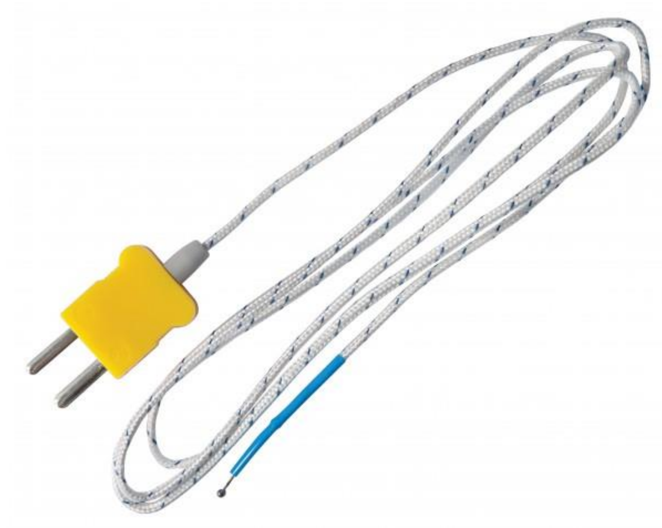


Figure 4-5 Schematic Diagram PT 01

4.2.5 Environmental conditions sensor

It is important to mention, for a Performance Verification Analysis in outdoor measurements, is necessary to take into account the environmental conditions. Focus on temperature, relative humidity, irradiance in the same plane of the irradiance, irradiance in horizontal plane, wind and direction of the speed. This features can do it a comparison point in the different latitudes. It is not the same to measurement in the Nordic Latitudes than in the Tropical Zone.

Thinking about possible growth of Las Nubes Project as Research Center, the weather station should not be exclusive of the Photovoltaics Performance Verification Plant, but must also serve other studies required. However, it is necessary a sensor for the PV array, the irradiance in the same plane. In the next paragraphs be described both equipment.

Irradiance in the same plane

According to the standard IEC 61853-1, it is necessary to take data of the irradiance of the same plane of the PV array. This measurement it is necessary to do comparison of the real efficiency of a PV module. The sensor selected for this measurement is the pyranometer SP-214 of apogee instruments. The main features are described in table 4-5.

Table 4-5. Main features Pyranometer SP-214 of Apogee Instruments *[46]*

Feature	Description
Cosine Directional Response at 75°	±5%
Absolute Accuracy	±1%
Spectral Range	360 to 1120nm
Output Range	0 to 5V
Sensitivity	2.0mV per W/m2
Calibration Factor	0.5W/m2 per mV
Power Source required	5V
Response time	1ms
Temperature Response	±0,04%/°C
Operating temperatures	-40 to 70°C
Dimensions	23,50x23,50x28,mm

Figure 4-6 illustrates the pyranometer SP-214. It is possible to see this instrument is an easy install device. And it counts with certifications ISO and World Meteorological Organization (WMO).

Figure 4-6 Pyranometer SP-214 Apogee Instruments *[46]*

Weather station

Las Nubes Project pretends to convert, in collaboration with the Sustainable Energy Initiative, in a research center focus on renewable energy. For this reason, it is necessary to take into account an accuracy weather station. For this project is propose to use the weather station Wireless Vantage Pro2 6163 including UV & Solar Radiation of the company DAVIS.

There is a solar power high accuracy weather station than allows to measure rainfall, temperature, humidity, wind speed and direction, UV and solar radiation. All of this things are checked under the standard and quality observations for use by National Oceanic and Atmospheric Administration and National Institute Standard and Technology (NIST). Among the main features that has, it is the wireless communication. This is important because it will be installed in a conservation center, for this reason it is necessary not to be invasive installation. In the same way, this weather station is powered by a solar panel and has a battery backup system. Main features of this weather station are described in Annex B1.

Costa Rica has an appropriate conditions for solar production. Unlike the countries with largest number of photovoltaics, Costa Rica has a better conditions than other latitudes during the year, the temperature is relatively constant as the solar irradiation. In addition, Costa Rica has not dramatically changes in seasons

However, for a testing purposes, it is not possible to buy this weather station. But, to collect meteorological data was used the sensor DHT22 of Aosong Electronics for measure the environmental temperature and relative humidity. This is a low cost sensor that meets with the temporally requirements. Other meteorological dates are taken of Meteorological Service of Canada (MSC) [47] for the prototype testing period. The main features are presented in table 4-6.

Table 4-6 Main features sensor DHT 22 [48]

Feature	**Description**
Power Supply	3.3V-6V
Output signal	Digital Signal Via Single Bus
Sensing element	Polymer humidity capacitor & DS18B20 for detecting temperature
Measuring range	Humidity 0-100%RH Temperature -40 to 125°C
Accuracy	Humidity+-2% Temperature+-0,2°C
Resolution	Humidity 0,1% Temperature 0,2°C
Sensing Period	Average 2s

Figure 4-7 shows a general representation of the sensor and dimensions in mm.

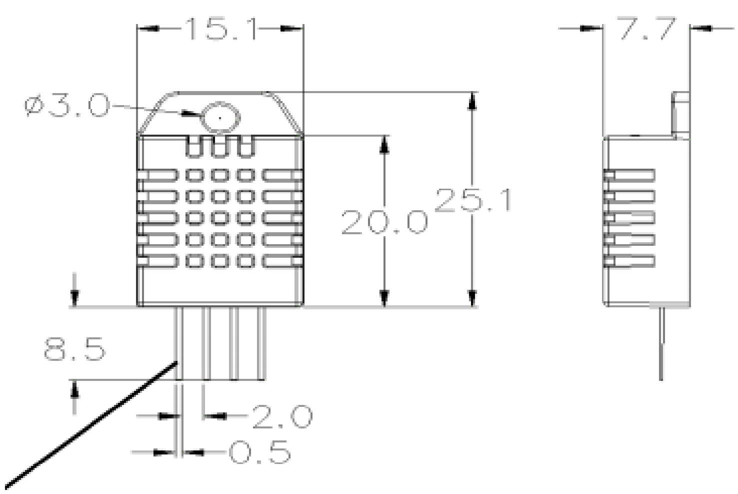


Figure 4-7.Sensor DHT 22, general view and specifications *[48]*

4.2.6 Communications modules

The module select for the communication process is **APC Series Transparent Transceiver Module APC 220-43** of the manufacturer APPCON Technologies. It is a cost-effective and easy applied module that not only can transmit transparent data with large data buffer zone, but also can provide more than 100 channels. Also has a communication ratio of 1000m at 2400bps in light sight, which meets the needs of the project. The mean features are presented in Table 4-7.

Table 4-7. Main features APC220-43 RF Module [49]

Feature	**Description**
Communication Distance (2400bps)	1000 meters
Output power	20mW
Frequency	418Mhz to 455Mhz
Channels	More than 100
Modulation	GFSK
Interface	UART/TTL
Received sensitivity	-113dBM@9600bps
Data buffer	Exceed 256 bytes
Supply Voltage	3.5-5.5V
Transmit current	42mA
Receiving Current	28mA
Sleeping current	5µA

One of the most important characteristics of this modules are the modularity and the compact design. The main dimensions of RF Modules are presented in Figure 4-8.

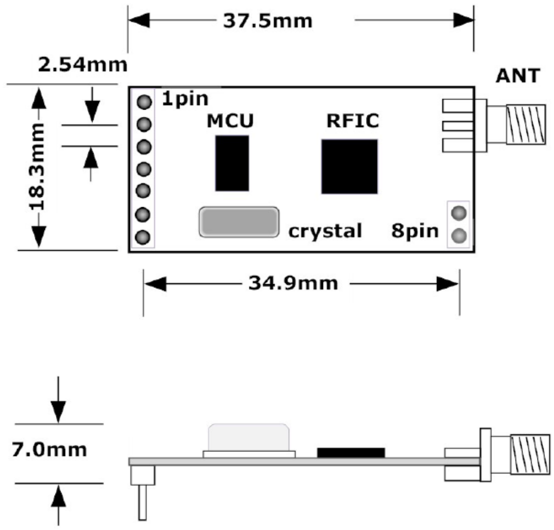


Figure 4-8 Dimensions of APC 220-43 RF Module *[49]*

For the first test of the prototype are selected the operation frequency of 434 MHz, this frequency is located near of the middle point of the operation range of the module and the maximal output power does not violate the regulations in Costa Rica, established in the *Ley General de Telecomunicaciones de Costa Rica* (General Telecommunications Law of Costa Rica) approved in 2008. [50] In appendix A-2, it is the development of the link budget and the theorical power link for the system and the characteristics selected.

4.2.7 Data Back Up System

Although the device has the capacity to send data to a more advanced computer system, it is not possible to ensure that the information can be received by the other device, for many different reasons. So, it is important to design any alternative of the information collected. According with the already selected components, a good option to appoint this backup system is to use Security Digital (SD) card. For this proposal, it is selected SD Card Slot Reading Writing Modules, figure 4-9 illustrates this component.

Figure 4-9 SD Card Slot Reading-Writing Modules *[51]*

4.3 Signal Conditioning and Calibration

For accuracy measurements it is necessary to ensure that the signals arriving at the microcontroller are filtered in appropriated way. The microcontroller receives this electrical signals and the convert into a real values that describes the phenomenon being measured. For this reason is also important to do a calibration process, to obtain a real conversion equation.

The controller selected, the Arduino Mega 2560, has 16 analog inputs pins with and ADC converter integrated. Each input has an impedance of 10 kΩ and it can handles up to 40mA. For this to values, all the signals have to be conditioned. To guarantee that the microcontroller will be undamaged. This section talks about the strategies for each sensor integrated in the system

4.3.1 Current Sensor

As is shown in the section 4.2.2, the current sensor selected is ACS712 of the company Allegro. The output value is optimal for the reading in the ADC, because the maximum value is 5 volts not exceeding the voltage input limit of the ATMega2560. This sensor has an acceptable response, but it is possible to improve the performance of this sensor. Figure 4-10 shows the relation between the noise response and the external filter applied.

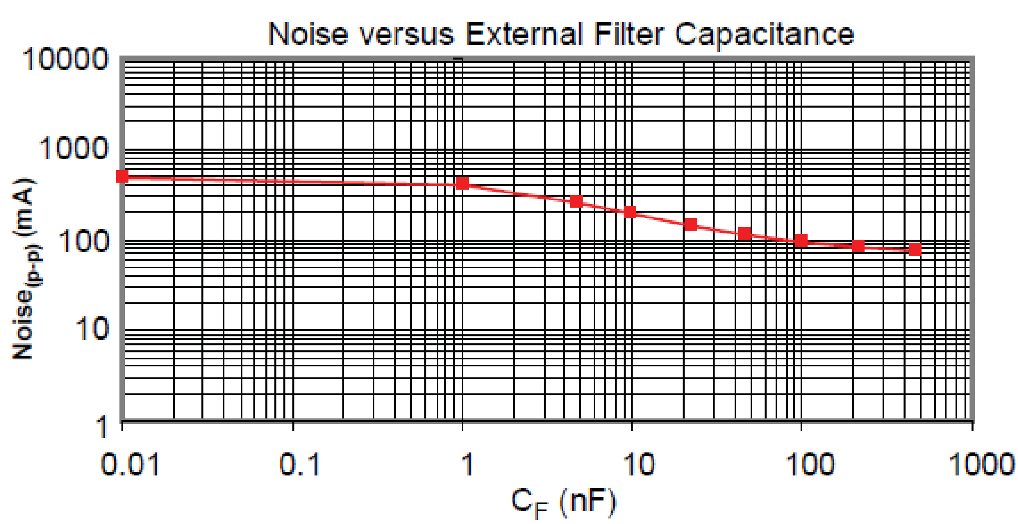


Figure 4-10. Noise vs External Filter Capacitance ASC712 *[42]*

As it is possible to see in this figure, the minimum value of the noise is after 400nF. To get the best performance, a capacitive filter of 470nF is selected. According with the specification of the datasheet, it used this filter represents a delay of 1120µS in the rise time of the sensor. But for the necessities of the project, it is in the range (maximum sample time: 1 minute). To prevent overload, it is used a 10A fuse in the input of the circuit and 5,1V diode Zener in the output of the circuit.

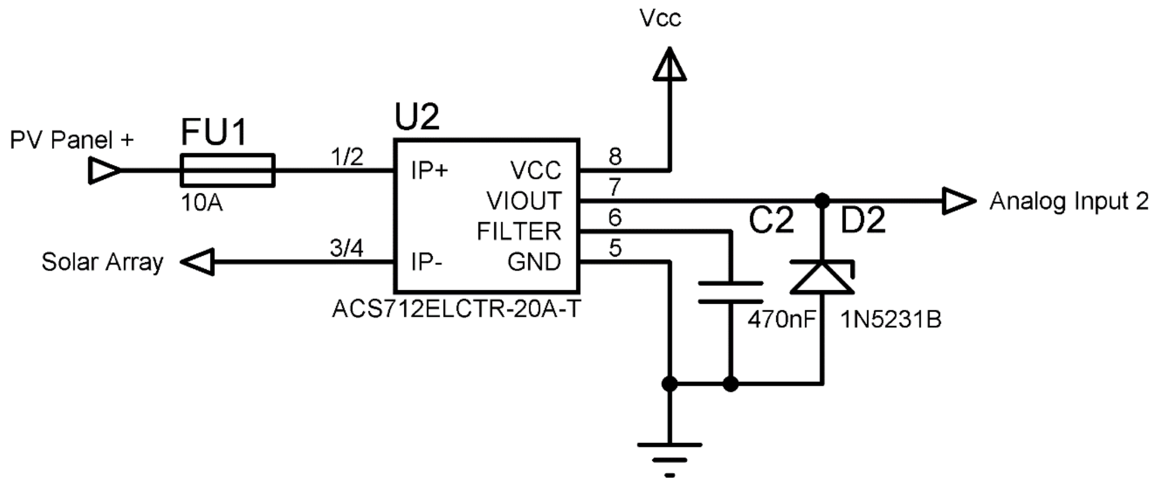


Figure 4-11 Current sensor, electrical configuration

According to the datasheet, this sensor has a sensitivity of 100mV/A. The Atmega 2560 ADC has a 1024 digital counts that represents the full scale, it means 5V. No test current, through the output voltage is 2.5V, because this sensor can be measure current in two direction. For this information, it is possible to obtain the equation conversion implemented in the microcontroller.

$$1ADC_{count} = \frac{1023}{5} * V_{in}$$

(4-4)

$$V_{in} = 2{,}5 + 0{,}100 * I$$

(4-5)

Merging and developing equations 4-4 and 4-5 it is possible to obtain the equation conversion implemented on the microcontroller:

$$I_{in} = 0{,}048875 * ADC_{count} - 25$$

(4-6)

Then this equation had to be corroborated in the laboratory with experimental results. The process is described in section 5.2.1. With the equation 4-3 is obtained an error of 0,03%. Figure 4-12 represents the linear relation between the ADC counts and current measured with the certified amp meter EX310 of Extech Instruments [52].

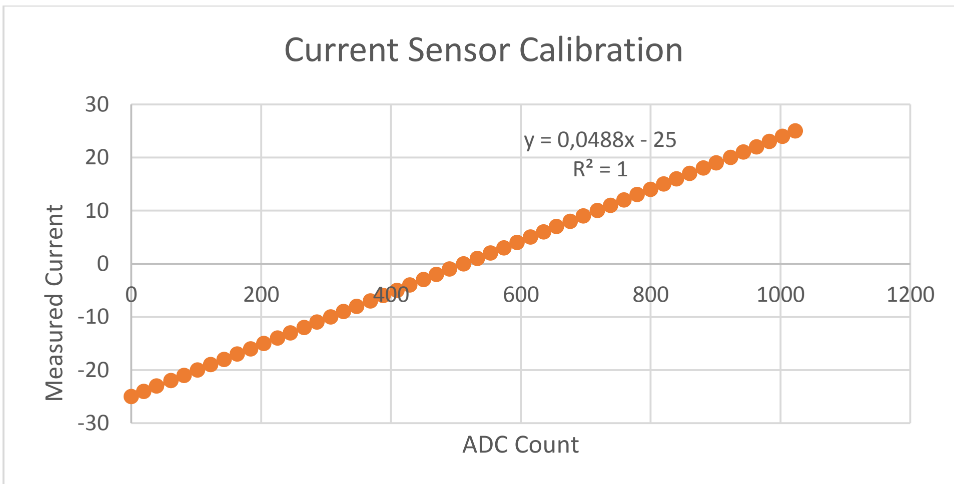


Figure 4-12 Current Sensor Calibration

4.3.2 Voltage Sensor

For the voltage sensor are selected a high precision voltage divider, as it was described in section 4.2.3. According to the equation 4-2, for a maximum input value of 55V are selected one resistor of 10k and 1kΩ. In this way, it is possible to guarantee that the maximum value in the ADC are not exceed the limit. For get a best accuracy of the signal are implemented a capacitive filter using a 1pF ceramic capacitor. And for protect the ADC input from overvoltage, a 5,1V Zener diode are used for voltage regulator. Figure 4-13 represents the circuit diagram for this sensor.

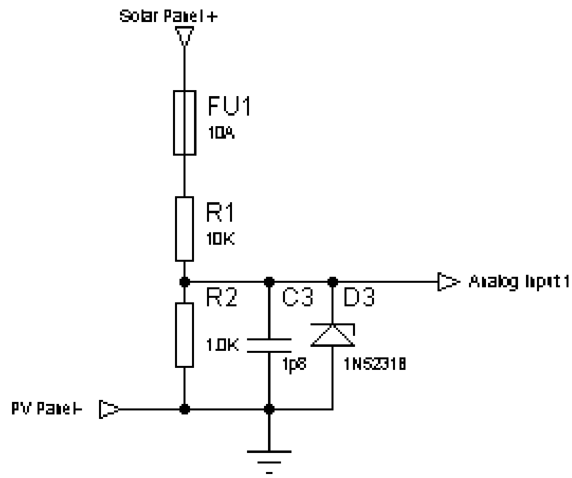


Figure 4-13 Voltage Sensor, electrical configuration

Atmega 2560 ADC has a 1023 counts that represents a maximum input voltage of 5V that represents that each one ADC count equivalents 0,0048828V, in a combination with equation 4-3 obtain one first approximation given by:

$$Vin = ADC_{count} * 0{,}00488 * (R1 + R2)/R2$$

(4-4)

This equation should be tested in the laboratory. For this proposal, a variable voltage is applied, measured by the certified voltmeter and check the digital output of the ADC through the serial monitoring tool of the Arduino. The certified voltmeter used is EX310 of Extech Instruments [52]. The results are illustrated in figure 4-14.

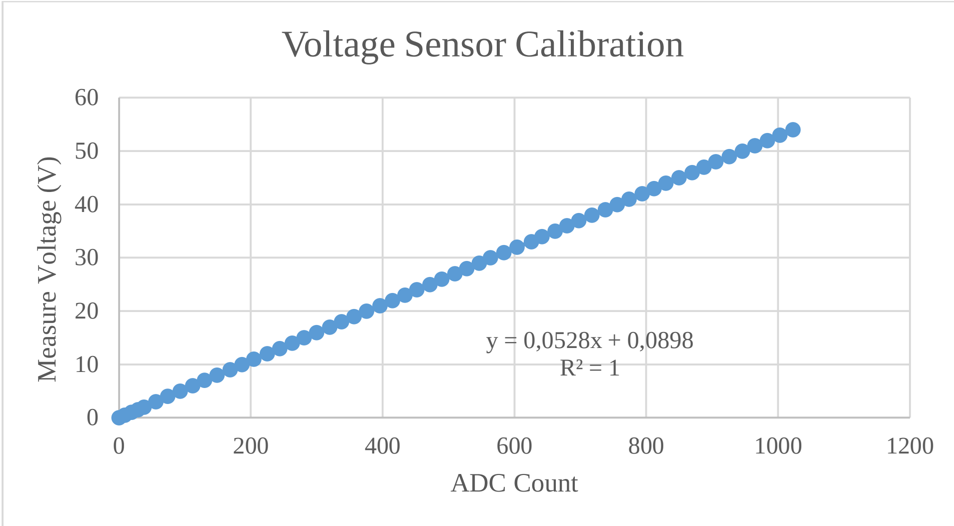


Figure 4-14. Voltage Sensor Calibration

In the figure 4-14 is shown the experimental approximation of the voltage measure value. Compare the measured value with the value estimated by equation 4-4, an average error of -1,2094% is obtained. It is applied the same analysis, with the experimental equation is obtained and error of -0, 0121%. For this reason, for the ADC conversion into voltage are use the expression:

$$Vin = ADC_{count} * 0{,}0528 + 0{,}0898$$

(4-5)

4.3.3 Temperature Sensor

For the surface temperature of de PV panels, it used a thermocouple TP-01 type K. According to the datasheet information, there is a not powered sensor. And this sensor provides a voltage output range from 0-50mV. Figure 4-15 shows the span difference between the output sensor and the ATMega2560 ADC input range.

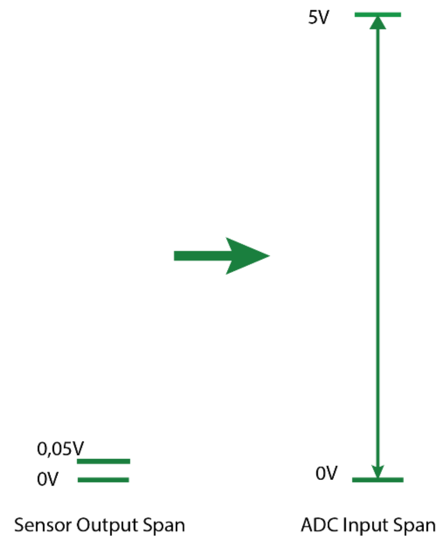


Figure 4-15.Required amplification for thermocouple TP-01.

