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Theme

Study of a Photovoltaic System used for Agriculture in the Sahara of El Oued

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Before the jury

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General Introduction

Today, much of the world's energy production comes from fossil sources (oil, natural gas, coal, etc.). The consumption of these sources gives rise to greenhouse gas emissions and consequently to an increase in pollution.

It is technically and economically feasible to make significant efforts to reduce human activities that negatively influence the climate and the environment. One of the possibilities is to increase the rate of production of electrical energy from non-fossil and renewable resources. On-going operations and research studies have shown that this type of renewable energy has major advantages to increase the participation rate of these energies that are specific to electricity production, while limiting the negative impact on energy consumption and environment. Today, renewable energy sources, particularly solar and wind power are the fastest growing energy sources [1]. Their development, especially solar energy, at the residential and industrial level is considerable.

Without a doubt, solar energy is a great asset for our country. Indeed, Algeria has one of the largest solar deposits in the Mediterranean basin. With more than two million square kilometers, Algeria receives a large amount of sunshine daily to produce maximum energy. It should be known that on a horizontal surface of $1m^2$, one can have a power of the order of 5kWh. In addition, over almost the entire national territory, the duration of insolation exceeds 2000 hours annually and can reach 3900 hours in the highlands and the Sahara [2].

In this context and particularly in the Saharan regions, this photovoltaic solar energy can be used for pumping water. All this is more interesting because of the remoteness of these regions from the "classic" electricity grid. In these areas, water is often available but the operating conditions to make it more accessible to people are not within their reach.

Another very important coincidence favors the use of this type of energy for pumping water is that the demand for water, especially in agriculture, reaches its maximum in hot and dry weather where it is precisely the moment where we have access to the maximum of solar energy.

One of the first difficulties that arise by the use of a photovoltaic source is the low conversion efficiency, in particular the problem of the flawed coupling between the photovoltaic generator and the load being either continuous or alternative. This is the problem of transferring the maximum power of the photovoltaic generator "PVG" to the load, which often suffers from a bad adaptation. As applications are numerous, this problem remains widely open.

The work presented in this thesis deals particularly with this problem of optimizing photovoltaic systems used for irrigation in sites where the expansion of the network is difficult or too expensive. To achieve our objectives, we proposed and exploited three important axes:

- ❖ The optimal choice of the angle of inclination of the solar panels to maximize the solar radiation uptake,
- ❖ The use of the MPPT technique (Maximum Power Point Tracker) to maximize the extraction of power,

Our contribution is to improve the performance of the photovoltaic system, in other words to maximize the power delivered to the load, based on these criteria above.

In the first chapter, a synthesis of the most used forms of energy in the world is exposed. It is followed by a general presentation on the massive integration of renewable energy into the energy grid. At the end of the chapter, we present a strategy focused on the development of inexhaustible resources such as solar and their use to preserve fossil resources. We also discuss the importance of this clean energy to diversify the electricity generation network and contribute to sustainable development in Algeria.

The second chapter gives general explanations on the solar field. After having exposed the general equations of the computation on the solar radiation and the energy produced in the site of EL-OUED, we present the model of computation of the solar radiation on a horizontal and inclined surface. We will then show the importance of tilting solar panels to collect as much solar energy as possible.

The third chapter presents a technical explanation of the conversion of solar energy into electrical energy, in other words the "photovoltaic effect". We have detailed the electrical characteristics of the solar cells and the method of coupling between the photovoltaic generator and the load.

In the fourth chapter, the general composition of a photovoltaic pumping system, as well as the theoretical elements allowing to size the current pumping stations are presented.

In the last chapter and as a practical example, we apply what our acquired knowledge and our optimization contribution on the use of a photovoltaic pumping system to irrigate an area of 2.5 hectare of palm trees and olive trees in El Oued.

1.1. Introduction

Today, throughout the world electricity is a fundamental need for economic development. Its relative importance grows with technical progress, industrialization and the need for modern comfort. The increase in production is synonymous with improved quality of life and wealth creation. However, fossil fuels currently provide the majority of this production, but faced with the depletion of these energy resources, environmental problems and the considerable increase in energy needs, the search for new energy resources is one of the priorities of the energy policy of many countries. Renewable energies represent an ecological alternative to fossil fuels. Their operation would provide electricity everywhere, especially isolated sites, and avoid the creation of new power lines. For a better understanding of the importance of renewable energies, and especially solar energy, this chapter presents a summary of the forms of energy consumed most in the world. We focused on the production of electricity from solar energy since this is the subject of our research. We also detail the milestones of an ambitious renewable energy development program in Algeria.

1.2. World Electricity Production

Global electricity production is rising sharply, especially to meet the needs of emerging countries. Currently, most of the world's electricity comes from the decomposition of fossil fuel (oil, coal or natural gas) or nuclear fuels. But, this trend is changing and other sources of energy such as renewable energies will gradually replace fossil fuels that are exhaustible and polluting. Figure 1.1 shows the distribution of resources on global electricity production in 2016[3].

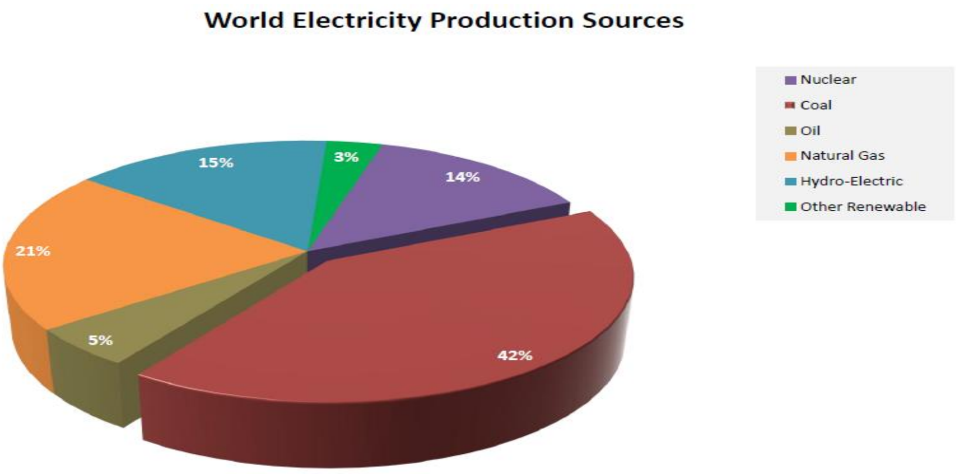

Figure 1.1: Gross Electricity Production by Source 2016.

1.3. Photovoltaic Energy

Renewable energy comes from natural resources such as the sun, in contrast to energy derived from finite resources based on fossil fuels like coal and oil that sooner or later will run out. Serious interest in renewable energy was sparked following the Arab oil embargo of 1973 and since then much progress has been made towards exploiting a variety of renewable energy resources, including solar, wind, hydropower, geothermal, biofuels, biomass, and ocean waves and tides. Put together, these are often referred to as the 'renewable energy mix'.

Apart from being clean, free and abundant, the renewable energy mix, especially solar and wind, have already achieved commercial acceptability, economic viability and compatibility with existing modes of energy generation, making them a serious alternative to traditional means of energy provision. Given the central place that energy occupies in society, there is no doubt that renewable energy as a whole will assume greater significance for a sustainable future of our planet.

