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**DESIGN OF A NUMERIC ACQUISITION
DEVICE BY LABVIEW OF A
PHOTOVOLTAIC PANEL**

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DEDICATION

I dedicate this modest work to:

My parents

My brothers

My friends

My teachers

And all those who carry Algeria in their hearts.

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LIST OF ABBREVIATION

PV	Photovoltaic
Voc	Open circuit voltage
Isc	Short circuit current
Vmp	Maximum power point voltage
Imp	Maximum power point current
MPPT	Maximum power point tracker
FF	Fill Factor
η	Efficiency ratio
PL	Solar power
Pmp	maximum electrical power
P&O	The Perturb and observe
INC	Incremental conductance
P	Power generated with the PV panel
I	Current generated with the PV panel
V	Voltage generated with the PV panel
DC	Direct current
AC	Alternating current
IL	light generated current
Q	Charge of Electron ($Q= 1.6 \times 10^{-19} \text{ C}$).
K	Boltzmann Constant ($k= 1.380 \ 649. \ 10^{-23} \text{ J / K}$)
R_s, R_{sh}	Cell Series and Shunt Resistance (Ohms).
T	Time
STC	The five parameters starting from data provided by manufacturers
N	Number of calculations
Iload	Current applied on the load
Vload	Voltage applied on the load
MPPT-PA	Maximum power point tracker Performance Analysis
Ldr	light dependent resistors
PWM	Pulse Width Modulation
UART	Universal Asynchronous Receiver / Transmitter
PVG	Panel voltaic generator
δ	The instantaneous change in the value

Introduction

For a century, the massive use of the energy resources such as coal, petroleum, natural gas and to some extent, nuclear energy, has raised the standard of living of the world's for all mankind, especially in developed countries. However, the abrupt increase in the petroleum prices that occurred in 1973 caused an increased interest in other energy resources. In Algeria, even if the solar energy low development and massive reserves of oil and naturel game, everyone is unanimous in saying that there will come a day when the depletion of fossil fuels will be inevitable. To address these concerns, the use of renewable resources sounds like the best solution because they are:

- Endless on a temporal human scale.
- Harmless to the environment (less CO2 releases).

Among these renewable resources, solar energy, which is available anywhere on earth, represents theoretically 900 times the global demand in energy. Because of its location, Algeria has one of the most important solar potential in the world (an average Sun exposure of more than 3000 hours/year), which makes it suitable for the implantation of solar energy conversion systems, in particular photovoltaic systems [1]. The economic sector of energy in Algeria includes local production and importation of primary energy, their eventual transformation into secondary energy carriers, transport of these agents and their final consumption, as well as the flow of imports and exports of energy.

Algeria receives an average of 3000 hours/year of solar radiation, it has the most important solar potential of the Mediterranean basin (169440 TWh/year). The average of the received solar energy in coastal regions is 1700 kWh/m²/year while it is 1900 kWh/m²/year on highlands and 2650 kWh/m²/year in the Sahara (see table 1). It has been proved that alone, the solar potential of the Sahara could cover all the needs of energy in the world if we put the necessary amount of investments in this field [2].

region	Coastal region	High lands	Sahara
Surface %	4	10	86
Average sunshine duration (hours/year)	2650	3000	3500
Average energy (kWh/m ² /year)	1700	1900	2650

Table 1. Solar potential of Algeria [3].

CHAPTER I

INTRODUCTION TO PHOTOVOLTAIC SYSTEM

I.1 Introduction

Photovoltaic cell is a fundamental device for PV systems. Such systems consist of multiple components based on electrical connections and mechanical components like mountings and different way of regulating and modifying the electrical output.

I.2 Solar resource

Solar energy has progressed more than any other renewable resource. The energy is obtained from the radiations that are electromagnetic waves emitted by the sun. As the distance between sun and earth is much larger, very small part of solar radiation reaches earth surface which becomes more lessened due to ions and dust particles. Sunlight received on any earth surface depends on several factors such as timings of the day, landscape, weather, season and geographical locations. The solar radiation intensity, which reaches earth surface directly, is approximately 1370 W/m². This intensity value is named as solar constant.

So, earth surface receives solar energy equal to 3.2 EJ/y. By comparing this energy to global energy consumption, it becomes 7000 times more than the required energy [4]. If this available energy or even of a part of it can be harvested, the global energy problems, then, could be solved. Photovoltaic efficiency depends on spectral distribution of sun but these are of two types, defined by photovoltaic industry and the (ASTM) American Society for Testing and Materials. The normal standard in which the solar radiation has dependence on the distance travelled (air mass).

Other one is the global standard in which diffused radiations spectrum is considered. The solar radiation becomes diffused due to atmospheric conditions like dust and clouds. Pyranometer is used to measure these diffused radiations. This instrument measures solar radiation for each wavelength, hence, it gives total power value accurately.

I.3 Normal test conditions

Performance of different PV units can be compared based on uniform or standard conditions. The parameters of PV units or cells are, generally, given in a manufacturer's data sheet. Following standard test conditions (STC) are used for measurements [4]:

- Irradiance = 1000 w/m²
- Ambient temperature = 25 C
- Spectral distribution with air mass = 1.5

I.4 Introduction to photovoltaic

The most important part of photovoltaic systems is the photovoltaic cell. The types of material used in making the solar cells and the type of connecting PV systems influence greatly the output generated by the PV system like we will discuss in this chapter.

A PV cell is a semiconductor diode as shown in Figure I.1, working on the principle theory of photoelectric effect which is defined as any material exposed to light generates charge. Solar radiations are basically photons of different frequencies and energies.

Each material has a band gap between conduction and valence bands and electrons go into conduction bands when the energy of incident photon becomes greater than band gap energy.

Now, electric field is applied to drift conduction band electrons in semiconductor material and this movement of electrons is called current. A metal plate is usually deposited on bottom and top of PV cells to collect the current for external use. Hence, band gap energy corresponds to threshold energy which in turn gives threshold frequency of a semiconductor material. In photovoltaic material, photoelectric emission rate can be increased by increasing light intensity.

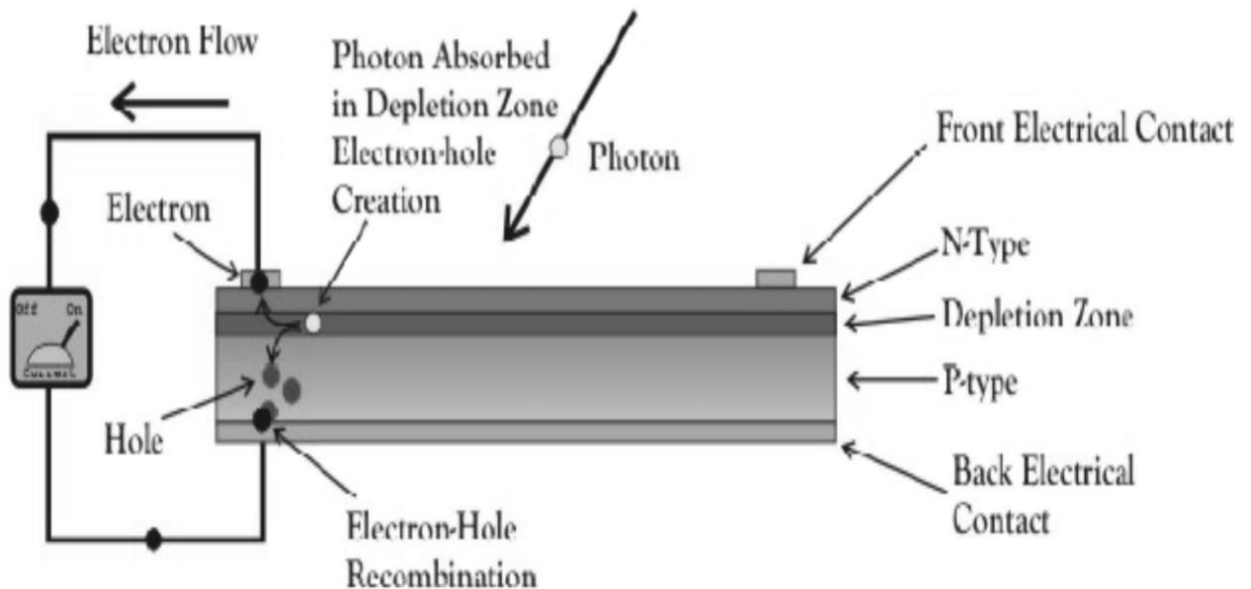


Figure I.1 Photo electric effect of PV cell [4].

I.5 Photovoltaic systems:

Different interconnected components are used to make photovoltaic systems. The applications of photovoltaic system range from providing power to small devices to feed electricity to main grid.

There are mainly two types of photovoltaic systems, stand-alone system and grid connected system as shown in below Figure I.2.

The major difference between the two PV systems is the load demand that should be matched with solar energy output which known as stand-alone system. When PV systems are used with other power sources like wind or thermal generators, then, it is classified as hybrid system.

I.5.1 Standalone systems

Stand-alone systems were the first cost-effective photovoltaics application especially in remote areas where connection to utility grid was not feasible. This system will be extended for rural electrification in the developing world.

This system is also used for water pumping system, communication system and mobile equipments.

In general, this system comprises of control and power conditioning units (inverters, converters), storage elements with solar modules and the load.

Hybrid systems in cases where the requisite energy from photovoltaic modules is not practically feasible and economical other means such as diesel generator used in conjunction with PV systems.

Thus this system ensures the demands of energy are met while photovoltaic supply is utilizing fully.

I.5.2 Grid connected systems

Grid connected photovoltaic systems energized by PV connected to main utility grid that actually provides opportunity while protecting the environment to adequate energy.

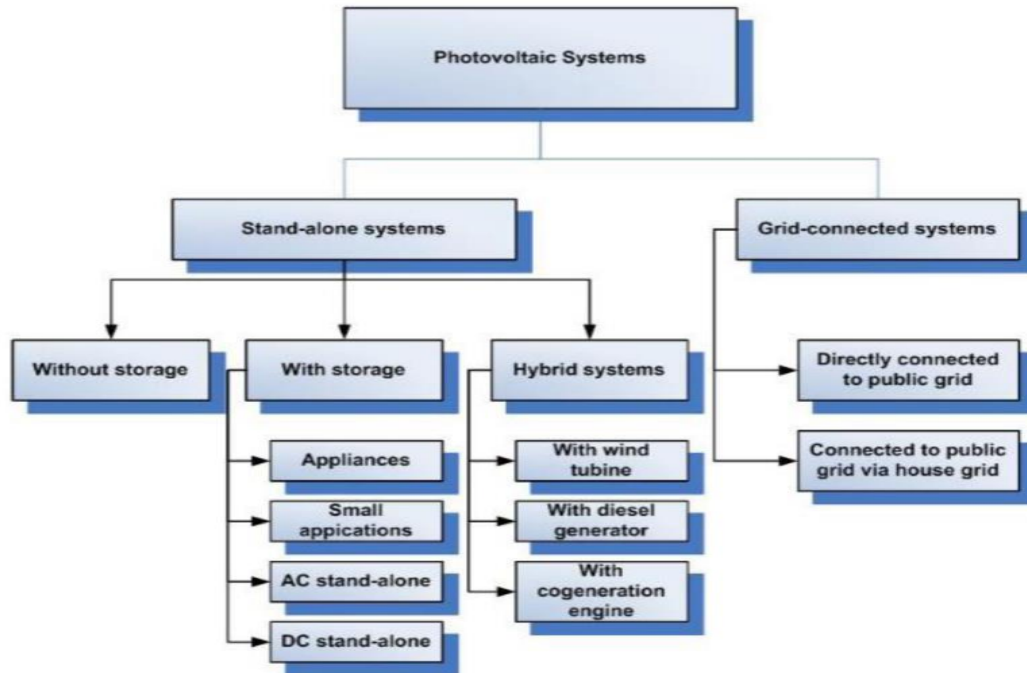


Figure I.2 Classification of photovoltaic system.

I.6 PV cells

Modules and Arrays: Typically, a photovoltaic cell gives voltage of 0.5 to 0.8 V at the output. This voltage output of a PV cell depends on the semiconductor material.

Each PV cell power production is very low, so numbers of photovoltaic cells are used in series to make a photovoltaic module as shown in Figure I.3.

Photovoltaic modules are joined in parallel and series fashion to make PV arrays. So, PV cells are either connected in series to add voltages of each cell with same current (for high voltage requirement) or connected in parallel to add current passing through each PV cell with same voltage (for high current requirement) to get desired power.

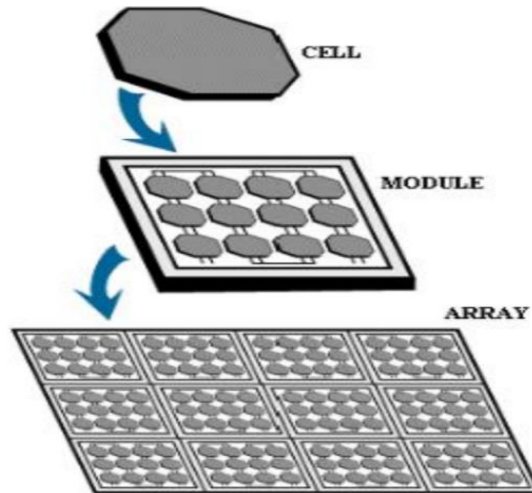


Figure I.3 PV cells, modules and arrays.

I.6.1 Characteristics of a PV cell

The main three significant parameters on the photovoltaic characteristics are open circuit voltage (V_{oc}), short circuit current (I_{sc}) and maximum power point (V_{mp} , I_{mp}). The maximum power that achieved from photovoltaic cell is occurs at a point on the bend in the I-V curve known as the maximum power points.

The typical I-V relationship of a photovoltaic cell is shown in Figure I.4. Generally, these parameters are provided in the data sheet by manufacturers of a particular photovoltaic cell or module.

When the PV cell is connected to an external load, the electrical characteristics of the load determine the actual point on the I-V curve at which the photovoltaic cell operates. PV cells are often connected to the load through a MPPT (maximum power point tracker) which regulates cell voltage so that cell operates at maximum power point.

I-V curve shape is same and does not change for module or array of photovoltaic cells but it is scaled which depends on number of cells joined together.

Environmental parameters such as ambient and cell temperatures, irradiance, wind speed and dust affects the shape by disturbing the maximum power points on I-V curve [6].

Current and Power vs. Voltage 1

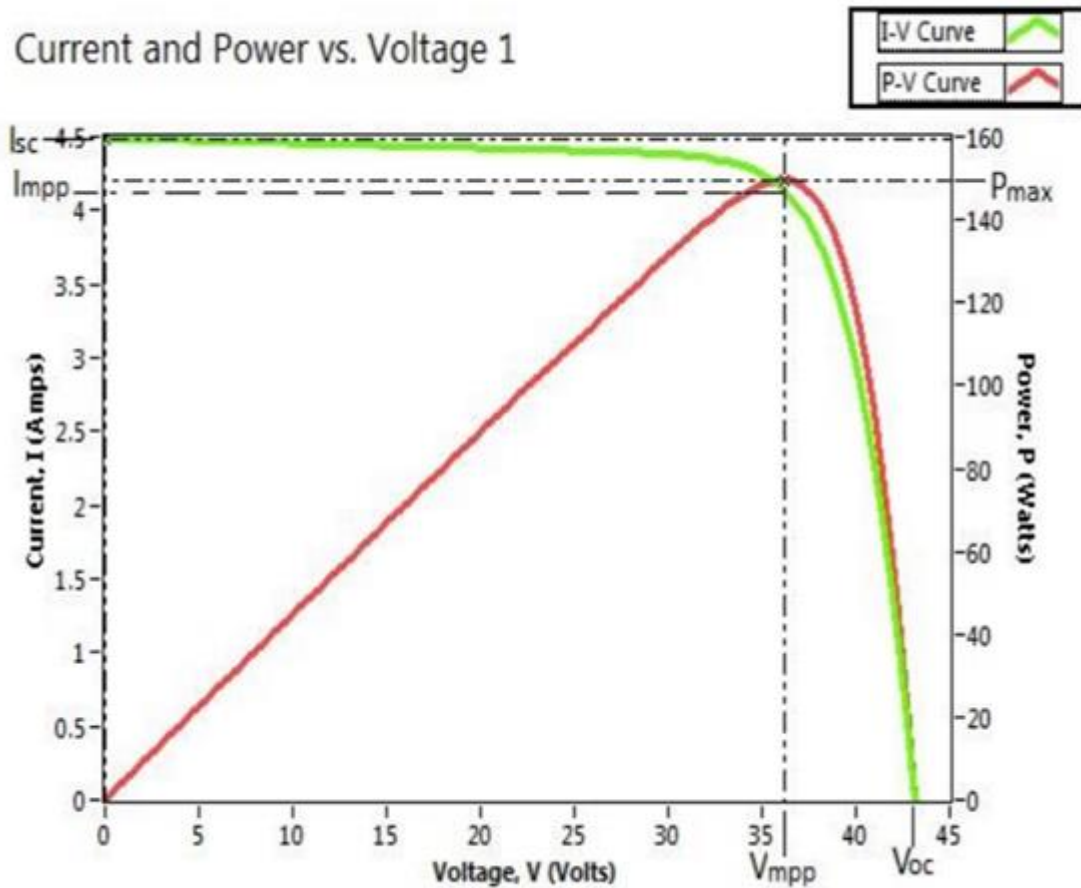


Figure 1.4 I-V, P-V characteristics of PV cell.

One more essential parameter of the photovoltaic characteristics is known as the Fill Factor (FF). The fill factor is basically determining the quality of the solar cell. PV cell operation is better when the fill factor value is close to unity.

$$FF = \frac{V_{mpp} * I_{mpp}}{V_{oc} * I_{sc}} \dots\dots\dots 1.1$$

Efficiency (η): The ratio of maximum electrical power (Pmp) output to solar power (PL) input that received by the cell surface is defined as efficiency

$$\eta = \frac{V_{mpp} * I_{mpp}}{PL} \dots\dots\dots 1.2$$

The PV industry's future is promising as the quality of PV modules continues to increase. Higher efficiencies cell and modules are expected in future due to the continuous improvement of

manufacturing processes and technologies. For the next decade, crystalline silicon devices are expected to remain dominant due to the material availability and cost [6].

I.7 Materials used in PV cell

Photovoltaic cells are made of semiconducting materials that produce electric current from solar radiation.

There are two types of solar cells available commercially [7]:

- thin film solar cells
- crystalline silicon solar cells

Traditional solar cells are made from Silicon material. Currently, most manufactures are using Silicon for to making solar panels for commercial market. In fact, 95 percent of the solar cells are produced of the Silicon element worldwide [7].

One of the main reasons can be because of majority of silicon elements on earth, so it is very cheap compared to other solar cells' materials. However, efficiency of Silicon solar cell can decline due to high temperature (Hot sunny days) [8].

There are four various types of silicon solar that we will see explained here.

I.7.1 Monocrystalline silicon solar cells

Thin wafer silicon is the oldest solar cell technology and the most popular at the market, this kind of silicon solar cells is known as monocrystalline solar cell, because of cells are sliced from large single crystals which have been painstakingly grown under carefully controlled condition. The cells are a few inches across, and a number of cells are laid out in a grid to create panel. The efficiency of monocrystalline silicon solar cell can be reached up to 24.2%, which is useful for installation in small areas [9].

I.7.2 Polycrystalline silicon solar cells

The polycrystalline silicon solar cells are produced silicon wafers in molds of multiple silicon crystals rather than a single crystal in terms of condition of growth, it does not need to control like Monocrystalline Silicon cells, therefore, it is cheaper and less efficient (up to 19.2%) in comparison with Monocrystalline Silicon cells.

I.7.3 Amorphous silicon solar cells

In most devices, especially, in small electronic applications like calculators amorphous silicon solar cell is used. In this kind of silicon solar cells which is perform invert with silicon crystals growing, silicon is deposited in a thin layer on to a backing substrate, such as metal, glass or plastic. They are very tiny, therefore panel can be made flexible, and also their performance during low sunlight is better than crystalline panels. But, on the other hand, the amorphous panels are able to convert sunlight into electricity with less efficiency (10%), so they are not suitable for roof installation.

I.7.4 Hybrid silicon solar cells

Companies strive to find a way to improve efficiency, longer life, and to reduce the cost.

The Sanyo company, has released a Hybrid cell whereby a layer of amorphous silicon is deposited on top of single crystal wafers. In this manner, efficiency is improved, and the performance of Hybrid silicon solar does not reduce because of indirect sunlight and high temperatures [9].

CHAPTER II

MAXIMUM POWER POINT TRACKING ALGORITHM

II.1 Introduction

The output power of photovoltaic solar cell has non-linear characteristics. Solar cells have a complex relationship between solar radiation and temperature. To increase output efficiency and decrease generated power cost, the maximum power point tracking(MPPT) technique is widely used. With MPPT algorithms implemented, we can track the maximum power point all the time.

First, it reads the output from the PV panels, analyzes and calculates the output power, then changes the value to obtain the maximum power of any given environmental conditions.

With a software implementation, a selection of algorithms can be chosen to achieve a higher efficiency. The graph below is an ordinary photovoltaic panel IV curve. From this graph, it can be seen that the IV curve effected by solar radiation and temperature. To obtain the maximum power, the product of current and voltage has to reach the maximum level.

When the weather changes, for instance, the sun blocked by a piece of cloud will decrease solar radiance sharply, then the maximum power point will have corresponded change.

The purpose of MPPT is to locate and keep tracking the maximum power point, even if the solar radiance or temperature change rapidly. The figures II.1 and II.2 show the fluctuation of the I-V curve under changing temperature and irradiation [10].