For this thermocouple exists an instrumentation amplifier model AD595, of the manufacturer Analog Devices. This instrumentation amplifier is a certified integrated circuit for this proposal. It bring an output range from0-5V, with a low impedance voltage output of: 10mV/°C. [53]. Figure 4-16 shows a functional block diagram of this amplifier.

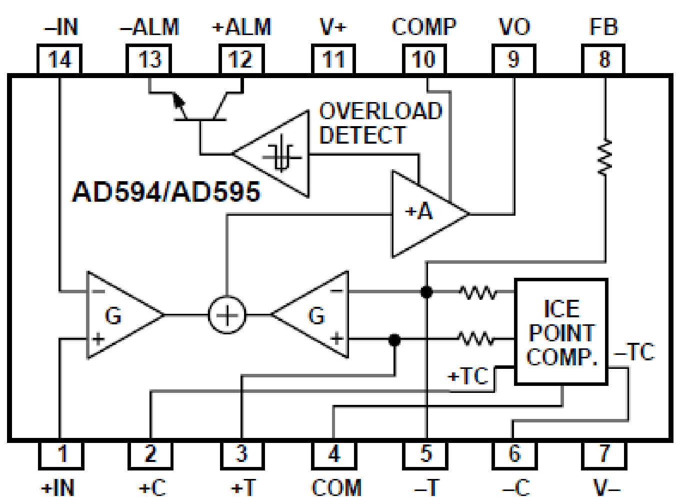


Figure 4-16 Functional Block Diagram ADS594 *[53]*

With this amplification is possible to get the conversion equation for the microcontroller. The amplifier has a sensitivity of 6mV/°C. And the ADC converter has a conversion factor of 0,0048828Vol/ADC_{count}. With this information, it is possible to obtain the information to obtain the next equation of conversion:

$$Temp[°C] = 0{,}0048828 * ADC_{count} * 60$$

(4-6)

The amplifier is connected in a single supply configuration that means the sensor can measured from 0 to 300°C. An electrical connection diagram is presented in figure 4-17.

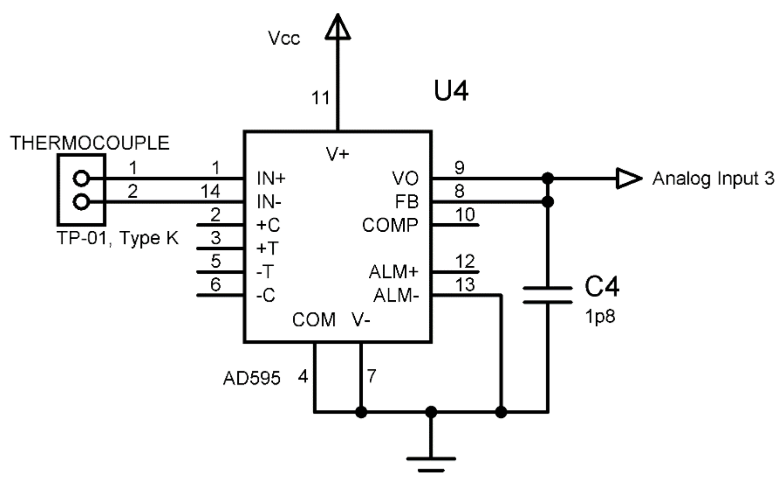


Figure 4-17 Thermocouple and amplifier AD595, Electrical configuration

4.3.4 Pyranometer

According to the technical information of the pyranometer SP-212, it is not necessary to do a signal conditioning for a reading in the ADC channel. The output ranges from 0-5V, in the same way of the ADC input required of ATMega2560. This sensor is certified by NREL and ISO. And according with this calibration the factor is 0.5 W/m^2 per mV. It means that 1 V equivalent to 500W/m^2. In the other hand, ATmega2560 has a 1024 digital counts. In other words, 1ADC count means 0,048828Volt. Then, is easy to obtain the relation for the microcontroller conversion, given by 4-7:

$$Irradiance\ [W/m^2] = 0{,}0488828 * ADC_{input} * 500$$

(4-7)

A basic capacitor filter and 5.1 V Zener diode are used to filter the signal and protect the input of ADC from overload. Electrical connection is illustrated in figure 4-17:

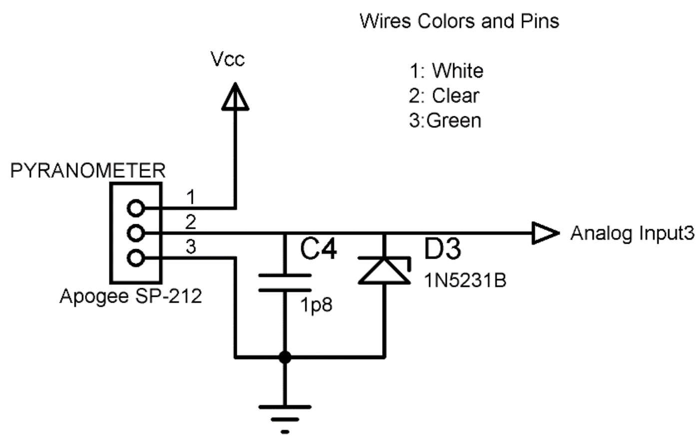


Figure 4-18 Pyranometer, electrical configuration

4.4 Overall Electronic Circuit

Before to present the overall electronic circuit, it is necessary to understand the electrical system and all the environment that the device are located. For this reason Figure 4-19 shows the general diagram of the system and the location of the monitoring system.

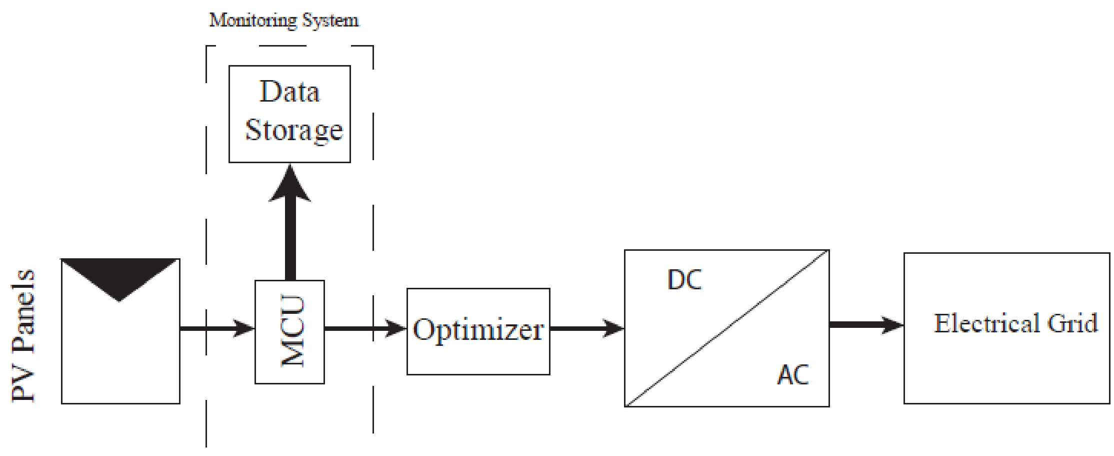


Figure 4-19. Block Diagram System

According to the quantity of ADC inputs of the microcontroller, it is possible to do measurements to 5 PV panels simultaneously, using one microcontroller. A lot of measurements can be taken in the system describe in Figure 4-19. In this case, the monitoring system is focus on the dc performance verification. For this reason, the system is integrated immediately in the output of the panel. This measurement allows to do a studies related with the solar panels, like degradation analysis. But, it is possible to add other systems to obtain data of other part of the system, like the optimizer or the inverters to see efficiency issues. Now it will be make a little definition about the other components of the Photovoltaics System.

Then, the connections of the PV Panels are given to an optimizer, also knows like MPPT (Maximum Power Point Trackers), which are important to make sure that the solar panel is given the maximum power available. The selection of this component is not taken into account in this project, but is an important component in the efficiency of the system. The connection is driven to the inverter system, to transform DC voltage into AC voltage and finally provide the electrical load to electricity. Some of the inverters have a MPPT integrated, it is common that these two components can be viewed as a single component. A detailed three-line diagram is given in Appendix Section.

The overall electronic is shown in Figure 4-20, that provides all the tags of the different sensor/circuits implemented in the solution. An enlarged view and the overall circuit diagram is founded in the Appendix Section. It is important to mention, that two LED indicators are integrated in the circuit as a visual sign that the device is turn on and then that has normal activity.

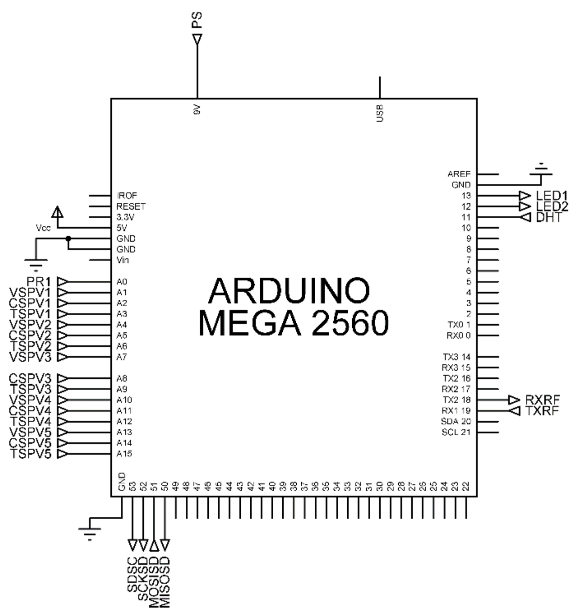


Figure 4-20. Overall Circuit

In complement with the figure, Table 4-8 shows all the electrical connections in the microcontroller. There given and identification tags, to make easy the mounting of the circuit.

Table 4-8 Electrical connections in microcontroller

Tag	Description	Signal	Pin connection
PS	Power Supply	Power Input	9V
Vcc	Power Supply	Power Output	5V
GND	Power Supply	Power Ground	Ground
PR1	Pyranometer	Analog Input	A0
VSPV1	Voltage Sensor PV Panel 1	Analog Input	A1
CSPV1	Current Sensor PV Panel 1	Analog Input	A2
TSPV1	Temperature Sensor PV Panel 1	Analog Input	A3
VSPV1	Voltage Sensor PV Panel 1	Analog Input	A1
CSPV1	Current Sensor PV Panel 1	Analog Input	A2
TSPV1	Temperature Sensor PV Panel 1	Analog Input	A3
VSPV2	Voltage Sensor PV Panel 2	Analog Input	A4
CSPV2	Current Sensor PV Panel 2	Analog Input	A5
TSPV2	Temperature Sensor PV Panel 2	Analog Input	A6
VSPV3	Voltage Sensor PV Panel 3	Analog Input	A7
CSPV3	Current Sensor PV Panel 3	Analog Input	A8
TSPV3	Temperature Sensor PV Panel 3	Analog Input	A9
VSPV4	Voltage Sensor PV Panel 4	Analog Input	A10
CSPV4	Current Sensor PV Panel 4	Analog Input	A11
TSPV4	Temperature Sensor PV Panel 4	Analog Input	A12
VSPV5	Voltage Sensor PV Panel 5	Analog Input	A13
CSPV5	Current Sensor PV Panel 5	Analog Input	A14
TSPV5	Temperature Sensor PV Panel 5	Analog Input	A15
SDSC	Slave Selected SD Slot	I/O Digital	53
SCK	Slave Clock Input SD Slot	I/O Digital	52
MOSI	Master out, slave in SD Slot	I/O Digital	51
MISO	Master in, slave out SD Slot	I/O Digital	50
TX1	RX RF module	UART	19
RX1	TX RF module	UART	18
LED 1	LED indicator 1	I/O Digital	13
LED 2	LED indicator 2	I/O Digital	12
DHT	RH and Temperature Sensor	I/O Digital	11

4.5 Power Supply

For analyze the solution for the power, it is necessary to determine the electrical consumption of the monitoring system. In this proposal, it analyses the energy consumption of each sensor and module include in the overall circuit. That supposes a maximum consumption possible in the device. Table 4-9 summarizes this analysis.

Table 4-9 Electrical consumption in the monitoring system

Q	TAG	Description	Voltage Needed (V)	Current Needed (mA)	Power per component(mW)
1	PR1	Pyranometer	5-24	0,3	5
5	CSPV	Current Sensor PV Panel	4-8	10	50
5	TSPV	Temperature Sensor PV	5	1	5
1	RF	RF Module	5	40	200
1	SD	SD Slot card	5	40	200
1	DHT	RH and Temperature Sensor	3,3-5,5	1,5	8,25
2	LED	LED indicator	5	10	565

With the past analysis is possible to say that all the components can be powered by the microcontroller, because the microcontroller has the capacity to give the current per pin maximum of 40mA. It is important to mention that, in the case of the RF module and the SD card are the maximum consumption possible. According to Table 4-9, it is possible to see that the maximum current demanded for the circuit is 160 mA in a maximum load.

In this case the circuit was powered by the battery 3.7V 5000mAh, with an autonomy time of 30 hours. This battery is connected to a Boost Converter to provided supply to the battery and solar Lipo charger are implemented.

4.6 Programming

Now, it is the described of the process of programming the monitoring system prototype. According to the description of the project in previous sections, this part are divided in to principal areas: the microcontroller and computer system configuration.

4.6.1 Microcontroller

Figure 4-21 shows the general diagram for the microcontroller. This diagram allows to understand the logic sequence of the program in the process of data acquisition.

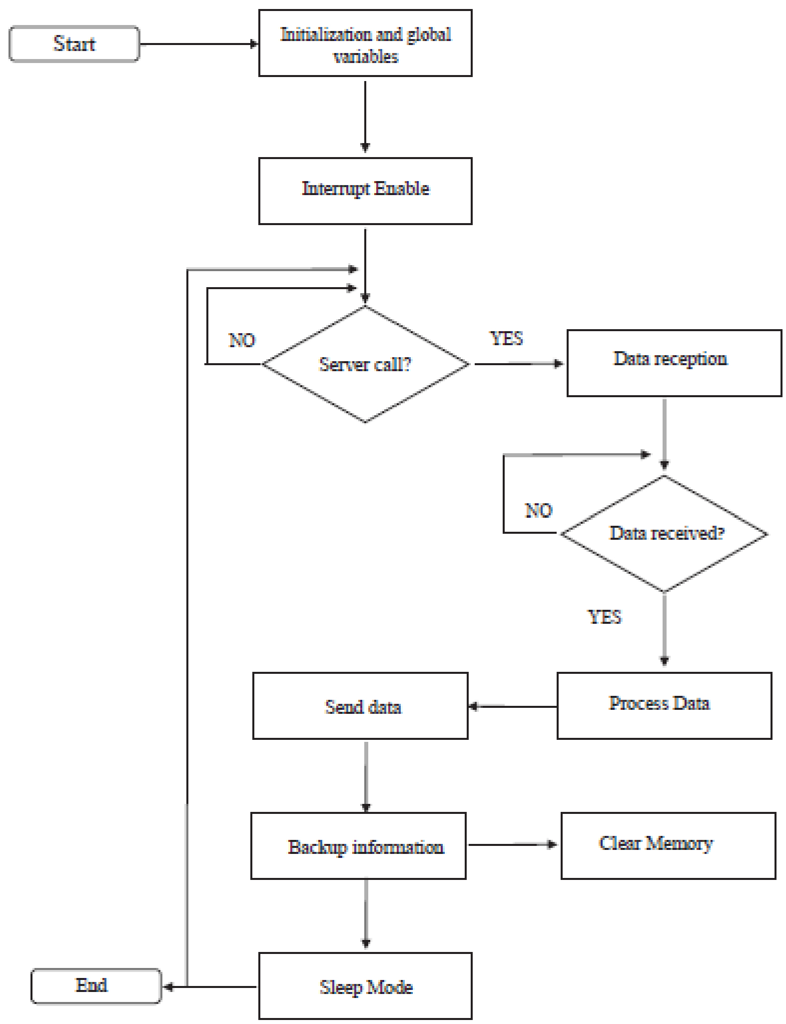


Figure 4-21Flow chart diagram for the microcontroller

That is possible to see in last figure the principal actions that have to do the microcontroller are:

- Initialization: In this first step, it is necessary to configure all the inputs/outputs pines of the microcontroller. Also in this part, the microcontroller do the initialization of the serial port for the communication system.
- Acquisition: reading of each data in all the analog inputs that it used. In this case the system has 5 readings per channel and calculate the average of the reading received. In this way is possible to get an accuracy measurement with the statistical technique of Moving Average.
- Process data: Conversion of the data into the value that it measured. In this case, are used the conversion equations described in the section 4.3. With the suggest of the standard IEC 61724, the data has the format:
  - DATA RECORD 1: PV FS G_I FS T_m FS V_A FS I_A FS P_A
  - DATA RECORD 2: PV FS G_I FS T_m FS V_A FS I_A FS P_A

Where PV is the code of the PV that the system takes the measurement, G1 is the total irradiance, in the plane of the array, Tm is the temperature of the module, VA is the output voltage, IA is the output current, PA is the Output power and FS is the field separated, in this case is selected the comma (ASCII44). One of the most relevant part of this data, is that is possible to accept in several countries and may facilitate the exchange of data between organizations.

- Send data: The data storage in the microcontroller are send by the RF modules to the computer. This communication is done via the serial port of the microcontroller. For the case of this device, the next parameters are selected:
  - Baud rate: 9600
  - Data Bits:1
  - Stop bits:1
  - Parity: 0

This configuration is also implemented in the COM port of the computer, to be able to communicate the devices. The configuration of the RF modules is presented in Appendix

- Backup Information: Before clean the EEPROM of the microcontroller the data obtained is storage in a SD card.

It is important to mention that the sample time of the measurement is every 10 seconds. This time is according the data time of the standard.

4.6.2 CPU

Once the microcontroller send the data it is necessary to receive by the computer. In this case, the general diagram flow is shown in Figure 4-22.

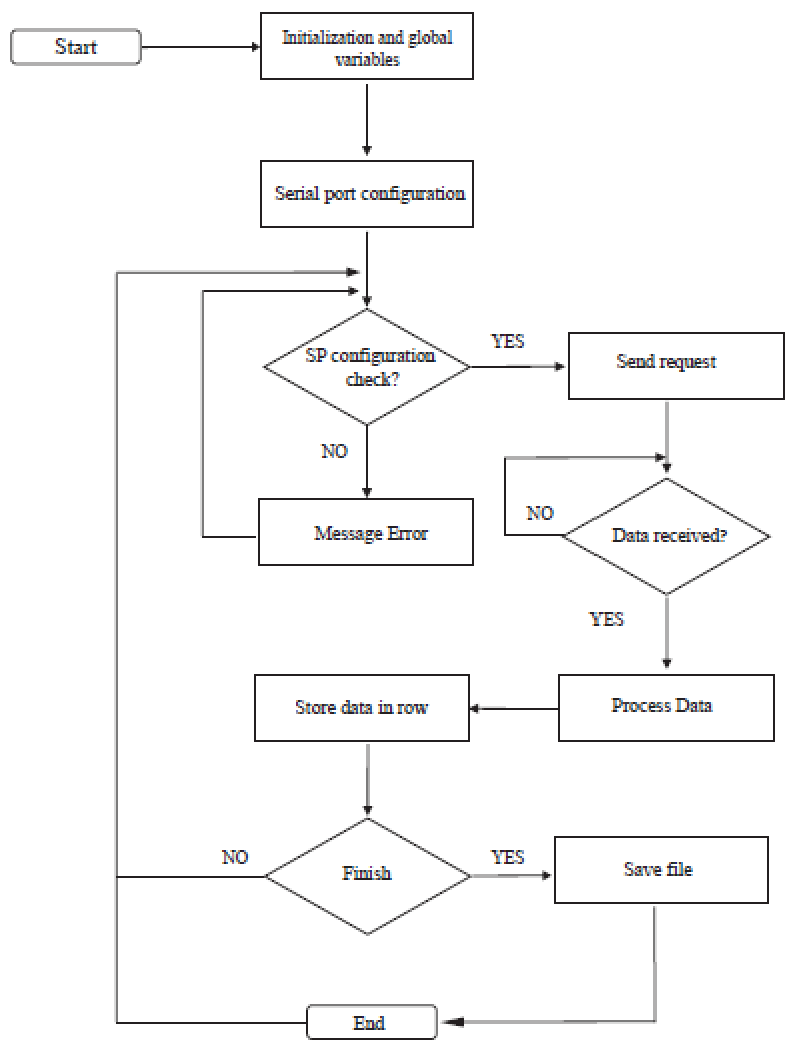


Figure 4-22 Flow chart for the computer program.

According with the past figure, it is possible to identify the principal stages of the program developed:

- Serial port configuration: It is necessary to establish the link between the devices. For this reason a manual entry of the COM port and Baud rate are necessaries as first step to initialize the program.
- Confirmation: The software needs to ensure, that the port configured in the last step is founded in the device. For this reason, a corroboration it is necessary. In case that the software does not found the COM port, display a message error.
- Send request: if the device is configure property, the software send a message to the microcontroller to indicate that is ready for receive data.
- Received data: In this process, the software store data in global variables.
- Storage data: According the format implemented to send data by the microcontroller is easy to accommodate this data into the rows, for easy visualization in excel.