Solar energy has two main technologies: solar thermal and photovoltaics (or PV). Solar thermal technology can provide both heat and electrical energy. About 169,440TWhr/year, which is equivalent to 5000 times the current energy usage in the country, may potentially be harnessed and used to support various applications [4]. For domestic use, Algerian houses can be fitted with solar thermal systems, exploiting solar radiation to heat water through flat plate collectors or evacuated tubes (Figure 1.2). For electricity generation, it is possible to use concentrating solar technology to focus solar energy and run steam and gas turbine plants that drive electric generators. On the MW scale, solar farms (with many solar units) may be installed in the Algerian desert using solar towers (as operational in Spain) where solar radiation is focused onto the top of a tower from concentrating mirrors Concentrating solar technology can also be used to provide hot water.

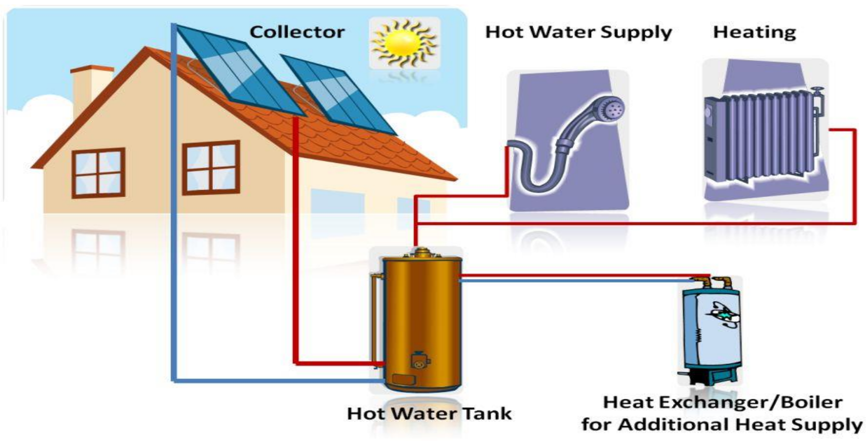

Figure 1.2: Domestic Use of Solar Thermal for Hot Water.

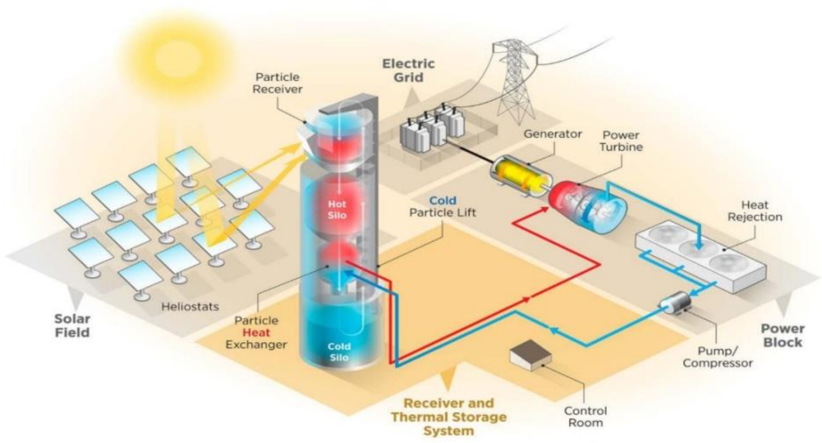

Figure 1.3: Concentrating Solar Energy for Electricity and Heating.

For electricity generation, it is possible to use concentrating solar technology to focus solar energy to run steam and gas turbine plants that drive electric generators. On the MW scale, solar farms (with many solar units) may be installed in the Algerian desert using solar towers (as operational in Spain) where solar radiation is focused onto the top of a tower from concentrating mirrors (Figure 1.3). Concentrating solar technology can also be used to provide hot water.

With PV panels, solar radiation is directly converted into electricity. This technology is widely used around the world and is considered a well-developed and mature technology. Algeria's capacity from PV is estimated at 13.9Twhr/year [4] and can be applied in various contexts, such as attaching small panels to the roofs of houses, large panels on schools, hospitals and supermarkets, and installing large scale PV farms. The electricity generated from PV can also benefit isolated communities to support farming activities, e.g. by pumping water from wells or by operating solar refrigerators to preserve food and medicine. A major industrial application of PV panels is for desalination plants to produce drinking water, which is not an abundant source in the country. As an example of Algeria's use of solar energy, a hybrid power plant in Hassi R'Mel has been operational since 2011, where solar energy is combined with natural gas to produce 150MWe of which 25MWe is from concentrating solar energy [5]. Future projects include a PV station in southern Ghardaia, and a PV solar farm near the capital in Rouiba.

1.4. Electricity Generation by Photovoltaic Energy

The year 2015 saw a significant boost in renewable energy electricity generation, with the major increases sounding much like the local weather forecast for today: a mix of sunshine and wind. Total generating capacity went from 1701GW in 2014 to 1849GW in 2015, a 9% increase. The biggest percentage increase in new generating capacity comes from solar, with photovoltaic power increasing by 28% (227GW, up from 177GW) and concentrated solar power providing 4.8GW, up 12% from the previous year. Wind power blew in an extra 63GW, bringing its total to 433GW in 2015. Although hydropower only increased by 2.7%, it is still the largest renewable energy source, delivering 1064GW of electricity worldwide. Electricity from geothermal and biofuels round out the remaining 120GW [6].

Renewable Energy Generation				
Source	**GW 2014**	**GW 2015**	**Increase (GW)**	**Increase (%)**
PV	177	227	50	28.25%
CSP	4.3	4.8	0.5	11.63%
Wind	370	433	63	17.03%
Hydro	1036	1064	28	2.70%
Geothermal, Bio	114	120	6	5.26%
Total	1701.3	1848.8	147	8.67%

Table 1.1: The Development in Renewable Energy Electricity Generation in the Years 2014-2015.

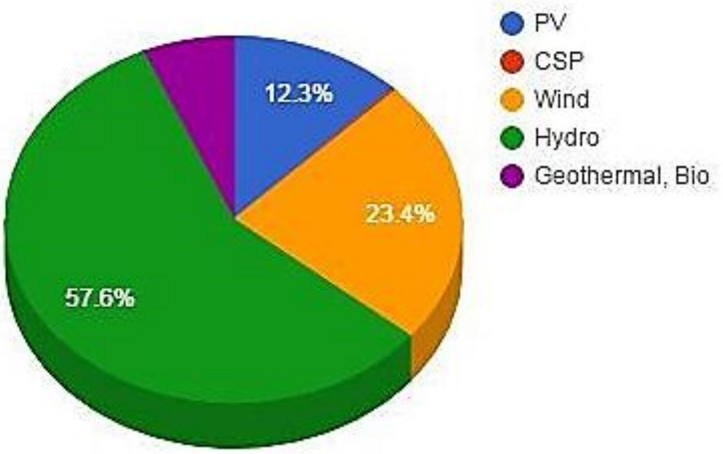

Figure 1.4: Distribution of Renewable Electricity Generation Worldwide 2015.

As one can see, the share of renewable electricity has been increasing overall since 2011 (from 17.9% in 2011 to 20.8% in 2015), an increase of almost three percentage points in four years. We can therefore say that, renewable energies have strengthened their place in the global structure of electricity production.