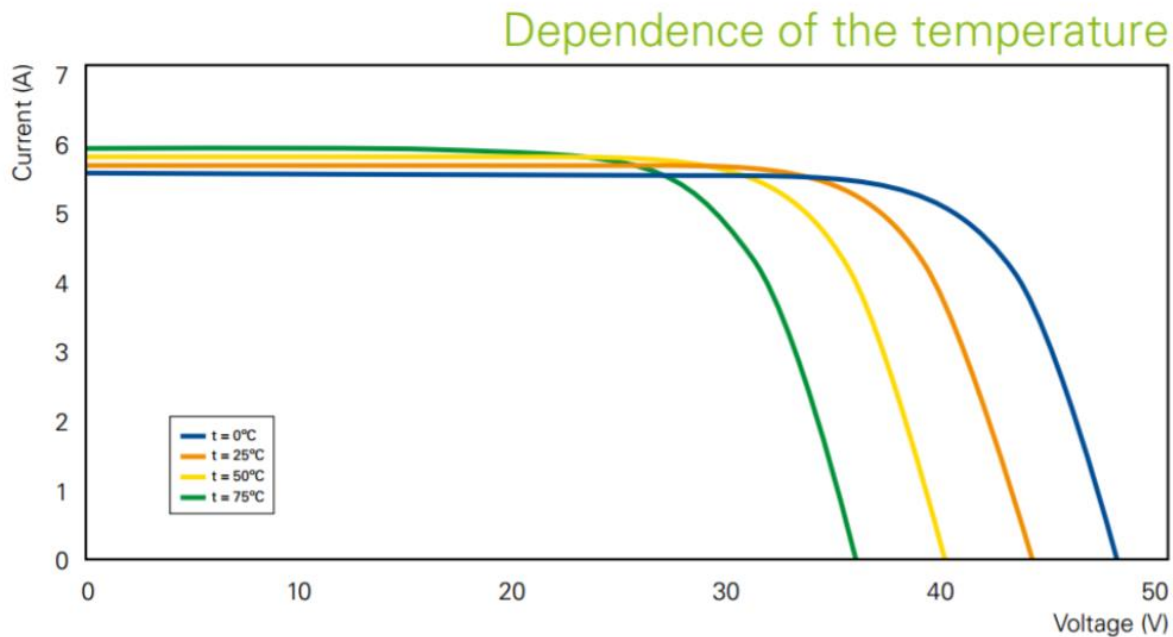


Figure II.1 Solar cell temperature flex output.

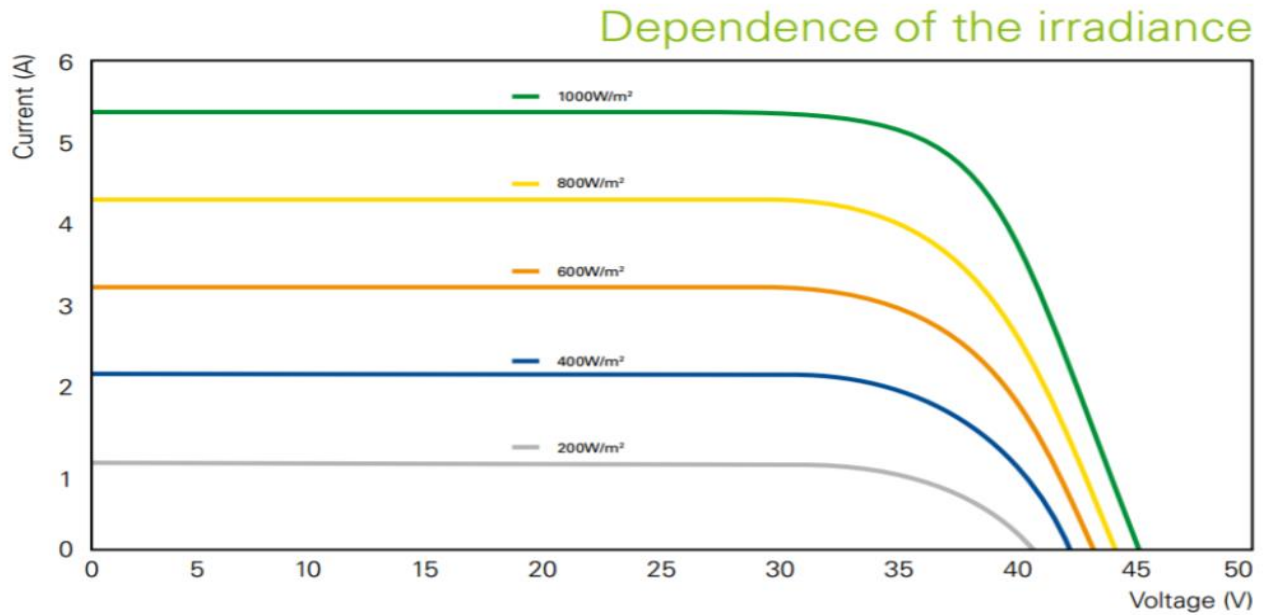


Figure II.2 Solar cell irradiation flex output.

II.2 MPPT perturb and observe method

There are many algorithms. The Perturb and Observe(P&O) and the incremental conductance (INC) methods are being used in most of MPPT products because they have simple principle and easy implementation.

When this algorithm is operating it will read the operating parameters and calculate and change the mppt accordingly.

The figure (II.3) describe the algorithm of MPPT perturb and observe method.

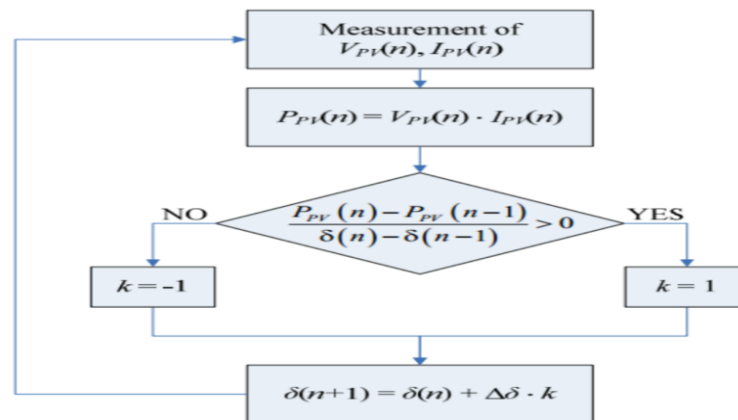


Figure II.3 P&O Algorithm.

The problem in the perturb and observe algorithm is that, it has to perturb all the time, which means when the maximum power point is under steady state, this algorithm will generate oscillations. Another problem is that it is unable to track the maximum point in a rapidly changing weather because of its step change value is determined.

To solve the first problem, if the measured power value is steady, or if measurement noise is considered, changed in a tiny range, the controlled value does not change. Then it will stop the oscillation near the maximum power point.

To solve the second problem, the step variable can be set according to the power change level, for example the step controlled variable can be calculated by using a constant as a slope times power change value. Then when the power change rapidly, controlled value changes in large step and vice versa. The flow chart of the Improved P&O algorithm becomes like the chart exist in the figure II.4 [11].

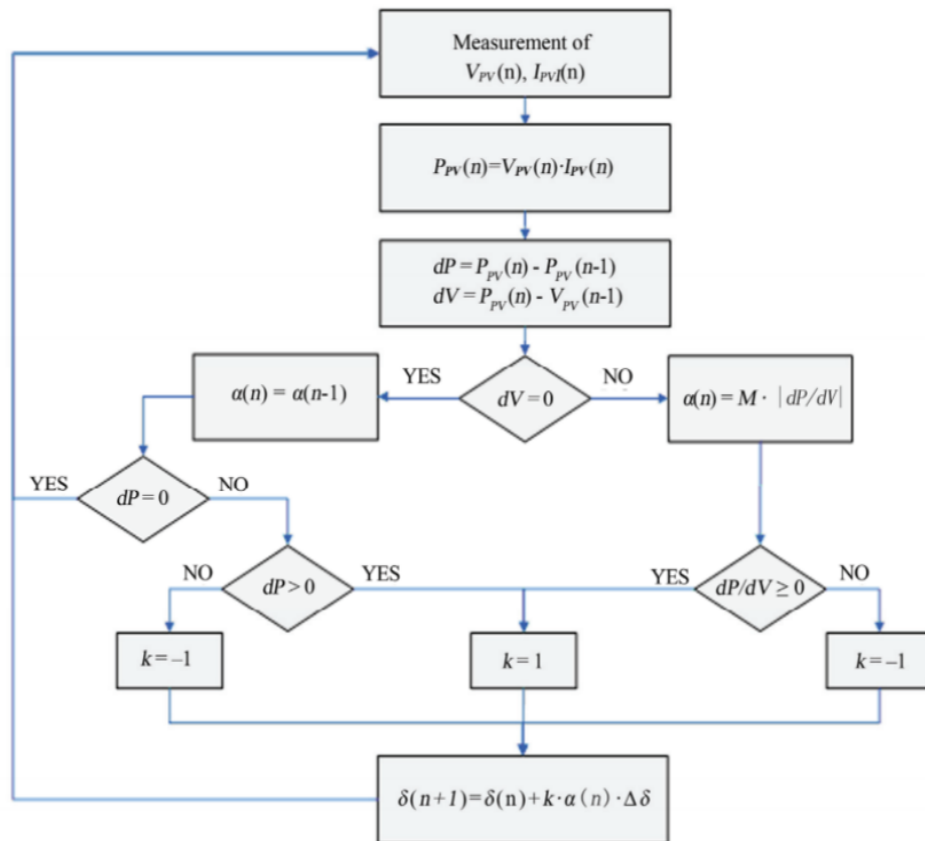


Figure II.4 Improved P&O algorithm.

II.3 MPPT Incremental conductance method

The incremental conductance (INC) algorithm is based on observation of IV curve. The maximum power point must happen on the top of the IV curve so here is the following equation

$$\frac{dP}{dI} = 0 \tag{II.1}$$

Since power can be represented as current multiply by voltage, so

$$\frac{dP}{dI} = \frac{d(IV)}{dI} = V + I \frac{dV}{dI} = 0 \tag{II.2}$$

When the operating point is at right of maximum power point, this equation will less than zero. So for getting closer to the maximum power point the current must increase. the figure II.5 shows the INC algorithm flow chart.

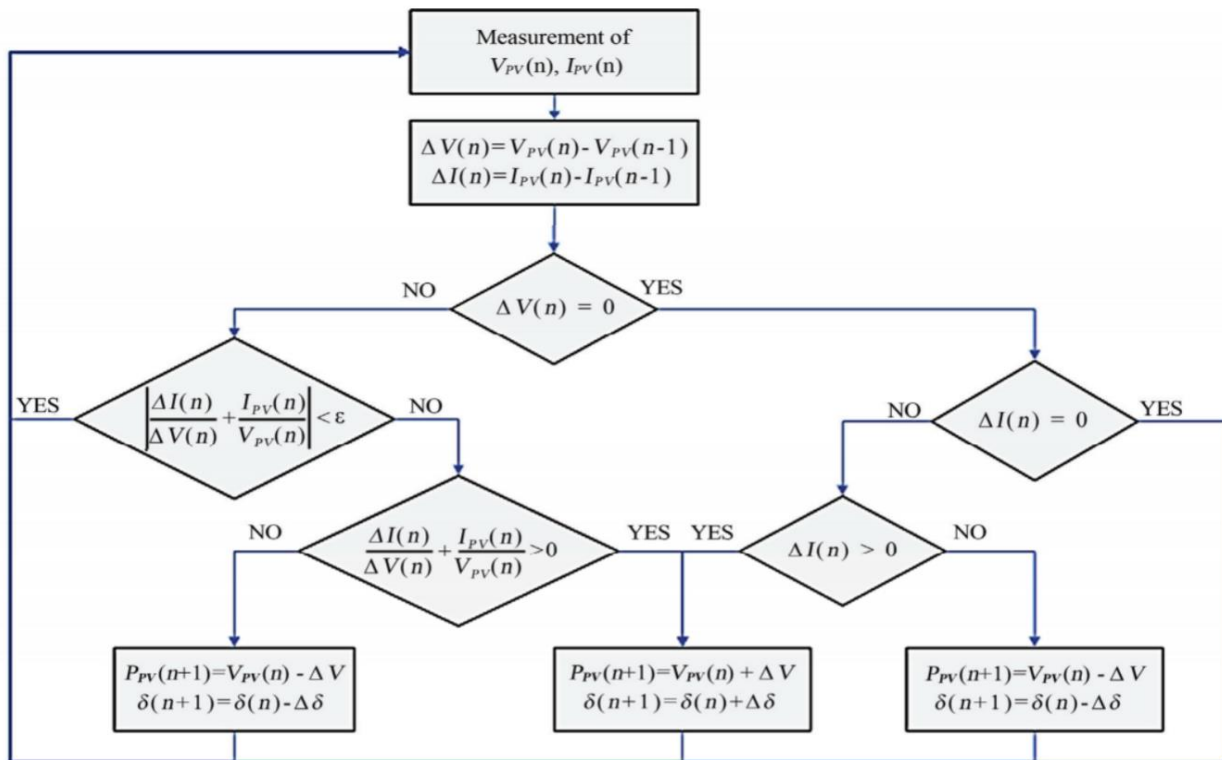


Figure II.5 Incremental Conductance algorithm [8].

The incremental conductance method has advantages over the P&O method that it does not have the oscillating around maximum power point and it can track under rapidly varying irradiation conditions.

However, this method has oscillations and abnormal performance under rapidly changing conditions. For instance, the output value is implemented through the control of the duty cycle. If the duty cycle is less than 0.6, the change of controlled value is not significant. [12]

To improve dynamic performance, there are several algorithms proposed. For example, fractional-order incremental method tries to describe dynamical behaviors as fractional-order diffusion to improve dynamic performance. [13] It uses the fractional-order method to compare the I-V changes towards high order change.

Assume that $f(x)$ is a monomial of the form.

$$f(x) = x^k. \tag{II.3}$$

The first derivative is as usual

$$f'(x) = \frac{d}{dx} f(x) = kx^{k-1}. \tag{II.4}$$

Repeating this gives the more general result that

$$\frac{d^a}{dx^a} x^k = \frac{k!}{(k-a)!} x^{k-a}, \tag{II.5}$$

Repeating this gives the more general result that

$$\frac{d^a}{dx^a} x^k = \frac{\Gamma(k+1)}{\Gamma(k-a+1)} x^{k-a}. \tag{II.6}$$

According to incremental conductance equations, the I-V can be described as fractional-order differentiation.

$$\frac{d^a I(V)}{dV^a} = \lim_{\Delta V \rightarrow 0} \frac{I(V) - aI(V - \Delta V)}{\Delta V^2} \quad \dots\dots\dots \text{II.7}$$

$$\frac{d^a I}{dV^a} \approx \frac{I - aI_O}{(V - V_O)^a} \quad \dots\dots\dots \text{II.8}$$

A stands for the fractional differential order. This equation above is used to express the fractional-order incremental changes of the current and voltage of the PV array. If a = 1, it returns the change velocity.

For 0 < a < 1, it can be termed as the fractional rate of the change. Then the incremental conductance can be modified as

$$\begin{aligned} \frac{d^a}{dV^a} \left(-\frac{I_O}{V_O} \right) &= \left(-\frac{1}{V_O} \right) \frac{d^a I_O}{dV^a} + (-I_O) \frac{d^a V_O^{-1}}{dV^a} \\ &= \left(-\frac{1}{V_O} \right) \frac{\Gamma(2)}{\Gamma(2-a)} (I_O)^{1-a} + (-I_O) \frac{\Gamma(0)}{\Gamma(-a)} V_O^{-1-a} \end{aligned} \quad \dots\dots\dots \text{II.9}$$

Where

$$\Gamma(n) = (n-1)! \text{ Res}(\Gamma, -n) = \frac{(-1)^n}{n!}, n = 0, -1, \dots \quad \dots\dots\dots \text{II.10}$$

The incremental changes in current and voltage become

$$d^a I \approx (I - aI_O) = \delta I \quad \dots\dots\dots \text{II.11}$$

And

$$dI^a \approx (V - V_O)^a = \delta V^a \quad \dots\dots\dots \text{II.12}$$

Respectively

The flow chart below shows that the fractional-order incremental conductance algorithm. It adjusts the controlled value using the instantaneous values I and V at present cycle and their corresponding values IO and VO stored at the end of the previous iteration

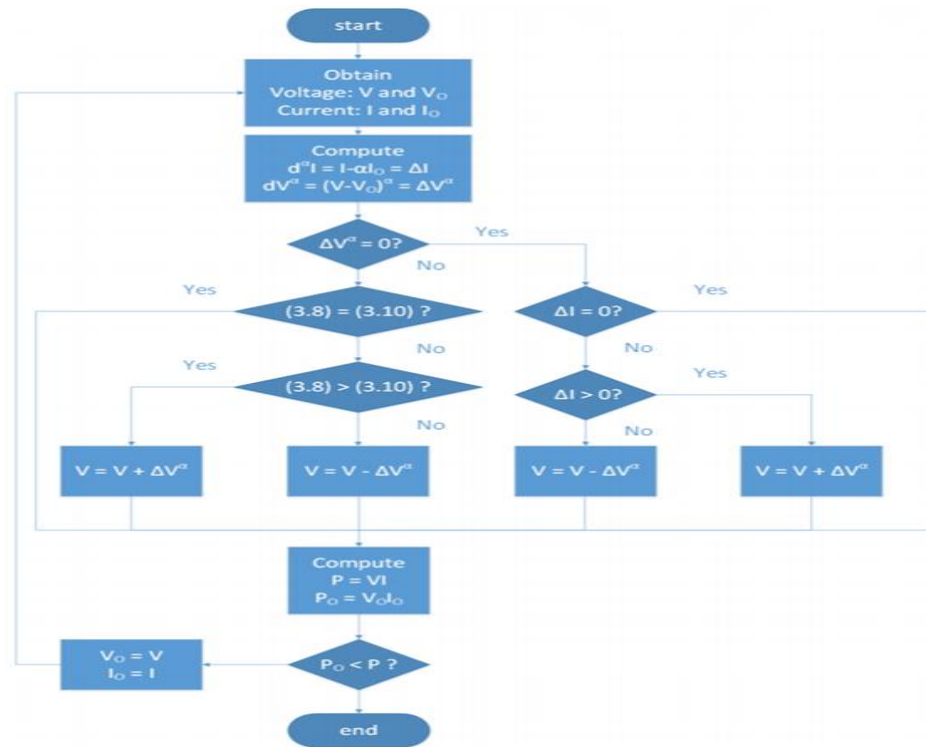


Figure II.6 Fractional order incremental conductance algorithm.

II.4 Conclusion

Both enhanced algorithms are very capable of tracking the MPPT point at all times with the best results. The difference is the needed capability of the system to employ the algorithms, like we see in the equations II.11 and II.12 the required capabilities of the incremental conductance algorithm is minimal and since the Arduino UNO have 2 kilobytes of RAM we chose to go with it in the simulation part.

CHAPTER III

IMPLEMENTATION OF A PHOTOVOLTAIC-MPPT PERFORMANCE ANALYZER

III.1 Introduction

In this part we show existing diagnostic methods. When looking for diagnostic methods, one must differentiate between two functions: detection and localization. Certain methods used or proposed perform detection function only. While some others perform the function location after fault detection has been performed. In this chapter, we will focus on the most frequently used to detect the diagnostic problems of the PV system, and at the end of the chapter I will explain the selected diagnostic system that will be used in the simulation.

III.2 The importance of using a diagnostic system

The energy produced by a PV system depends on various factors such as:

- Nominal characteristics of the system components,
- Electrical and geometrical configurations.
- Weather conditions of the installation site.
- Shadowing.
- PV plant availability [14].
- Fault that may occur during normal operations.

A certain number of different problems may therefore cause energy losses in the PV plant. Some losses can be related to the PV plant, these include errors in tracking the maximum power point, dispersion module parameters (mismatch), wiring losses and aging [15].

Others are influenced by environmental characteristics such as operating temperature and solar radiation level. In addition, other losses are related to the power conditioning unit (DC / DC and DC / AC converters).

Diagnosis methods can be generally categorized in two groups: non-electric methods such as visual (discoloration, browning, surface soiling, delamination) and thermal (thermal extraordinary heating) and electric methods (dark/illuminated I–V measurement, transmittance line diagnosis, RF measurement).

Among these methods, the nonelectric methods need frequent visual check of the PV array in order to observe the color changes of the modules or the thermal properties such as hotspots. These methods need thermal cameras or other equipment in front of the array.

In contrary, the electrical methods need only the measurements of the output electrical signature such as voltage and current.

Thus, fault diagnosis using electrical methods is more advantageous and promising for the monitoring and diagnostic PV systems.

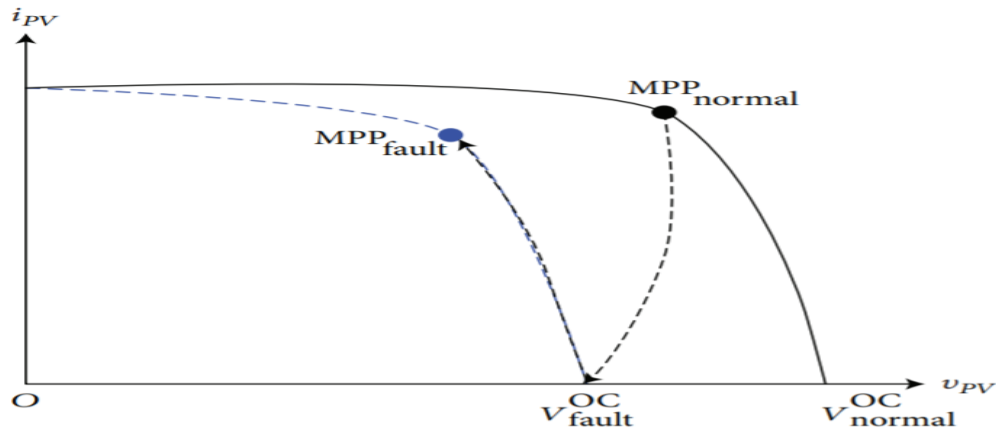


Figure III.1 Change of operating point due to the interaction between fault and MPPT.