The system was developed in a Macros of Excel with a Visual Basic script. That is because Excel provides and standard columns format for analysis. In this way, it is easy to export to other software for extensive analysis or a faster analysis. And it is a common program in the computer with Windows like operating system.

4.7 Mounting Structure

According to the necessities of the project it is necessary created a preliminary design for the mounting structure for the Photovoltaics Performance Verification. This section will address in the considerations for the design process and some special characteristics about the implementation of the photovoltaics performance verification plant in Las Nubes.

4.7.1 Solar Assessment

The project will be development in the Conservation Center Las Nubes, located on the South Pacific slope of the Talamanca range in Southeast Costa Rica. To the northeast of the property is Chirripo National Park which continues into La Amistad National Park. This National Refuge are limit with the Biological Corridor Alexander Skutch. In this moment, it is start with a building of Operations Center called Lillian Meighen Wright Centre. The extension territorial zone is approximated 124,67 ha.

Location

For next analysis and create a real proposal, the place selected for the location of the Performance Verification Plant is on the coordinates 9°22´52´´N and 83°36´15´´W. This location has an altitude of 1081. In this place there is a field with a size of 20m x 20m. This is not the final location of the plant, because it necessary to add with the General Site Operations Plan of the Conservation Center. However, a small changes in the location will not greatly affect the results presented in this section. The location of the place selected are presented on Figure 4-23.

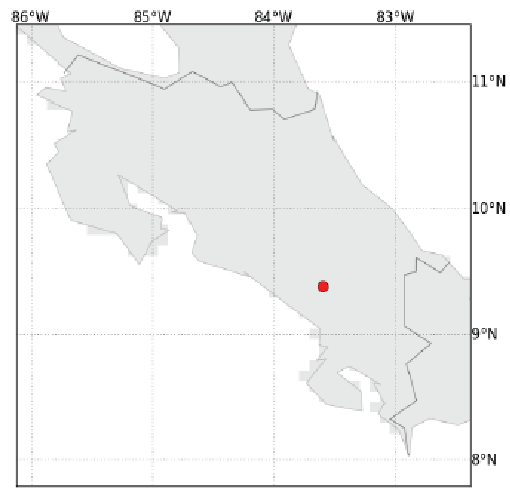


Figure 4-24 Location PV Performance Verification Plant, obtained by SolarGIS

True South

In the same way of all the PV installations in the Northern Hemisphere, the installations are oriented south to increase the solar gain. [2]. But, there is a difference between the magnetic south (that is indicates with the compass) and the true south. The difference is given by the Earth´s no uniform, conductive, fluid outer core that consist mainly of iron and nickel. For this problem, there is implemented an east west correction that is either add to the magnetic south compass reading.

In the case of this project, an acceptable east-west correction factor are given by National Centers for Environmental Information of United States, which provides a Magnetic Fields Calculator [54]. A simulation in this calculator estimates that the declination in location of the project is 1,59° W in May 1st, 2015 and a progress declination of 0,15° W per year. For simulation considerations was used the World Magnetic Model (MMM). This model is produced with US and UK defense agencies and it is the most recommended model prediction. With this possible to obtain the true south for the location project, given by equation 4-8:

$$\theta_{True\ South} = 180° + 1{,}59° = 181{,}59° \approx 182° \quad (4\text{-}8)$$

Irradiation Data

With the settings of latitude, longitude and solar true south it is possible to create a simulation about the Sun Path and the irradiation data in the location selected. For this simulation is used the online high-resolution database SolarGIS® [55]. It is a solar database developed by GeoModel Solar. This database is considered as most accuracy database for solar applications and it is widely used by students and professional involved with solar energy. Figure 4-25 and Figure 4-26 show the result of irradiation data obtained in the simulation. Tables source of this graphics are presented in Appendix A-3.

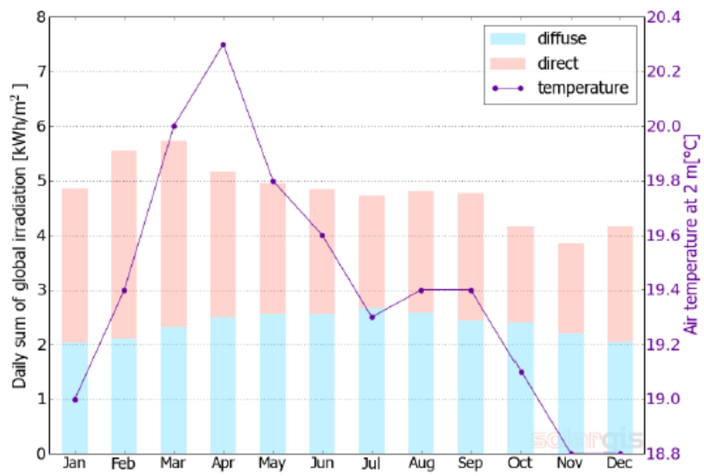


Figure 4-25 Global Horizontal Irradiation and air temperature estimated by SolarGIS

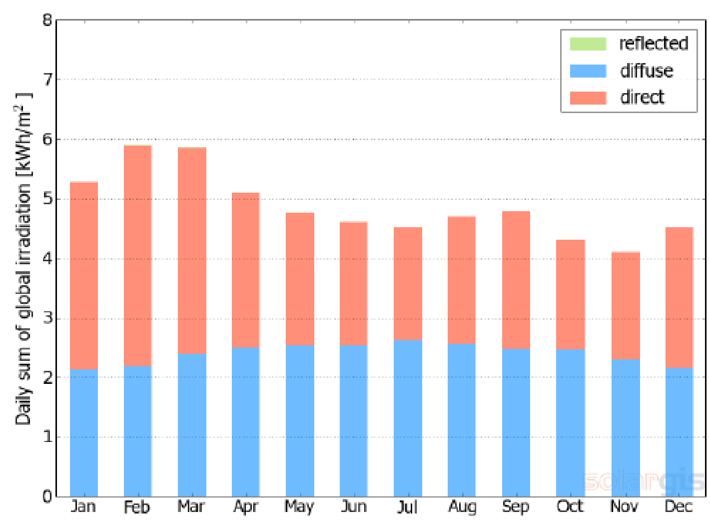


Figure 4-26 Global in plane irradiation estimated by SolarGIS

According to Figure 4-25 and Figure 4-26 it is possible to see how the irradiation and the temperature remains constant, compare than other latitudes like Canada. This condition confirms the good conditions that Costa Rica has in term of Solar PV energy production. In a year this location receives 1749,6 kW/m^2 in horizontal plane and 1775,8kW/m^2. The average temperature around the year is 19,4°C.

Solar Path and Tilt angle.

In all solar system, the tilt angle is one of the most important aspects to take account in the design process. The selection of an optimal tilt angle is important to prevent and energy loses, related with optical phenomena, especially for the light incidence angle in the module plane. [56]. Solar panels have the maximum performance when the photovoltaic surface catches the sunlight in a perpendicular way. Unfortunately, the zenith of the Sun change according the month of the year. A clear diagram of tilt angle is shown in Figure 4-27.

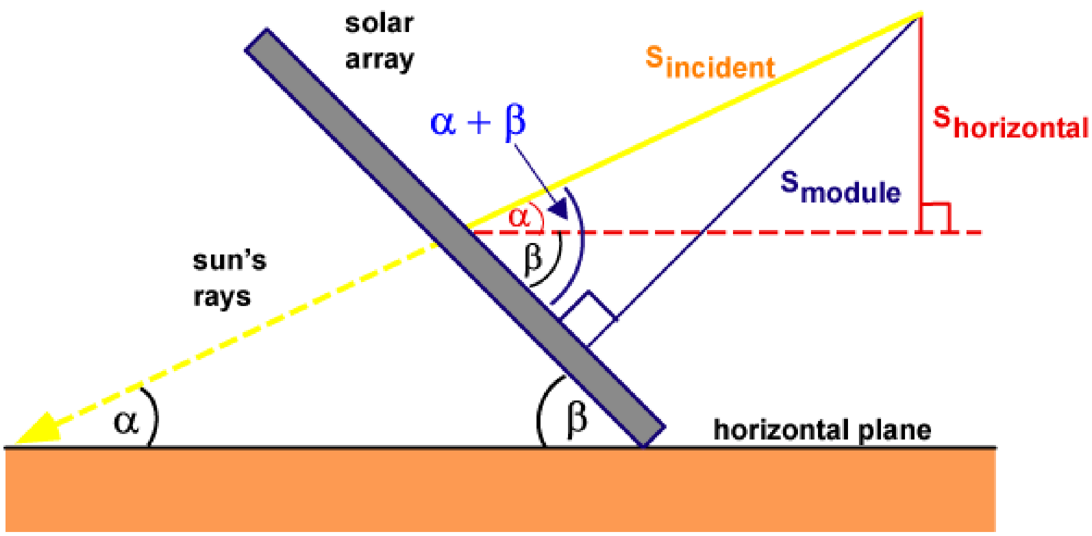


Figure 4-27. Tilt angle for PV panel *[57]*.

The best performance of the tilt angle are given by:

$$\beta = 90 - \alpha \tag{4-9}$$

Where β is the tilt angle and α is the sun elevation. For this reason, it is necessary to consider the variation of the Sun during the year. In this proposal, an online tool provide by University of Oregon, called *Sun Path Chart Program* [58], was used. This online tool allows to obtain the sun position graphically. The result for the location of the project is shown in Figure 4-28 and alternative Sun Path representation is presented in Appendix A-4.

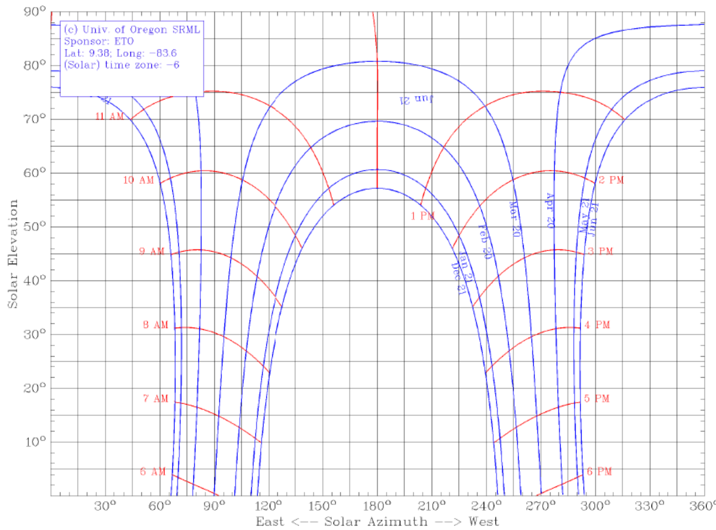


Figure 4-28. Sun Path Chart for the location of the project

Now with the data obtained in Figure 4-28 and equation 4-9, it is possible to determine the optimal tilt angle for the project. For the June 21st, the tilt angle optimal is 9,2°. The main idea to obtain the best tilt angle, for no tracker installation, is to obtain the most constant radiation around the year. For this location, this angle are determined by 10° in the analytical way and this result is consisted with the result obtained by SolarGIS, in automatically way. The representation of direct radiation around the year is illustrated in Figure 4-29. This estimation was obtained by the online tool development by PVEducation [57]. In this graph it is possible to see how the direct radiation during the year is steadily and represents a valid approach.

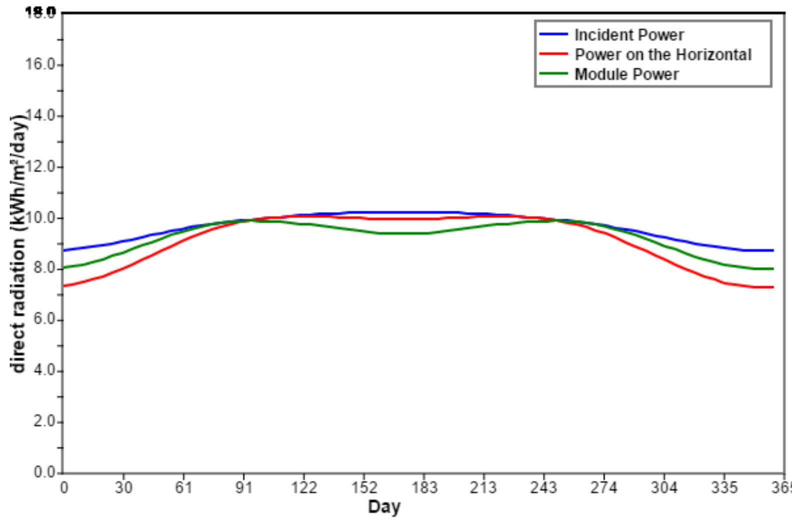


Figure 4-29. Direct Radiation around the year with a tilt angle of 10°.

With this information, it can ensure that the place selected in Las Nubes presents optimal conditions to operate the plant. However, the final decision of the place that will be located the Performance Verification Plant depends of the Master Plant of Las Nubes, that it is designed in this moment.

4.7.2 Load considerations and stress verification

To the development of the design analysis for the structure of the PV panels, it is necessary to do a mechanical load budget and special conditions for the structure. According to the standard IEC 61853 for an accuracy performance of PV technologies is necessary to measure three modules per manufacturer. According to Table 3-3, ten different brands are distributed in Costa Rica. For this reason 30 modules will have to be install in the best scenario. The configuration selected for the orientation selected for the PV panels is in landscape. According to this considerations and the analysis for the best performance obtained in the last section, it is possible to get the initial parameters of the design.

In this case the structure has to get the next characteristics:

- Total area: 48,84m^2
- Total load: 605,74kg
- Distributed load: 12 kg/m^2
- Distributed pressure: 117,72 Pa.
- Tilt structure: 10°.
- Minimum height: 1,5m.

Also is important to take into account other considerations, like the soil foundation and the wind loads. It is not possible to obtain data in this moment about the soil foundation and for this reason is necessary to re-validate the proposed design. On the other hand, according with the Costa Rica Regulation [59] the wind load was considered as 55 kg/m^2. But is more important the design by the seismic code, for this reason it have to be considered. The CAD tool implemented for this solution is SolidWorks 2013. The racking system selected is manufacturer by the company IronRidge. A general solution of the structure are shown in Figure 4-30 in this figure is also presented the coordinates system that will be used in next analysis.

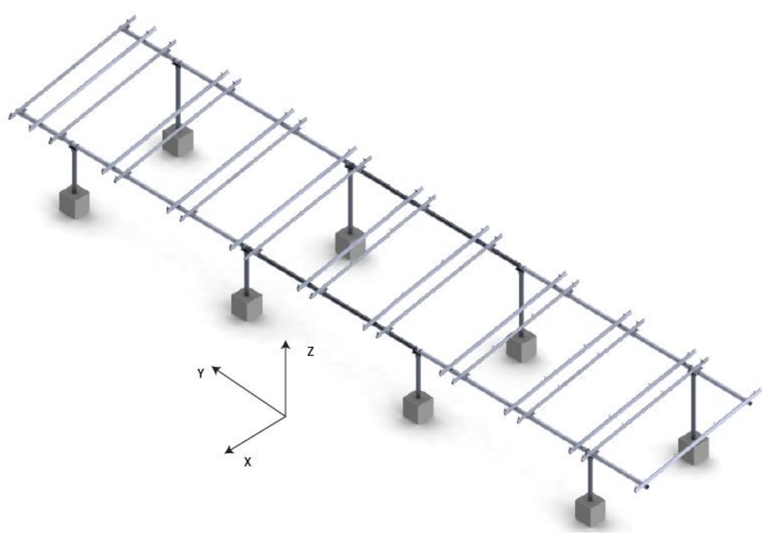


Figure 4-30 General View of the Structure

As it seen in the last figure, the structure is divided in 20 rails two per array panel. Each array panel is composed by three solar modules of the same model. The length of the rail are 11 feet (3,3528m). The main mechanical properties of the rail are given in Table 4-10.

Table 4-10 Mechanicals properties of XR100 Rail *[60]*

Property	Value
Material	6005A-T5
Beam Height	76,2 mm
Weight/Linear Foot	428,6448g
Total cross sectional Area	520,0644e-6m^2
Section Modulus(X-Axis)	8,242639e-06 mm^3
Moment of Inertia(X-Axis)	350,8830918e-09m^4
Moment of Inertia(Y-Axis)	75,75411946e-09m^4
Torsional Constant	6,817019e-06m^4
Polar Moment of Inertia	13,73147473e-09m^4

Stress Verification Axis X

For the configuration selected, the stress in the rail was verified. In this case, the supports of the rails are a 1ft (0,308m) from the edge of the rail and 9ft (2,7432m) to the other support. With the consideration of Table 4-10 and supposed a distributed pressure per rail of 11, 72 N/m^2, was realized a finite element analysis for the rail. The results are shown in Figure 4-31

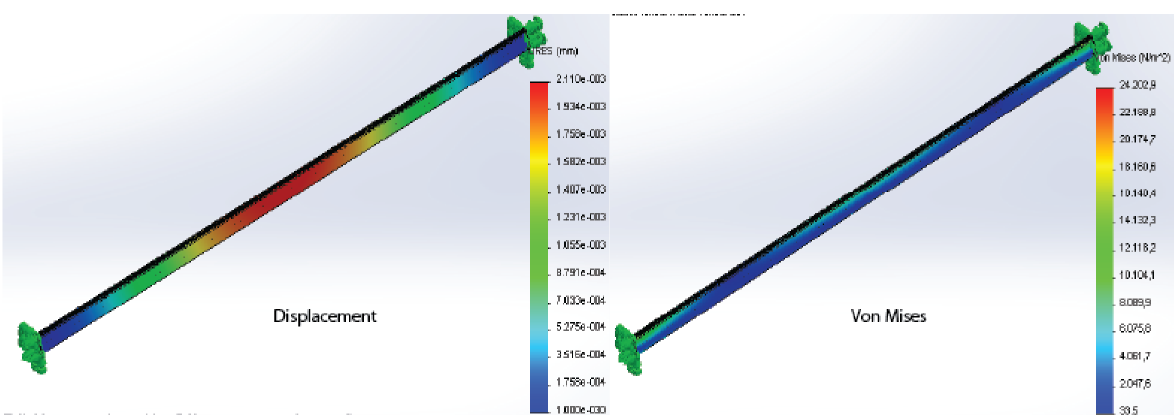


Figure 4-31 Finite Element Analysis for XR100 Rail

In the last figure it is possible to see how the maximum Von Mises Stress in the component is of 24,202kPA which means a safety factor of 600. The maximum displacement at the midpoint is around 0,00211mm, in the direction of the pressure. Also the stress was corroborated in the Rail Connector with the beam. With a load of 500 N/m^2 that represents the weight of the PV panel and the rail. Figure 4-32 shows the principals results of the analysis.

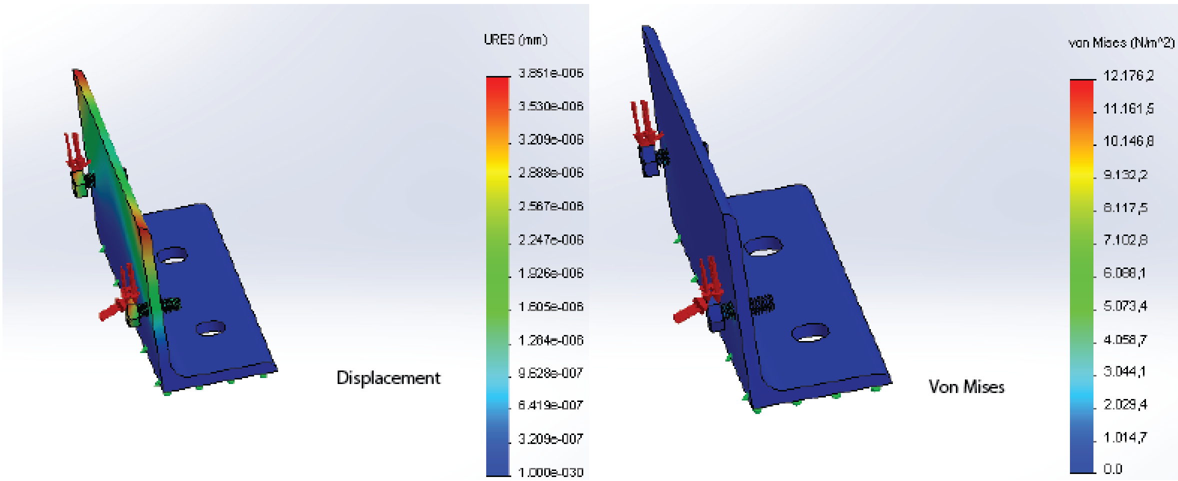


Figure 4-32 Finite Element Analysis for Rail Connector

Stress Verification Axis Y

In the Axis Y was selected like principal component and 3" Schedule 40 pipe. This pipe is make of structural steel ASTM A53 B. The pipe is used like column and a beam to support the rail. A Finite Element Analysis was development to determine the principal stress and behavior of the structure in this point. The Static load for this configuration is 58 N/m^2 that represents the distributed load product of its weight plus the weight of the XR100 Rail.