1.4.1. Average Annual Growth Rate of Renewable Sectors 2002-2012

Hydraulics has been alone for many years to compensate for the advance of fossil fuels. This is no longer the case today. The contribution of new renewable electricity generation technologies has been decisive in countering the increase in the share of conventional electricity in the global total.

Over the period 2002-2012, the growth of non-hydro renewable sector production was almost five times faster than that of hydropower, that to say an annual average of 15.1% compared with 3.1% for the hydraulic sector.

Also, the share of renewable sectors without hydro has taken three percentage points in the world's electricity production, from 1.6% of the total in 2002 to 4.6% in 2012. In contrast, the share of Hydropower lost 0.5 point in the global total (from 16.7% in 2002 to 16.2% in 2012).

A detailed sector-by-sector analysis makes it possible to show on the histogram of figure 1.3 that it is the solar electricity production which displays the highest average annual growth rate over the period (2002-2012) more than 50.6 %.

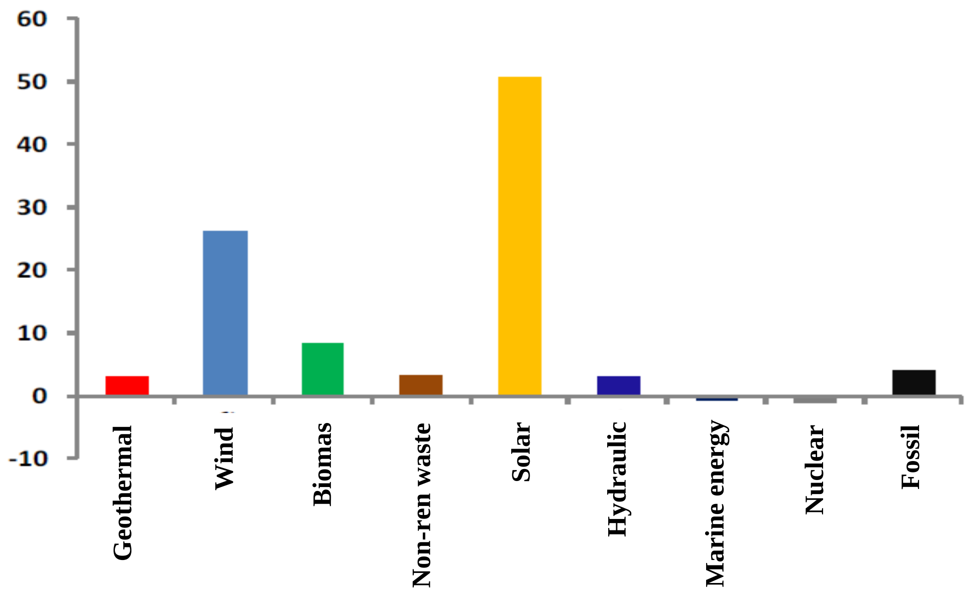

Figure 1.5: Average Annual Growth Rate 2002-2012. [7]

1.4.2. Total Global Solar Photovoltaic Capacity in 1995-2011

Germany is the leading producer of energy from photovoltaic, with an installed capacity of 16630MW in 2011. It is followed by Italy with a power of 8260MW. Japan is in third position with 6740MW of installed capacity. There is also Spain with 3120MW and the United States with 3000MW installed. Other countries, such as China and France, are considering developing this energy source considerably [8].

The two figures below show the increase in global photovoltaic capacity (1995-2011) and the top ten countries in 2011.

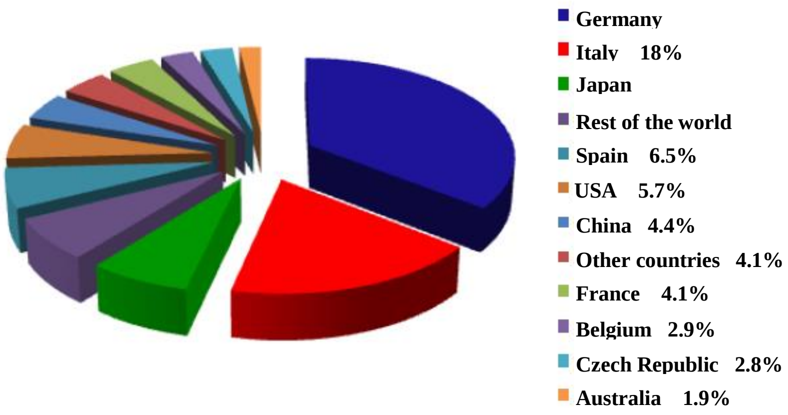

Figure 1.6: Operational Capacity of Solar Photovoltaic for the Ten Leading Countries in 2011.

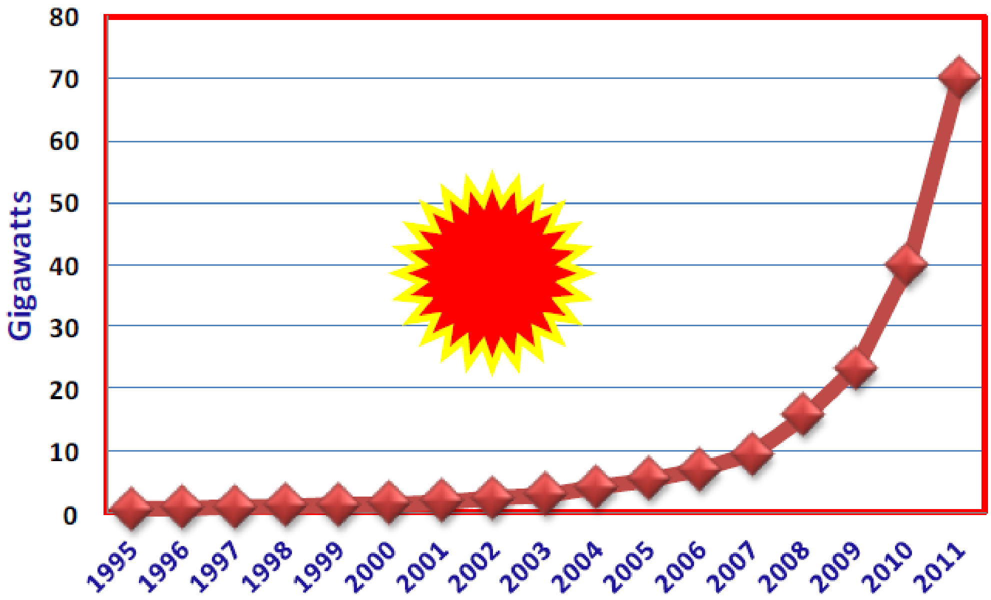

Figure 1.7: Total Global Solar Photovoltaic Capacity in 1995-2011.

1.4.3. Status of Renewable Energy in Algeria

Algeria is a country where fossil energy is abundantly available. As it is the 10th world biggest gas reserve and 3rd biggest African oil reserve, the energy future of this country seems certain, or used to.