III.3 States and signals of the diagnostic method

- Defect: an intolerable deviation of at least one characteristic property or system parameter of acceptable standard operating conditions.
- Failure: a permanent interruption in the ability of the system to perform the function required under specific operating conditions.
- malfunction: is an intermittent irregularity in the performance of the function desired system.
- Error: is a deviation between the measured or calculated value of an output variable and these correct real or theoretical values.
- Disturbance: is an unknown or uncontrolled input influencing the system.
- Residual: fault indicator, based on the deviation between the measurements and the value calculated based on model equations.
- Symptom: a change in the observed amount of normal behavior

III.3.1 Function

- Fault detection: determination of the faults presented in the system and the detection.
- Fault isolation: determination of the type of location (location) and the fault detection. monitoring fault detection.
- Fault identification: determination of the weight (simple or big), the variation over time of the fault behavior. Followed by fault isolation.
- Fault diagnosis: determination of the type, weight, location and time of detection of the default. Followed by fault isolation.
- Monitoring: continuous task in real time determining system conditions physical, by recording information, recognizing and indicating abnormalities in behavior.
- Supervision: monitoring the physical system and taking appropriate action to maintain the operation in the event of a fault.

III.3.2 Models

- **Quantitative model:** use of static and dynamic relationships between system variables and parameters in the order of describing the behavior of the system in quantitative mathematical terms.
- **Qualitative model:** use of static and dynamic relationships among the variables of the system in the order of describing the behavior of the system in terms qualitative as causality and if-then rules.
- **Diagnostic model:** a set of static or dynamic rules that bind variables of specific inputs

III.3.3 The properties of systems

- **Reliability:** ability of the system to perform the requested function under conditions of the beginning, in a given possibility, in a given period of time.
- **Safety:** ability of the system not to cause danger to people, equipment or the environment.
- **Availability:** probability that a system or equipment will operate in a way satisfactory and effectively, at any point in time.

III.3.4 Performance criteria of a diagnostic system

How to ensure that the diagnostic system developed is the most efficient possible? To answer such a question, it is first necessary to define by virtue of what criteria the system can be evaluated.

In general, we can group the various detection system performance criteria as follows [14]:

1. Detectability.
2. Isolability.
3. Sensitivity.
4. Robustness.
5. Economic cost.
6. Development time.

- **Detectability** The concept of detectability is the ability of the diagnostic system to be able to detect the presence of a fault in the system. It is strongly linked to the notion of indicators of defects (symptoms): the symptom generator must in a certain way be sensitive to the faults that we want to detect.

- **Isolability** is the ability of the diagnostic system to trace directly to the origin of the default. An alarm very often generates new alarms and it therefore becomes difficult to find the faulty component. The property of Isolability is linked to the structure of symptoms and the detection procedure itself.

- **Sensitivity** characterizes the ability of the system to detect faults of a certain amplitude. It depends not only on the structure of the symptoms but also on the amplitude of the measurement noise with that of the fault.

- **Robustness** determines the system ability to detect faults independently modeling errors (sensitivity of the symptom to defects and insensitivity to disturbances). Usually, robustness is defined with respect to all inputs unknown.

The Speed of detection can be a determining factor. Likewise, the economic costs will condition the diagnostic strategy or the replacement of the system.

III.4 Diagnostic methods of a PV generator

We can distinguish two main categories of diagnostic methods of a generator PV, methods non electric and they need human interference and constant checking, and the electric methods that use monitoring system to automatically check for the errors on the I-V curve or the factors to see any errors that can affect the power generating,

III.4.1 Non-electric methods

There are several non-electrical, destructive or non-destructive methods, to diagnose the fault at the P V cell level. The main fault that can occur at this level is the crack of the cell. We can cite as methods:

- Mechanical tests of bending.
- Photoluminescence and electroluminescence imaging.
- Thermography tests [15, 16].

For the diagnosis of PV modules, the imaging method (thermal camera) infrared is widely applied [17].

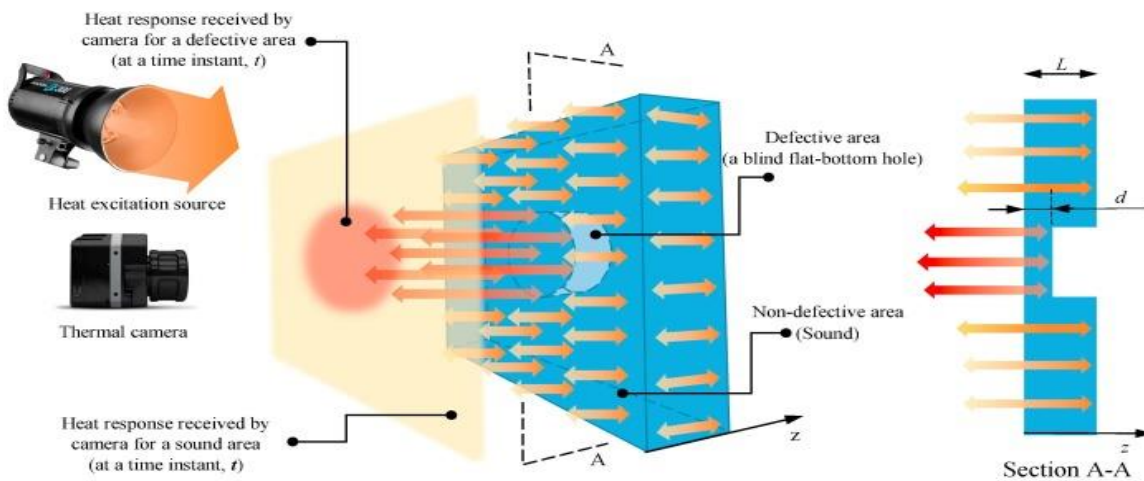


Figure III.2 Characterization using active infrared thermography.

Some successes in fault location using the thermal imager like:

- Leakage current in the cubicle.
- An increase in the resistance of the connection between cells.
- Abnormal heating of cells.
- Conduction of the bypass diode [18].

This method can also be applied for the connectors in the junction box, the functionality of the anti-reverse diode.

III.4.2 Electrical methods

In these methods, the most common measured quantities are:

- The current delivered by the PV panel.
- The voltage across the PV panel.
- The insulation resistance between the positive and negative terminals of the PV panel.

It is also possible to add the additional quantities that are the temperature site ambient temperature and sunlight to electrical measurements [17].

The measurements on the AC side are larger in number because they are directly related to energy. The used measurement in most of the diagnostic methods are for the parameters

- AC current of the pv system.
- AC voltage of the pv system.
- AC current of the mppt.
- AC voltage of the mppt.
- Heat.
- Radiation.

From the measurements written in the two previous paragraphs, it is easy to deduce:

- Instantaneous DC power
- The energy produced over different periods (depending on the storage capacity of data) DC and AC sides. We often add:
- The operating time of the inverter
- The date of commissioning
- System failure alerts (mainly insulation faults)

III.5 Most commonly used diagnostic systems

A proper diagnosis is an essential element to guide proper and successful isolation and fix the PV system errors. For these reasons, classification systems that detect errors automatically are necessary, we will discuss them and chose the best for our current system.

III.5.1 Diagnostic by the I-V curve analysis

The general approach to assess the electrical performance of a PV system is based upon the capability of analytically describing the I–V characteristic of the PV component for each operative temperature and solar radiation.

Traditionally, the analytical models used in the study of these phenomena evaluate the behavior of the PV cell by assimilating it into an equivalent electrical circuit that includes some non-linear components. These electrical equivalent circuits are based on some unknown parameters, from three to seven, depending on the complexity of the model. The most common and used of them is the single diode based equivalent circuit model, which is characterized by five unknown parameters. First of all, I_{PH} (light or photo-generated current) represents the charge carrier generation in the semiconductor layer of the PV cell caused by the incident radiation.

Due to the presences of the diode, there is one unknown parameter, I_0 (reverse-bias saturation current for the diode) and η (the ideality factors of the diode). R_{SH} (parallel or shunt resistance) expresses the losses due to the high-current path through the semiconductor throughout the mechanical defects and the leakage current to the ground.

Finally, R_S (series resistance) represents the internal losses due to current flow and the connection between cells. The I-V curve, and therefore the parameters, of a PV panel vary with radiance and cell temperature.

Anyhow, the reference value of each parameter can be calculated starting from its value in the

operating conditions and vice versa [19].

Once the parameters have been obtained, the I-V characteristic can be estimated by this equation:

$$I = I_{PH} - I_o \cdot \left(e^{\frac{V+I \cdot R_S}{n \cdot V_t}} - 1 \right) - \frac{V + I \cdot R_S}{R_{SH}} \quad \dots\dots\dots \text{III.1}$$

The procedure here proposed for monitoring and diagnostic purposes is based upon the comparison between the measured I-V curve in real working conditions and that one approximated starting from the estimated parameters.

In particular, the methodology adopted can be described by following steps:

- Calculation of the five parameters starting from data provided by manufacturers.
- Estimation of the I-V curve in theory as a threshold.
- Measurement of solar radiation and cell temperature (in the real working condition);
- Calculation of the five parameter in the real working condition through relations proposed in [19].
- Estimation of the I-V characteristic in real working condition using the calculated parameters.
- Measurement of the partial I-V curve.
- Calculation of the error between the measured and the estimated I-V curve

If the I-V curve is equal to the theory value of the threshold, then there are no anomalies in the measured I-V characteristic, no faults are detected, the five parameters can be estimated and stored in order to develop a long term diagnostic analysis.

While, if the I-V curve is lower than the threshold a fault is detected, the estimated five parameters are not stored and a short term diagnostic procedure can be launched to identify the location and the type of fault.

the example of the operation can be found in the figure III.1.

The block diagram of the algorithm here developed is shown in Figure III.3.

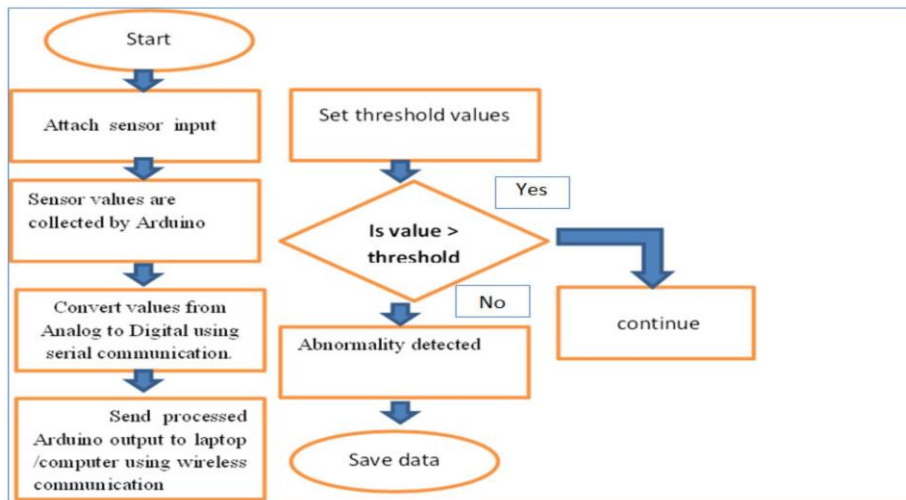


Fig III.3 Block diagram of the procedure here proposed for monitoring and diagnostic purpose.

III.5.2 Diagnosis by modeling and identification

The principle of detection is based on the comparison of the measured parameters with the parameters associated with normal operation. The representative parameters of the process are obtained by the identification method.

Identification is the determination, from knowledge of the input and output signals, of a mathematical model belonging to a given class (behavioral, functional, etc.) for which the dynamic or static behaviors are equivalent to those of the process within the meaning of a given criterion.

In general, the identification of a system means the determination of a simulation model, that is to say the choice of a mathematical function and the extraction of its parameters from experimental data Figure III.4.

The estimation of parameters concerns the determination of the model coefficients from the experimental data for a given model. The terminology “estimate” refers to the fact that the extracted variable values are subject to errors.

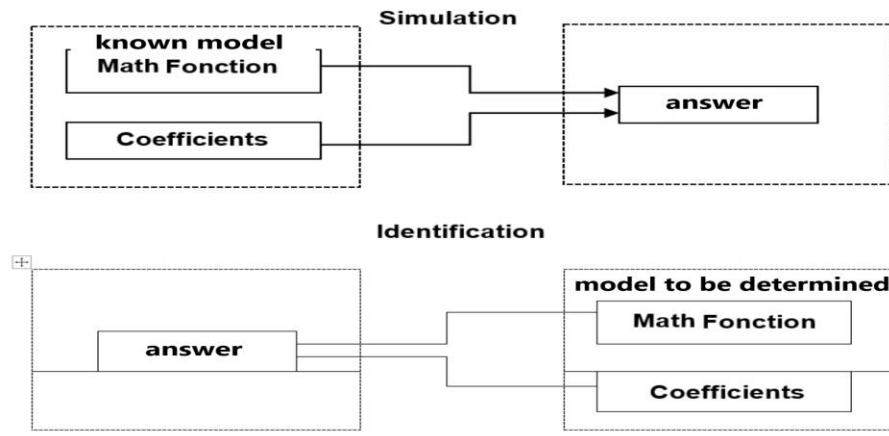


Figure III.4 Relationship between simulation and identification [19].

III.5.3 Diagnosis with fuzzy logic

Fuzzy logic is a basic control system that relies on the degrees of state of the input and the output depends on the state of the input and rate of change of this state.

In other words, a fuzzy logic system works on the principle of assigning a particular output depending on the probability of the state of the input.

III.5.3.1 Principle of the fuzzy system

Fuzzy logic works on the concept of deciding the output based on assumptions.

It works based on sets. Each set represents some linguistic variables defining the possible state of the output. Each possible state of the input and the degrees of change of the state are a part of the set, depending upon which the output is predicted.

It works on the principle of If-else-the, i.e. If A AND B Then Z.

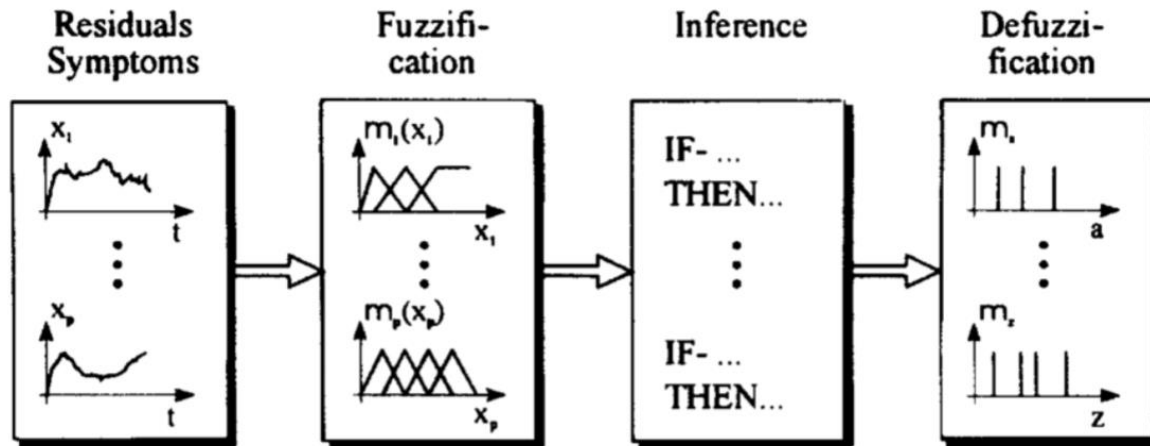


Figure III.5: General diagram of symptom assessment [20].

A Fuzzifier which transforms the measured or the input variables in numerical forms into linguistic variables.

A Controller performs the fuzzy logic operation of assigning the outputs based on the linguistic information. It performs approximate reasoning based on the human way of interpretation to achieve control logic.

The controller consists of the knowledge base and the inference engine. The knowledge base consists of the membership functions and the fuzzy rules, which are obtained by knowledge of the system operation according to the environment.

The Defuzzifier

Finally, the fuzzy information of the defects must be converted to clear sets (example yes-no declaration for the various faults). This can be done by the computer or by the operator.

III.6 The method of diagnostic suggested

The choosing of the diagnostic system is deferent on every case, every deferent system has deferent targeting (city greed, house, company, school project) and money investing (government, investor or simple project) and system capabilities, sense the system we are using is arduino uno the best system must have 2 categories checked for it to be chosen:

- The capabilities of the system.
- The efficiency of the diagnostic method.

III.6.1 Concept and principle of the proposed MPPT performance analysis technic

A system will be called MPPT-PA (Maximum Power Point Tracking Performance Analyzer) measure the values of the two powers by comparing component namely:

- The maximum power of PVG calculated by the MPPT (M_{PP}).
- And the DC output power delivered to the load (P_{load}).

These measurements are outcomes by the physical interconnection of our MPPT-PA system between the PVG and the MPPT for one side (far Upstream) and between the MPPT and load for the other side (far Downstream)

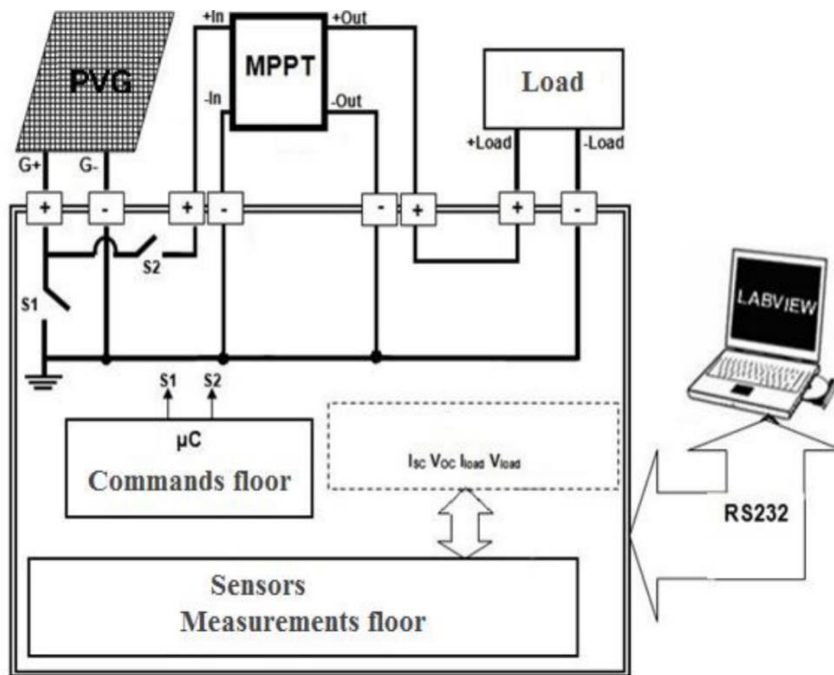


Fig III.6 Block diagram of MPPT-PA system [21].

III.6.2 Maximum power reference (P_{mp})

The maximum power reference (P_{mp}) is the maximum power that can be delivered by the PVG in an instant weather conditions. This power is the result of the arithmetic product of the optimum

current (I_{mp}) and the optimum voltage (V_{mp}) as:

With : $P_{mp} = I_{mp} \cdot V_{mp}$ III.2

$$I_{mp} = k_i \cdot I_{sc} \quad \text{..... III.3}$$

$$V_{mp} = k_v \cdot V_{oc} \quad \text{..... III.4}$$

III.6.3 Choice of multipliers K_i and K_v

It has been verified experimentally that there is a dependency between the short circuit current (I_{sc}) and the maximum current that can deliver a PVG (I_{mp}), and for the open circuit voltage (V_{oc}) and the PVG maximum voltage that can apply under certain climatic conditions [21].

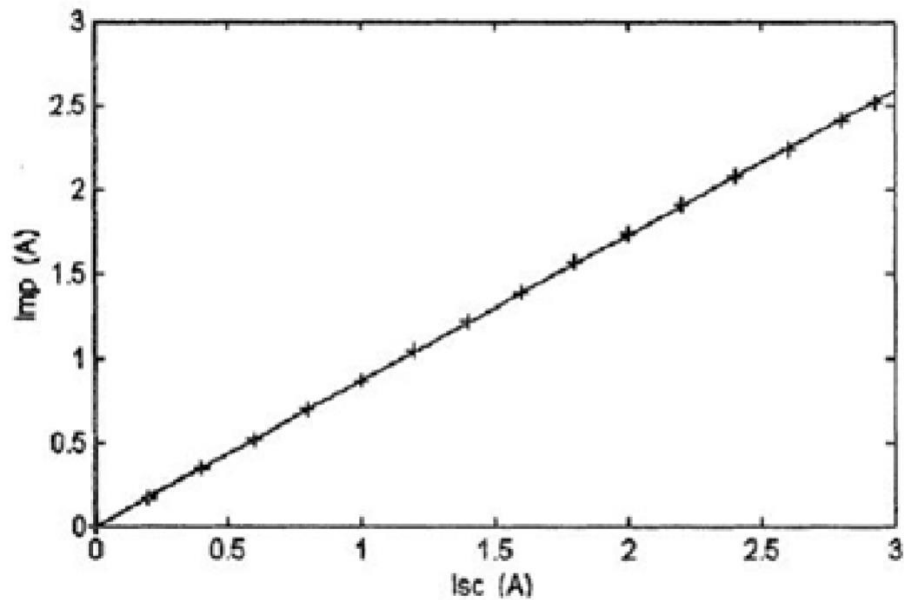


Figure III.7 Dependence between "the current corresponding to maximum power" and "short circuit current" for an OFFC panel [21].