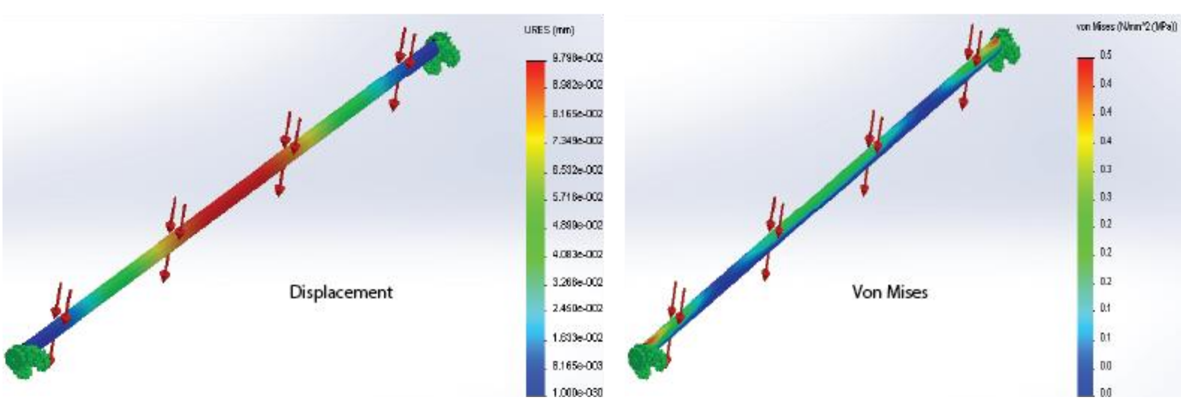


Figure 4-33Finite Element Analysis for 3" Schedule 40 Pipe.

The figure shows how the Von Mises Stress is around 0,5Mpa that means, the safety factor for this component in this configuration is around 450 with a deformation of 0,00972mm in the central part of the component.

Stress Verification Axis Z

In the axis Z, the most important think to verify is the resistance of the concrete founding. For the case of the proposal, a foundation of 40cmx40cmx40cm was selected to put in each column. A Finite Element Analysis was make for this component.

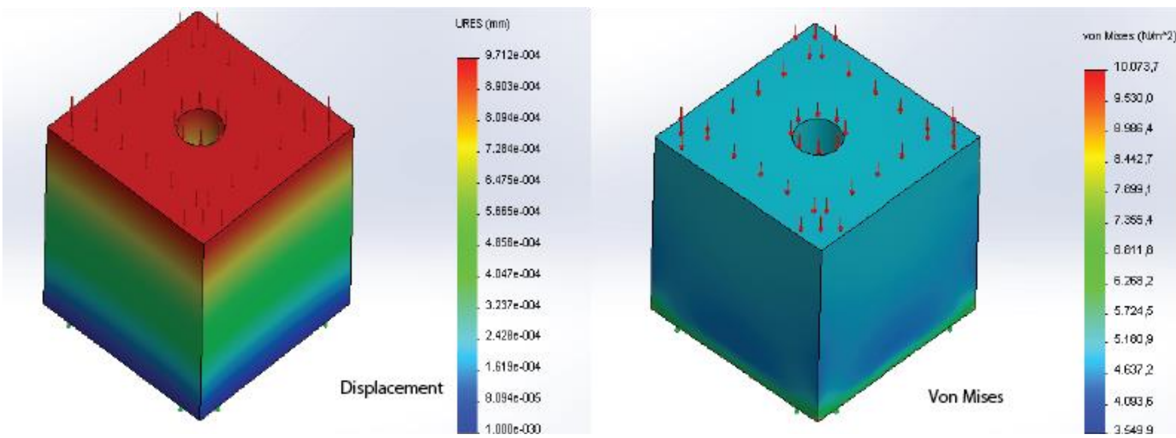


Figure 4-34. Finite Element Analysis in foundation

All the analysis reflects that the structure in the configuration proposed can work. However, this is a preliminary version, because is necessary for confirm the results to do a site assessment, to get more information related of the wind load and the soil foundation.

Final View

A final view can be observed in Figure 4-35. More technical details can be found in Appendix A6.

Figure 4-35 Final View

Chapter 5 Assembly and Testing

This chapter is aimed to show the fulfillment of the object regarding the assembly of the texting model. In this chapter it will described all the process implemented to test the device both in the laboratory and field test. And the end of the chapter is shown some results obtained of the evaluation of two PV panels.

5.1 Methodology

For a prototyping and make all the electrical connections of the sensor it was developed the circuit for the measurement of one panel in a breadboard. Figure 1 shows the breadboard assembly.

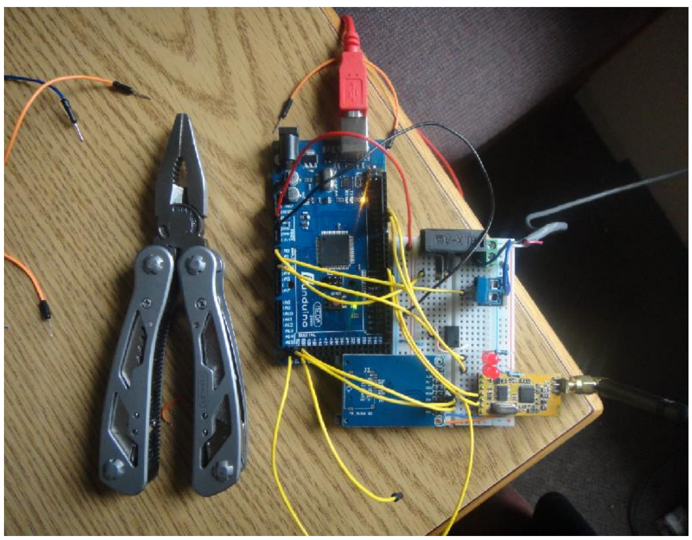


Figure 5-1. Breadboard connections for test the prototype

As it shown in section 5.2.2 the system was tested in real conditions to obtain data from a PV panel. For this reason a more compact assembly for the circuit was made, as is shown in Figure 5-2. Also the device was placed in the Junction Box *FSE PVC ¾"* of the company *Carlon.* This box owns with the seal EA42728 of UL that indicates the degree of protection against water.

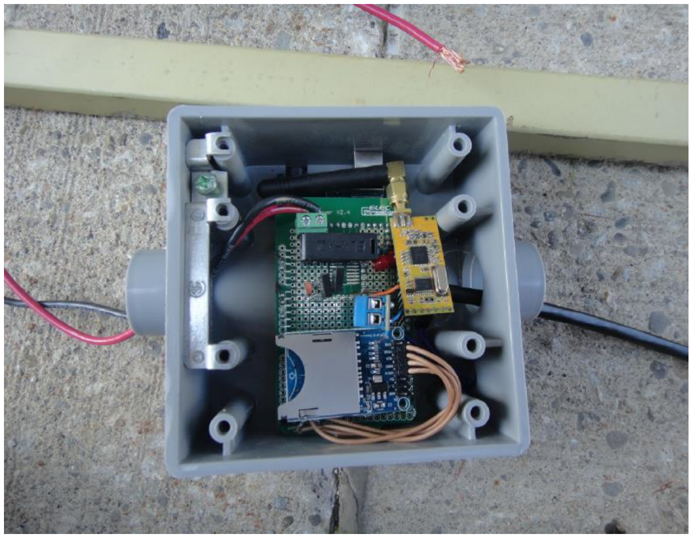


Figure 5-2 Final testing prototype

5.2 Testing process

This process is divided in two process. The laboratory test, are development in the laboratory and the utilization of Voltage/Current Source to do the calibration and characterization of the sensors and the IEC 61724 checking test. On the other hand, the field test was implemented to do and small outdoor performance verification of two modules that provides York University. The next section describes these two process.

5.2.1 Laboratory Test

Calibration and Sensor Characterization.

For calibration process the prototype was operated in the laboratory and tested with a voltage supply. This test was created to obtain the real behavior of the sensors selected. Figure 5-3 illustrates this process.

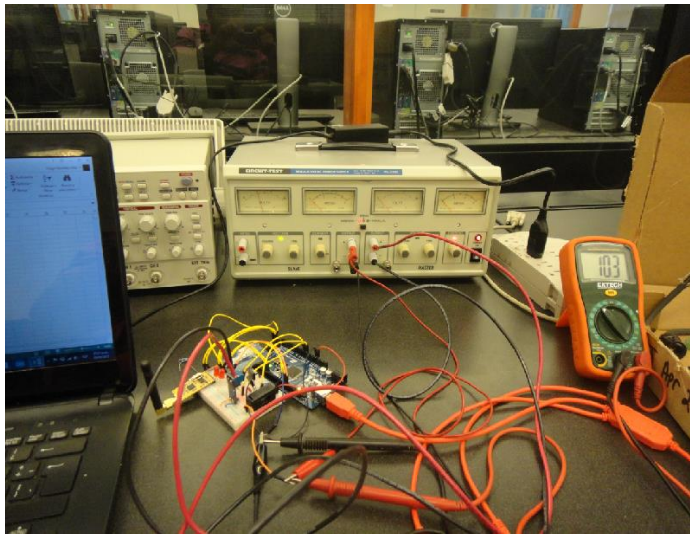


Figure 5-3. Laboratory Test

With this test was possible to calibrate the sensor and describe the real behavior. All the results obtained was presented in section Signal Conditioning and Calibration of Chapter 4. Then the results of the calibration was corroborated, once are programming in the microcontroller. For collaboration of the system was implemented a Multimeter EX310 of Extech Instruments power measurements and for the temperature corroboration was used and FLUKE16 In addition after each day of field measurement to the PV modules, a validation was development in the laboratory. This test was approved satisfactorily. For this reason, is possible to collect data and the results are presented in the next sections.

Checking Test IEC-61724

The standard IEC-61724 proposes a method of checking the data of the acquisition system. This test is related only for the system without the sensors. For each sensor, different procedures are applied. The checking test consist in a simulation of the input signals involved focus of the signals of irradiance, ambient temperature, voltage and current. For this reason, this process was developed in the laboratory and the main results are summarized in Table 5-1.

Table 5-1 Checking Data Test IEC 61724

TEST	Description	Test Day	Error	Status
Check of linear response	A constant dc signal shall be applied to the input terminals. The difference between the result measured by data acquisition system and scaling factor shall be less than ± 1% of the full scale. This procedure should be performed at input signals of 0%, 20%,40%, 60%, 80% and 100%	May 4th, 2015	0% all AI[2]	Ok
Check of Stability	A constant dc signal of 100% of full scale shall be applied to the input terminal for 6 h. The fluctuation of the measured value of this signal shall be kept within ± 1 % of full scale.	May 5th, 2015	0,01% AI 14 Other AI 0%	Ok
Check of integration	An input signal of a rectangular wave having an amplitude Zm shall be applied to the channel and its measured values integrated over time period Td (recommended to be at least 6 h). The amplitude Zm for each channel is recommended to be the maximum input level expected from the sensor. The results obtained shall be equal to Zm × Ùd ± 1 %.	May 6th, 2015	0,02% AI 1, 2 & 9 Other AI 0%	Ok
Check of zero value integrals	The channel shall be short-circuited, and its measured values integrated over time period Td of at least 6 h.	May 7th, 2015	0 % all AI	Ok

According with Table 5-1 it is possible to see how the system developed for this proposal can operate with the requirements of the standard. IEC 61724 establishes that this check should be made every to year, with the aim to get and accuracy data. If the error is greater than the established, it is necessary to correct with software or hardware and re-verified. The sensors should be calibrated according the best practices for each sensor. For the case of this project, it is recommended to do it every year.

[2] AI: Analog inputs

5.2.2 Field Test

A field test inside the campus of York University was developed, measurement real PV Panels. For the field test, was used to PV Panels model DAY448MC of the manufacturer Day. The datasheet of this solar panel is provided in Annex B1-6. The site that was developed this testing process is next to the Faculty Environmental Studies, specifically in geographical coordinates 43° 46' 17'' N, 79° 30' 17'' W. A satellite image of the place is shown in Figure 5-4.

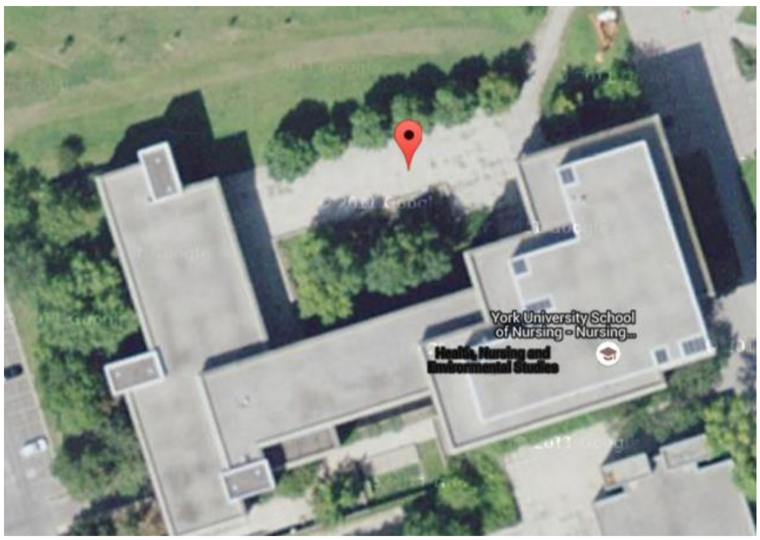


Figure 5-4. Field test location

For this location, a preliminary analysis was conducted by Solar GIS. The main features of this analysis are presented in Appendix A5. Also a real solar assessment was development with the equipment *Sun Eye 210* development by *Solmetric®.* In this case was taken 9 measurements around the perimeter rough of 4, 57 meters (15 feet) per 4,57 meters. Figure 5-5 shows the process of the data in Sun Eye.

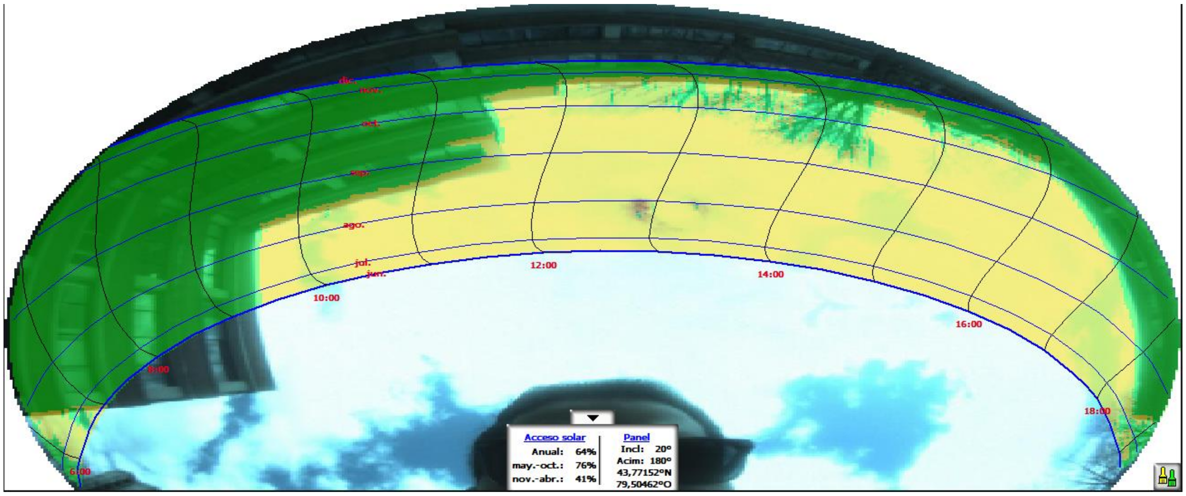


Figure 5-5 Sky Image Capture Sun Eye 210

Once obtained the data is possible to get some results about the solar access. It is possible to see how the place of the measurement has and 79% around the year of Solar Access. That is and acceptable percentage for testing proposals, taken account that the place is near to the Faculty and there is no traffic of people, that could interfere with the testing period. Figure 5-6 and illustrates the solar access in the point selected.

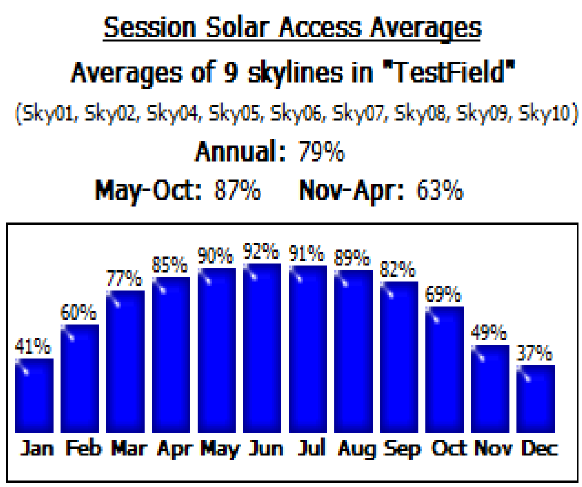


Figure 5-6 Solar Access in Field Test

For the test of the prototype two solar panels DAY448MC the testing process during the day of May 15th and May 27th. The measurements cannot obtained all of the days, because the panels were not in a fixed plant and all the testing process for security process has to be supervised.

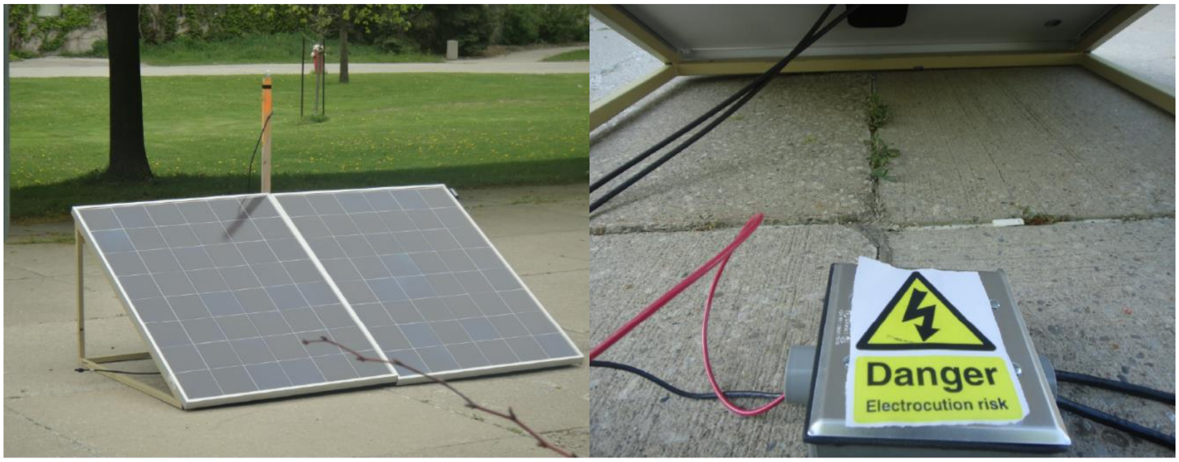


Figure 5-7. Outdoor Performance Verification with two solar panels DAY448MC

5.3 Results

Around 2600 rows of data was collected per panel per day. It is important to mention that the losses data in the RF communication was 0,045%. The computer that works as server was located at 100 m of the location of the measurements inside the Faculty of Environmental Studies.

With the data collect is possible to determine the behavior of the PV modules during the test dates. A no linear correlation, can be determine in a simple view, between panel temperature, irradiance and output power. Figure 5-8 shows the behavior of the temperature of the PV Panel Temperature, the environmental temperature and the irradiance for May 16th, 2015. It is important to mention the meteorological conditions for this day. It was a cloudy day, with an average temperature of 23°C, relative humidity of 46% and wind speed 2,31m/s.

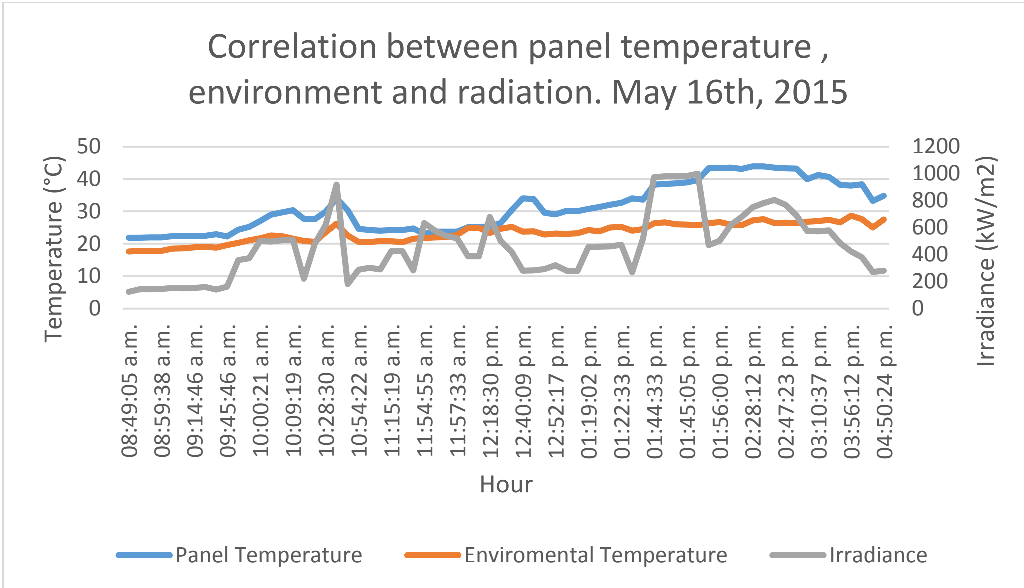


Figure 5-8 Correlation between panel temperature, environment and radiation. May 16th, 2015

For the same day is possible to obtained and idea of the output power of the system and the irradiance in the same plane. This relation is possible to see in Figure 5-9

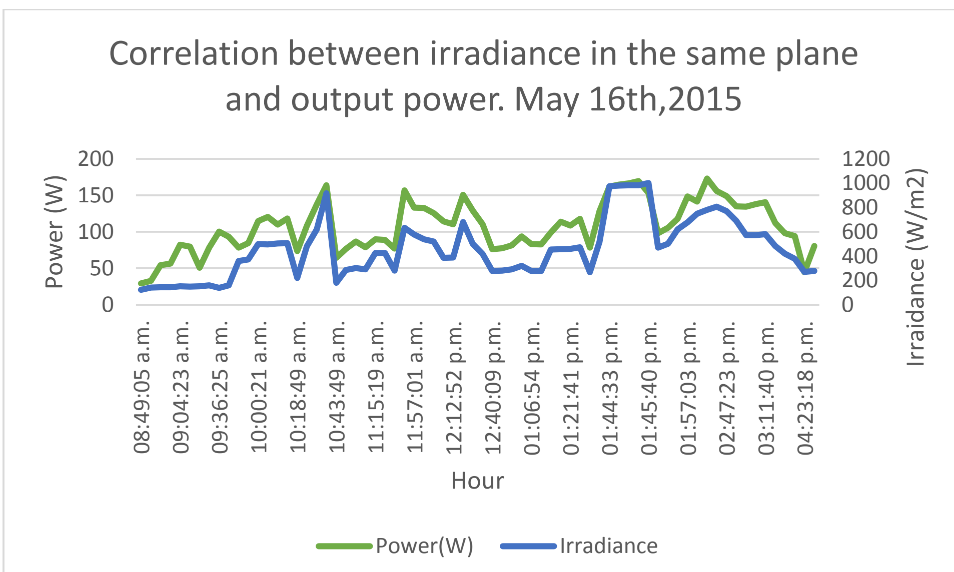


Figure 5-9 Output power and irradiation, May 16th, 2015.