Today, Algeria has to face a phenomenon that questions the whole national energy system. Whereas the stocks of fossil energy are constantly decreasing, the electricity demand, on the contrary, has experienced a yearly growth of more than 7%. But, if the situation does not improve by the next years, Algeria will have to import a very large part of its electricity. Even if the huge availability of fossil energy was a big asset once, we can today talk about real dependence, as shown by the 2013 energy mix [9]:

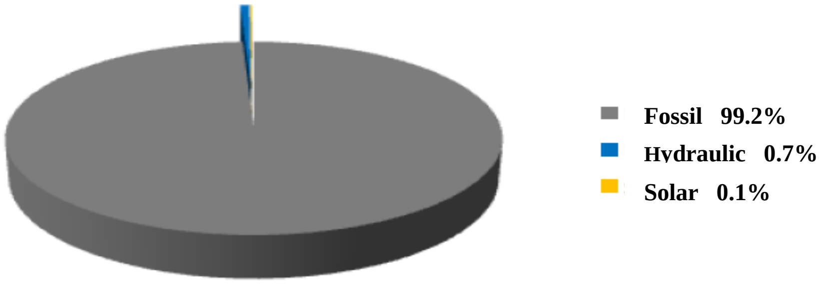

Figure 1.8: Distribution of Algeria's National Electricity Production in 2013.

Indeed, in 2013, the renewables were only 0.8% of the electricity production (0.7% of hydraulic, with an installed capacity of 389GW hand only 0,1% of solar, with an installed capacity of 11GWh of photovoltaic and 56GWh of thermodynamics). Fossil energy thus represents the largest part of the mix (99.2%).

1.5. Renewable Energies in Algeria

Because of Algeria's major fossil fuel reserve and the absence of environmental policies, the development of renewable energies has lagged far behind. According to the Ministry of Energy and Mines, the national electricity capacity exceeds 56.74TWh with 0.45 TWh peak only for renewable energies (in 2012) [7]. Today, and given the challenges that these sources of sustainable energy represent, their promotion is one of the main thrusts of the country's energy and environmental policy. On the other hand, Algeria has many major assets: a considerable potential of renewable energies and an energy policy favoring a more significant contribution of renewable energies.

- **Solar Potential**

Due to its geographical location, Algeria has one of the largest solar deposits in the world. The duration of sunstroke on almost the entire national territory exceeds the 2000 hours annually and reaches the 3900 hours (highlands and Sahara). The energy received daily on a horizontal surface of $1m^2$ is of the order of 5kWh over most of the national territory, that is to say nearly 1700 kWh / m^2 / year in the North and 2263 kWh / m^2 / year in the South of the country [2]. The mapping below shows the annual global solar radiation in Algeria.

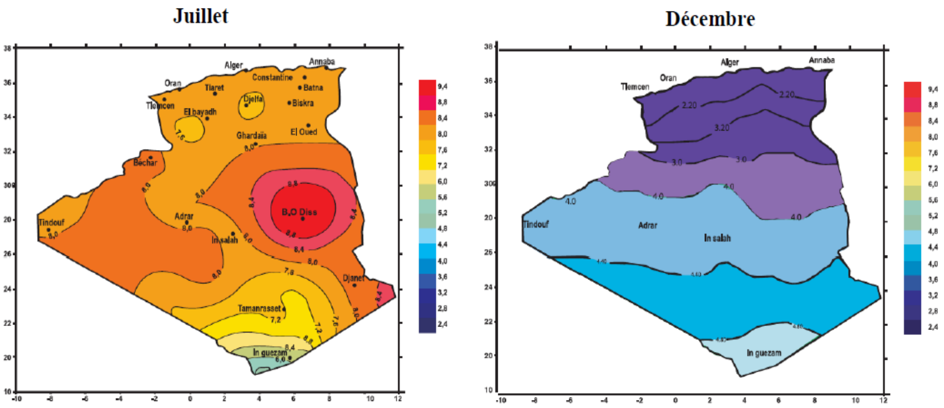

Figure 1.9: Global Daily Irradiation Received on a Plain Surface in the Months of July and December.

1.5.1. Development of Renewable Energies In Algeria

	1st phase 2015-2020 [MW]	2nd phase 2021-2030 [MW]	TOTAL [MW]
Photovoltaic	3000	10575	13575
Wind	1010	4000	5010
CSP	-	2000	2000
Cogeneration	150	250	400
Biomass	360	640	1000
Geothermal	05	10	15
TOTAL	4525	17475	22000

Table 1.2: Phases of the Algerian Renewable Energy Program 2015-2030

Algeria is committed to renewable energies in order to provide global and sustainable solutions to environmental challenges and problems of preservation of fossil energy resources through the launch of an ambitious program for the development of renewable energies. Renewable energy was adopted by the Government in February 2011 and revised in May 2015. Algeria is embarking on a new sustainable energy era. The updated Renewable Energy Program is to install renewable power of around 22,000

MW by 2030 for the domestic market, with the option of export as a strategic objective, if the market conditions are met.

1.5.2. Renewable Energy Development Program

Through this renewable energy program, Algeria intends to position itself as a major player in the production of electricity from the photovoltaic and wind sectors and by integrating biomass, cogeneration, geothermal energy by the year 2021. These energy sectors will be the engines of sustainable economic development capable of stimulating a new model of economic growth.

As the national potential for renewable energies is strongly dominated by solar energy, Algeria considers this energy as an opportunity and a lever for economic and social development, particularly through the establishment of industries that create wealth and jobs.

Algeria's strategy in this area aims to develop a genuine renewable energy industry combined with a training and knowledge capitalization program, which will ultimately make it possible to employ local Algerian engineers, particularly in the field of engineering and project management. The renewable energy program, for the electricity needs of the national market, will create several thousand direct and indirect jobs. [10]

1.5.3. Consistency of the Renewable Energy Development Program

The consistency of the renewable energy program to be achieved for the national market over the 2015-2030 period is 22,000 MW, distributed by sector as follows:

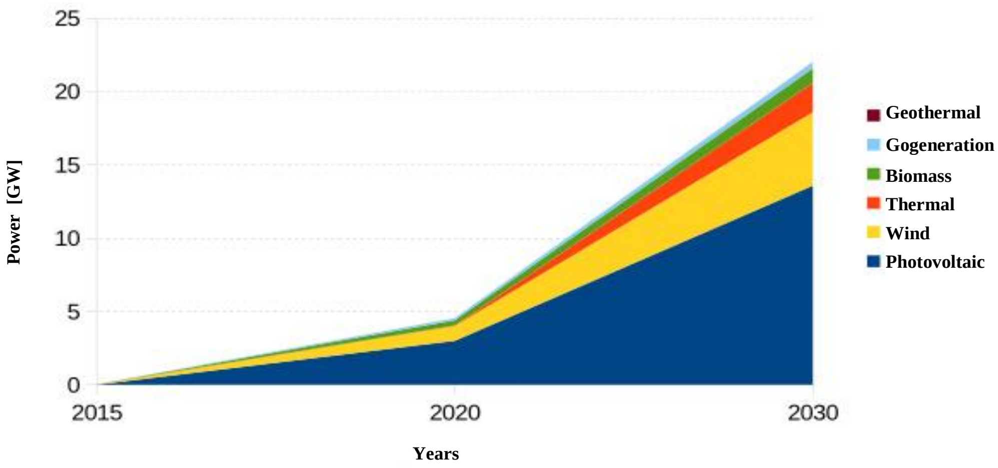

Figure 1.10: The Program Objectives Accumulated by Sector [10].