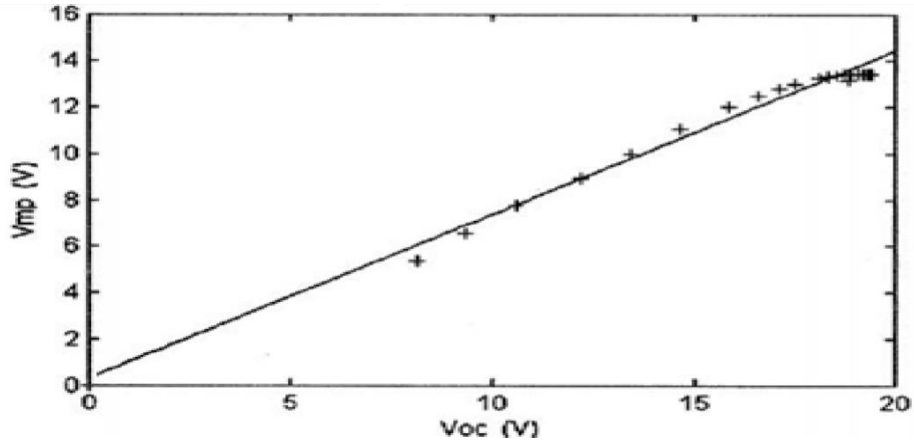


Figure III.8 Dependence between "the voltage corresponding to the maximum power" and "open circuit voltage" for an OFFC panel [21].

Ki and Kv respectively represents the slopes of two straight curves. Ki and Kv are called respectively a current factor and a voltage factor and they are respectively equal to 0.86 and 0.71. By analogy, we can also define the product (Ki * Kv) by the form factor of PVGas:

$$FF = \frac{P_{mp}}{I_{SC} \cdot V_{OC}} = K_i \cdot K_v \quad \text{..... III.5}$$

III.6.4 Real power delivered by the MPPT

The real power delivered by the MPPT (Pload) is the result of the arithmetic product of the current (Iload) and voltage (Vload) as:

$$P_{load} = I_{load} \cdot V_{load} \quad \text{..... III.6}$$

III.6.5 Performance factor

The performance factor (PF) is quite different from the energy efficiency of the MPP. In fact, it is the ratio of the power extracted from the PVG (delivered to the load) (Pload) and the maximum power that can generate the PVG (Pmp), under the same climatic conditions

$$PF = \frac{P_{load}}{P_{mp}} * 100 \quad \text{..... III.7}$$

III.6.6 Principle of dynamic measurement method (Online measure)

The principle of the proposed method resolves the sampling of the short-circuit current I_{sc} and the open circuit voltage V_{oc} in a T period without a permanent disconnection of the MPPT from the PV conversion chain.

Simply disconnect this MPPT during this period T_{sw} to take the open circuit voltage V_{oc} then short-circuit the PVG to pick up the short-circuit current I_{sc} then reconnect the MPPT to the PVG.

Given the temperature and radiation (two slow phenomena), these two main parameters that will modify the characteristic of a PV generator and which will cause a subsequent modification of the maximum power point, variations in time are negligible compared to the decoupling period of the MPPT.

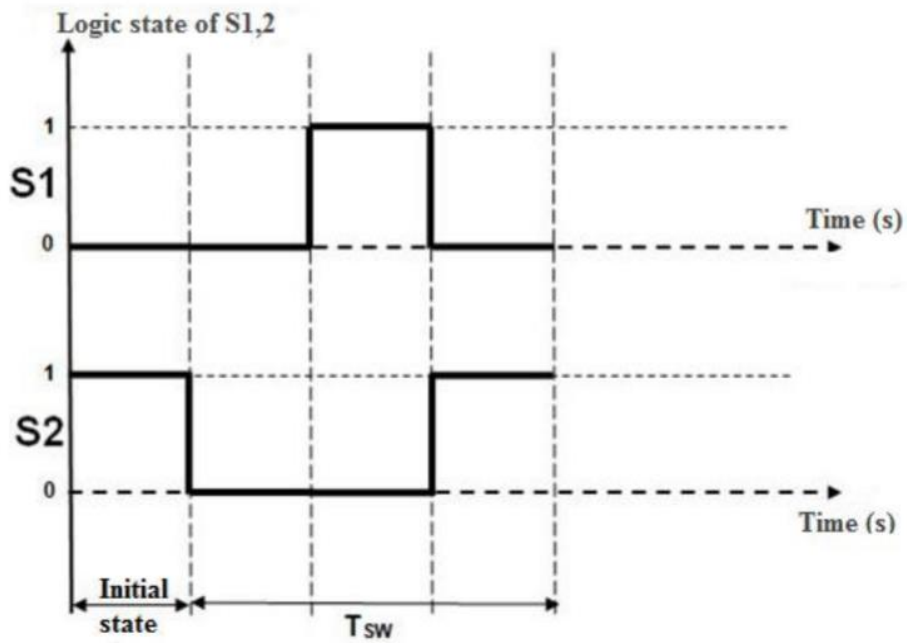


Figure III.9 Logic states chronogram of S1 and S2 for a T_{sw} period.

With:

$$S_{1,2} = \begin{cases} 1 : \text{Switch On} \\ 0 : \text{Switch Off} \end{cases}$$

STEP	S1	S2	Action
INITIAL	0	1	The MPPT is coupled to the PVG
1	0	0	Measuring the open circuit voltage Voc (PVG is isolated)
2	1	0	Measurement of short circuit current Isc current (PVG is shorted)
3	0	1	Measurement of current Iload and voltage Vload delivered to the load (MPPT is reconnected to the PVG)

Table 2 Switching scenario of S1 and S2 to ensure the online measure.

To ensure the reliability of our MPPT-PA system, we opt for the measurement by redundancy of the necessary values. This is resolved by the extent of N values of each parameter in one switching period Tsw and take the average of each parameter.

Parameters to measure	Average value
Short-circuit current Isc (A)	$\overline{I_{sc}} = \sum_0^N \frac{I_{scn}}{N}$
Open circuit voltage Voc (V)	$\overline{V_{oc}} = \sum_0^N \frac{V_{ocn}}{N}$
Current delivered to the load by MPPT Iload (A)	$\overline{I_{load}} = \sum_0^N \frac{I_{loadn}}{N}$
Voltage applied across the load by MPPT Vload (V)	$\overline{V_{load}} = \sum_0^N \frac{V_{loadn}}{N}$

Table 3 Calculate the average of the parameters values for the analysis.

Equation for calculating the value N:

$$N = \frac{T_{sw}}{t_{one\ sample\ aquaring}} \quad \dots\dots\dots \text{III.8}$$

With:

$T_{one\ sample\ aquaring}$: Time to take a single acquiring of four variables parameters

The particularity of this proposed strategy is that the measurement of climatic parameters including temperature and illumination is not indispensable.

III.6.7 Errors in current, voltage and power

View that the performance factor is based on the relationship between the optimum power that can deliver the PVG and power delivering to load by the MPPT regulator, this one can lead to errors on the components of powers mentioned previously (currents and voltages) as:

$$\Delta I = I_{mp} - I_{Load} \quad \dots\dots\dots \text{III.9}$$

$$\Delta V = V_{mp} - V_{Load} \quad \dots\dots\dots \text{III.10}$$

$$\Delta P = P_{mp} - P_{Load} \quad \dots\dots\dots \text{III.11}$$

III.7 Conclusion

In this chapter we proposed a complete diagnostic method for detecting errors in the system and continuation of the evaluation of the system, increased series-resistance losses, and heat and radiation and MPPT errors in PV systems, based on the measurement and analysis of the full I-V characteristic of the PV theoretic capabilities and the real parameters by the information of the data sheet on the PV panel capacity on known heat and radiation parameters.

CHAPTER IV

HARDWARE IMPLEMENTATION

IV.1 Introduction

MPPT-PA system includes a conversion part a transmission part a control part and a power switching part. Our MPPT-PA is designed on the basis of an Arduino Uno card a current sensor's module a voltage divider as a voltage sensor's module and switch modules (relay) [21].

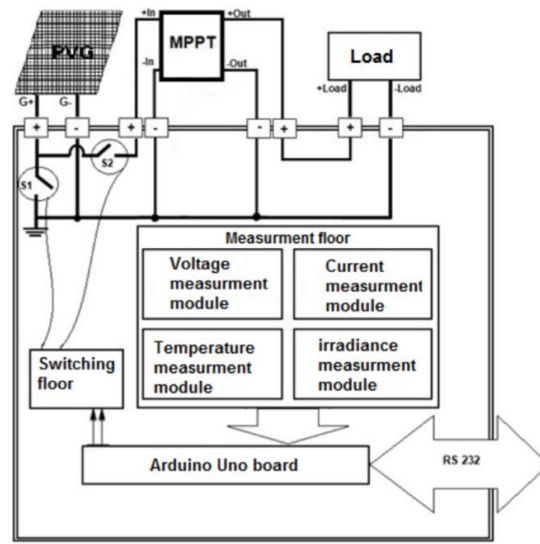


Figure IV.1 Block diagram of the modular structure of the MPPT-PA.

After simulating the diagram with Protus program is given by figure (IV.2)

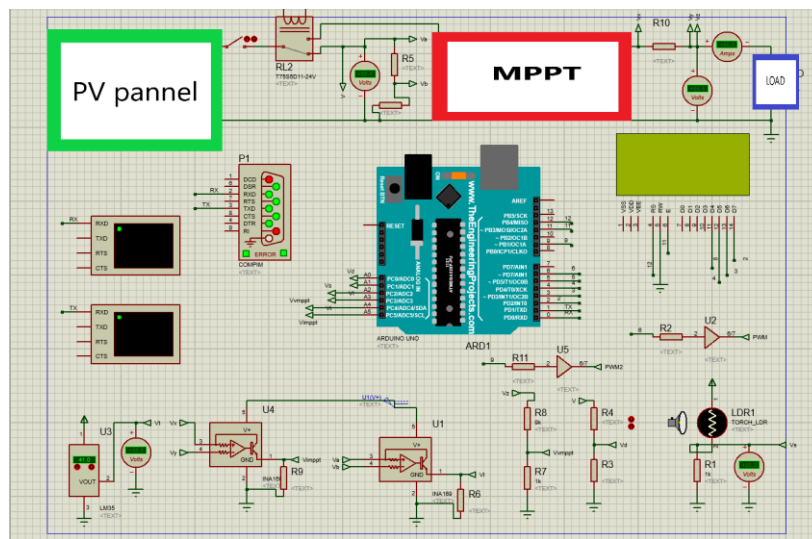


Figure IV.2 MPPT-PA Implementation using ISIS-PROTEUS.

IV.2 Sensors

Sensors are a crucial part of any diagnostic and observation system and for the MPPT, they feed the system with information that help him detect the MPPT point and evaluate the system.

We will discuss the sensors used and their capabilities and accuracy that help the system function better.

IV.2.1 The LM35 humidity and heat sensor

The LM35 is the best heat sensor available for low budget project with very high accuracy and long life span that is perfect for this kind of projects.

IV.2.1.1 Introduction

In general, a temperature sensor is a device which is designed specifically to measure the hotness or coldness of an object. LM35 is a precision IC temperature sensor with its output proportional to the temperature (in °C). With LM35, the temperature can be measured more accurately than with a thermistor [23].

It also possesses low self-heating and does not cause more than 0.1 °C temperature rise in still air. The operating temperature range is from -55°C to 150°C. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It has found its applications on power supplies, battery management, appliances, etc.

The sensor circuitry is sealed and not subject to oxidation. The LM35 generates a higher output voltage than thermocouples and may not require that the output voltage be amplified. The LM35 has an output voltage that is proportional to the Celsius temperature. The scale factor is 0.01V/°C.

The LM35 does not require any external calibration or trimming and maintains an accuracy of +/-0.4°C at room temperature and +/-0.8° C over a range of 0°C to +100°C [23]. Another important characteristic of the LM35 is that it draws only 60 micro amps from its supply and possesses a low self-heating capability.

The LM35 is a linear temperature sensor that comes directly calibrated in Celsius. The analog output is directly proportional to the temperature in Celsius: 10 mV per degree Celsius rise in temperature.

1.2.1.2 Working principle of LM35

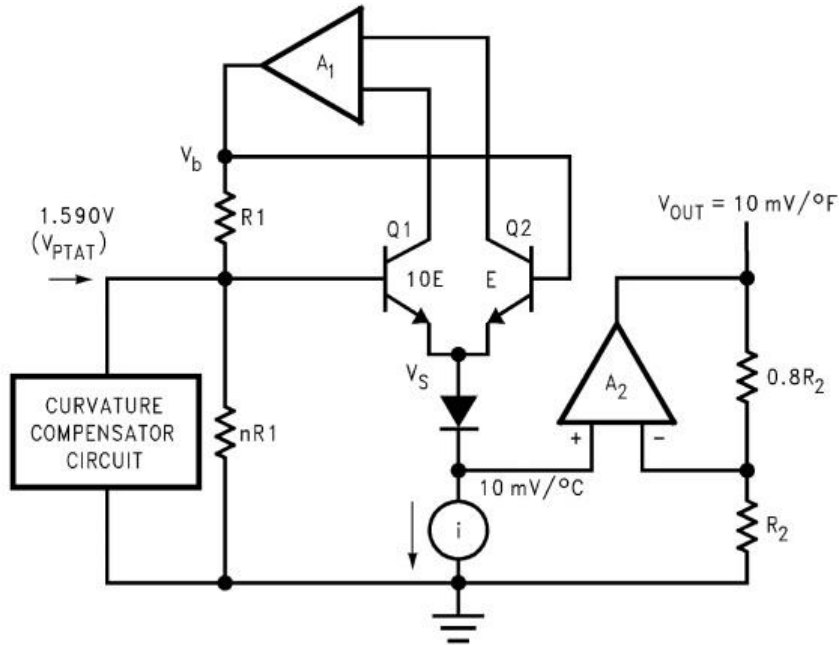


Figure IV.3 Internal Block Diagram for LM35 [24].

There are two transistors in the center of the drawing. One has ten times the emitter area of the other. This means it has one tenth of the current density, since the same current is going through both transistors.

This causes a voltage across the resistor R1 that is proportional to the absolute temperature, and is almost linear across the range. The "almost" part is taken care of by a special circuit that straightens out the slightly curved graph of voltage versus temperature [24].

The amplifier at the top ensures that the voltage at the base of the left transistor (Q1) is proportional to absolute temperature by comparing the output of the two transistors.

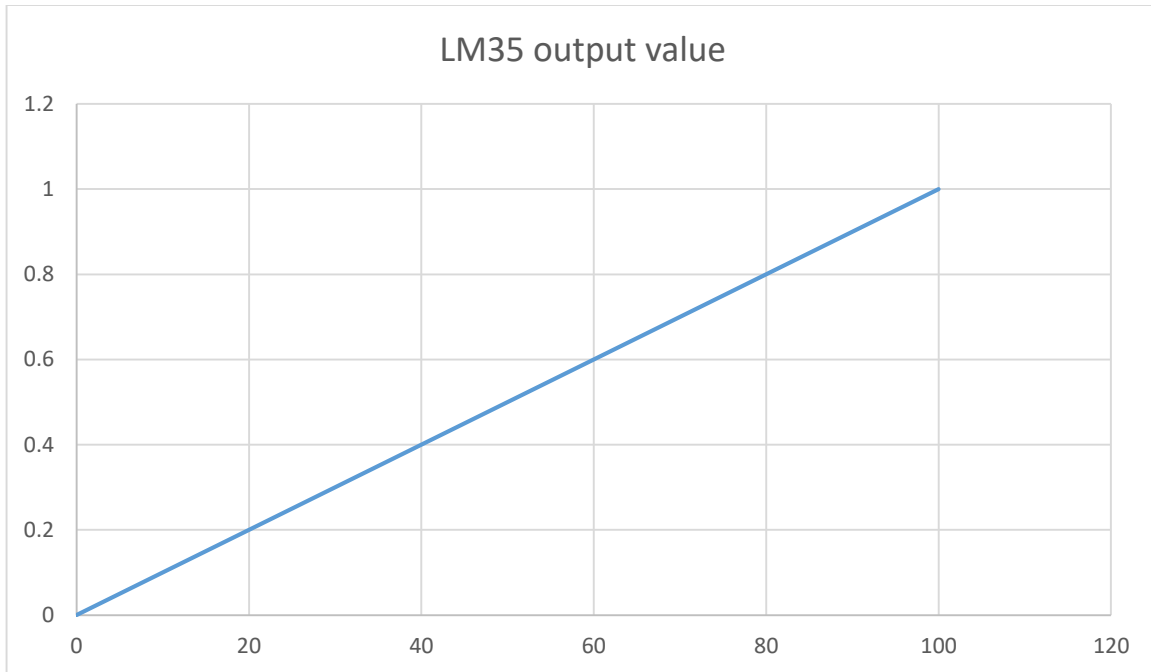


Figure IV.5 the output (voltage) vs input (Celsius) for the LM35.

IV.2.2 Photoresistor

the Photoresistor sensor is simple effective way to calculate the value of the radiation in certain place we will discuss the effectiveness and how it work in this chapter

IV.2.2.1 Introduction

The light sensor is developed based on the photoelectric effect principle of semiconductors. It can be used to detect the intensity of ambient light, and it can also be used to detect the difference in light between different colored surfaces.



Figure IV.6 Real looks of the photoresistor.

IV.2.2.2 Definition of the light sensor

The light sensor usually refers to a device that can sensitively sense the light energy of ultraviolet light to infrared light and convert the light energy into an electrical signal.

The light sensor is a kind of sensing device, which is mainly composed of light-sensitive elements.

It is mainly divided into four categories:

- Ambient light sensor.
- Infrared light sensor.
- Sunlight sensor.
- Ultraviolet light sensor.

Due to its advantages such as high accuracy and easy microcomputer connection for automatic real-time processing, it has been widely used in the measurement of electrical and non-electrical quantities. However, the electrical measurement method is susceptible to interference. In the AC measurement, the frequency response is not wide enough and there are certain requirements on the withstand voltage and insulation.

IV.2.2.3 Working principle of the light sensor

The light sensor works according to the principle of the photoelectric effect. The photoelectric effect refers to the phenomenon that certain special substances can convert light energy into electrical energy after absorbing light.

The photoelectric effect can be divided into two types:

- External photoelectric effect.
- Internal photoelectric effect.

The external photoelectric effect refers to the fact that under the light irradiation, electrons can be emitted from the inside of the material to generate electricity. The photocell and photomultiplier are originals based on the external photoelectric effect. Correspondingly, the internal photoelectric effect occurs inside the substance [25].

When light is irradiated onto the substance, the resistivity inside the substance is changed, thereby generating electromotive force.

Photoelectric elements such as photoresistors and photovoltaic cells are made based on the internal photoelectric effect.

IV.2.2.4 Principle

It works based on the semiconductor photoelectric effect. The Photoresistor is non-polar and is purely a resistive element. It can be applied with DC voltage or AC voltage.

Working characteristics of the Photoresistor:

- When the light is on, the resistance is small.
- When the light is off, the resistance is large.

The stronger the light, the smaller the resistance, when the light stops, the resistance returns to its original value (the range is limited par Spectral range from ultraviolet to infrared) [25].

IV.2.2.5 Features

- The internal photoelectric effect has nothing to do with the electrode (only related to the photodiode), that is, a DC power supply can be used.
- Sensitivity is related to the semiconductor material and the wavelength of the incident light
- Epoxy resin package, high reliability, small size, high sensitivity, fast response speed, and good spectral characteristics.

IV.2.2.6 The internal block diagram for light sensor resistance

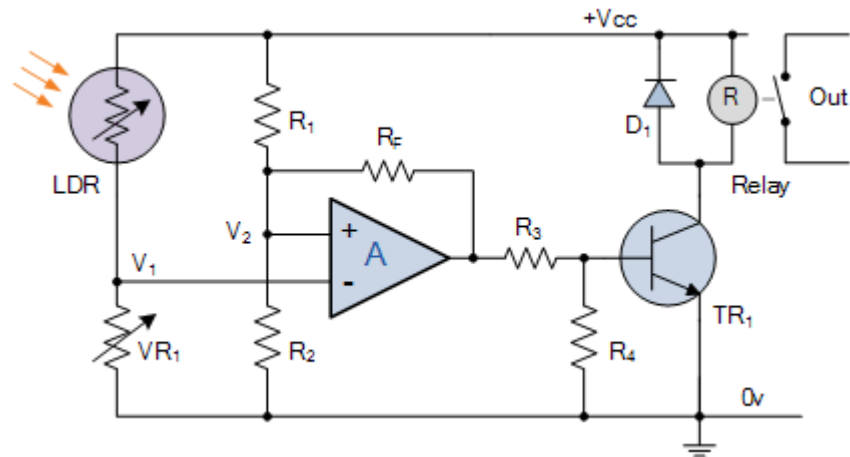


Figure IV.7 Block diagram for light sensor resistance [25].

In this basic dark sensing circuit, the light dependent resistor LDR1 and the potentiometer VR1 form one adjustable arm of a simple resistance bridge network, also known commonly as a Wheatstone bridge, while the two fixed resistors R1 and R2 form the other arm.

Both sides of the bridge form potential divider networks across the supply voltage whose outputs V1 and V2 are connected to the non-inverting and inverting voltage inputs respectively of the operational amplifier.

The operational amplifier is configured as a Differential Amplifier also known as a voltage comparator with feedback whose output voltage condition is determined by the difference between the two input signals or voltages, V1 and V2.

The resistor combination R1 and R2 form a fixed voltage reference at input V2, set by the ratio of the two resistors. The LDR – VR1 combination provides a variable voltage input V1 proportional to the light level being detected by the Photoresistor. As with the previous circuit the output from the operational amplifier is used to control a relay, which is protected by a free wheel diode, D1.