Once it is possible to obtain data for one day, it is possible to see the data obtained for the days when test were performed on the device. Figure 5-10 represents the data obtained for the energy yield during the days that the device was tested.

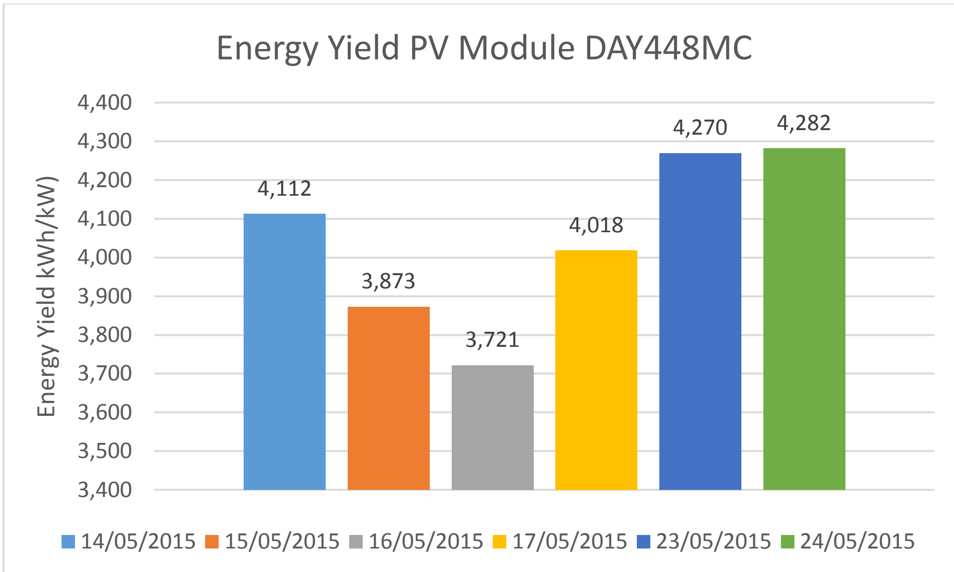


Figure 5-10 Energy Yield.

According with the last figure, for the testing period the energy yield is around 4,04 (kWh/kW) The main differences of this value are related with the weather conditions. To continue with this analysis, Figure 5-11shows the performance ratio obtained during the days of the measurements. The Performance Ratio was estimated according with equation

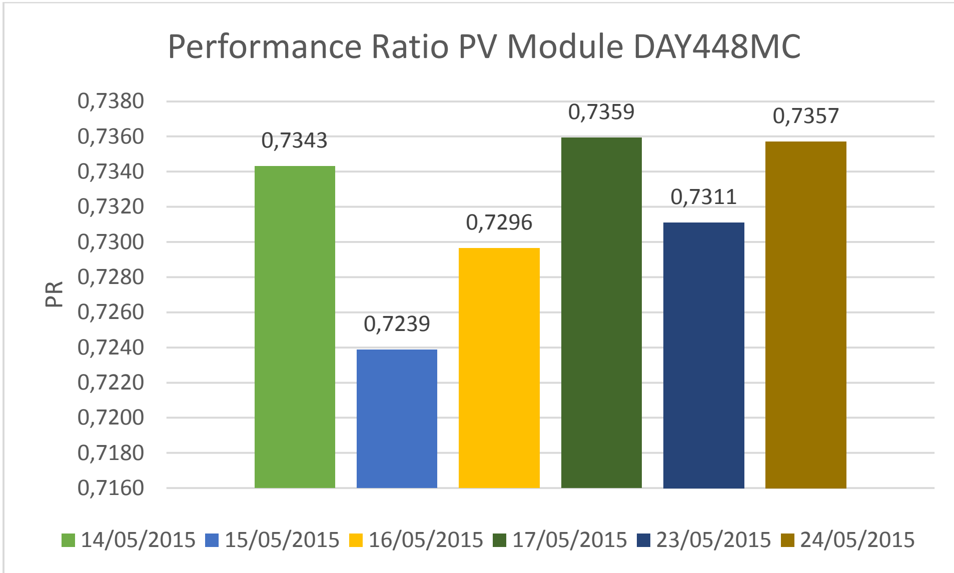


Figure 5-11 Performance Ratio

Chapter 6 Recommendations and conclusions.

6.1 Recommendations

Las Nubes has great potential for photovoltaic generation. And it is the case of all the territory of Costa Rica. The location presents an opportunity to conduct studies no available in the region, as was mentioned above. As a Conservation Center Las Nubes it should position itself as one of the main centers of renewable energy in the region. Starting at the first stage, with solar energy. Right now, in the Conservation Center is started the building called Lillian Meighen Wright Center. This building will serve as a hub for an international research. In this way, it is necessary that the Photovoltaic Performance Verification Plant is integrated with the development of the center.

With this conditions, a group of recommendations are given for the creation of this plant in Las Nubes, as described below:

- Integration to Master Plant with Lillian Meighen Wright Center: this action is important to star working according to guidelines are already in the Center. Also, it is a good deed, to join efforts in the same direction.
- Site Assessment: despite the analysis presented in this chapter, it is necessary to corroborate some of the information in the site. The main mention are:
    - Shading analysis: because the Conservation Center is located in the rainforest, a tall trees can be produced shading and this is an undesirable effect for the efficiency of the plant.
    - Wind load. It is necessary to verify the effect of the wind in this terrain.
    - Soil foundation: it is necessary to see the soil has the capacity to support the structure of the plant. Also is important to make sure about the field has an ideal topographic conditions to development the project.
- Networks of academic cooperation: the main propose of the Center is collaborate with academic development and research in the region. For this case, it is necessary to created links with Costa Rica Universities. With the present project a relationship with Costa Rica Institute of Technology begins to form. This collaboration should be established with other universities, according to the objectives of the center. On the

other hand, a cooperation with other national institutions like ACESOLAR or ICE and international institutions as Kortright or IEC is necessary for improve the scope desired.

- Networks of professional and business collaboration: As a research center, it is indispensable to essential to created alliances with manufacturers, distributors and companies that can obtained the materials for the research. In this case, with the Solar Energy Business. Taking advantage of York University to settle in Canada.
- Funding: much of the current development of the project due to funding. Therefore, it can be considered as good choice for the development of the plant.

6.2 Conclusions

Under the description of the present report, was possible to conclude

- The proposed design of the monitoring system for a Photovoltaics Performance Verification Plant meets with the IEC 61724 and IEC 61853 standards, both in the processability (error less than 0.1%) and accuracy (less than 2%) .
- The field test during the six days of measurement shows shows that the PV panel DAY 448MC have and Energy Yield of 4,04kWh / kW and Performance Ratio 0.73. These results should not be considered binding , due to the period in which the tests are developed
- The proposed mechanical design meets the desired characteristics in the initial budget effort, with a safety factor of 50, at the most critical study.
- Las Nubes, has much potential to have a Verification Photovoltaic Plant . However; you need to perform a series of steps that allow the establishment and operation thereof.

List of References

[1] O. Edenhofer and Intergobernamental Panel on Climate Change, Renewable energy sources and Climate Change Mitigation: Special report of the Intergovernmental Panel on Climate Change, New York: Cambrigde University Press, 2012.

[2] K. Jäger, O. Isabella, A. Smets, R. van Swaaij and M. Zeman, Solar Energy. Fundamentals, Technology and Systems, Delf: Delf University of Technology, 2014.

[3] Instituto Costarricense de Electricidad, "Plan Piloto Generación Distribuida Para Autoconsumo," ICE, San José, 2015.

[4] MINAE, "VI Plan Nacional de Energía 2012-2030," MINAE, San José, 2011.

[5] ARESEP, "AR-NT-POASEN-2014," Imprenta Nacional, La Uruca, San José, 2014.

[6] Fraunhofer-Instiut für Solare Energiesysteme, "STC Measurements," 2015. [Online]. Available: http://www.ise.fraunhofer.de/en/service-units/callab-pv-cells-callab-pv-modules/callab-pv-modules/stc-measurements. [Accessed 10 febrero 2015].

[7] A. Fahrenbruch and R. Bube, Fundamentals of Solar Energy.Photovoltaic Solar Energy Conversion, New York: Academic Press Inc, 1983.

[8] Sustainable Energy Initiative, "Sustainable Energy Initiative, YorkU," 02 Marzo 2012. [Online]. Available: http://sei.info.yorku.ca/. [Accessed 15 Diciembre 2014].

[9] Las Nubes, "About US," Agosto 2014. [Online]. Available: www.lasnubes.org. [Accessed 15 febrero 2014].

[10] Kortight Centre For Conservation, "About us," 2014. [Online]. Available: http://www.kortright.org/. [Accessed 9 febrero 2015].

[11] Sustainable Technologies Evaluation Program, "STEP," 2015. [Online]. Available: http://www.trca.on.ca/the-living-city/programs-of-the-living-city/sustainable-technologies-evaluation-program.dot. [Accessed 03 Enero 2015].

[12] T. Helmut, "Analysis of the Technical Potential and Profiability of Photovoltaic in Costa Rica," M.Sc.Thesis Technical University Of Munich, San Jose, Costa Rica, 2014.

[13] J. Clarkson and C. Eckert, Design process improvement: A review of current practice, London, UK: Springer, 2005.

[14] A. Luque and H. Steven, HandBook of Photovoltaic Science and Engineering, John Wiley & Sons: Chenai, 2011.

[15] S. Wenham, M. Green, M. Watt and R. Corkish, Applied Photovoltaics, London: Earthscan, 2007.

[16] S. Aldous, Z. Yewdall and L. Sam, "A Peek Inside a PV Cell," *Home Power,* vol. I, no. 121, pp. 64-68, 2007.

[17] K. Mertens and G. Roth, Photovoltaics: Fundamentals, Technology and Practice, Chichester: John Wiley & Sons Ltd., 2014.

[18] M. Green, K. Emery, Y. Hishikawa, W. Warta and E. Dunlop, "Solar Cell efficiency tables," *Progress in Photovoltaics: Research and Applications,* vol. 23, no. 1, pp. 1-9, 2015.

[19] T. Esram and P. Chapman, "Comparison of Photovoltaic Array Maximun Power Point Tracking Techniques," *IEEE Transations on Energy Conversion,* vol. 22, no. 2, pp. 439-449, June, 2007.

[20] D. Pysch, A. Mette and W. Glunz, "A review and comparison of different methods to determine the series resistance of solar cells," *Solar Energy & Solar Cells,* no. 96, pp. 1698-1706, 2007.

[21] P. Hernday, "Field Applications for I-V Curves Tracers," SolarPro, August 2011. [Online]. Available: http://solarprofessional.com/articles/design-installation/field-applications-for-i-v-curve-tracers?v=disable_pagination. [Accessed 29 March 2015].

[22] National Center for Photovoltaics, "Home Page," NREL, 01 October 2014. [Online]. Available: http://www.nrel.gov/ncpv/. [Accessed 20 March 2015].

[23] G. Makrides, B. Zinsser, M. Norton and G. Georghiou, "Performance of Photovoltaics Under actual Operating Conditions," InTech, 16 March 2012. [Online]. Available: http://cdn.intechopen.com/pdfs-wm/32596.pdf. [Accessed 02 March 2015].

[24] T. Markvart, "Review Radiation damage in solar cells," *Journal of Material Science: Materials in Electronic,* vol. I, pp. 1-12, 1990.

[25] R. Kenny, G. Friesen, D. Chianese, A. Bernasconi and E. Dunlop, "Energy rating of PV modules: comparison of methods and approach," *Photovoltaic Energy Conversion, 2003. Proceedings of 3rd World Conference. IEEE,* vol. II, pp. 2015-2018, 2003.

[26] E. Skoplaki and J. Palyvos, "On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations," *Solar Energy,* vol. V, no. 83, pp. 614-624, 2009.

[27] D. L. King, J. A. Kratochvil and W. E. Boyson, "Temperature coefficients for PV modules and arrays:measurements methods, difficulties and results," *Photovoltaic Specialist Conference IEEE,* no. 36, pp. 1183-1186, 1997.

[28] NREL, "Weather-Corrected Performance Ratio," April 2013. [Online]. Available: http://www.nrel.gov/docs/fy13osti/57991.pdf. [Accessed 14 April 2015].

[29] H. Häberlin, Photovoltaics System Design and Practice, Berne: John Wiley & Sons, 2012.

[30] Spire Corporation, "Spire showcases Spin-Sun Simulator," 05 September 2011. [Online]. Available: http://www.pv-magazine.com/news/details/beitrag/spire-showcases-spi-sun-simulator_100004190/#axzz3WShKuwRv. [Accessed 22 March 2015].

[31] International Electrotechnical Commision, *IEC IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules-Design qualification and type approval,* Genova: IEC, 2006.

[32] R. Hren, "Understanding PV module Specifications," *Home Power,* vol. I, no. 195, pp. 96-102, 2011.

[33] E. Skoplaki and J. A. Palyvos, "Operating temperature of photovoltaics modules: A survey of pertinent correlations," *Renewable Energy,* vol. I, no. 34, pp. 23-39, 2009.

[34] International Electrotechnical Commission, *IEC 61724: Photovoltaic system performance monitoring-Guidelines for measurements, data exchange and analysis,* Geneva: IEC, 1998.

[35] B. Marion, J. Adelstein, K. Boyle, H. Hayden, B. Hammond, T. Fletcher, B. Canada, D. Narang, D. Shugar, H. Wenger, A. Kimber, L. Mitchell, G. Rich and T. Townsend, "Performance Parameters for Grid-Connected PV Systems," in *Procedings of the 31st IEEE Photovoltaics Specialists Conference,* Lake, Buena Vista, USA, 2005.

[36] T. Tsanakas, M. Karoglou, E. T. Delegou, P. N. Botsaris, A. Bakolas and A. Moropoulou, "Assesment of the Performance and Defect Investigation of PV Modules after Accelerated Ageing Test," *Renewable Energy and Power Quality Journal,* vol. X, no. 11, March, 2013.

[37] G. TamizhMani, K. Paghasian, J. Kuitche, M. Gupta Vemula and G. Sivasubramanian, "Photovoltaic Module Power Rating per IEC 61853-1 Standard: A Study Under Natural Sunlight," Arizona State University. Photovoltaic Reliability Laboratory (PRL), Arizona, 2011.

[38] Sustainable Technologies Evaluation Program, "Photovoltaics Performance Verification," Toronto and Region Conservation, 2012. [Online]. Available: https://www.thelivingcitycampus.com/solar-city-partnership-pvpv. [Accessed 28 February 2015].

[39] International Electrotechnical Commision, *IEC 61853-1: Photovoltaic (PV) module performance testing and energy rating- Part 1:Irradiance and temperature performance measurements and power rating*, Geneva: IEC, 2011.

[40] Arduino, "Arduino Mega 2560," Arduino, 2015. [Online]. Available: http://arduino.cc/en/Main/arduinoBoardMega2560. [Accessed 28 February 2015].

[41] B. Drafts, "Methods of Current Measurement," 2010. [Online]. Available: http://fwbell.com/downloads/files/Methods_Current_Measurement.pdf. [Accessed 28 March 2015].

[42] Allegro Microsystems, "Fully Integrated, Hall Effect-Based Linear Current Sensor IC with 2.1 kVRMS Isolation and a Low-Resistance Current Conductor," 2013. [Online]. Available: http://www.allegromicro.com/~/media/Files/Datasheets/ACS712-Datasheet.ashx. [Accessed 05 March 2015].

[43] Measurement Computing, Data Adquisition Handbook, United States of America: Measurement Computing, 2012.

[44] Vishay Foil Resistors, "High Precision Foil Resistor with TCR of 2ppm/ °C," 02 March 2015. [Online]. Available: http://www.vishaypg.com/docs/63001/63001.pdf. [Accessed 30 March 2015].

[45] RDF Corporation, "PT 100 Platinum Resistance Temperature Detector 22810 "StikonTM"," 2014. [Online]. Available: http://pdf.datasheetarchive.com/indexerfiles/Datasheet-029/DSA00508973.pdf. [Accessed 20 March 2015].

[46] Apogee Instruments, "Owner´s Manual Pyranometer, Models SP-212 and SP-215," 2014. [Online]. Available: http://www.apogeeinstruments.co.uk/content/SP-212_215manual.pdf. [Accessed 13 April 2015].

[47] Meteorological Service of Canada, "Toronto Wheater Forecast," Goverment of Canada, 2015. [Online]. Available: https://weather.gc.ca/city/pages/on-143_metric_e.html. [Accessed 04 May 2015].

[48] Adafruit, "Digital-Output relative humidity & temperature sensor/module," 2014. [Online]. Available: http://www.adafruit.com/datasheets/DHT22.pdf. [Accessed 20 April 2015].

[49] APPCON Technologies, "APC Series Transparent Transceiver Module," 12 March 2008. [Online]. Available: http://www.dfrobot.com/image/data/TEL0005/APC220_Datasheet.pdf. [Accessed 20 March 2015].

[50] Gobierno de Costa Rica, "Ley General de Telecomunicaciones," 30 June 2008. [Online]. Available: http://www.imprentanacional.go.cr/pub/2008/06/30/COMP_30_06_2008.pdf. [Accessed 20 April 2015].

[51] Adafruit, "SD Card Slot Reading-Writing," 2014. [Online]. Available: www.adafruit.com. [Accessed 10 April 2015].

[52] Extech Instrumentes, "Compact Multimeters EX310," 2014. [Online]. Available: http://www.extech.com/instruments/resources/datasheets/EX300series.pdf. [Accessed 28 April 2015].

[53] Analog Devices, "Monolithic Thermocouple Amplifiers with Cold Junction Compensation," 1999. [Online]. Available: http://www.analog.com/media/en/technical-documentation/data-sheets/AD594_595.pdf. [Accessed 25 April 2015].

[54] National Centers For Enviromental Information, "Magnetic Field Calculators: Declination," National Oceanic and Atmospheric Administration, 2015. [Online]. Available: http://www.ngdc.noaa.gov/geomag-web/#declination. [Accessed 1 May 2015].

[55] GeoModel Solar, "SolarGIS," GeoModelSolar, 2015. [Online]. Available: http://solargis.info/. [Accessed 2 May 2015].

[56] M. Ebert, H. Stascheit, I. Hädrich and E. Urlich, "The impact of angular dependent loss measurement on PV module energy yield prediction," in *29th European PV Solar Energy Conference and Exhibition*, Amsterdam, 2014 .

[57] PVEducation, "Solar Radiation on a Tilted Surface," PVEducation.org, 2014. [Online]. Available: http://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-tilted-surface. [Accessed 1 May 2015].

[58] Solar Radiation Monitoring Laboratory, "Sun Path Chart Program," University of Oregon, March 2007. [Online]. Available: http://solardat.uoregon.edu/SunChartProgram.html. [Accessed 2 May 2015].

[59] J. Gutierrez, "Evaluación por código de viento: Costa Rica," 2010. [Online]. Available: http://www.disaster-info.net/PED-

Sudamerica/leyes/leyes/centroamerica/costarica/otranorm/Evaluacion_Codigo_por_Viento.pdf. [Accessed 30 Apr 2015].

[60] Ironrigde, "Engineering Design Guide," 2015. [Online]. Available: http://files.ironridge.com/groundmounting/IronRidge_GM_EngineeringDesignGuide.pdf. [Accessed 26 April 2015].

[61] W. Tomasi, Electronic Communications Systems: Fundamentals trough advance, New Jearsey: Pearson/Prentice Hall, 2004.

[62] 4GonSolutions, "Fresnel Zones," 2015. [Online]. Available: http://www.4gon.co.uk/solutions/technical_fresnel_zones.php. [Accessed 05 May 2015].

[63] Sun Earth Tools, "Sun Path," Sun Eart Tools, 2015. [Online]. Available: http://www.sunearthtools.com/dp/tools/pos_sun.php?lang=en. [Accessed 3 May 2015].