Solar Photovoltaic

Over the 2014-2020 period, the goal is to achieve an integration rate of Algerian capacities of 80%. To do this, it is planned the construction of a silicon manufacturing plant. In addition, it is expected that a national subcontracting network will be set up for the manufacture of inverters, batteries, transformers, cables and other equipment used in the construction of a photovoltaic power plant.

Algeria should also have, over the same period, designs, procurement and realization capabilities capable of achieving an integration rate of around 60% by Algerian companies.

It is also planned to set up a certification center for equipment for renewable energy installations. Over the period 2021-2030, the objective is to achieve an integration rate higher than 80%. Therefore, the production capacity of photovoltaic modules should be extended to 200 MWp / year. This period would be marked by the development of a national subcontracting network for the manufacture of equipment needed for the construction of a photovoltaic power plant. [11]

Solar Thermal

The 2011-2013 period will see the launch of studies for the local manufacture of equipment in the solar thermal sector.

Over the 2014-2020 period, an integration rate of 50% is expected through the implementation of three major projects that will be carried out in parallel with engineering capacity building actions:

- Construction of a mirror factory;
- Construction of energy storage equipment;

Over the period 2021-2030, the integration rate should be greater than 80% thanks to the realization of the following projects:

- Extend the manufacturing capacity of mirrors;
- Expansion of the manufacturing capacity of heat transfer fluid and energy storage equipment; and expansion of the manufacturing capacity of power block equipment; [11]

1.6. Conclusion

In this chapter, we have given a brief description of the world's electricity production. Our studies focused on the use of renewable energies in Algeria, which in 2013 represented a very low percentage of less than 0.8%. We also presented the structure of an ambitious renewable energy development program to cover a share of the national demand for electricity. The goal is to achieve by 2030 an integration rate of more than 40% of electricity production.

According to our study, it appears that the most interesting renewable energy from the point of view of energy characteristics in Algeria remains solar photovoltaic. This energy is widely available with immense potential. This potential favors its use for power supply, particularly isolated sites in various regions in Algeria.

2.1 Introduction

As we know, photovoltaic solar energy is a new alternative source to conventional fossil resources, but the low conversion efficiency of photovoltaic systems requires the optimization of the system. In this chapter, we analyze the problem of optimization of solar radiation and we detail the importance of tilting solar panels to maximize the efficiency of the system.

In any solar energy conversion system, knowledge of global solar radiation is extremely important for optimal design and prediction of system performance [12].

The most commonly used parameter for estimating global solar radiation is the duration of sunshine. This duration can be easily measured. Data is available in [13]. In the previews studies, different mathematical models have been used in the calculation of global radiation on a horizontal or inclined surface. In our study, we use the model of "LIU and JORDAN" which is a simple and efficient model [12].

The main objective of this study is to show the importance of the optimal inclination angle to maximize the global solar uptake for an inclined solar panel.

2.2 Preliminary notions for calculating solar energy

Before detailing the calculations of the solar irradiation, certain notions and basic principles that are worth mentioning. There are several variables that will be mentioned and used several times afterwards.

2.2.1 Day number

In many solar energy applications one needs to calculate the day number (DN) corresponding to a given date. DN is defined as the number of days elapsed in a given year up to a particular date [12]. DN for typical days are summarized in the following table.

Month	JA	FE	MR	AP	MY	JU	JUL	AU	SE	OC	NO	DE
Date	1	5	6	11	18	22	3	8	15	7	2	9
Day of the year	1	36	65	101	138	173	184	220	258	280	306	343

Table 2.1: List of typical days per month provided by Klein [5]

2.2.2 Solar declination angle

The Sun declination angle δ is defined to be that angle made between a ray of the Sun, when extended to the center of the earth and the equatorial plane. We take δ to be positively oriented whenever the Sun's rays reach the center of earth by passing through the Northern hemisphere[14]..

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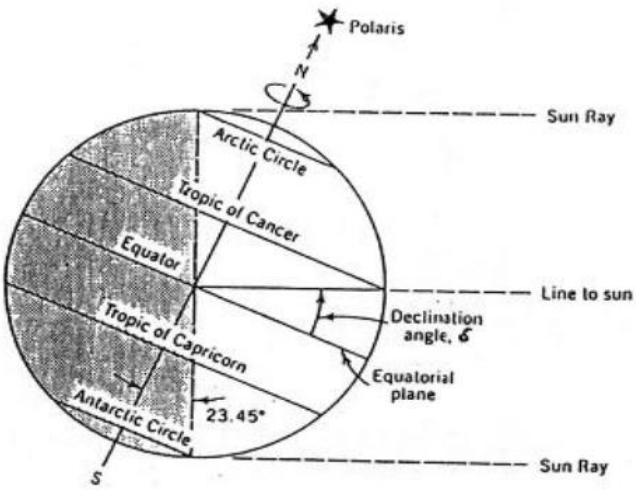


Figure 2.1: The solar declination angle.

The declination angle is described in figure 2.1. The equation used to calculate the declination angle in radians on any given day is [3]:

$$\delta = 23.45 \frac{\pi}{180} sin\left[2\pi \left(\frac{184+n}{36.25}\right)\right] \quad [2.1]$$

Where:

δ: declination angle (degree);

n: the day number, such that n = 1 on the 1st January.

The declination angle varies between -23.45° (on December 21st) and + 23.45° (on June 21st).

2.2.3 Solar day

A solar day is the interval between two successive appearances of the sun on meridian (like a line of longitude). A solar day have an average length of 24 hours[14].

$$SD = 12 + \frac{w}{15} \qquad [2.2]$$

Where: w is the earth's orbital angular speed.

2.2.4 Duration and rate of insolation

On clear skies and during the day s_0 (from sunrise to sunset), the ground receives maximum solar radiation. But the effective duration of sunshine s of an ordinary day is less than this maximum duration.

The maximum duration is calculated by the following expression:

$$s_0 = \frac{2}{15} cos^{-1}(-tan\Psi tan\delta) \qquad [2.3]$$

Where:

δ: The declination angle.

Ψ: Latitude of location.

The insolation rate is given by the expression [14]:

$$\sigma = \frac{s}{s_0}$$

2.2.5 Position of the Sun

The direction of the sun in the sky is identified by two angles:

- **The elevation angle:**

The elevation angle α (used interchangeably with altitude angle) is the angular height of the sun in the sky measured from the horizontal. The elevation is 0° at sunrise and 90° when the sun is directly overhead (which occurs for example at the equator on the spring and fall equinoxes)[14].

The elevation angle varies throughout the day. It also depends on the latitude of a particular location and the day of the year.

It can be calculated from:

$$\sin(\alpha) = \sin(\Psi)\sin(\delta) + \cos(\Psi)\cos(\delta).\cos(\omega_s) \qquad [2.4]$$

Where:

Ψ: Latitude of location.

The hour angle ω_s at sunrise is obtained by writing sin (α) = 0

$$\cos(\omega_s) = -\tan(\Psi)\tan(\delta) \quad [2.5]$$

- **The Azimuth Angle:**

The azimuth is the local angle A between the direction of due North and that of the perpendicular projection of the Sun down onto the horizon line measured clockwise[14]. Thus, we have the azimuth values: 0° = due North, 90° = due East, 180° = due South and 270° = due West.