When the light level sensed by the LDR and its output voltage falls below the reference voltage set at V2 the output from the op-amp changes state activating the relay and switching the connected load.

Likewise, as the light level increases the output will switch back turning “OFF” the relay. The hysteresis of the two switching points is set by the feedback resistor R_f can be chosen to give any suitable voltage gain of the amplifier.

The operation of this type of light sensor circuit can also be reversed to switch the relay “ON” when the light level exceeds the reference voltage level and vice versa by reversing the positions of the light sensor LDR and the potentiometer VR1. The potentiometer can be used to “pre-set” the switching point of the differential amplifier to any particular light level making it ideal as a simple light sensor project circuit [27].

IV.2.2.7 The output

From the data sheet of the manufacturing company we find this equation in the range of 0-6000 radiation to be almost linear and we can extract equation to calculate the results correctly

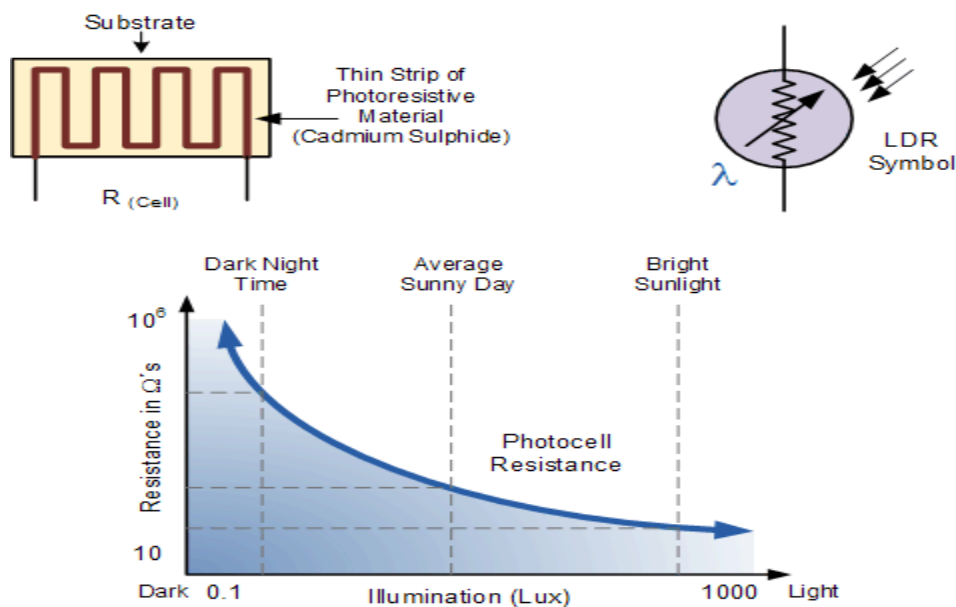


Figure IV.8 The behavior of the LDR in different illuminations [25].

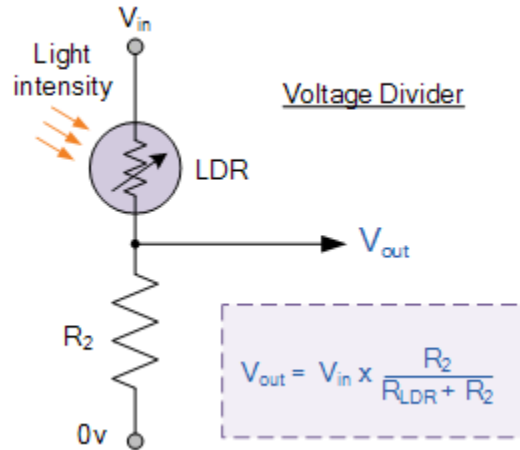


Figure IV.9 Equations of the used LDR system [25].

IV.2.2.8 Applying the light sensor model to the simulation

From the image IV.7 we can find the equation of the Rldr by Applying it with the input we find

$$LDR = (50000/V_s) - 10000 \quad \dots\dots\dots \text{III.1}$$

And the rate between the input and the output will be

$$\text{Lux} = (V_{\text{sensor}} * 5 * 181818) / 100 \quad \dots\dots\dots \text{III.2}$$

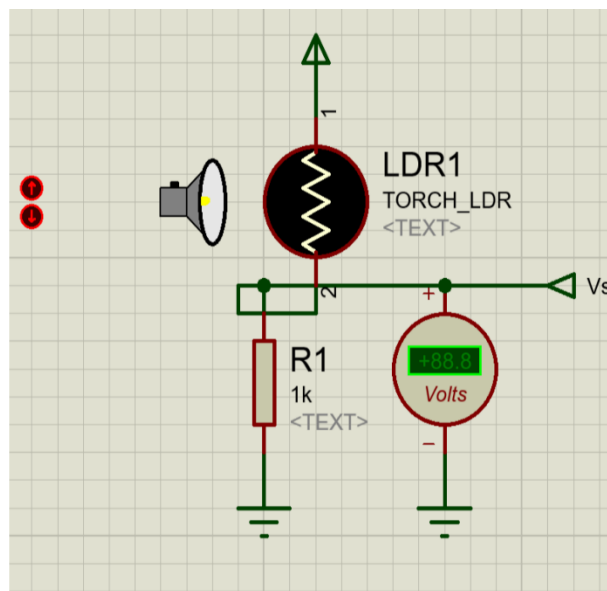


Figure IV.10 Simulation of the photoresistor.

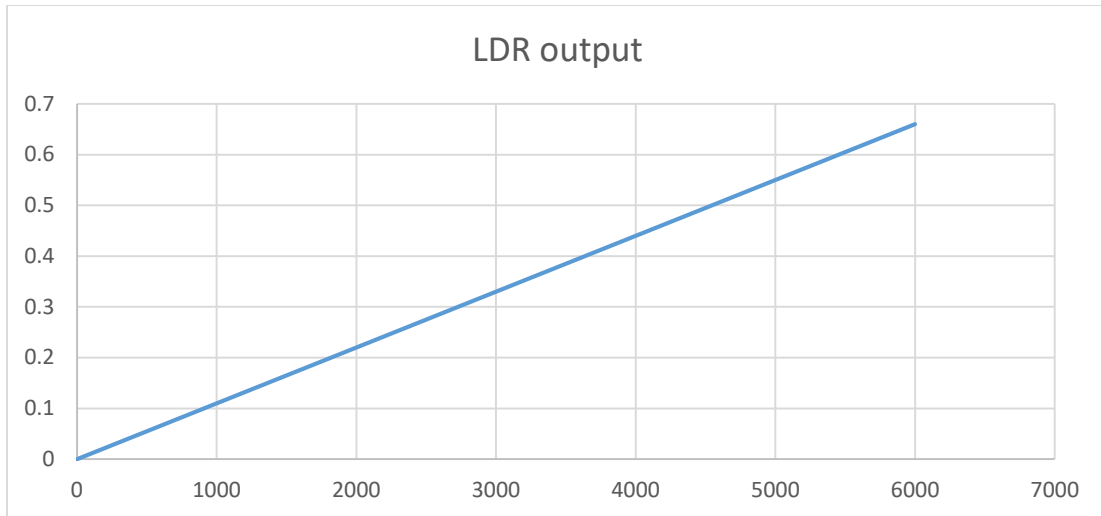


Figure IV.11 Output (volt) vs input of LDR (ohm).

IV.2.3 INA169 sensor

IV.2.3.1 Introduction

The INA169 is a "high-side current monitor," which means that you place a resistor (a "shunt resistor") on the positive power rail and the INA169 measures the voltage drop across that resistor. The INA169 outputs a small current based on the measured voltage drop. If you place a resistor from the output of the INA169 to ground, you can measure the voltage at the output. With some basic math, the output voltage gives you the current through the shunt resistor.

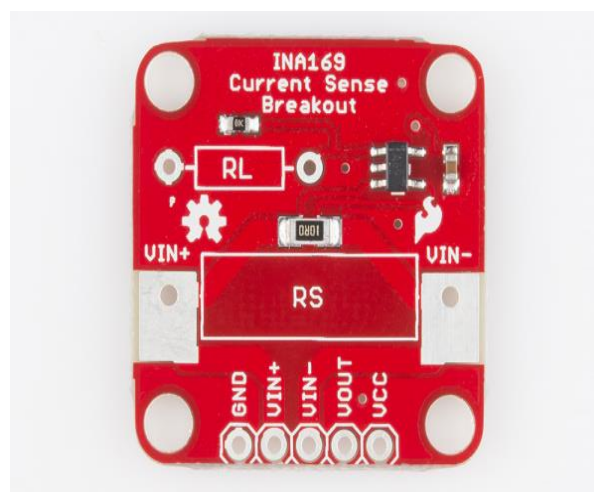


Figure IV.12 INA169 Board.

IV.2.3.2 Working principle of the INA 169 sensor

The breakout board consists of a shunt resistor (R_S), the INA169 chip, and an output resistor (R_L). While R_S and R_L might appear to have 2 resistors, only one is populated on the board [28].

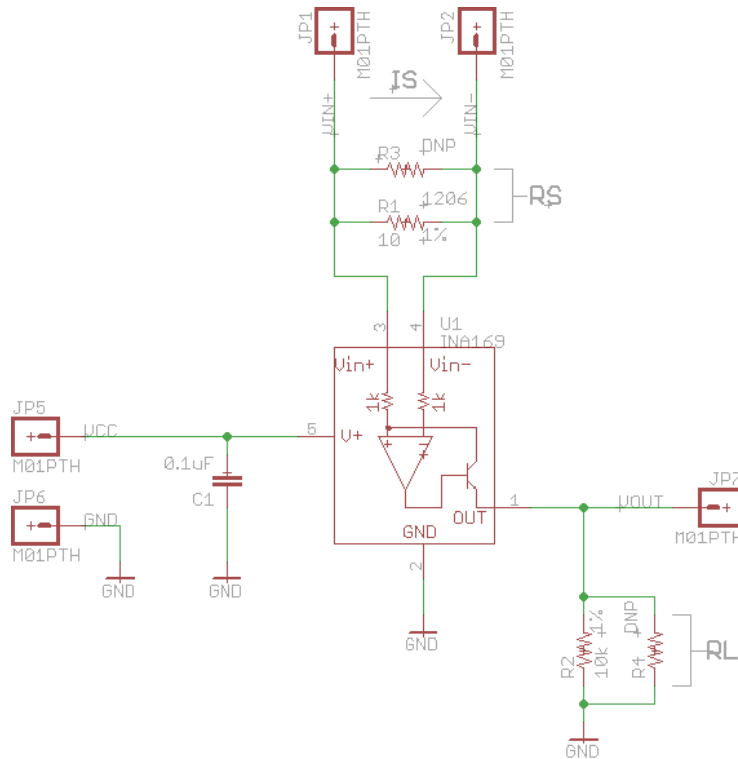


Figure IV.13 INA169 Current sensing breakout schematic.

As current passes from V_{IN+} through R_S to V_{IN-} , it creates a voltage drop across R_S . The op-amp inside of the INA169 chip measures the difference between the V_{IN+} and V_{IN-} voltages and outputs a voltage based on that difference. The output of the op-amp is amplified through the internal transistor, which sources a current out of the INA169 chip. As that current passes through R_L to ground, a voltage level is generated at V_{OUT} .

IV.2.3.3 Modifying functionality

The INA169 cannot sense any differences across R_S greater than 500mV, and the output error increases once the voltage across R_S dips below 35mV. If you include the voltage drop across the internal transistor, this means that the default setup of the breakout board is limited to measuring a current range of about 3.5mA to 35mA.

we can change that range, R_S and R_L can be replaced with resistors of different values. R_S can be removed and replaced with another resistor fairly easily.

R_L is a bit more difficult as it is a small, surface mount resistor. Changing either of the resistors changes the equation from above.

With R_L at 10kΩ, changing R_S gives us the following ranges [28]:

RS	Current Sense Range
10Ω	3.5mA - 35mA
1Ω	35mA - 350mA
0.1Ω	350mA - 3.5A

IV.2.3.4 Measuring current

The voltage at V_{OUT} can be measured using an oscilloscope or an analog-to-digital converter. A bit of math is needed to convert to the source current (I_S):

$$I_S = \frac{V_{OUT} \times 1k\Omega}{R_S \times R_L} \quad \dots\dots\dots \text{III.3}$$

I_S is the current we want to measure.

V_{OUT} is the voltage we measured at the output of the INA169.

1kΩ is a constant resistance value we need to include due to the internals of the INA169.

R_S is the value of the shunt resistor. If you do not modify the board, then this is set at 10Ω.

R_L is the value of the output resistor. If you do not modify the board, then this is set at 10kΩ.

With the example used in my tests we modified the R_S and R_L to get desire outcome

R_S= 0.1 ohm

R_L= 50k ohm

With that the outcome change to

$$I_S = 5 * V_{out} \quad \dots\dots\dots \text{III.4}$$

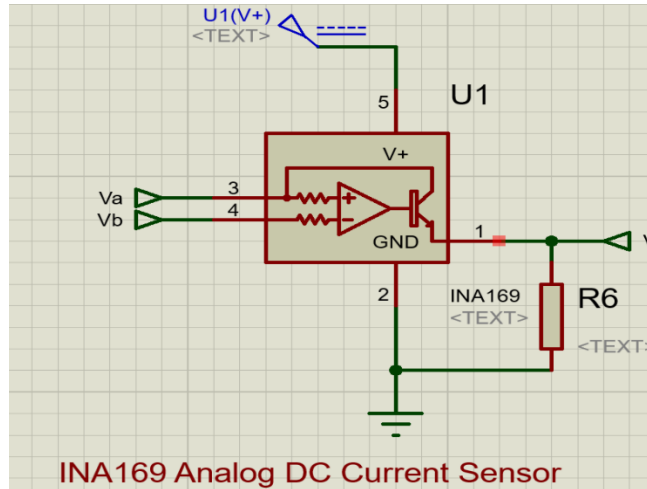


Figure IV.14 The INA169 in simulation.

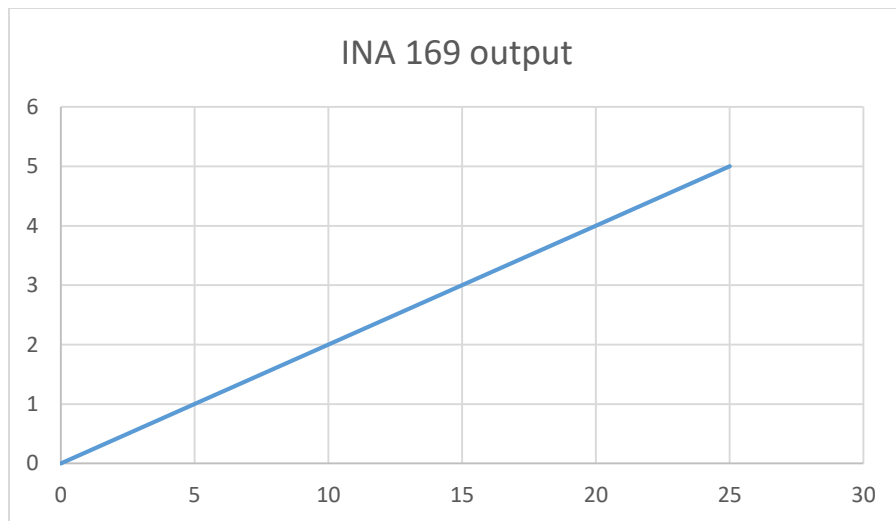


Figure IV.15 The relation between the output (volt) and the input (ampere) of the INA 169.

IV.2.4 Voltage sensor

Voltage sensor is one of the most important part of the simulation for both the diagnostic and MPPT calculation operations.

IV.2.4.1 Introduction

the Arduino Uno is able to measure voltages up to 5V, there are no additional connections needed and the voltage to be measured must be connected directly to the analog input A0 of the Arduino UNO.

The analogue A0 which is used to measure a maximum voltage of 5V, the input voltage is given to the analog input pin of the Arduino. The reference voltage of the A0 is 5V. The A0 in Arduino

UNO is of 10-bit resolution. Hence, the input voltage is calculated by multiplying the analog value at the analog pin with 5 and dividing the value with 2^{10} i.e. 1024. So all we need to do in this case is to make sure that the voltage is divided and doesn't pass the 5 v threshold and for that we need to use a voltage divider

IV.2.4.2 Voltage divider

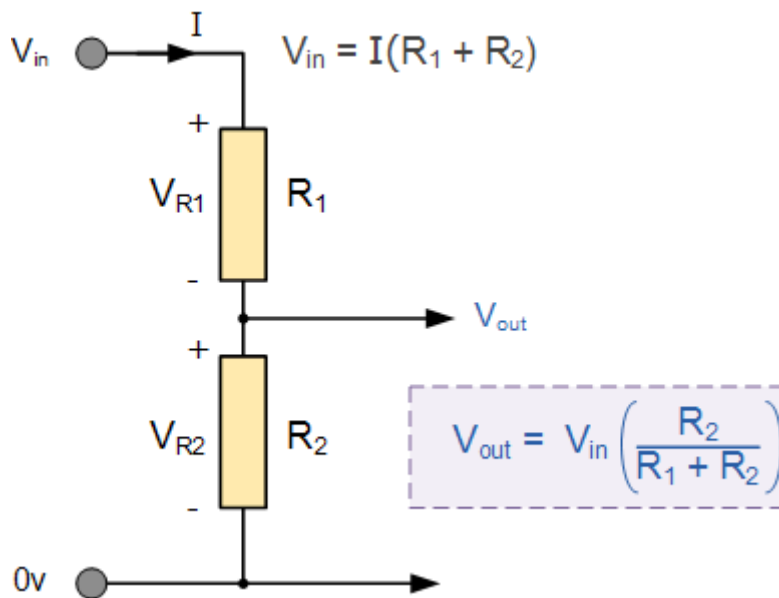


figure IV.16 Voltage divider.

This simple circuit splits the supply voltage proportionally across each resistor in the series chain with the amount of voltage drop being determined by the resistors value, the current through a series resistor circuit is common to all resistors.

So a larger resistance will have a larger voltage drop across it, while a smaller resistance will have a smaller voltage drop across it.

The circuit shown consists of just two resistors, R_1 and R_2 connected together in series across the supply voltage V_{in} . One side of the power supply voltage is connected to resistor, R_1 , and the voltage output, V_{out} is taken from across resistor R_2 . The value of this output voltage is given by the formula:

$$R_2 = \frac{(V_{OUT})(R_1)}{V_{IN} - V_{OUT}} \quad \dots\dots\dots\text{III.5}$$

IV.2.4.3 Applying the voltage divider to the simulation

the use of the voltage divider is deferent for the V_{load} and the V_{oc} because of the maximum voltage between them is deferent (V_{pv} max voltage = 25) (V_{load} max voltage = 50)

and for that we will divide the voltage differently in both cases for the need we have in the simulation.

IV.2.4.3.1 Voltage divider for the V_{load}

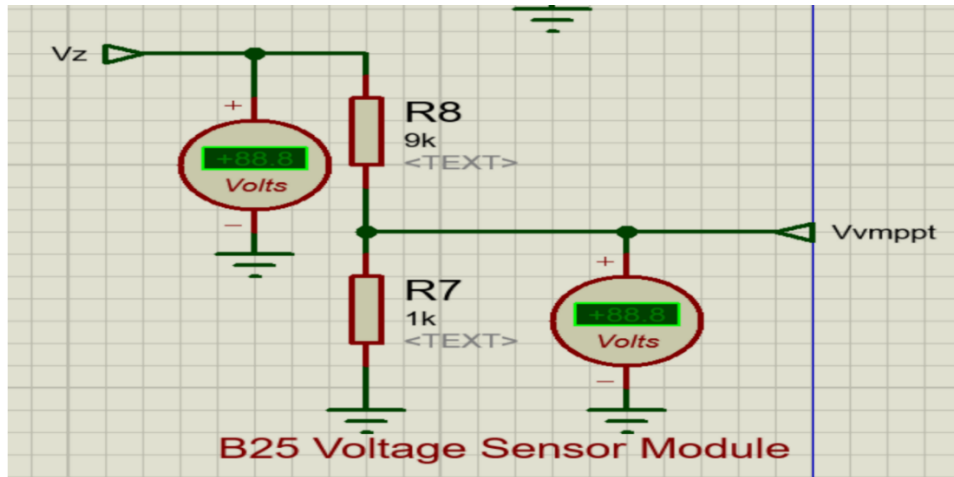


Figure IV.17 MPPT Voltage divider.

$$V_{load} = V_z \cdot R_3 / (R_2 + R_3) \quad \dots\dots\dots\text{III.6}$$

$$V_{load} = V_z / 10 \quad \dots\dots\dots\text{III.7}$$

V_z the voltage coming from the load

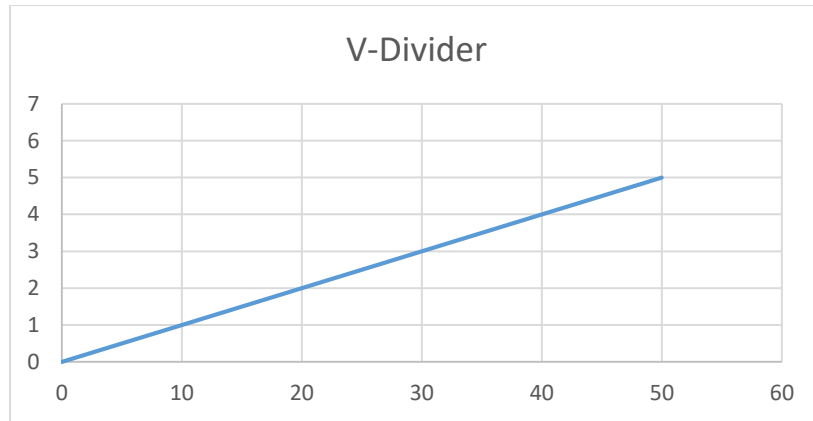


Figure IV.18 The relation between the output (volt) and the input (volt) of the MPPT voltage divider.