A. Appendixes

A-1 Glossary

Air Mass (AM): a body of air with horizontally uniform temperature, humidity and pressure. In terms of Solar Energy, defines the direct optical path length through the Earth´s atmosphere.

Azimuth: the direction of a celestial object from the observer, in this case the Sun. It is expressed as the angular distance from the north point to the point at which a vertical circle passing through the object intersects horizon.

Bottom up: Design technique that taking the design proceeding from the bottom of a hierarchy upward or from the beginning of a process forward.

CAD (Computer-Aided Design): refers to the software that can be used to create a two dimensional drawings or three-dimensional (3D) models.

Electron/Hole diffusion: the net movement of the electrons from region of high concentration to a region of low concentration.

Finite Element Analysis: is related with a study developed by a computer system that uses the finite element method to analyze a material or object and find how applied stresses will affect the material or design.

Hall Effect: the production of a potential difference across an electrical conductor when magnetic field is applied in a direction perpendicular to that flow of current.

ICE (Spanish: Instituto Costarricense de Electricidad): there is the institution in charge to provided solutions of electricity and telecommunications in Costa Rica.

IEC (International Electrotechnical Commission): is the international standards and conformity assessment body for all fields of electrotechnology.

Internal Spectral Response: is the number of electron-hole pairs colleted under short circuit conditions relative to the number of photons entering the material.

Irradiance: the flux of radiant energy per unit area (normal to the direction of radiant energy)

Moving Average: a succession of averages derived from successive segments of series of values.

POASEN (Spanish: Plan de Operacion y Administración del Sistema Eléctrico Nacional). Regulation which is currently under discussion in Costa Rica, which regulates the national electricity system and has a photovoltaic solar energy regulations.

PV (photovoltaic): related to the production of electric current at the junction of two substances exposed to light.

PVPV: Photovoltaics Performance Verification Program located at Kortright Center.

Photoelectric effect: emission or ejection of electrons from the surface of, generally, a metal in response to incident light.

Thin Film: a second generation solar cell that is made by depositing one or more thin layers.

Serial Port: a connector by which a device that sends data one bit at a time may be connected to a computer.

Sun path: refers to the apparent significant seasonal and hourly positional changes of the Sun as the Earth rotates.

Von Misses Stress: A mechanical design criterion suggest that the yielding of the materials begins when the second deviatoric stress invariants reaches a critical value.

Zenith: the highest point reached by a celestial or other object.

A-2 RF Link Budget

The implementation of the project have not a specifically location inside the conservation area. For the calculation of Fresnel Zone, it takes into account that both transmitter and receiver in pure line sight unobstructed. [61] That is the most recommended configuration. Fresnel Zone are illustrated in figure A-1.

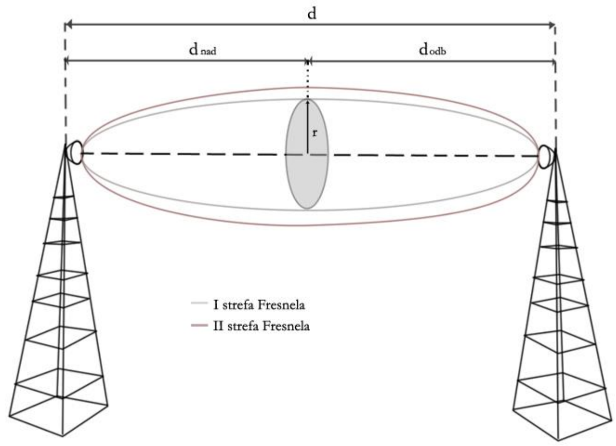


Figure A-1. Fresnel Zone *[62]*

The calculation of the Fresnel Zone are given by:

$$r_n = \sqrt{\frac{n * \lambda * d_1 * d_2}{d_1 + d_2}}$$

(A2-1)

To do simple this calculation, for the first zone, it is assumed n=1, the transmitter distance (d1) and receptor distance (d2). So D are in kilometers and f in GHz: converting A2-1 into:

$$r_1 = 8.657\sqrt{\frac{D}{f}}$$

(A2-2)

According the section 4.2.6 D=1 Km and f=0,434 GHz, whereby the first radius of Fresnel Zone is 13,14m. This value can use like a first approximation to predict the reliability of the line sight. It is necessary to have a proportion higher than 60%. This means that the location should have a clear height bigger than 7,8m.

The power between transmitter and receptor are given simplified by equation A2-3, since the data sheet provides information loss between devices:

$$P_{Rx} = P_{Tx} + G_{Tx} - L_{fs} + G_{RX}$$

(A2-3)

Where:

$P_{Rx:}$ Receptor Power (dBm)
P_{Tx}: Transmitter Power (dBm)
G_{Tx}: Transmitter Gain (dBi)
L_{Fs}: Free space loss (dB)
G_{Rx}: Receptor Gain (dBi)

The free space loss are given by equation A2-3:

$$L_{FS} = 32{,}45(dB) + 20 \cdot \log(f \cdot D)$$

(A2-4)

The frequency f are given in MHz and the distance D are given in km. For the RF modules selected the free space loss are 125,19dB and the receptor power are 13dBm, equivalent to 19,95mW. This value meets with the Costa Rica Law, whose maximum allowed value is 250mW.

A-3 Configuration of RF Modules.

Appcon Technologies provides an own tool to configure the APC220 RF modules this software called RF Magic. This software allows set up all the parameters of the modules. This modules also includes a USB adapter for a better connection with the computer.

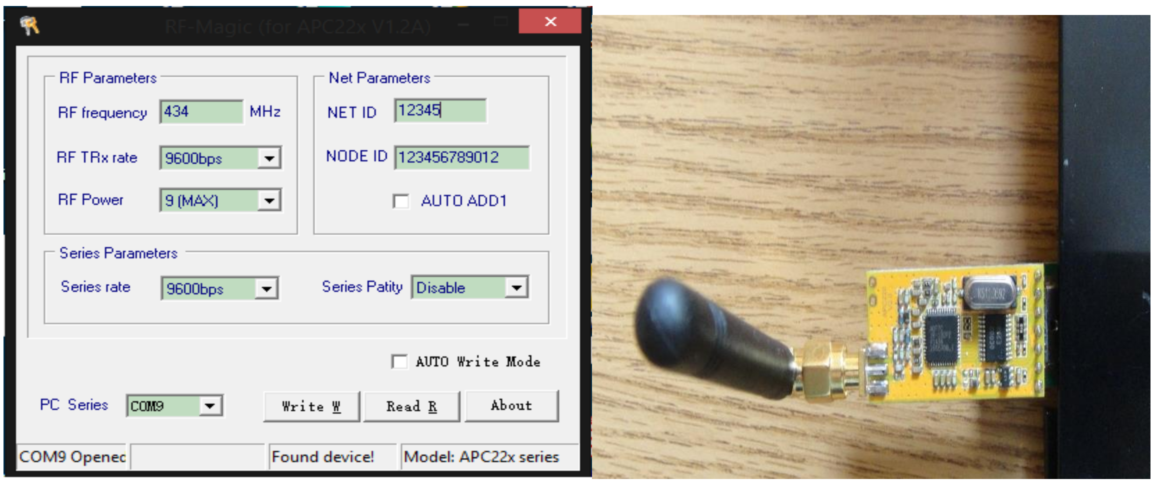


Figure A-2 APC220 RF Modules configuration

For the implementation test. There is used the next parameters.

RF Frecuency: 434 MHz

RF TRx rate: 9600 bps

RF Power Level: 9(Max)

Series rate 9600 bps

Series Patity: Disable

NET ID: 12345

NODE ID 123456789012 (module CPU) and 123456789011 (module 2 MCU)

A-3 Tables sources of Figure 4-25 & Figure 4-26

Table A-1 Global Horizontal Irradiation and air temperature estimated by SolarGIS

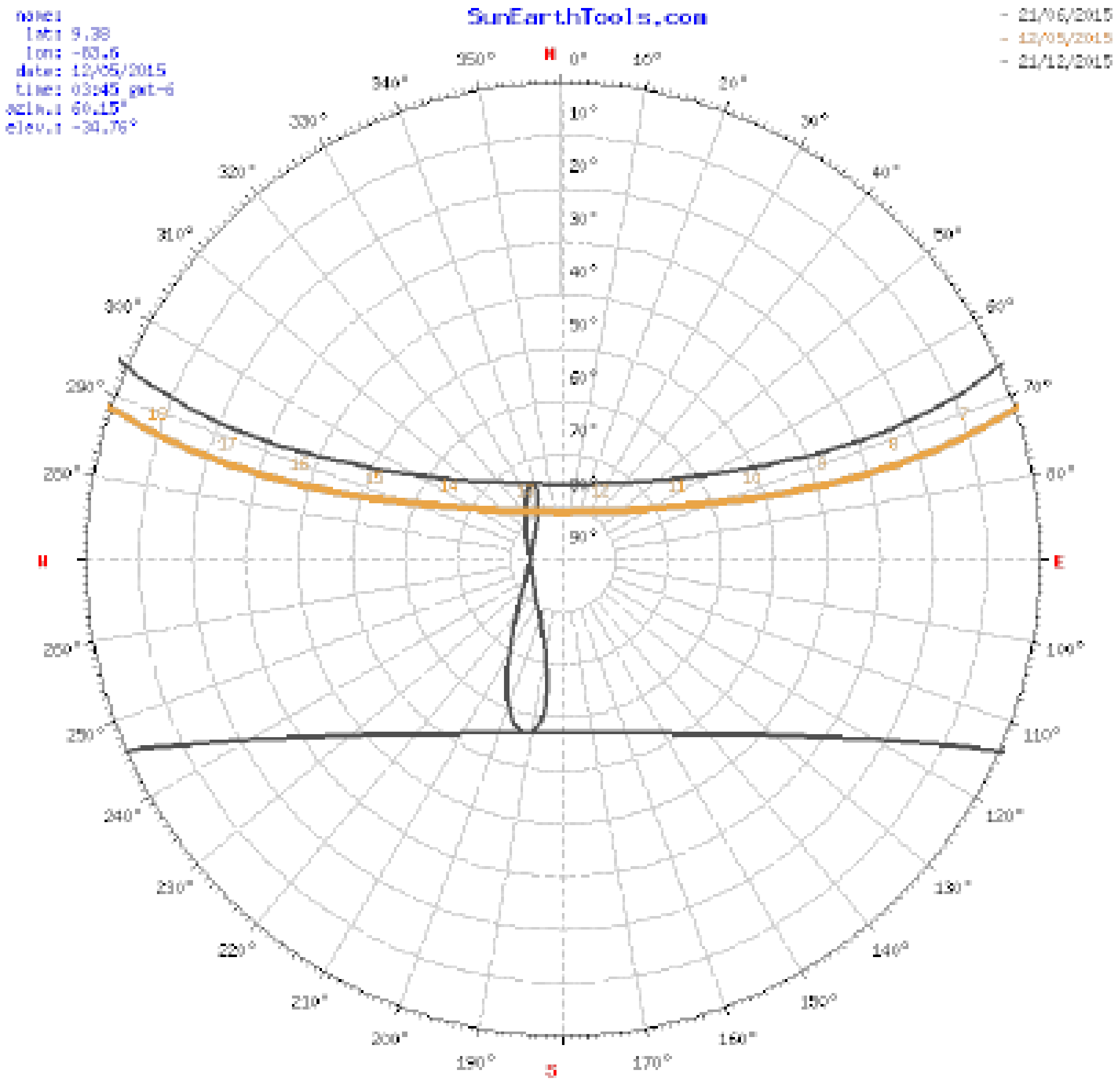
Month	Monthly sum of global irradiation [kWh/m^2]	Daily sum of global irradiation [kWh/m^2]	Daily sum of diffuse irradiation [kWh/m2]	Daily (diurnal) air temperature [°C]
Jan	150,5	4,85	2,03	19,0
Feb	155,5	5,55	2,10	19,4
Mar	177,6	5,73	2,32	20,0
Apr	155	5,17	2,51	20,3
May	153,4	4,95	2,56	19,8
Jun	145,4	4,85	2,57	19,6
Jul	146,4	4,72	2,66	19,3
Aug	149	4,81	2,58	19,4
Sep	143	4,77	2,44	19,4
Oct	129	4,16	2,40	19,1
Nov	115,5	3,85	2,21	18,8
Dec	129,1	4,16	2,05	18,8
Year	1749,4	4,79	2,37	19,4

Table A-2 Global in Plane Horizontal Irradiation estimated by SolarGIS

Month	Monthly sum of global irradiation [kWh/m2]	Daily sum of global irradiation [kWh/m2]	Daily sum of diffuse irradiation [kWh/m2]	Daily sum of reflected irradiation [kWh/m2]	Losses of global irradiation by terrain shading [%]
Jan	163,5	5,27	2,14	0,0	1,00
Feb	164,8	5,89	2,19	0,0	0,90
Mar	181,3	5,86	2,38	0,0	0,70
Apr	152,9	5,09	2,51	0,0	0,70
May	147,8	4,76	2,53	0,0	0,80
Jun	138,4	4,61	2,53	0,0	0,80
Jul	140,5	4,52	2,62	0,0	0,90
Aug	145,6	4,69	2,57	0,0	0,70
Sep	143,9	4,79	2,47	0,0	0,80
Oct	133,7	4,31	2,46	0,0	1,20
Nov	122,9	4,10	2,29	0,0	1,00
Dec	140,5	4,52	2,15	0,0	1,00
Year	1775,8	4,86	2,40	0,0	0,90

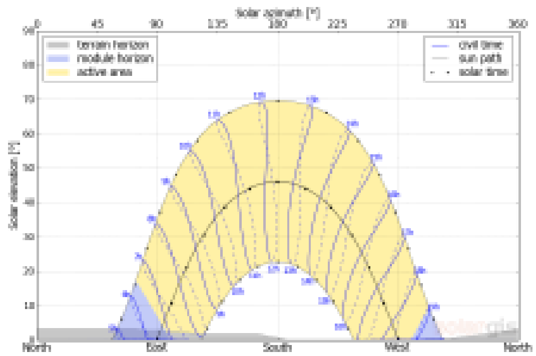
A-4 Alternative representation of Sun Path

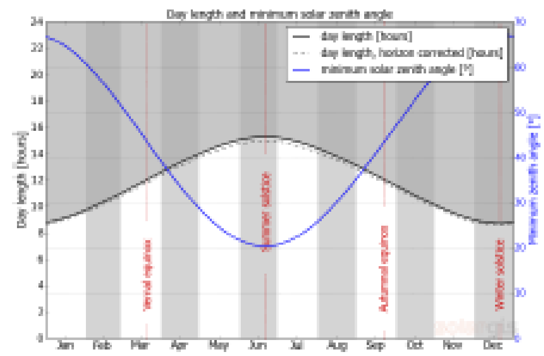
The present representation is obtained by the online tool developed by Sun EarthTools [63]



A-5. Solar Gis analysis for the location of the field test in York University.

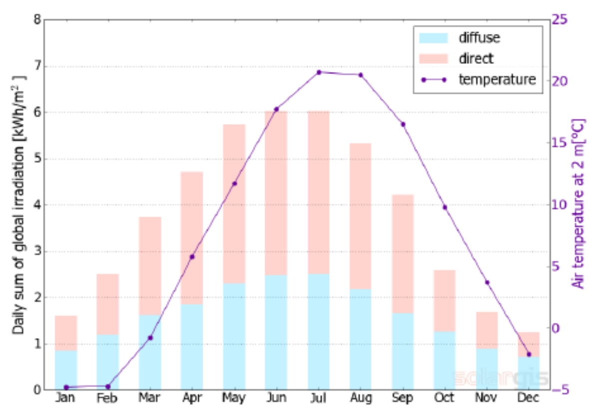
SUN PATH





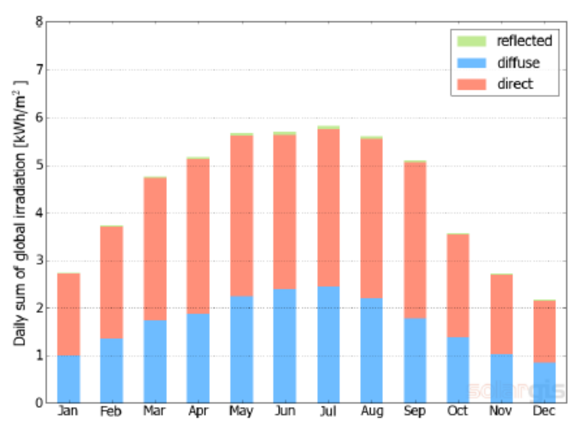
Global Horizontal Irradiation

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	50	1.60	0.84	-4.8
Feb	70	2.50	1.19	-4.7
Mar	116	3.74	1.61	-0.8
Apr	141	4.70	1.83	5.8
May	178	5.74	2.30	11.7
Jun	181	6.02	2.48	17.7
Jul	187	6.02	2.51	20.7
Aug	165	5.32	2.18	20.5
Sep	126	4.21	1.66	16.5
Oct	80	2.58	1.26	9.8
Nov	51	1.68	0.89	3.7
Dec	39	1.25	0.71	-2.1
Year	**1382**	**3.79**	**1.62**	**7.9**



Global in-plane irradiation

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	85	2.73	0.99	0.02	0.3
Feb	104	3.73	1.35	0.03	0.2
Mar	148	4.76	1.73	0.04	0.2
Apr	155	5.17	1.87	0.05	0.2
May	176	5.68	2.24	0.06	0.2
Jun	171	5.70	2.38	0.07	0.2
Jul	180	5.82	2.44	0.07	0.2
Aug	174	5.60	2.20	0.06	0.2
Sep	153	5.10	1.78	0.05	0.2
Oct	111	3.57	1.38	0.03	0.2
Nov	81	2.71	1.02	0.02	0.3
Dec	67	2.16	0.84	0.01	0.3
Year	**1605**	**4.40**	**1.69**	**0.04**	**0.2**



A-6. Project Drawings

GE 01.00.00

Code	Format	Sheet	Description
GE 001	A4	1	General Index
ED 01.01.00	A3	2	One Line Diagram
ED 01.02.00	A3	3	Overall Electronic Diagram
MS 01.01.00	A3	4	Mounting System: General
MS.01.01.01	A3	5	Mounting System: Details

Las Nubes

YORK U UNIVERSITÉ UNIVERSITY

PROJECT
Monitoring system for Photolvoltaics Performance Verification Plant Las Nubes Project

Design: H.Sánchez Ortiz

Draw: H.Sánchez Ortiz

GE 01.00.00

INDEX

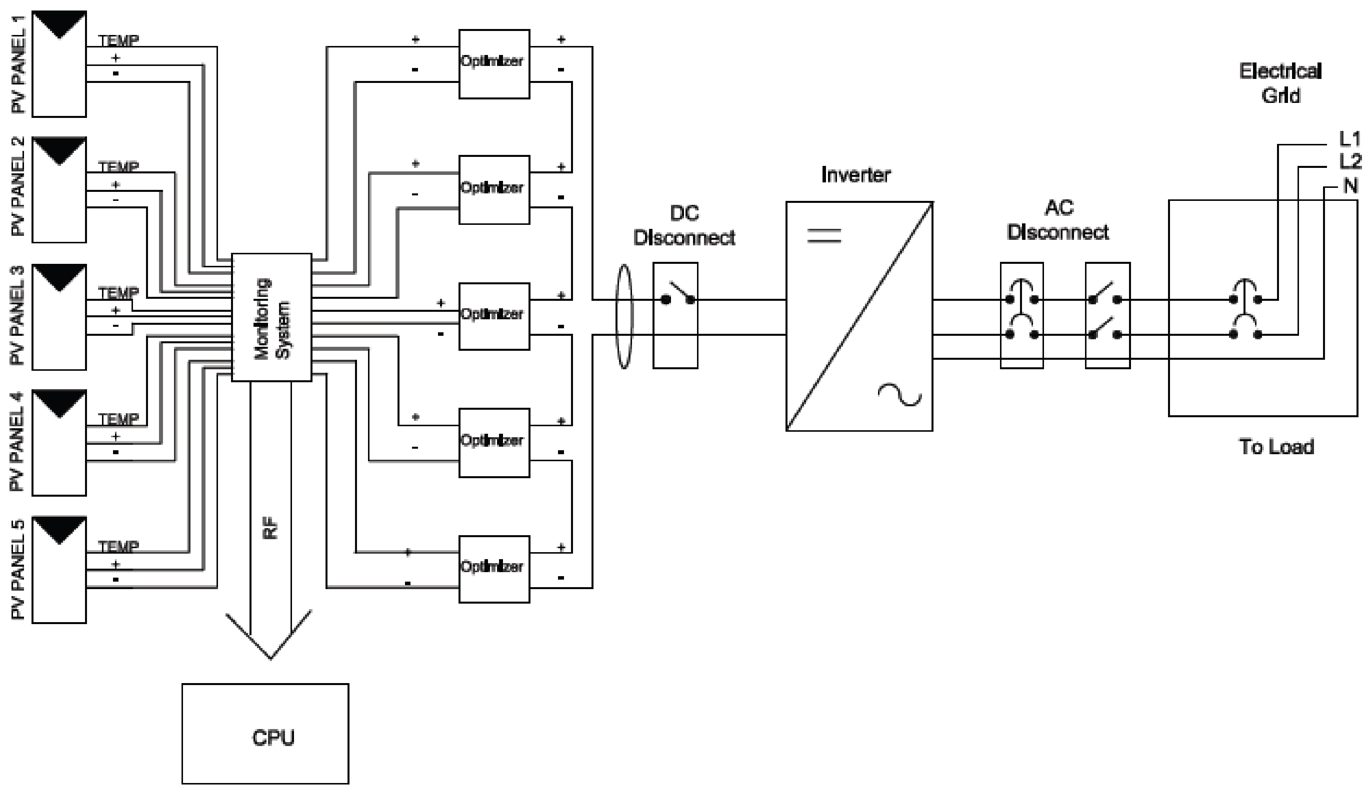
Key Notes:

System

Units	Scale	Sheet
NA	NA	1 of 5

Date: 20150601

ED 01.01.00



Las Nubes

YORK UNIVERSITÉ UNIVERSITY

PROJECT
Monitoring system for Photolvoltaics Performance Verification Plant Las Nubes Project

Design H.Sánchez Ortiz
Signat.
Draw H.Sánchez
Signat.