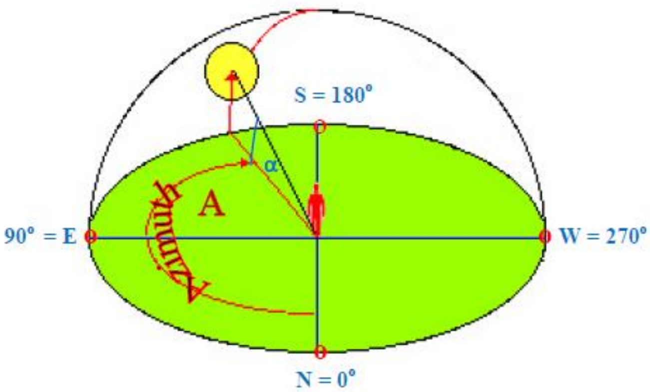


Figure 2.2: The azimuth angle variations throughout the day.

It can be calculated from the following equation:

$$\sin(A_z) = \frac{\sin(\omega_s)\cos(\delta)}{\cos(\alpha)} \quad [2.6]$$

The azimuth angle at sunrise (A_{SR}) can be calculated from:

$$\sin(A_{SR}) = -\sin(\omega_s)\cos(\delta)$$

These two angles are shown in Figure 2.4:

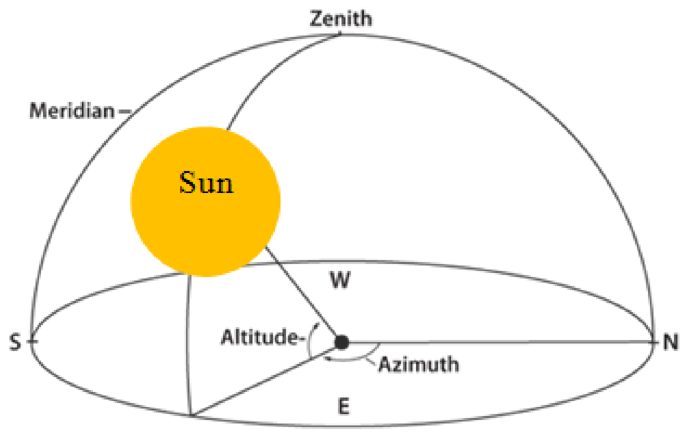


Figure 2.3: Position of the sun.

2.2.6 The hour angle

The hour angle ω_s is an expression describing the difference between local solar time and solar noon. Although it is calculated directly from measurements of time, it is expressed in angular units (degrees)[14].

The hour angle measures time after solar noon in terms of one degree for every four minutes, or fifteen degrees per hour. Time after solar noon is expressed using a positive hour angle, and time before solar noon, a negative hour angle. Therefore, at two hours before solar noon, the hour angle is -30 degrees, and at two hours after solar noon it is +30 degrees[14].

The following figure depicts the relationship between the hour angle and local solar time in the Northern Hemisphere:
It is noticed that the hour angle does not directly correspond to the spatial position of the sun like the altitude and azimuth angles; it requires only time measurement.

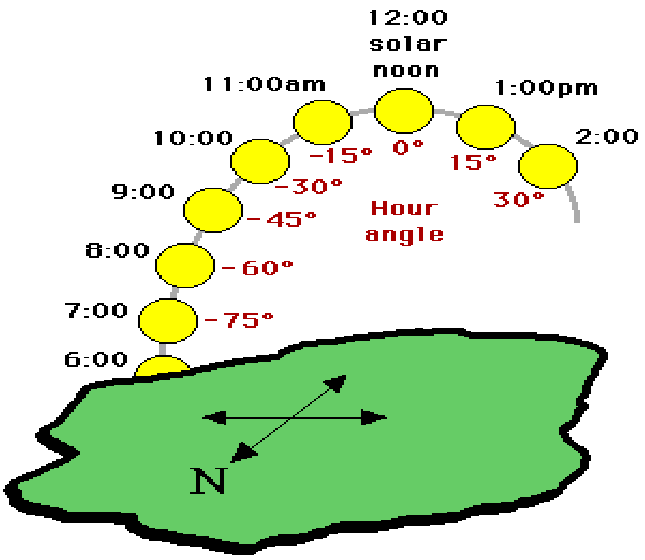


Figure 2.4: The relationship between the hour angle and local solar time.

2.3 Importance of solar panels position and orientation

Solar Panel Orientation refers to our azimuth setting. Most of the energy coming from the sun arrives in straight line. A solar panel or solar array will capture more energy if it is facing directly at the sun, perpendicular to the straight line between the position of the panels installation and the sun. Then we need to have the solar panel turned towards the terrestrial equator (either facing south in the northern hemisphere, or north in the southern hemisphere) so that during the day its orientation allows the panel to catch the greatest possible amount of solar radiation possible. There are different ways of achieving the required solar panel orientation. We could just point the PV panel or array due south or north using a compass, find the central angle between the summer and winter azimuth settings or more accurately position the panels relative to the central solar noon. The solar noon refers to the highest position of the sun as it arcs across the sky and is different to 12:00 o'clock noon or midday as a measurement of time. Generally the solar noon occurs between 12:00 o'clock and 14:00 o'clock depending upon the location. It is very important when positioning and aligning a solar panel or array that no part of a solar panel or solar array are ever shaded from the sun as we need 100% solar radiation across the panel. Check that the elements that surround the panel or array (trees, buildings, walls, other panels, etc.) to be sure that they will not cast a shadow on the panels at any time of the day or year.

Solar Panel Tilt refers to our zenith or elevation setting. Once the best azimuth position is found, the next parameter that is a key to producing the most solar electricity is the elevation of the PV panel. For a fixed solar installation, it is preferred that the PV panels are installed with a centralized tilt angle representing the vernal equinox, or the autumnal equinox, and in our example data above this would be about 38 degrees (38^o).

However, this tilt orientation is not as critical with regards to the solar panels orientation as even at a tilt angle of nearly 45 degrees (45^o) with respect to the suns solar rays will still receive more than 75 percent as much energy per unit surface area as it does when it is optimally aligned.

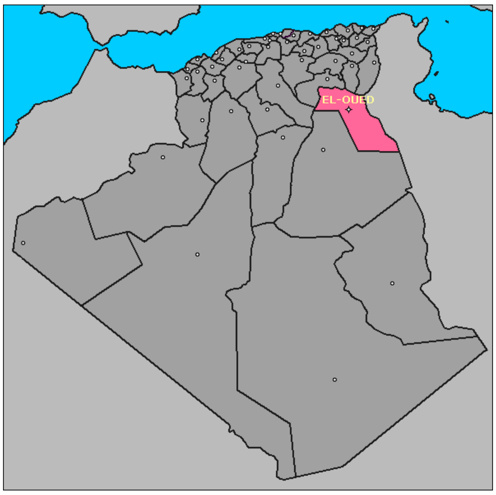
Then a misalignment of up to 15^o either positive or negative makes very little difference to a photovoltaic panels output. Ideally, solar panels should be located where they will receive as much sunlight as possible, averaged out during the course of the day and the course of the year.

The solar panel orientation and tilt of a fixed solar PV panel or array can also be optimized for a particular month or season during the year. For example, a solar power system might be designed to produce maximum power output only in the winter months in order to reduce peak electricity costs thus, the system should be installed so that the optimum solar panel orientation and tilt occurs for the maximum winter power output.