IV.2.4.3.2 Voltage divider for the V_{oc}

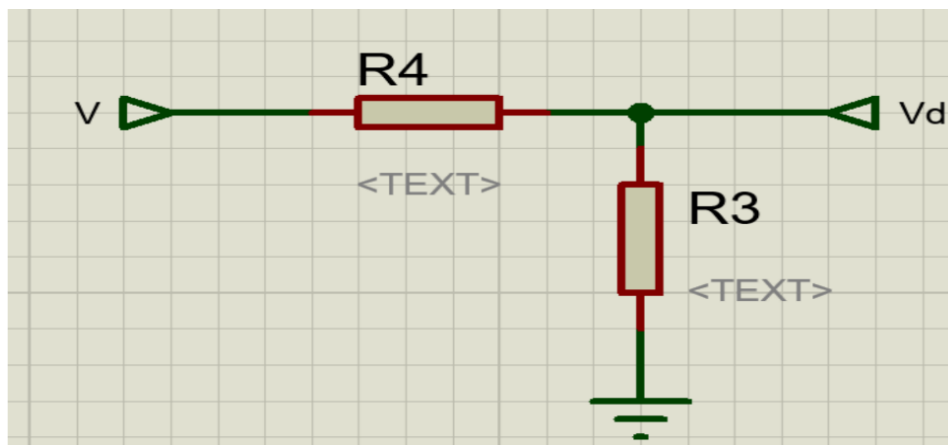


Figure IV.19 PV Panel voltage divider.

$$V_{oc} = V * R3 / (R2 + R3) \quad \dots\dots\dots III.8$$

$$V_{oc} = V / 5 \quad \dots\dots\dots III.9$$

V the voltage coming from the short-circuit

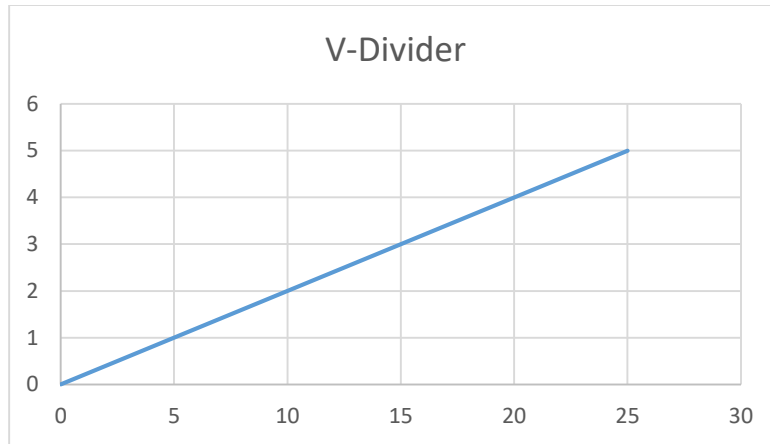


Figure IV.20 The relation between the output (volt) and the input (volt) of the PV panel voltage divider.

IV.3 DC-DC converter (cuk converter)

A cuk converter uses a capacitor to store energy. The Cuk converter takes its name from its inventor. The Cuk consists of two inductors, two capacitors, a switch (usually a transistor) and a diode.

The basic diagram of a Cuk converter is represented by figure below. A drawback remains regarding the inversion of the sign of the output voltage relative to that of the input. By its structure, the Cuk converter can work with output voltages smaller or larger than the input voltage.

The basic operation of a Cuk converter in continuous conduction mode is the subject of this section. In steady state, the average inductance voltages are zero, the cuk coverture vary the voltage on and off to reach the maximum power point calculated with the arduino.

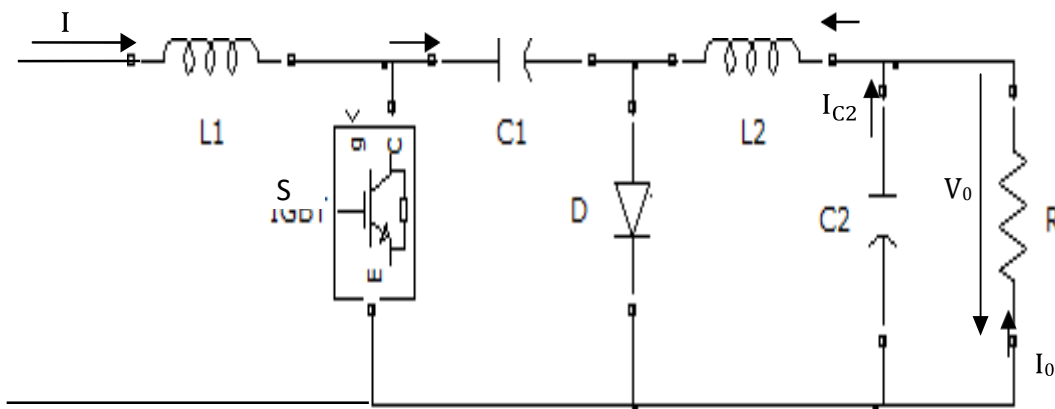


Figure IV.21 Cuk coverture [29].

IV.4 Arduino-PWM cycle.

PWM (Pulse Width Modulation) it is a technique used to simulate duty cycle. The Arduino digital pins either gives us 5 (when turned HIGH) or 0V (when turned LOW) and the output is a square wave signal.

IV.4.1 Principle of PWM

In DC-DC converters, the output voltage must be regulated to be constantly equal to a reference voltage, since the supply voltage V and the load characteristics may vary.

A method of regulating the output voltage $V_0(t)$ to obtain an average voltage consists of continuously adjusting the switch control duty cycle

This method of varying the width of the control pulses of the switch is called the Pulse Width Modulation (PWM) method.

The control signal of the switch S should be developed by comparison between the duty cycle D and a sawtooth voltage V_{DS} as follows:

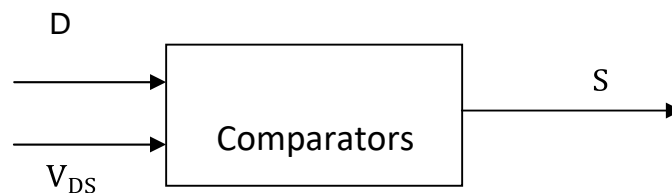


Figure IV.22 Principle of PWM (DC / DC).

- When $D > V_{DS}$: $S = 1$, the switch S is commanded to close (ON state).
- When $D < V_{DS}$: $S = 0$, the switch S is commanded to open (OFF state).

The PWM of the Arduino is 255

- If PWM =255 its open all the time
- If PWM =0 its closed all the time

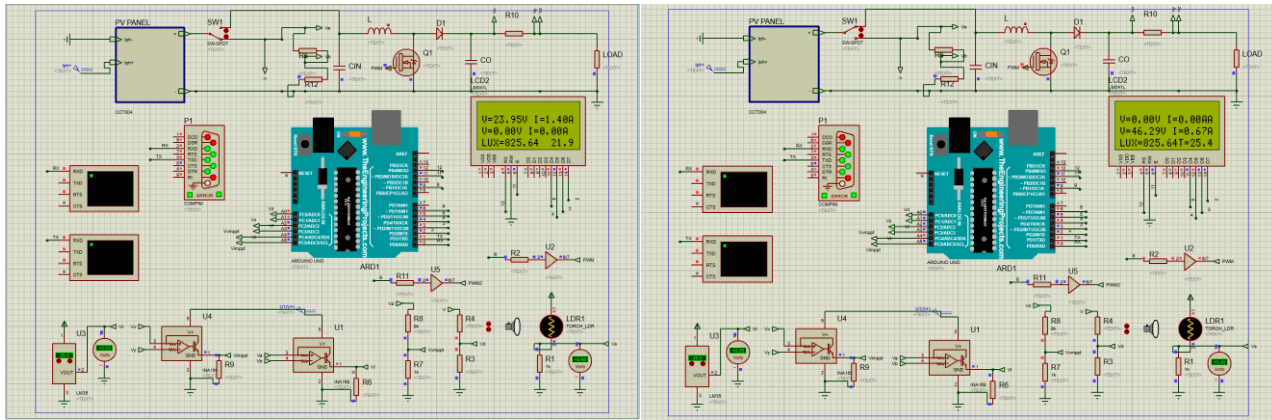
And with varying the PWM between 0 and 255 we get the desired output of duty cycle that can help switch the diagnostic part between the short circuit and the mppt for minimum lose in productivity (to the manual).

And it regulates the Cuk coverture to the desired mppt output.

With this technic we can control the simulation to maximum efficiency [30].

IV.5 Testing the mppt algorithm and simulation efficacy

With simple testing of the system we find this results:



IV.6 Conclusion

The increase in the output after implementing the mppt is 39.45%. Which is really good output percentage for the pv system which was achieved by using the sensors to calculate the primary parameters of the system (heat, radiation, voltage...etc.), and mppt to enhance the output to maximum value possible.

with assessing the parameter and compare to output of the short circuit and load outputs we can assess the efficiency of the performance of the system which can lead to discovering the faults of the system if something happens and fixed properly and fast with in turn lead to more performance and increased life cycle of the pv panel.

CHAPTER V

SUPERVISION OF THE SYSTEM WITH LABVIEW

V.1 LabVIEW introduction

National Instruments LabVIEW is a graphical programming language that has its roots in automation control and data acquisition. Its graphical representation, similar to a process flow diagram, was created to provide an intuitive programming environment for scientists and engineers. The language has matured over the last 20 years to become a general purpose programming environment.

LabVIEW has several key features which make it a good choice in an automation environment. These include simple network communication, turnkey implementation of common communication protocols (RS232, GPIB, etc.), powerful toolsets for process control and data fitting, fast and easy user interface construction, and an efficient code execution environment.

V.1.1Ni LabVIEW background

LabVIEW, which stands for Laboratory Virtual Instrumentation Engineering Workbench is a graphical programming language first released in 1986 by National Instruments (Austin, TX). LabVIEW implements a dataflow paradigm in which the code is not written, but rather drawn or represented graphically similar to a flowchart diagram.

- **Program** execution follows connector wires linking processing nodes together. Each function or routine is stored as a virtual instrument (VI).
- **the front panel** which is essentially a form containing inputs and controls and can be displayed at run time.

A block diagram where the code is edited and represented graphically, and a connector pane which serves as an interface to the VI when it is imbedded as a sub-VI.

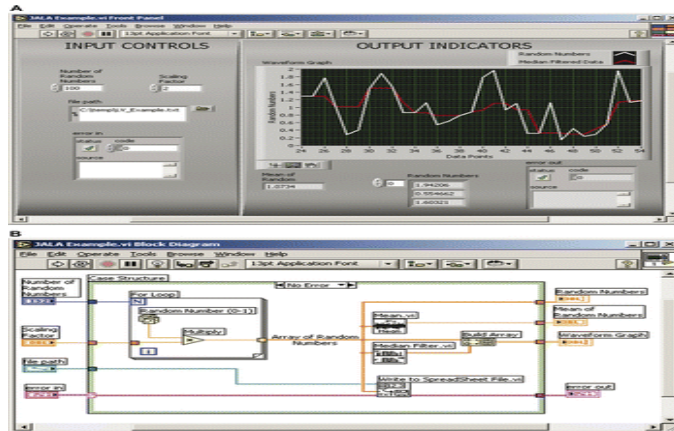


Figure V.1 Exemple NI LabVIEW VI.

Unlike most programming languages, LabVIEW compiles code as it is created thereby providing immediate syntactic and semantic feedback and reducing the time required for development and testing.

Writing code is as simple as dragging and dropping functions or VIs from a functions palette onto the block diagram within process structures (such as for Loops, or Case Structures) and wiring terminals (passing input values, or references). Unit testing is simplified because each function is separately encapsulated. Memory allocation/deallocation is automatically managed by LabVIEW.

The functions that generate data take care of managing the storage for the data. Associated memory is automatically deallocated if the data are no longer being used.

When passing data to a sub-VI, LabVIEW uses pass-by-value semantics with pass-by-reference implementation. There are also functions in LabVIEW that allow developers to manage memory explicitly. NI LabVIEW supports multithreaded application design and executes code in an inherently parallel rather than sequential manner, as soon as a function or sub-VI receives all of its required inputs, this is unique from a typical text-based environment where the control flows line by line within a function.

When sequential execution is required, control flow can be enforced by use of structures such as Sequences, Events, or by chaining sub-VIs where output data from one VI is passed to the input of the next VI.

Similar to most programming languages, LabVIEW supports all common data types such as integers, floats, strings, and clusters (structures) and can readily interface with external libraries, ActiveX components, and .NET framework. Each data type is graphically represented by wires of different colors and thickness.

The development environment provides a variety of debugging tools such as break-points, probes (trace), and single-step. Applications can be developed using a variety of design patterns such as Client-Server, Consumer-Producer, and State-Machine.

There are also UML (Unified Modeling Language) modeling tools that allow automated generation of code from UML diagrams and state diagrams. The GOOP toolkit (Endevo, Stockholm, Sweden) enables full object oriented programming support for LabVIEW, including inheritance [31].

V.1.2 Process monitoring

All systems and jobs can be monitored remotely by a distributed application known as the Process Monitor. This application allows multiple users to monitor active jobs across all systems for status and faults

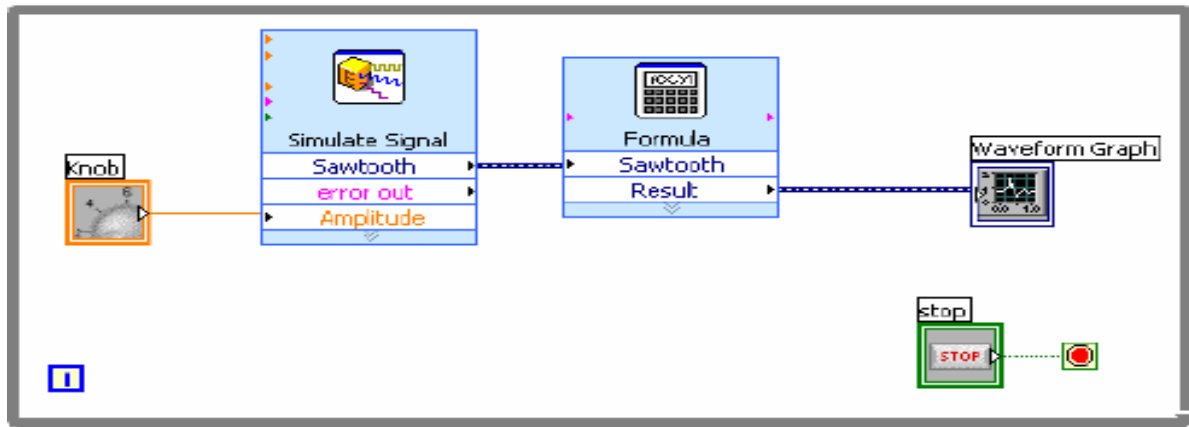


Figure V.2 Example of the block diagram.

V.2 The simulation of the LabVIEW supervision system

The results of simulation are given by the figures (V.3, V.4 and V.5).



Figure V.3 The performance of the main 6 outputs of the system.

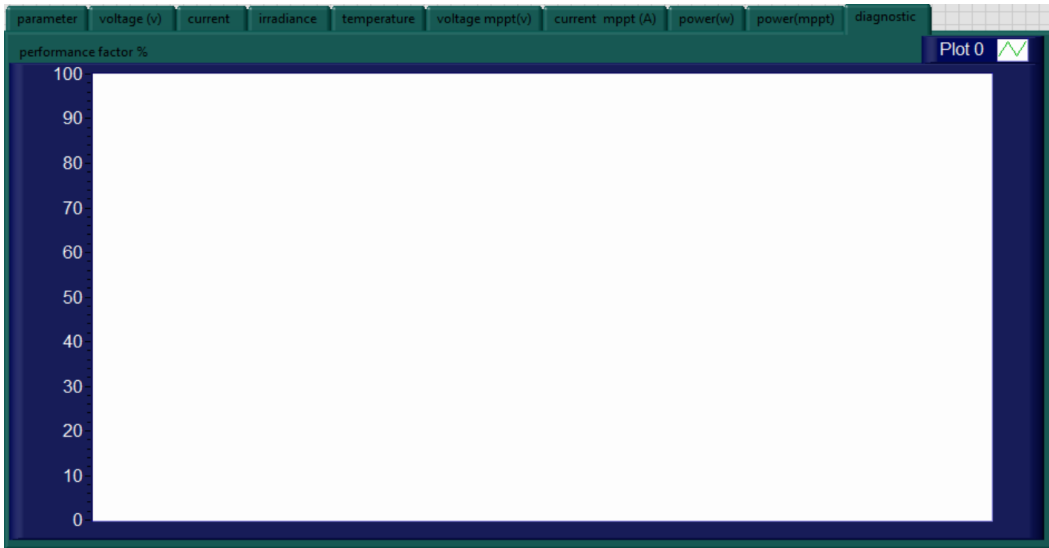


Figure V.4 The performance factor % of the system.

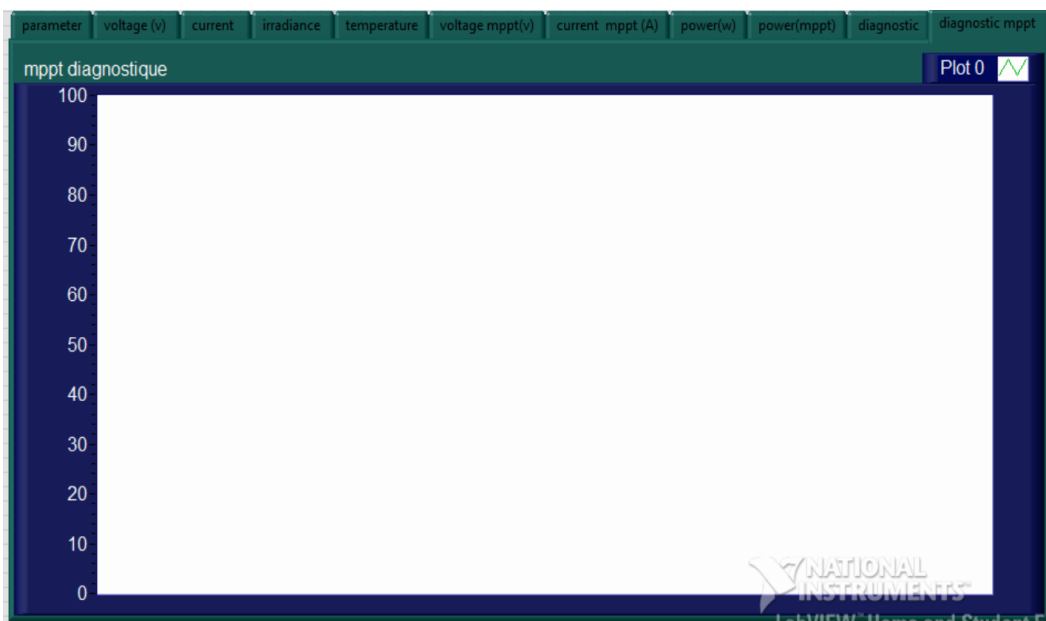


Figure V.5 The MPPT diagnostic.

If the MPPT factor is between 65 or more its working properly.

as we can see in this panel the main 6 outputs of the simulation can be viewed at real time progress in this panels what makes the continuation of the evaluation of the system possible with the performance factor at all times without dismantling and viewing the work with human interference witch give more access to info all the time and more productivity for the pv panel

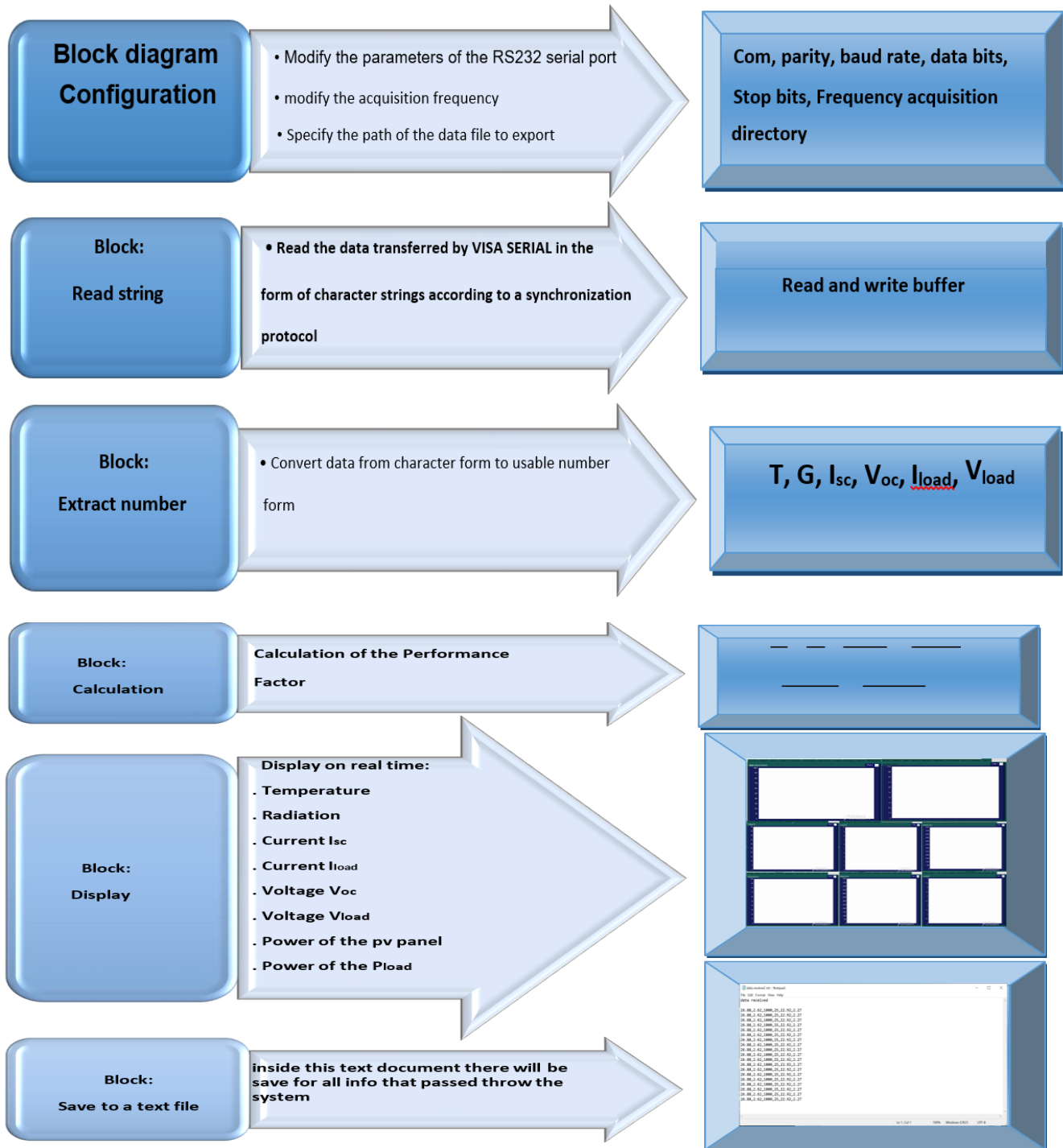


Figure V.6 Block diagram of the MPPT-PA interface.