ED 01.01.00

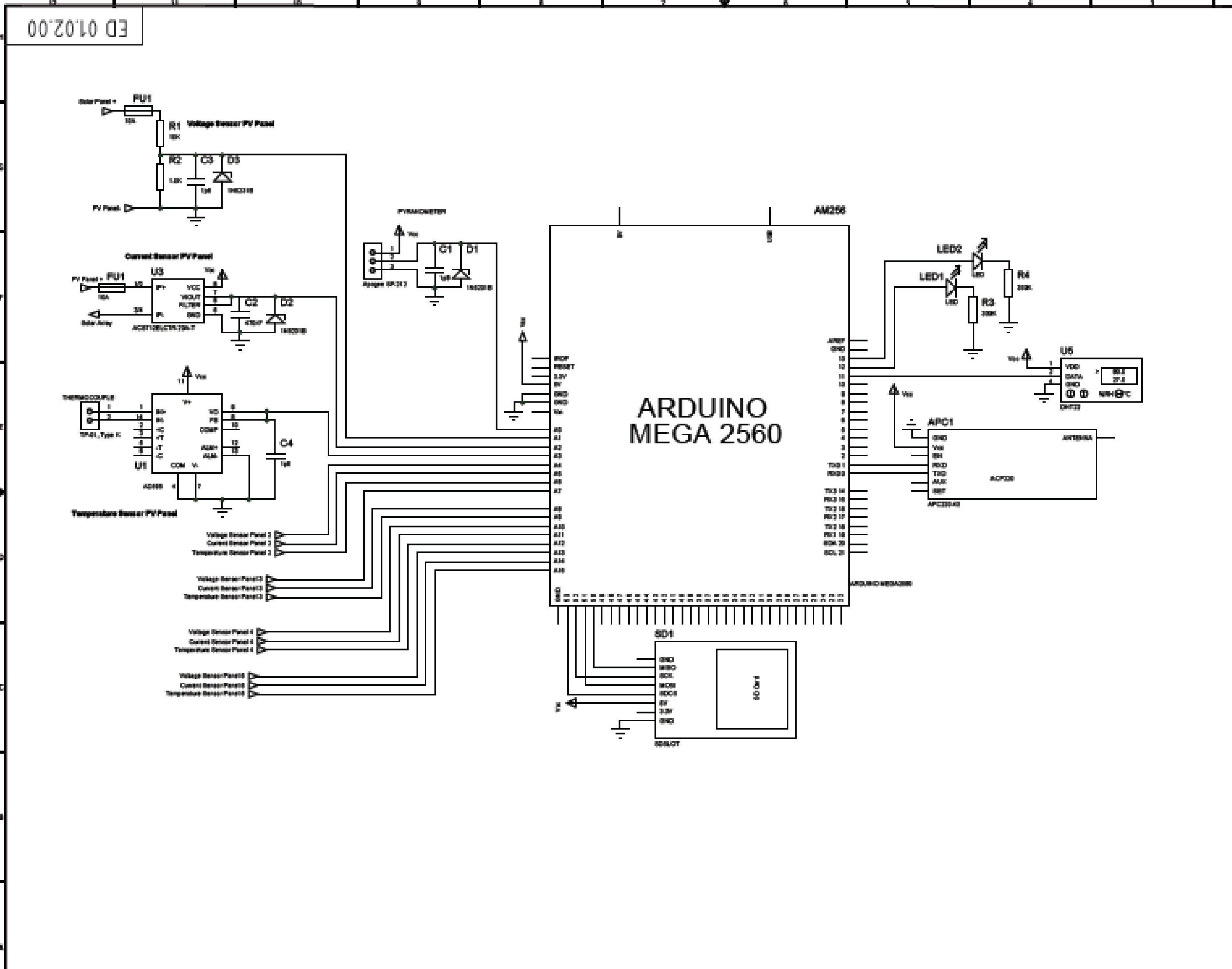
One Line Diagram

Key Notes:
General Diagram Representation of One Line Diagram.

Units	Scale	Sheet
Meters	NA	2 of 5

Date: 20150601

j



Las Nubes

YORK UNIVERSITÉ UNIVERSITY

PROJECT
Monitoring system for Photolvoltaics Performance Verification Plant Las Nubes Project

Design	H.Sánchez Ortiz
Draw	H.Sánchez

ED 01.02.00

Overall Electronic Diagram

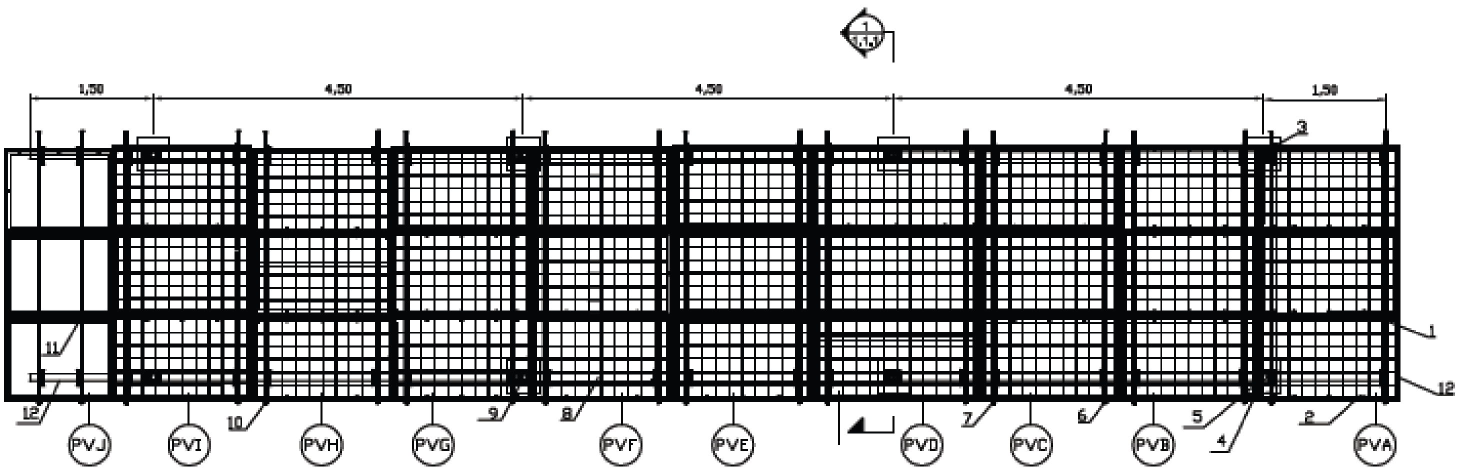
Key Notes:

Units	Scale	Scale
NA	NA	3 of 5

Date: 20150601

k

MS01.01.00



TMS1

Format	Position	Designation	Denomination	Qty.	Notes
A3		MS.01.01.00	General Drawing		
A3		MS.01.01.01	Section Detail		
			Parts		
A3	1	MS.01.01.02	Mid Clamp 50mm	20	Plan Provide By IronRigde
A3	2	MS.01.01.03	PV Panel	30	Distribution details in TMS2
A3	3	MS.01.01.04	Back Column	4	Schedule 40 Steel Pipe 3"
A3	4	MS.01.01.05	Front Column	4	Schedule 40 Steel Pipe 3"
A3	5	MS.01.01.06	Concrete Foundation	8	2500 PSI Concrete
A3	6	MS.01.01.07	XRS Rail 11'	20	Plan Provide By IronRigde
A3	7	MS.01.01.08	End Clamp 50mm	12	Plan Provide By IronRigde
A3	8	MS.01.01.09	Cross Rail B	2	Schedule 40 Steel Pipe 3"
A3	9	MS.01.01.10	Top Cap	8	Plan Provide By IronRigde
A3	10	MS.01.01.11	End Clamp 40mm	28	Plan Provide By IronRigde
A3	11	MS.01.01.12	Mid Clamp 40mm	28	Plan Provide By IronRigde
A3	12	MS.01.01.13	Cross Rail A	4	Schedule 40 Steel Pipe 3"
	13	MS.01.01.14	Conector Rail	40	Plan Provide By IronRigde

TMS2

Code	Manufacturer	Model	End/MidClamp Used
PVA	ET Solar	P660 250	50mm
PVB	Aleo	S18J250	50mm
PVC	Lorentz	LC250-P60	40mm
PVD	Jinko	JK310P-72	40mm
PVE	Kyocera	KD255	50mm
PVF	Yingli Solar	YGE60	40mm
PVG	Sunrise	P660 250	40mm
PVH	Canadian Solar	CS6P-250	40mm
PVI	Renesola	Virtus 260w	40mm
PVJ	Solar Frontier	CHSMM6610M	40mm

Las Nubes

YORK UNIVERSITÉ UNIVERSITY

PROJECT
Monitoring system for Photolvoltaics Performance Verification Plant Las Nubes Project

Design	H.Sánchez Ortiz	
Signat.		
Draw	H.Sánchez	
Signat.		

MS 01.01.00

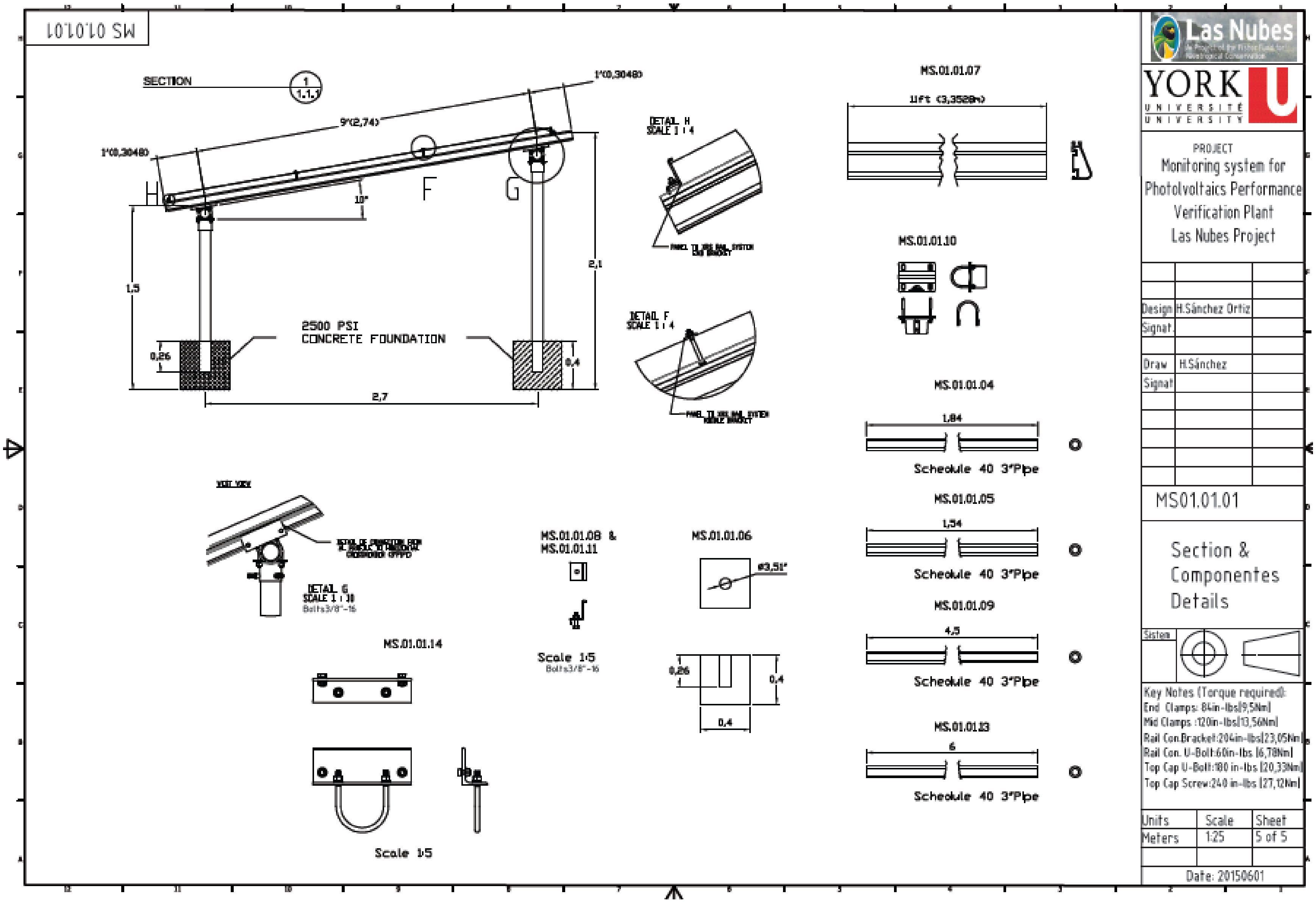
Mounting System General

Sistem

Key Notes
Per ASCE 7-05/Wind Loading
Maximum Panel Weight is 144 Pa
XRS Rail, Aluminium Aloy 6105
Panel Hardware 18-8
Pipe A53 GR

Units	Scale	Sheet
Meters	1:50	4 of 5

Date: 20150601


MS 01.01.01
SECTION
1
1.1.1
9'(2,74)
1'(0,3048)
10°
F
G
H
1,5
2,1
0,26
0,4
2,7
2500 PSI
CONCRETE FOUNDATION
DETAIL H
SCALE 1 : 4
DETAIL F
SCALE 1 : 4
DETAIL G
SCALE 1 : 10
Bolts3/8"-16
MS.01.01.07
11ft (3,3528m)
MS.01.01.10
MS.01.01.04
1,84
Schedule 40 3"Pipe
MS.01.01.05
1,54
Schedule 40 3"Pipe
MS.01.01.09
4,5
Schedule 40 3"Pipe
MS.01.01.13
6
Schedule 40 3"Pipe
MS.01.01.08 &
MS.01.01.11
Scale 1:5
Bolts3/8"-16
MS.01.01.06
ø3,51"
0,26
0,4
0,4
MS.01.01.14
Scale 1:5
Las Nubes
YORK U
UNIVERSITÉ
UNIVERSITY
PROJECT
Monitoring system for
Photolvoltaics Performance
Verification Plant
Las Nubes Project
Design H.Sánchez Ortiz
Signat.
Draw H.Sánchez
Signat
MS01.01.01
Section &
Componentes
Details
Sistem
Key Notes (Torque required):
End Clamps: 84in-lbs(9,5Nm)
Mid Clamps :120in-lbs(13,56Nm)
Rail Con.Bracket:204in-lbs(23,05Nm)
Rail Con. U-Bolt:60in-lbs (6,78Nm)
Top Cap U-Bolt:180 in-lbs (20,33Nm)
Top Cap Screw:240 in-lbs (27,12Nm)
Units Meters
Scale 1:25
Sheet 5 of 5
Date: 20150601

m

A-7. Cost of the project

The cost of the project are divided in two areas. The monitoring system and the mounting system. The presents table only the cost of the materials used in the project.

Table A-3 Cost of the materials for the monitoring system

Qty.	**Description**	**Brand**	**Model**	**Price (CAD$)**
1	Microcontroller	Arduino	Arduino Mega 2560	55
5	Current Sensor	Allegro Microsystems	ACS712ELC-20A	40,47
5	High Precision Foil Resistor 10K	Vishay	Y07851K00000T9L	80,11
5	High Precision Foil Resistor 1K	Vishay	Y07851K00000T9L	80,11
5	Thermocouple PT-01 Type K		TP01	42,5
5	Amplifier Thermocouple	Analog Devices	AD595	63
1	RH & Temperature Sensor	Aosong Electronics	DHT22	5
1	RF module with antenna	Appcon Technologies	APC220	36
1	SD Memory Stick	Sparkfun		2,68
2	LED Lights		5mm	2
5	Zener Diode			0,6
10	10A Fuses 20mm	Cartrige		10,02
10	Fuse Case	Cartrige		4,80
1	Perfored Board			1
1	Lithium Ion 3.7 V 5000 mAh Battery	AltiTech		35,35
1	Lipo Charger			11,99
1	Boost Converter			5,95
	Resistors and Capacitor (Varies sizes)			5
Total				481,58

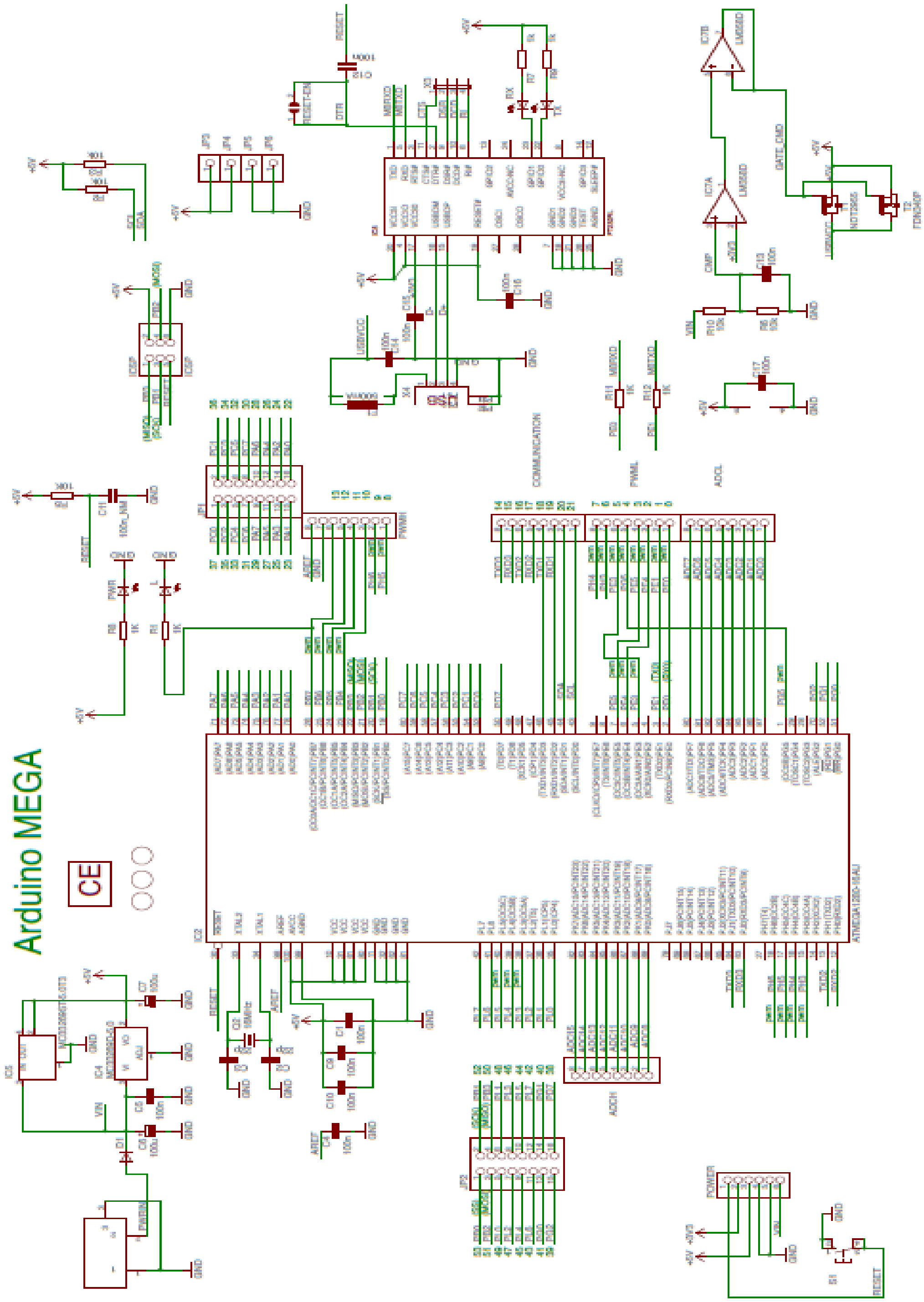
Table A-4 Cost of the Mounting System

Quantity	Part No.	Description	Price (CAD$)
20	XR-1000-132A	XR 1000 Rail 11'	1896
40	29-7001-000	SGA Rail Connector 3"	864
8	70-0300-SGA	SGA Top Cap 3"	624
20	29-4000-002	WEEB Grounding Lug	200
40	29-400-001	WEEB Compression Clip	84
3	29-4000-007	Wire Clips	50,4
2	XR-1000-CAP	End Clamps	36
10	29-7000-204	4-pack, End Clamp	144
10	29-70TB-108	4 pack, Mid Clamp	108
9		Schedule 40 Steel Pipe 3"	540
5		Concrete Bags	100
Total			4646,4

B. Annexes

B.1 Components Datasheets

B.1.1 Schematics of Arduino Mega



B.1.2 ASC712 Datasheet (Relevant Information)

Description (continued)

the device at up to 5× overcurrent conditions. The terminals of the conductive path are electrically isolated from the signal leads (pins 5 through 8). This allows the ACS712 to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques.