One of the most popular fixed solar power systems involves mounting a PV panel, or a set of PV panels, directly onto a steeply pitched roof that faces toward due south (or north) allowing for very little adjustment of both the solar panel orientation and tilt although most mounting brackets and support frames do allow for some small adjustments. Maximizing the power output from a home solar power system is desirable to both increase the solar panels efficiency and reduce the payback time.

But in order to maximize the power output from the solar panels, we need to keep the panels perfectly aligned with the sun. As such, a means of tracking the sun across the sky is required and a PV panel or PV array with tracking ability will yearly produce about 25 to 30% more power than one mounted on a roof in a fixed position. Also solar tracking can reduce the number of PV panels required by increasing the conversion efficiency[11].

2.4 Specification of the site EL OUED



- Altitude: 64m
- Longitude: 06°47'E
- Latitude :33°30 ' N
- Albedo: 0.2

2.5 Solar radiation outside the Earth's Atmosphere

The radiation intensity $\boldsymbol{H_0}$ (W/m^2) can be related to the sun's irradiation incident on an object, as a function of distance. The solar radiation outside the earth's atmosphere is calculated using the radiant power density (H_{sun}) at the sun's surface (5.961 x 10^7 W/m^2), the radius of the sun (R_{sun}), and the distance between the earth and the sun. The calculated solar irradiance at the Earth's atmosphere is about 1.36 kW/m^2[14]. The geometrical constants used in the calculation of the solar irradiance incident on the Earth are shown in the figure below.

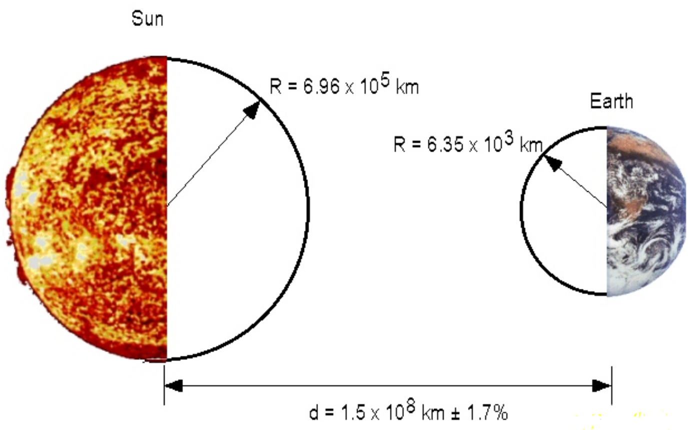


Figure 2.5: the solar irradiance incident on the Earth.

2.5.1 Irradiation

Irradiation is the rate of electromagnetic radiation incident on a surface, measured as the power received from the sun per unit area Extraterrestrial irradiation is at its higher value outside the atmosphere, on a horizontal plane. And it is calculated from the solar constant and the distance correction facture [15].

$$I = G_{SC}\left(1 + 0.033\, cos\frac{360n}{365}\right)(\cos(\Psi)\cos(\delta)\cos(\omega_s) + \sin(\Psi)\sin(\delta)) \qquad [2.7]$$

With:

G_{SC} : Solar constant [1367 w/m^2].

2.5.2 Hourly extraterrestrial radiation

For a given hour, the energy received from the sun on a horizontal surface is calculated by integrating equation [2.7] between two time angles ω_{s1} andω_{s2}.

We obtain the following equation:

$$I_0 = \frac{12.36}{\pi} G_{SC}\left(1 + 0.033\, cos\left(\frac{360n}{365}\right)\right)(\cos(\Psi)\cos(\delta)\,(\sin(\omega_{s2} - sin\omega_{s1}) + (\omega_{s2} - \omega_{s1})\sin(\Psi)\sin(\delta)$$

[2.8]

I_0 Unit is [W/m^2].

2.5.3 Daily extraterrestrial radiation

The extraterrestrial irradiation energy falling on a plane horizontal to the Earth's surface throughout a whole day, integrate equation [2.8] with respect to time between sunrise (ω =$-\omega_s$) and sunset (ω =ω_s). The resulting equation is:

$$H_0 = \frac{24}{\pi} G_{SC} \left(1 + 0.033\, cos\left(2\pi \frac{n}{365}\right)\right) (\cos(\Psi)\cos(\delta)\sin(\omega_s) + \omega_s \sin(\Psi)\sin(\Psi))$$

[2.9]

H_0 Unit is [Wh/m^2].

2.5.4 Monthly average daily solar radiation outside the Earth's atmosphere

To calculate the monthly average daily solar radiation, we use the equation (2.9). The result is shown in the following table:

Month	**JA**	**FE**	**MR**	**AP**	**MY**	**JU**	**JUL**	**AU**	**SE**	**OC**	**NO**	**DE**
Date	1	5	6	11	18	22	3	8	15	7	2	9
Day of the year	1	36	65	101	138	173	184	220	258	280	306	343
δ (°)	-23.01	-16.4	-6.37	7.91	19.5	23.44	22.97	15.96	2.21	-6.57	-15.66	-22.97
H_0[wh/ m^2.d]	5043	6204	7858	9896	1118.5	1151.4	1145.5	1071.7	9007	7722	6265	5037

Table 2.2: Values of monthly average daily solar radiation outside Earth's atmosphere.

2.6 Solar radiation inside the Earth's atmosphere

The solar radiation reaching the Earth's surface can be divided into two types of solar radiation: Direct beam solar radiation and diffuse solar radiation. Before reaching the ground, the solar radiation undergoes phenomena of diffusion, which describes the sunlight that has been absorbed, scattered, or reflected by molecules, dust, water vapor and particles in the atmosphere but that has still made it down to the surface of the earth. Direct radiation has a definite direction but diffuse radiation is just going any which way. Because when the radiation is direct, the rays are all travelling in the same direction, an object can block them all at once. The absorbed by molecules and particles radiation is transformed into heat.

The solar radiation that reaches the ground is composed of direct and diffuse radiation.

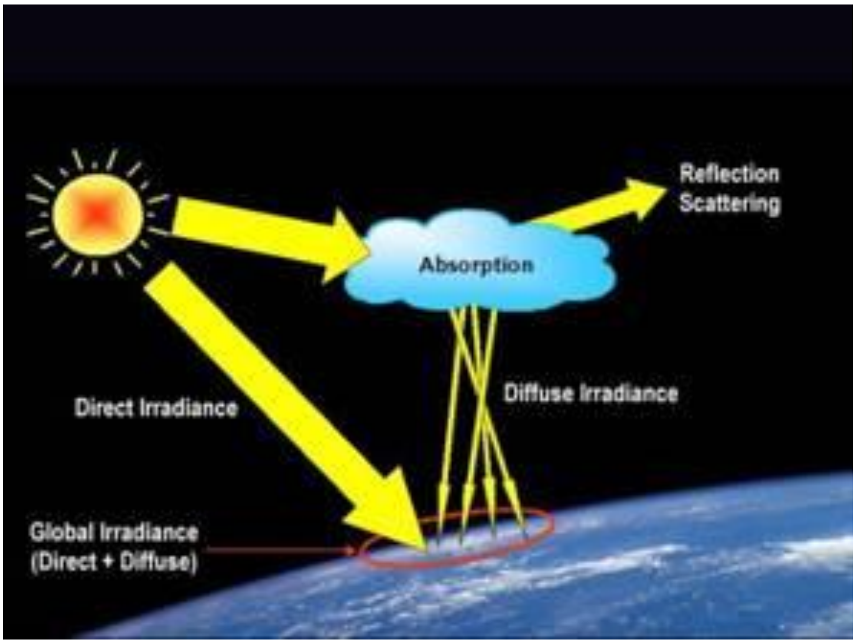


Figure 2.6: Direct and diffuse Irradiance.