V.3 Communication protocol

Communication is one of the most important aspects of real time diagnostic as it allow us to see the development of the system by minutes instead of the usual worker check every time what make it so much more efficient way to connect the arduino to the LabVIEW we use the following transmitting data methods.

V.3.1 Arduino communication protocol

The serial communication protocol used is called Universal Asynchronous Receiver / Transmitter (UART). UART is a form of serial communication because data is transmitted as sequential bits. The wiring involved with setting up UART communication is very simple: one line for transmitting data (TX) and one line for receiving data (RX). As you may expect, the TX line is used to for the data to send device, and the RX line is used to receive data. Together the TX and RX lines of a device using serial communication form a serial port through which communication can occur [32].

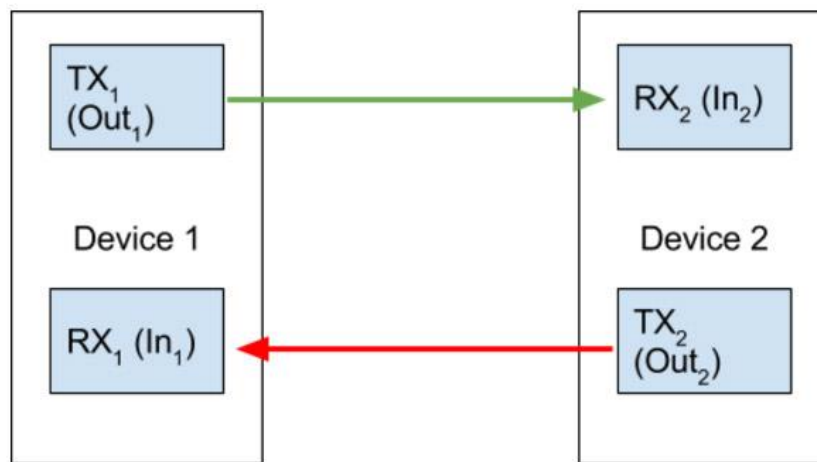


Figure V.7 Hardware connection diagram for UART.

The term UART actually refers to the onboard hardware that manages the packaging and translation of serial data.

For a device to be able to communicate via the UART protocol, it must have this hardware, On the Arduino Uno, there is one serial port dedicated for communication with the computer the Arduino is connected to. the USB, which stands for Universal Serial Bus, is a serial port! On the Arduino Uno, this USB connection is broken out through onboard hardware into two digital pins, GPIO 0 and GPIO 1, which can be used in projects that involve serial communication with electronics.

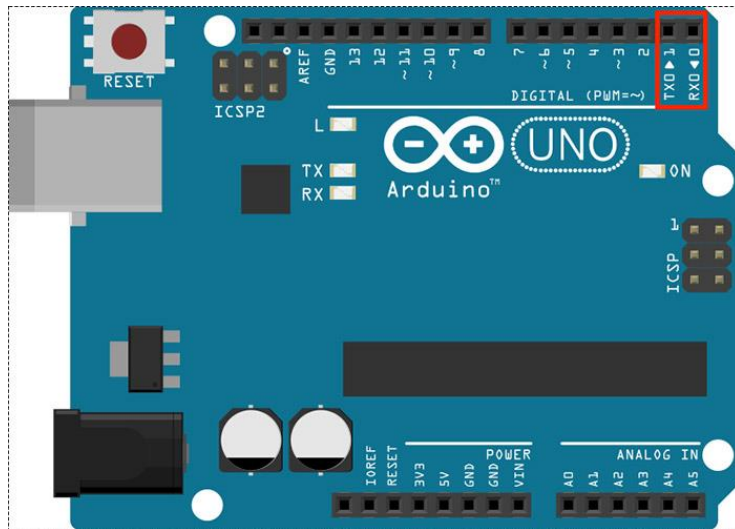


Figure V.8 GPIO 0 and GPIO 1 are serial Rx and Tx.

UART is called asynchronous because the communication does not depend on a synchronized clock signal between the two devices attempting to communicate with each other. Because the communication speed is not defined via this steady signal, the “sender” device cannot be certain that the “receiver” obtains the correct data. Therefore, the devices break data into fixed-size chunks to ensure that the data received is the same as the data that was sent.

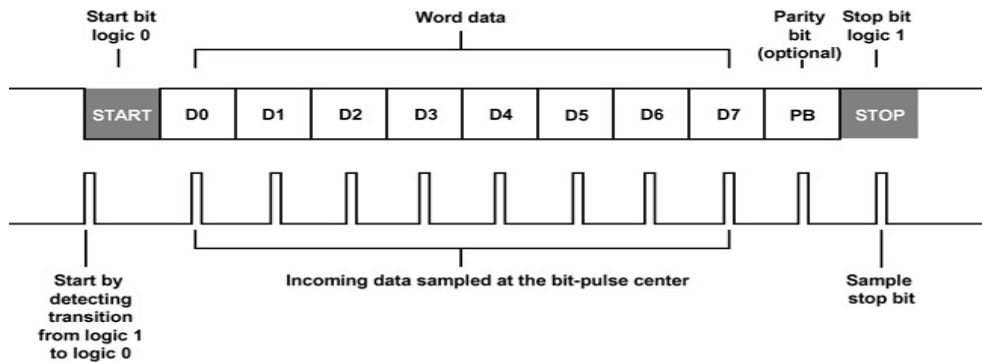


Figure V.9 UART Data packet.

Devices that communicate via UART send packets of pre-defined size that contain additional information regarding the start and end of the message and confirmation of whether the message was received correctly. For example, to begin communication, the transmitting device pulls the transmit line low, indicating the start of a data packet. Long-term, however, this means that UART is slower compared to a synchronized form of communication because only a portion of the data transmitted is for the devices’ applications (the rest is for the communication itself!)

One important aspect to note about UART communication is that it is designed for communication between only two devices at a time. Because the protocol only sends bits indicating the start of a message, the message content, and the end of a message, there is no method of differentiating multiple transmitting and receiving devices on the same line.

If more than one device attempts to transmit data on the same line, bus contention occurs, and the receiving devices will most likely receive garbage unusable data.

Furthermore, UART is half-duplex, which means that even though communication can occur bidirectionally, both devices cannot transmit data to each other at the same time .

V.3.2 Communication protocol applied with the source code

Order of sequences	Source code	Role	Data transmitted
1	float khaled;	CREAT VARIEBLE	////////////////
2	if (Serial.available()){ khaled = Serial.parseInt(); }	Read incoming data from LabVIEW	Read data
3	} if (khaled==5){ Serial.print(Vdiagno); Serial.print(","); Serial.print(ldiagno); Serial.print(","); Serial.print(lux_value); Serial.print(","); Serial.print(temperature); Serial.print(","); Serial.print(Vmppt); Serial.print(","); Serial.println(lmppt); }	If the data send from LabVIEW was the correct one (5 in this case) Create string that have all the data need to be transmitted as one long string and send it to LabVIEW	. Voc . Isc . Vload . Iload . Temperature . Irradiance . start and end bytes . buffer between deferent data signals

Table 5 Arduino code for serial communication.

V.4 Serial communication LabVIEW side

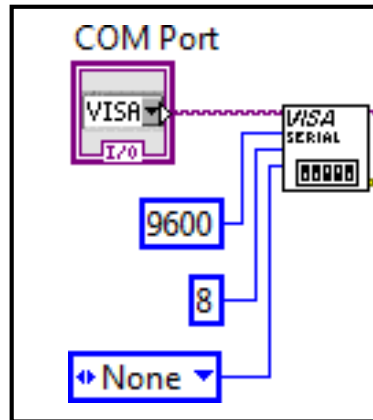
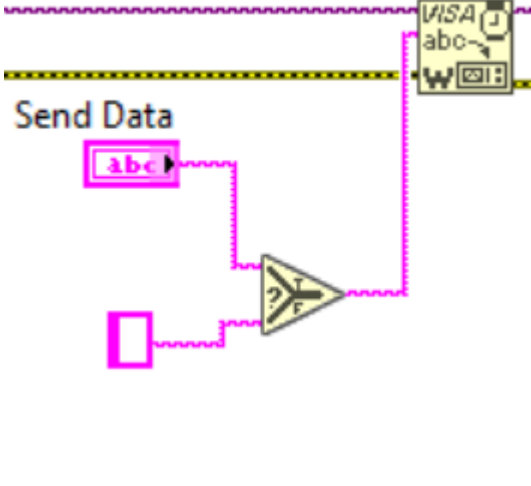
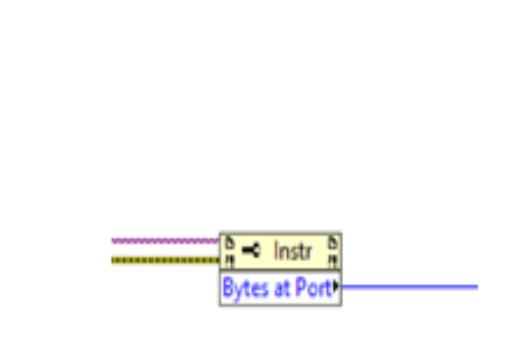
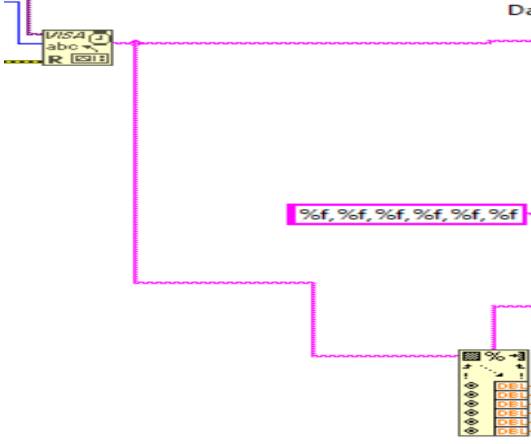


Figure V.10 Diagram of port configuration.

To start synchronized connection between LabVIEW and the Arduino we start with using technique named handshake that start the transmission of data after the 2 programs have started and running so there will be no lose data or overwhelming the visa port.

- The visa com part that initiate the serial port
- The button to send the message"5" to Arduino to start the handshake
- The visa write to send the message to the Arduino
- After the Arduino have received the message it starts sending the data to Protus

The order of blocks	The code	Role in the seial cominication	Objective
1		. synchronization of the data with the Arduino throw the parity bits. the speed of data transmitting .stop bit and start bit and word data lengths	Data resive : .The data from the arduino

2		<p>.send data to arduino to start the handshake and let the arduino know that labview is ready to receive data it is used to not overload the visa read with info before it's ready</p>	<p>Handshake</p>
3		<p>. the instrument bytes at port used to calculate the number of bytes received from the arduino</p>	<p>. the instrument receive the number of bytes at port</p>
4		<p>The arduino send the information as a string and cannot be translated without the scan from string instrument after translation is send data to be processed</p>	<p>. translate data from string to ascii</p>

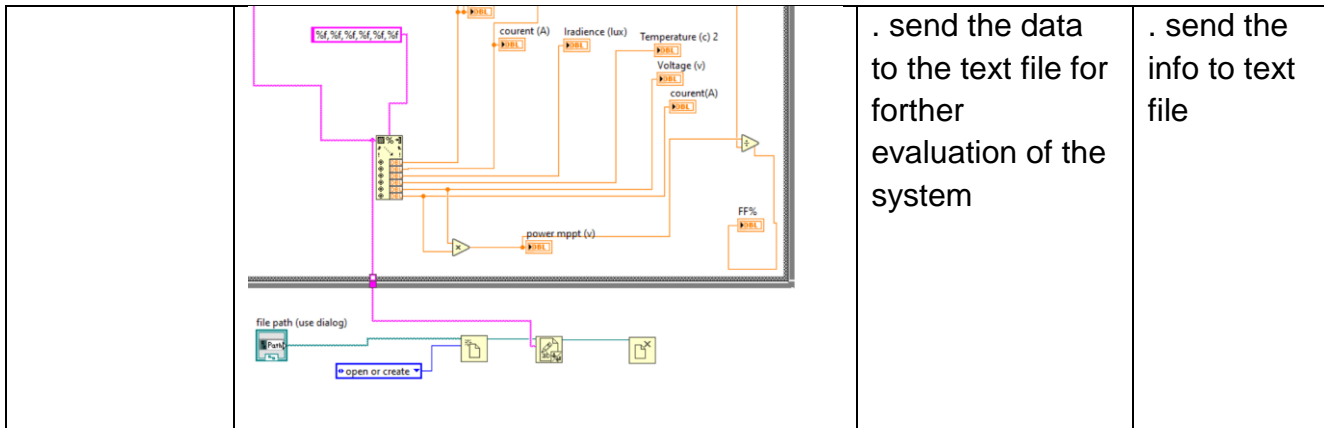


Table 6 The protocole of data transmission on the labview side.

The data that was resived Processed and passed for visual processing on the monitre.

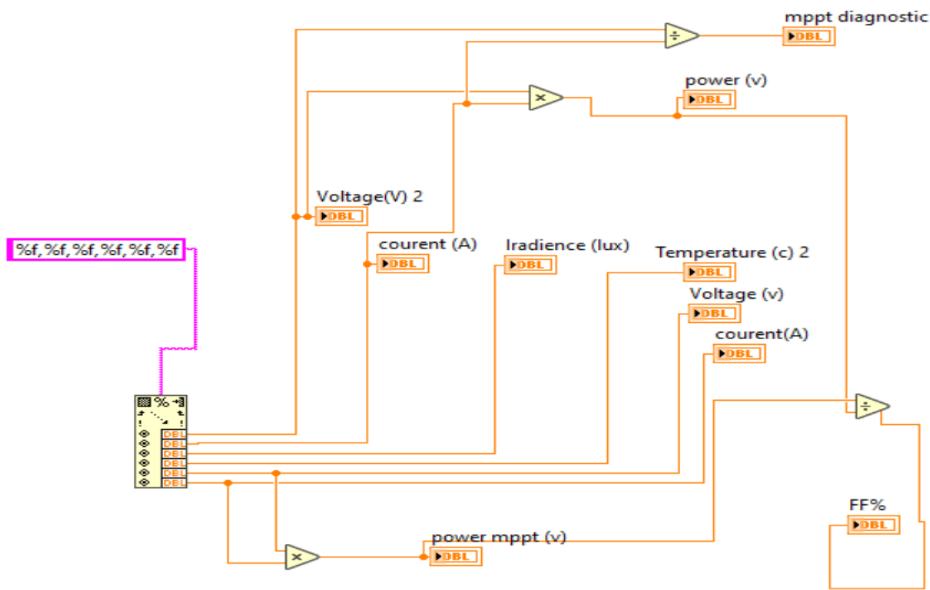


Figure V.11 The graphs on LabVIEW block diagrame.

V.5 Testing the acquisition of the system in real time in LabVIEW

Sending the data throw serial communication

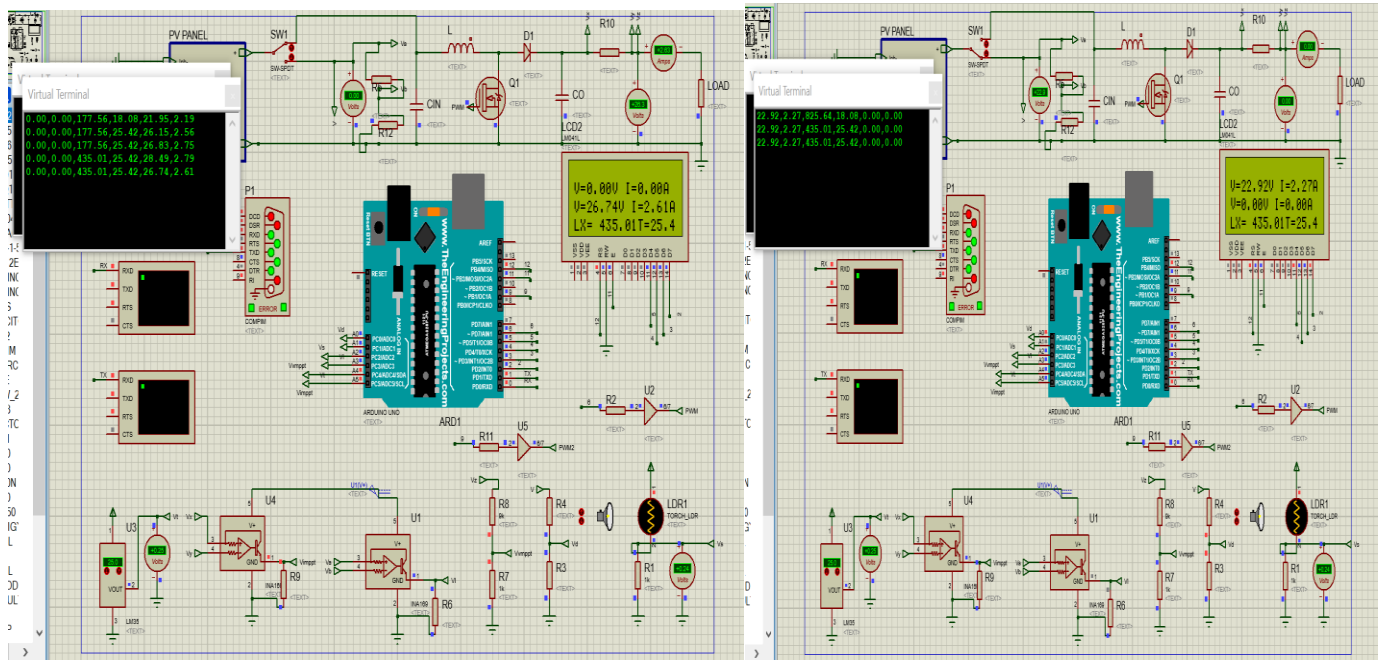


Figure V.12 Data transmitting throw Protus.

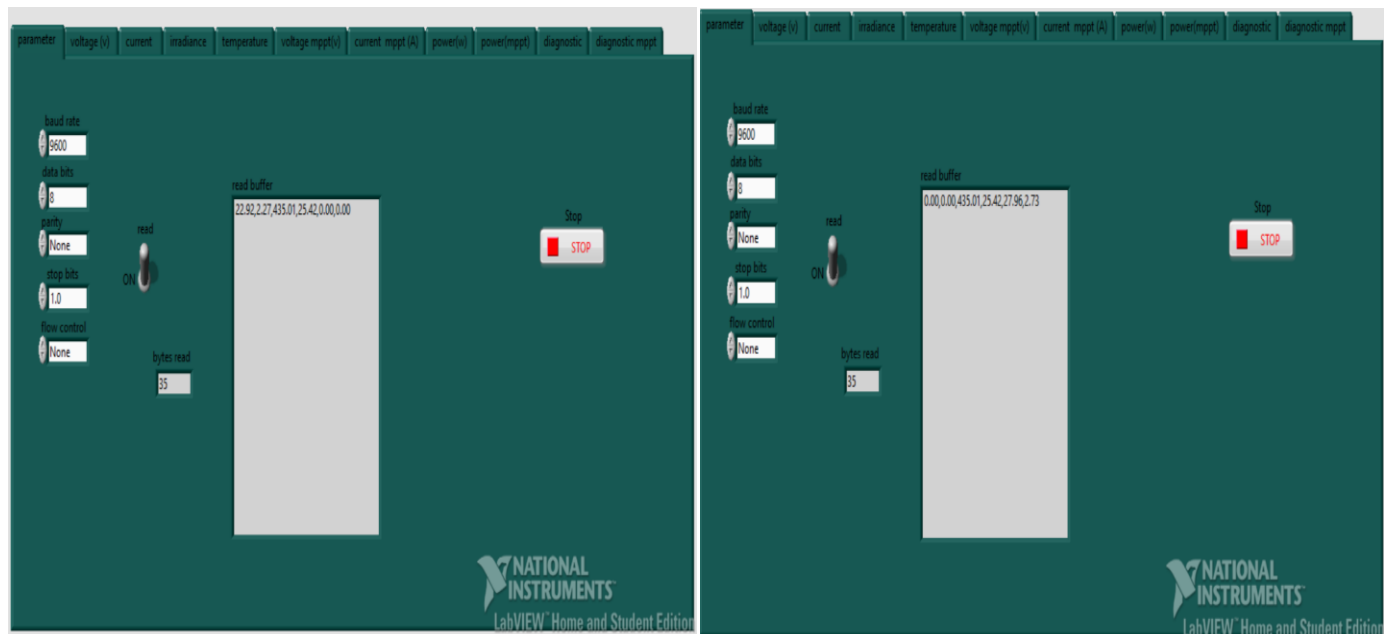


Figure V.13 Data reserving on the LabVIEW.