The ACS712 is provided in a small, surface mount SOIC8 package. The leadframe is plated with 100% matte tin, which is compatible with standard lead (Pb) free printed circuit board assembly processes. Internally, the device is Pb-free, except for flip-chip high-temperature Pb-based solder balls, currently exempt from RoHS. The device is fully calibrated prior to shipment from the factory.

Selection Guide

Part Number	Packing*	T_A (°C)	Optimized Range, I_P (A)	Sensitivity, Sens (Typ) (mV/A)
ACS712ELCTR-05B-T	Tape and reel, 3000 pieces/reel	–40 to 85	±5	185
ACS712ELCTR-20A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±20	100
ACS712ELCTR-30A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±30	66

*Contact Allegro for additional packing options.

Absolute Maximum Ratings

Characteristic	Symbol	Notes	Rating	Units
Supply Voltage	V_{CC}		8	V
Reverse Supply Voltage	V_{RCC}		–0.1	V
Output Voltage	V_{IOUT}		8	V
Reverse Output Voltage	V_{RIOUT}		–0.1	V
Output Current Source	$I_{IOUT(Source)}$		3	mA
Output Current Sink	$I_{IOUT(Sink)}$		10	mA
Overcurrent Transient Tolerance	I_P	1 pulse, 100 ms	100	A
Nominal Operating Ambient Temperature	T_A	Range E	–40 to 85	°C
Maximum Junction Temperature	T_J(max)		165	°C
Storage Temperature	T_{stg}		–65 to 170	°C

Isolation Characteristics

Characteristic	Symbol	Notes	Rating	Unit
Dielectric Strength Test Voltage*	V_{ISO}	Agency type-tested for 60 seconds per UL standard 60950-1, 1st Edition	2100	VAC
Working Voltage for Basic Isolation	V_{WFSI}	For basic (single) isolation per UL standard 60950-1, 1st Edition	354	VDC or V_{pk}
Working Voltage for Reinforced Isolation	V_{WFRI}	For reinforced (double) isolation per UL standard 60950-1, 1st Edition	184	VDC or V_{pk}

* Allegro does not conduct 60-second testing. It is done only during the UL certification process.

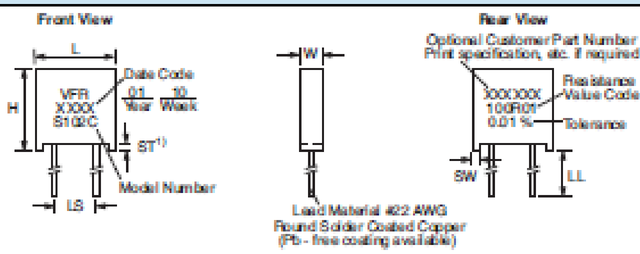
Parameter	Specification
Fire and Electric Shock	CAN/CSA-C22.2 No. 60950-1-03 UL 60950-1:2003 EN 60950-1:2001

B.1.3 Vishay Foil Resistors Datasheet (Relevant Information)

S Series

VISHAY FOIL RESISTORS
A VPG Brand

FIGURE 2 - STANDARD IMPRINTING AND DIMENSIONS



Note
1. Standoffs provided to allow proper flushing of flux, debris, and contaminates from under resistor after all solder operations.
2. The standoffs shall be so located as to give a lead clearance of 0.010" minimum between the resistor body and the printed circuit board when the standoffs are seated on the printed circuit board.

TABLE 2 - MODEL SELECTION

MODEL NUMBER	RESISTANCE RANGE (Ω)	MAXIMUM WORKING VOLTAGE	AMBIENT POWER RATING at + 70 °C	AMBIENT POWER RATING at + 125 °C	AVERAGE WEIGHT IN GRAMS	DIMENSIONS INCHES	DIMENSIONS mm	DIMENSIONS F [1] (INCHES)	TIGHTEST TOLERANCE VS. LOWEST RESISTANCE VALUE
S102C (S102J) [2]	1 to 150K	300	0.6 W up to 100K	0.3 W up to 100K	0.6	W: 0.105 ± 0.010 L: 0.300 ± 0.010 H: 0.326 ± 0.010 ST: 0.010 min. SW: 0.040 ± 0.005 LL: 1.000 ± 0.125 LS: 0.150 ± 0.005	2.67 ± 0.25 7.62 ± 0.25 8.28 ± 0.25 0.254 min. 1.02 ± 0.13 25.4 ± 3.18 3.81 ± 0.13		0.005 %/50 Ω 0.01 %/25 Ω 0.02 %/12 Ω 0.05 %/5 Ω 0.1 %/2 Ω 0.50 %/1 Ω 1 %/0.5 Ω
S102K (S102L) [2]	1 to 100K		0.4 W over 100K	0.2 W over 100K					
S104D (S104F) [1]	1 to 500K	350	1.0 W up to 200K	0.5 W up to 200K	1.4	W: 0.160 max. L: 0.575 max. H: 0.413 max. ST: 0.035 ± 0.005 SW: 0.050 ± 0.005 LL: 1.000 ± 0.125 LS: 0.400 ± 0.020	4.06 max. 14.61 max. 10.49 max. 0.889 ± 0.13 1.27 ± 0.13 25.4 ± 3.18 10.16 ± 0.51	(0.138) (0.565) (0.413)	
S104K	1 to 300K		0.6 W over 200K	0.3 W over 200K					
S105D (S105F) [1]	1 to 750K	350	1.5 W up to 300K	0.75 W up to 300K	1.9	W: 0.160 max. L: 0.820 max. H: 0.413 max. ST: 0.035 ± 0.005 SW: 0.050 ± 0.005 LL: 1.000 ± 0.125 LS: 0.650 ± 0.020	4.06 max. 20.83 max. 10.49 max. 0.889 ± 0.13 1.27 ± 0.13 25.4 ± 3.18 16.51 ± 0.51	(0.138) (0.890) (0.413) (0.7 ± 0.05)	
S105K	1 to 500K		0.8 W over 300K	0.4 W over 300K					
S106D	0.5 to 1M	500	2.0 W up to 400K	1.0 W up to 400K	4.0	W: 0.260 max. L: 1.200 max. H: 0.413 max. ST: 0.035 ± 0.005 SW: 0.050 ± 0.005 LL: 1.000 ± 0.125 LS: 0.900 ± 0.020	6.60 max. 30.48 max. 10.49 max. 0.889 ± 0.13 1.27 ± 0.13 25.4 ± 3.18 22.86 ± 0.51		
S106K	0.5 to 600K		1.0 W over 400K	0.5 W over 400K					

Notes
[1] S104F and S105F have different package dimensions (see the third column of dimensions). All other specifications are the same.
[2] 0.200" (5.08 mm) lead spacing available - specify S102J for S102C, and S102L for S102K.

B.1.4 Amplifier AD595 Datasheet (Relevant Information)

AD594/AD595–SPECIFICATIONS (@ +25°C and V_S = 5 V, Type J (AD594), Type K (AD595) Thermocouple, unless otherwise noted)

Model	AD594A			AD594C			AD595A			AD595C			
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Units
ABSOLUTE MAXIMUM RATING													
$+V_S$ to $-V_S$			36			36			36			36	Volts
Common-Mode Input Voltage	$-V_S - 0.15$		$+V_S$	$-V_S - 0.15$		$+V_S$	$-V_S - 0.15$		$+V_S$	$-V_S - 0.15$		$+V_S$	Volts
Differential Input Voltage	$-V_S$		$+V_S$	$-V_S$		$+V_S$	$-V_S$		$+V_S$	$-V_S$		$+V_S$	Volts
Alarm Voltages													
+ALM	$-V_S$		$-V_S + 36$	$-V_S$		$-V_S + 36$	$-V_S$		$-V_S + 36$	$-V_S$		$-V_S + 36$	Volts
–ALM	$-V_S$		$+V_S$	$-V_S$		$+V_S$	$-V_S$		$+V_S$	$-V_S$		$+V_S$	Volts
Operating Temperature Range	–55		+125	–55		+125	–55		+125	–55		+125	°C
Output Short Circuit to Common	Indefinite			Indefinite			Indefinite			Indefinite			
TEMPERATURE MEASUREMENT (Specified Temperature Range 0°C to +50°C)													
Calibration Error at +25°C[1]			±3			±1			±3			±1	°C
Stability vs. Temperature[2]			±0.05			±0.025			±0.05			±0.025	°C/°C
Gain Error			±1.5			±0.75			±1.5			±0.75	%
Nominal Transfer Function			10			10			10			10	mV/°C
AMPLIFIER CHARACTERISTICS													
Closed Loop Gain[3]		193.4				193.4			247.3			247.3	
Input Offset Voltage		(Temperature in °C) × 51.70 µV/°C			(Temperature in °C) × 51.70 µV/°C			(Temperature in °C) × 40.44 µV/°C			(Temperature in °C) × 40.44 µV/°C		µV
Input Bias Current		0.1			0.1			0.1			0.1		µA
Differential Input Range	–10		+50				–10		+50	–10		+50	mV
Common-Mode Range	$-V_S - 0.15$		$-V_S - 4$	$-V_S - 0.15$		$-V_S - 4$	$-V_S - 0.15$		$-V_S - 4$	$-V_S - 0.15$		$-V_S - 4$	Volts
Common-Mode Sensitivity – RTO			10			10			10			10	mV/V
Power Supply Sensitivity – RTO			10			10			10			10	mV/V
Output Voltage Range													
Dual Supply	$-V_S + 2.5$		$+V_S - 2$	$-V_S + 2.5$		$+V_S - 2$	$-V_S + 2.5$		$+V_S - 2$	$-V_S + 2.5$		$+V_S - 2$	Volts
Single Supply	0		$+V_S - 2$	0		$-V_S - 2$	0		$+V_S + 2$	0		$+V_S - 2$	Volts
Usable Output Current[4]		±5			±5			±5			±5		mA
3 dB Bandwidth		15			15			15			15		kHz
ALARM CHARACTERISTICS													
$V_{CE(SAT)}$ at 2 mA		0.3			0.3			0.3			0.3		Volts
Leakage Current			±1			±1			±1			±1	µA max
Operating Voltage at – ALM			$+V_S - 4$			$+V_S - 4$			$+V_S - 4$			$+V_S - 4$	Volts
Short Circuit Current		20			20			20			20		mA
POWER REQUIREMENTS													
Specified Performance		$+V_S = 5, -V_S = 0$			$+V_S = 5, -V_S = 0$			$+V_S = 5, -V_S = 0$			$+V_S = 5, -V_S = 0$		Volts
Operating[5]		$+V_S$ to $-V_S \le 30$			$+V_S$ to $-V_S \le 30$			$+V_S$ to $-V_S \le 30$			$+V_S$ to $-V_S \le 30$		Volts
Quiescent Current (No Load)													
$+V_S$		160	300		160	300		160	300		160	300	µA
$-V_S$		100			100			100			100		µA
PACKAGE OPTION													
TO-116 (D-14)		AD594AD			AD594CD			AD595AD			AD595CD		
Cerdip (Q-14)		AD594AQ			AD594CQ			AD595AQ			AD595CQ		

B.1.5 Pyranometer Datasheet (Relevant Information)

SPECIFICATIONS

Power Supply: 5-24 VDC** with a nominal current draw of 300 µA
**Sensors with a serial number smaller than 4502 should not be powered with more than 5 VDC.

Sensitivity: SP-212: 2.0 mV per W m^{-2}
SP-215: 4.0 mV per W m^{-2}

Calibration Factor: SP-212: 0.5 W m^{-2} per mV (reciprocal of sensitivity)
SP-215: 0.25 W m^{-2} per mV (reciprocal of sensitivity)

Calibration Uncertainty: ± 5 % (see Calibration Traceability below)

Measurement Repeatability: < 1 %

Non-stability (Long-term Drift): < 2 % per year

Non-linearity: < 1 % (up to 1250 W m^{-2}; maximum radiation measurement is 1250 W m^{-2})

Response Time: < 1 ms

Field of View: 180°

Spectral Range: 360 nm to 1120 nm (wavelengths where response is 10 % of maximum; see Spectral Response below)

Directional (Cosine) Response: ± 5 % at 75° zenith angle (see Cosine Response below)

Temperature Response: -0.04 ± 0.04 % per C (see Temperature Response below)

Operating Environment: -40 to 70 C
0 to 100 % relative humidity
Can be submerged in water up to depths of 30 m

Dimensions: 2.4 cm diameter and 2.8 cm height

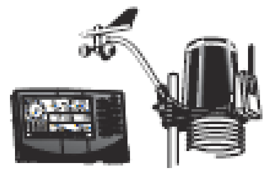
Mass: 90 g (with 5 m of lead wire)

Cable: 5 m of shielded, twisted-pair wire.
Additional cable available in multiples of 5 m
Santoprene rubber jacket (high water resistance, high UV stability, flexibility in cold conditions)
Pigtail lead wires

B.1.6 Meteorological Station (Relevant Information)

Wireless Vantage Pro2™ & Vantage Pro2™ Plus Stations

(Including Fan-Aspirated Models)



6152 6162
6153 6163

Vantage Pro2™ (6152, 6153) and Vantage Pro2™ Plus (6162, 6163) Wireless Weather Stations include two components: the Integrated Sensor Suite (ISS) which houses and manages the external sensor array, and the console which provides the user interface, data display, and calculations. The ISS and Vantage Pro2 console communicate via an FCC-certified, license-free, spread-spectrum frequency-hopping (FHSS) transmitter and receiver. User-selectable transmitter ID codes allow up to eight stations to coexist in the same geographic area. The frequency hopping spread spectrum technology provides greater communication strength over longer distances and areas of weaker reception. The Wireless Vantage Pro2 Plus weather station includes two additional sensors that are optional on the Vantage Pro2: the UV sensor and the solar radiation sensor.

The console may be powered by batteries or by the included AC-power adapter. The wireless ISS is solar powered with a battery backup. Use WeatherLink® for Vantage Pro2 and Vantage Vue® to let your weather station interface with a computer, to log weather data, and to upload weather information to the internet.

The 6152 and 6162 rely on passive shielding to reduce solar-radiation induced temperature errors in the outside temperature sensor readings. The Fan-aspirated 6153 and 6163 combine passive shielding with a solar-powered fan that draws outside air in over the temperature and humidity sensors, providing a much more accurate temperature reading than that available using passive shielding alone.

Integrated Sensor Suite (ISS)

(Includes product numbers: 6152, 6153, 6162, 6163, 6322, 6323, 6327 & 6328)

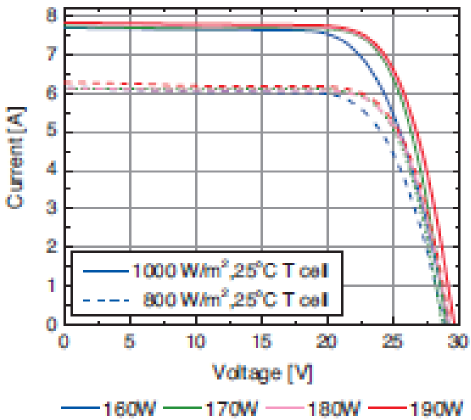
Operating Temperature	-40° to +150°F (-40° to +65°C)
Non-operating Temperature	-40° to +158°F (-40° to +70°C)
Current Draw (ISS SIM only)	0.14 mA (average), 30 mA (peak) at 4 to 6 VDC
Solar Power Panel	0.5 Watts (ISS SIM), plus 0.75 Watts (Fan-Aspirated)
Battery (ISS SIM /Fan-Aspirated)	CR-123 3-Volt Lithium cell / 2 - 1.2 Volt NiCad C-cells
Battery Life (3-Volt Lithium cell)	8 months without sunlight - greater than 2 years depending on solar charging
Battery Life (NiCad C-cells, Fan-Aspirated)	1 year
Fan Aspiration Rate (Fan-Aspirated only)	
Intake Flow Rate, full sun	190 feet/min. (0.9 m/s)
Intake Flow Rate, battery only	80 feet/min. (0.4 m/s)
Sensor Chamber Flow Rate, full sun	500 feet/min. (2.5 m/s)
Sensor Chamber Flow Rate, battery only	280 feet/min. (1.4 m/s)
Connectors, Sensor	Modular RJ-11
Cable Type	4-conductor, 26 AWG
Cable Length, Anemometer	40' (12 m) (included) 240' (73 m) (maximum recommended)

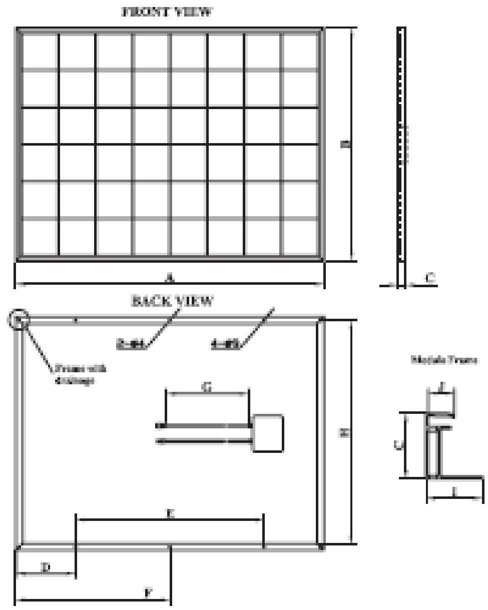
Note: Maximum displayable wind decreases as the length of cable increases. At 140' (42 m) of cable, the maximum wind speed displayed is 135 mph (60 m/s); at 240' (73 m), the maximum wind speed displayed is 100 mph (34 m/s).

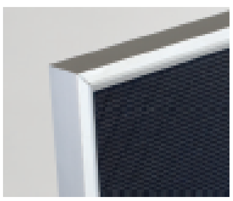
Wind Speed Sensor	Solid state magnetic sensor
Wind Direction Sensor	Wind vane with potentiometer
Rain Collector Type	Tipping bucket, 0.01" per tip (0.2 mm with metric rain adapter), 33.2 in^2 (214 cm^2) collection area
Temperature Sensor Type	PN Junction Silicon Diode
Relative Humidity Sensor Type	Film capacitor element
Housing Material	UV-resistant ABS, ASA plastic

ISS Dimensions (not including anemometer or bird spikes):

B.1.7 DAY 448 MC Datasheet Relevant Information







Day4™ Anodized Aluminum Frame
the unique design features: water drainage holes to reduce frame breakage due to freezing temperatures; multiple grounding holes for ease of installation; top frame surface has a beveled profile to reduce dirt and water trapping; deep glass frame slot increases strength and durability

	METRIC	IMPERIAL
A	1,307 mm	51.456 in.
B	991 mm	39.015 in.
C	35mm	1.377 in.
D	403mm	15.866 in.
E	501mm	19.724 in.
F	653.5mm	25.728 in. (Grounding holes on each side)
G	925 mm (±10mm)	36.417 in. (±0.393in.)
H	947mm	37.283 in.
I	30mm	1.181 in.
J	13mm	0.511 in.

2-ø4 denotes 2 holes (grounding holes) with a diameter of 4mm
4-ø9 denotes 4 holes (mounting holes) with a diameter of 9mm
NOTE: All dimensions are accurate within +/- 1.5 mm tolerance. Product dimensions in imperial inches [conversion of 1 mm equals 0.03937 inches, 1 kilogram equals 2.2 pounds] are provided for information purposes only.

Physical Specifications:

	METRIC	IMPERIAL
LENGTH:	1,307mm	51.46 inches
WIDTH:	991 mm	39.01 inches
DEPTH:	35 mm	1.38 inches
WEIGHT:	17.4 Kg	38.28 lbs Approx.

Mechanical Specifications:
GLASS: Solar low iron tempered
JUNCTION BOX: Tyco Solarlok Interconnection, output cables, male and female locking cable couplers
CELLS: 48 cells Multi Crystalline 156mm square [6 inches]
BACK SHEET: Multi-layer water resistant compound

Typical Electrical Performance at STC

Peak Power [Wp]	Watts	155*	160	165*	170	175*	180	185*	190
Max. Power Voltage [Vmp]	Volts	22.30	22.60	22.95	23.04	23.40	23.70	23.82	24.00
Max. Power Current [Imp]	Amps	6.97	7.08	7.19	7.38	7.48	7.60	7.77	7.92
Open Circuit Voltage [Voc]	Volts	28.00	28.30	28.60	28.80	29.20	29.40	29.51	29.70
Short Circuit Current [Isc]	Amps	7.55	7.70	7.80	7.90	8.05	8.10	8.20	8.30
Short Circuit Temp. Coefficient	mA/°C	7.80	7.80	7.80	7.80	7.80	7.80	7.80	7.80
Open Circuit Temp. Coefficient	V/°C	- 0.11	- 0.11	- 0.11	- 0.11	- 0.11	- 0.11	- 0.11	- 0.11
Max. Power Temp. Coefficient	%/°C	- 0.48	- 0.48	- 0.48	- 0.48	- 0.48	- 0.48	- 0.48	- 0.48

*Available March 31, 2007. NOTE: Electrical characteristics measured at STC (1000 W/m², AM 1.5 Spectrum, cell temperature 25°C). Module power tolerance +/- 5%. Day4 48MC Module Maximum Fuse Series Amps is15A, Maximum system voltage is 600V, Normal Operating Cell Temperature [NOCT] is 46°C.

DAY4 ENERGY

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