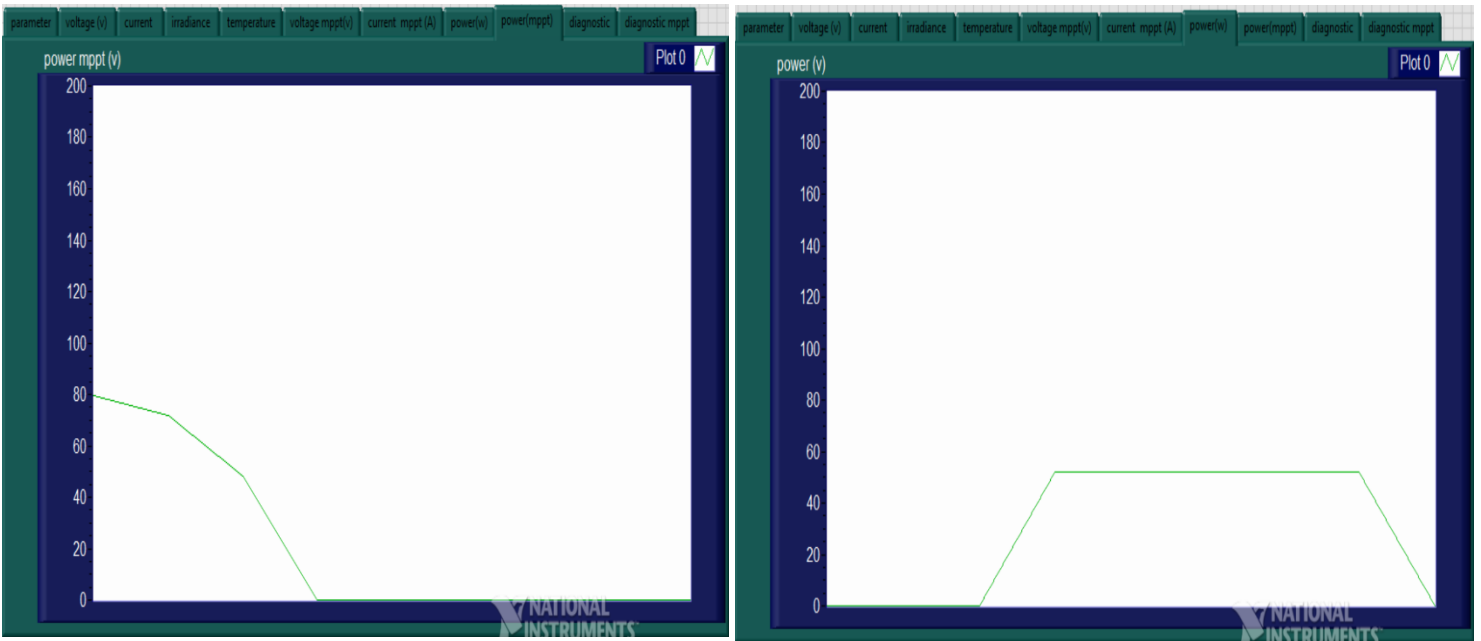


Figure V.14 DATA of the power of the MPPT vs short-circuit.

By saving the values of the short circuit and compare to the MPPT



Figure V.15 The encrase in the proformance of the PV panel.

Then sending the data to text file for further evaluation



Figure V.16 Text file of data stored

The data that was received show 39.4/100 increase in productivity from the power and with the continuous evaluation we can make sure that it continue to do so

V.6 Table of used materiel for application

The part that used for application are little deferent from the simulation due to corona virus limitation of travel to get the parts that can be used for the project, and the closer of the laboratory of the university so I was unable to get the sensors needed for the creation of the project.

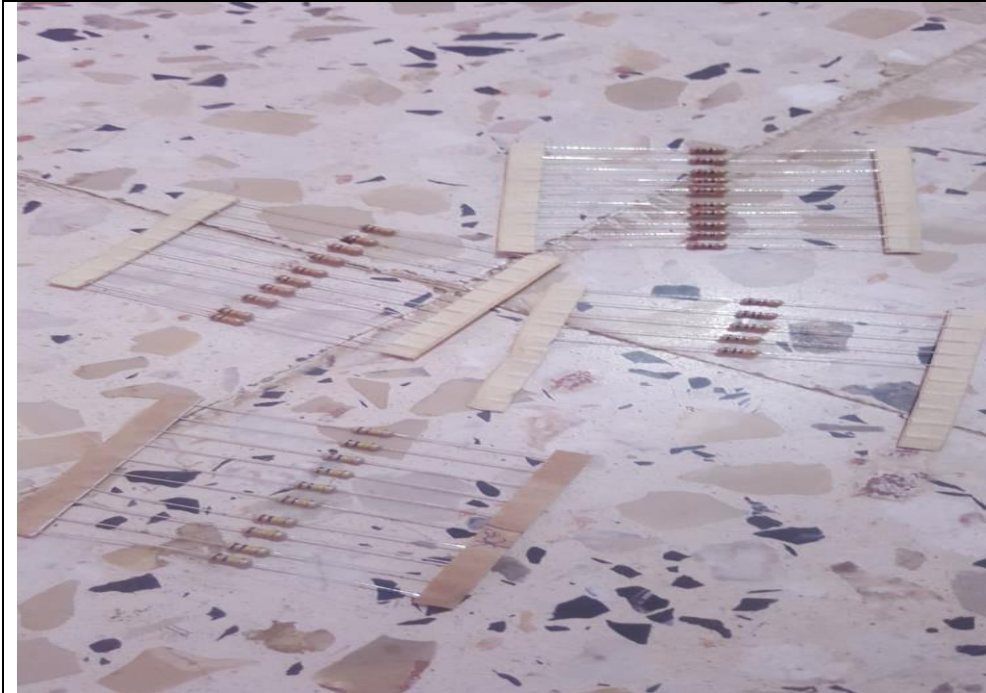
The parts that exist are



Used for the wiring of the arduino and connecting the deferent parts (sensors the pv panel ... etc.)



Used to create the serial communication between the arduino and the LabVIEW



Resistors used to calculate the voltage of the pv panel (explained in the past chapters) and protecting the sensors and arduino from damaging



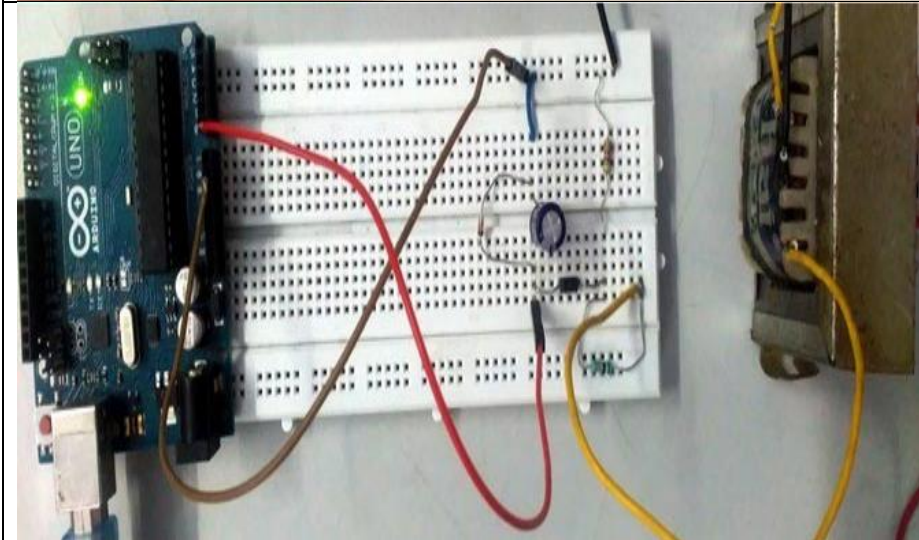
The arduino uno



Cables used to connect the arduino and sensors



pv panel



Simple boost buck coverture that was created when the lab of the university was open

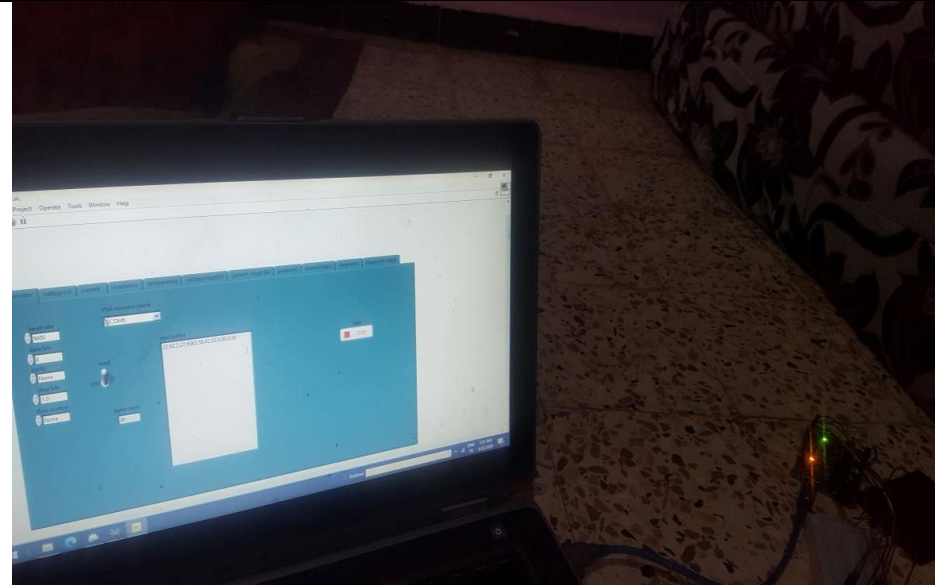
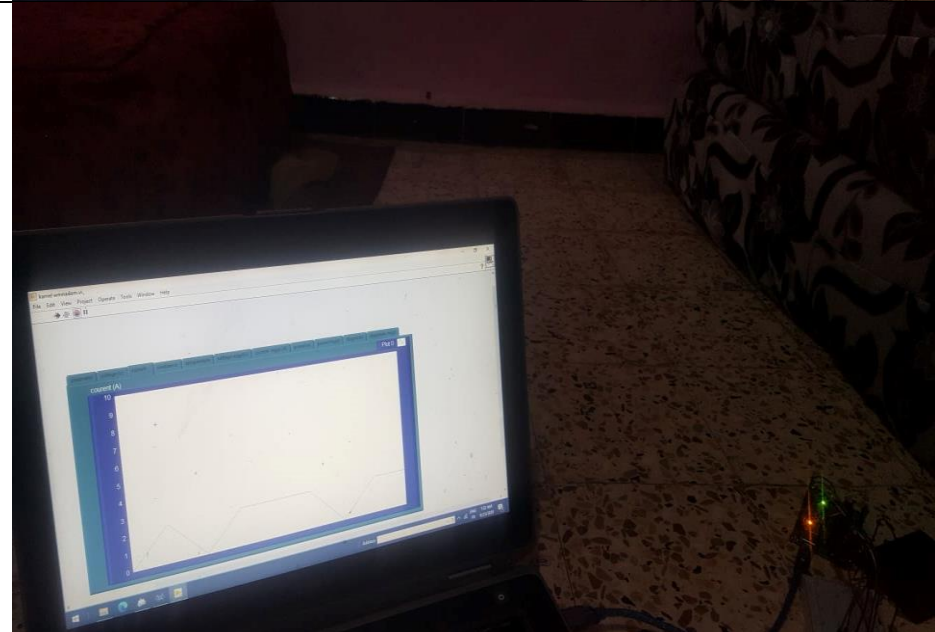
	<p>The data received from the arduino</p>
	<p>The values of the current doubled multiple times in order to be able to view it in LabVIEW with it reaching 0 sometimes due to the short circuit opening in place of the mppt for the diagnostic</p>

Table 7 Application parts.

V.7 Conclusion

In this chapter we created an observation system using LabVIEW and connected it to the simulation on Protus and the real live arduino, it worked as monitor for the values that the system produce in relation to the theoretical value provided by the manufacturer on the data sheet it allowed us to interfere and fix problems in early stages , early fixing of problems can save so much output from being lost to defaults and it save so much money that make the investing in the solar power worth it for more people and organization.

General conclusion

In the first chapter, we explained the PV panels and the concept of photovoltaic power generation and grid connection the effect of the connection between cells and the materials used for manufacturing the pv cell on the output generated and the necessity of the development of this type of energy generation in Algeria.

And after that we have shown the value in implementing MPPT system and explain the deferent types of the diagnostic systems and MPPT algorithms and the simplifications that can be applied to them in the chapters II and III.

in the chapter IV we explained the sensors used and their effectiveness and the accuracy of them because they generate real time data that can be used to calculate the value the MPPT point, and detect the errors of the system when they happen allowing for cheaper and more effective repairing.

and in the last chapter we explained the monitoring system we created for this project and how it works and connect to the Protus or the arduino UNO and how the serial communication between them works.

In general, the photovoltaic conversion system includes a photovoltaic generator and a power conditioning system with an MPPT control and a load.

As the PV generator thereof, has a relative characteristic of power. The maximum power remains only a single operating point defined by a known voltage and a current, called the maximum power point.

The change in the position of this point is expressed in terms of climate parameters (temperature and light). This requires a tracking system of this point so that the maximum power is continuously generated. The major problem of the MPPTs, is the difficulty to validate their performances.

It should be noted that few studies (or almost non) addressing this problem are cited in the literature. Therefore, the main objective of this work is the study of a new method of analyzing based on the outdoor measurement of maximum power in dynamic mode and also the development of an electronic device that could serve as an analyzer helping tool.

This device, which we called MPPT-PA will be responsible for monitoring the MPPT performance through a user interface developed in LABVIEW.

A performance factor was calculated to give an idea about what percentage is this MPPT is performing. It should be noted that the feature of this device is that the values of temperature and irradiance are not required in this process.

For the future implementation of the system I would requirement:

- Using more powerful processing data system then the arduino that will allow more complicated diagnostics systems that generally perform better.
- Using voltage sensor instead of the voltage divider, it will increase the cost but will increase the safety and prohormones of the system.

Abstract

A photovoltaic system or PV system is a power system designed to supply usable solar power by means of photovoltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the output from direct to alternating current, as well as mounting, cabling, and other electrical accessories to set up a working system. It also uses a MPPT tracking system to improve the system's overall performance (track the maximum power point).

A certain number of different problems may therefore cause energy losses in the PV plant. When looking for diagnostic methods, one must differentiate between two functions: detection and localization. Certain methods used or proposed perform detection function only. While some others perform the function location after fault detection has been performed.

In this work we created an observation system using LabVIEW and connected it to the simulation on Protus and the real live arduino, it worked as and it allowed us to interfere and fix problems in early stages, early fixing of problems can save so much output from being lost to defaults and it save so much money that make the investing in the solar power worth it for more people and organization.

Keywords:

Photovoltaic energy, MPPT, Sensors, Diagnostics, Supervision.

Résumé

Un système photovoltaïque ou système PV est un système d'alimentation conçu pour fournir de l'énergie solaire utilisable au moyen de l'énergie photovoltaïque. Il se compose d'un agencement de plusieurs composants, y compris des panneaux solaires pour absorber et convertir la lumière du soleil en électricité, un onduleur pour convertir la sortie du courant continu en courant alternatif, ainsi qu'un câblage et d'autres accessoires électriques pour mettre en place un système complet. Il utilise également un système de suivi MPPT pour améliorer les performances globales du système (suivre le point de puissance maximum).

Un certain nombre de différents problèmes peuvent entraîner des pertes d'énergie dans l'installation photovoltaïque. Lorsqu'on s'intéresse à la recherche de méthodes de diagnostic, il faut différencier deux fonctions : la détection et la localisation. Certaines méthodes utilisées ou proposées n'effectuent qu'une fonction de détection. Certains autres exécutent l'emplacement de la fonction après la détection de défaut.

Dans ce travail, nous avons créé un système de supervision utilisant LabVIEW et l'avons connecté à la simulation sur Protus en utilisant la carte arduino en temps réel, il a fonctionné comme contrôleur et nous a permis d'interférer et de résoudre les problèmes à un stade précoce, la résolution précoce des problèmes peut éviter que la production tombe en panne et cela permet d'économiser tellement d'argent et rendre l'investissement dans l'énergie solaire intéressante pour les personnes et les organisations.

Mots clés :

Energie photovoltaïque, MPPT, Capteurs, Diagnostique, Supervision

ملخص

النظام الكهروضوئي هو نظام طاقة مصمم لتوفير طاقة كهربائية قابلة للاستخدام عن طريق ضوء الشمس يتكون من عدة مكونات ، بما في ذلك الألواح الشمسية لامتصاص وتحويل ضوء الشمس إلى كهرباء ، وموج لتحويل التيار المستمر الناتج إلى تيار متناوب ، بالإضافة إلى الأسلاك وغيرها من الملحقات الكهربائية. كما أنه يستخدم نظام تتبع MPPT لتحسين الأداء العام للنظام (تتبع النقطة الأقصى الطاقة).

يمكن أن يؤدي عدد من المشاكل المختلفة إلى فقدان في الطاقة في النظام الكهروضوئي. عندما نهتم بالبحث عن طرق التشخيص ، يجب أن نفرق بين وظيفتين: الاكتشاف والتحديد. بعض الطرق المستخدمة أو المقترحة تؤدي فقط وظيفة الكشف. يقوم البعض الآخر بتحديد الموقع بعد اكتشاف الخطأ.

في هذا العمل ، أنشأنا نظام إشراف باستخدام LabVIEW وقمنا بتوصيله بالمحاكاة على Protus باستخدام لوحة اردوينو في الوقت الفعلي ، حيث كان يعمل كوحدة تحكم وسمح لنا بالتدخل وإصلاح المشكلات في المرحلة المبكرة ، يمكن أن يمنع حل المشكلات المبكر الإنتاج من الأعطاب وهذا يوفر الكثير من المال ويجعل الاستثمار في الطاقة الشمسية مفيداً للأفراد والمؤسسات.

الكلمات المفتاحية:

الطاقة الكهروضوئية ، MPPT ، مجسات ، تشخيص ، إشراف.

LIBRARY

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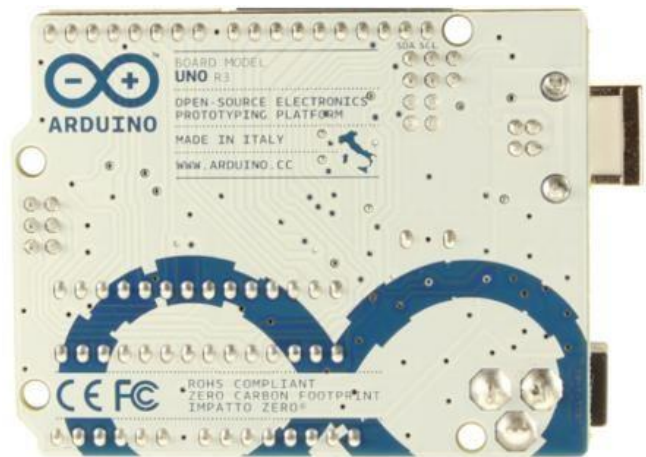
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APPENDIX

Arduino Uno



Arduino Uno R3 Front



Arduino Uno R3 Back



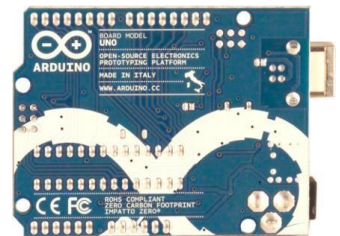
Arduino Uno R2 Front



Arduino Uno SMD



Arduino Uno Front



Arduino Uno Back

Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.

Revision 2 of the Uno board has a resistor pulling the 8U2 HWB line to ground, making it easier to put into DFU mode.

Revision 3 of the board has the following new features:

- 1.0 pinout: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible both with the board that use the AVR, which operate with 5V and with the Arduino Due that operate with 3.3V. The second one is a not connected pin, that is reserved for future purposes.
- Stronger RESET circuit.
- Atmega 16U2 replace the 8U2.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno

and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

- The power **VIN**. The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V**. This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. We don't advise it.
- **3V3**. A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND**. Ground pins.

pins are as follows:

Memory

The ATmega328 has 32 KB (with 0.5 KB used for the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using `pinMode()`, `digitalWrite()`, and `digitalRead()` functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the `attachInterrupt()` function for details.
- **PWM: 3, 5**
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication using the SPI library.
- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- **, 6, 9, 10, and 11.** Provide 8-bit PWM output with the `analogWrite()` function.

The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though it is possible to change the upper end of their range using the AREF pin and the `analogReference()` function. Additionally, some pins have specialized functionality:

- **TWI: A4 or SDA pin and A5 or SCL pin.** Support TWI communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with `analogReference()`.
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and ATmega328 ports. The mapping for the Atmega8, 168, and 328 is identical.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. For SPI communication, use the SPI library.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno from the **Tools > Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega16U2 (or 8U2 in the rev1 and rev2 boards) firmware source code is available.

The ATmega16U2/8U2 is loaded with a DFU bootloader, which can be activated by:

- On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2.
- On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode.

You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader). See this user-contributed tutorial for more information.

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2/16U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half- second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data. The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Four screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.