2.6.1 The Clearness Index

Next the clearness index (K_T) is defined as the ratio of the total irradiation reaching a horizontal plane at the location on the Earth's surface and the extraterrestrial irradiation on a horizontal plane above the location.[15] Thus K_T is an indication of how much of the Sun's radiation is lost to scattering and absorption in the atmosphere.

- The hourly clearness index:

$$K_T = \frac{I}{I_0}$$

- The daily clearness index:

$$K_T = \frac{H}{H_0}$$

- The average monthly index

$$K_T = \frac{\overline{H}}{\overline{H_0}}$$

I, H, $\overline{H}$ are the measured values of the global irradiation on a horizontal surface. These values are generally available and can be measured or can be referenced from weather station data. However, I_0, H_0, $\overline{H_0}$ can be calculated by their known formulas.

2.6.2 Estimation of diffuse irradiation on Earth

From the measurement of the average daily and monthly global irradiation, we can estimate the average daily diffuse irradiation H_d by the Beckman correlation:

$$\frac{\overline{H_d}}{H} = K_d = a + bK_T \qquad [2.10]$$

Where:

$\overline{H_d}$: The mean average daily diffuse irradiation.

K_d: Fraction of the extraterrestrial daily insolation transmitted through the atmosphere as diffuse radiation. And it is equal to:

$$K_d = \frac{D}{H_0}$$

Where:

D: Daily average diffuse radiation received on a horizontal surface.

And for the Algerian Sahara [15]:

$$\begin{cases} a = 0.91 \\ b = 0.98 \end{cases}$$

2.6.3 Calculation of the daily global irradiation on a horizontal surface

Based on the data measured between the years 2000 to 2006 by the EL OUED weather station [16], we have:

Month	JA	FE	MR	AP	MY	JU	JUL	AU	SE	OC	NO	DE
Insolation	240 ,2	248,6	276,5	288,6	307,5	345,9	351,9	331,7	274,4	257,2	233,6	228
$\overline{S}(h)$	7.74	8.17	8.36	9.13	9.3	10.8	11.5	10.64	9.26	9.43	8.3	7.35
$\overline{S_0}(h)$	9.87	10.53	11.44	12.69	13.77	14.18	14.13	13.42	12.19	11.42	10.6	9.86
$\overline{\sigma}$	0.78	0.77	0.73	0.71	0.67	0.76	0.81	0.79	0.75	0.82	0.78	0.74

Table 2.3: Average values of monthly insolation.

With:

$\overline{S(h)}$: The average daily insolation duration (measured).

$\overline{S_0(h)}$: The astronomical duration of the day (calculated).

The insolation rate is calculated by:

$$\bar{\sigma} = \frac{\bar{S}}{\bar{S}_0}$$

According to black's formula, the clearness index is obtained by:

$$K_T = b + c\bar{\sigma} = \frac{\bar{H}}{\bar{H}_0}$$

The values of the constants b and c are given by Beckman [5] for the Saharan region in Algeria:

$$\begin{cases} b = 0.3 \\ c = 0.43 \end{cases}$$

Month	JA	FE	MR	AP	MY	JU	JUL	AU	SE	OC	NO	DE
K_T	0.64	0.64	0.61	0.6	0.59	0.62	0.65	0.64	0.62	0.65	0.63	0.62
$\overline{H}$ [wh/m^2.d]	3214.4	3930.9	4825.3	6029.9	6603.5	7224.7	7445.2	6866.5	5643.7	5056.4	3988.7	3123.8

Table 2.4: Values of the monthly daily global solar irradiation on a horizontal surface.

2.6.4 Calculation of monthly and daily global irradiation on an inclined surface

Solar panels can be installed on the ground or on the roof facing south and away from shaded areas. They should have an angle so that the capture surface is perpendicular to the solar radiation.

For the design of solar systems, we need the average daily irradiation incident on a the surface of the sensor $\overline{H_T}$

Using the LIU and JORDAN model, the calculation of $\overline{H_T}$ is given by the following equation [15]:

$$\overline{H}_T = \overline{H_b} \cdot \overline{R}_b + \overline{H_d}\left(\frac{1+\cos\beta}{2}\right) + \overline{H}.\rho.\left(\frac{1-\cos\beta}{2}\right) \qquad [2.11]$$

With:

$\overline{R}_b$: the monthly average daily geometric factor, or the ratio between the monthly average daily beam radiation on the tilted surface and that on a horizontal surface. For a surface with γ = 0, $\overline{R}_b$ is expressed as:

$$\overline{R}_b = \frac{\cos(\Psi-\beta)\cos\delta\sin w_m + (\frac{\pi}{180}) w_m \sin(\Psi-\beta)\cos\delta}{\cos\Psi\cos\delta\sin w_s + (\frac{\pi}{180}) w_s \sin\Psi\cos\delta}$$

With w_m is the sunset hour angle for the sloped surface for the mean day of the month, which is given by:

$$w_m = min\begin{bmatrix} Cos^{-1}(-Tan\Psi Tan\delta) \\ Cos^{-1}(-Tan(\Psi - \beta)Tan\delta \end{bmatrix}$$

Where "min" means the smaller value of the two items in the brackets.

$\overline{H_d}$: The diffused irradiation component on a tilted surface.

$\overline{H_b}$: The direct irradiation component on a tilted surface, which is equal to $\overline{H_b} = \overline{H} - \overline{H_d}$.

ρ: Convention factor used to find the reflected (or albedo) component for a titled plane.

β: The slope of the surface considered in degrees.

w_m: The hour angle of the sunset on the inclined surface.

w_s: The hour angle of the sunset on the horizontal plane.

a) Inclination of an angle equal to latitude:

The monthly mean daily values of the global irradiation incident on an inclined surface are presented in the table below for

ρ = 0.2 (Albedo of location)

$\beta = \psi = 33$ (geographical latitude of location)

Month	JA	FE	MR	AP	MY	JU	JUL	AU	SE	OC	NO	DE
$\bar{H}$ [wh/m^2.d]	4437.9	5049.8	5668.1	6449.7	6599.3	7081.9	7329.1	7038.4	6273.3	6018.3	5094.3	4278.1

Table 2.5: The values of the monthly daily global solar irradiation for a slope equal to the altitude.

b) Optimal tilt of a solar panel:

To calculate the optimal angle of inclination for maximum irradiation received on an inclined sensor, the angle of inclination is varied in the typical day of the month to identify the angle at which the energy received has its highest value. In Table 2.5 below, we presented the optimal angles for each month with the corresponding maximum energy:

Month	JA	FE	MR	AP	MY	JU	JUL	AU	SE	OC	NO	DE
β_{opt}	14	19	26	37	41	43	43	41	33	27	19	13
$\bar{H}$ [wh/m^2.d]	4679.2	5189	5701	6458.8	6652.5	7174.2	7435.3	7097.9	6273.3	6049.6	5222.6	4510.1

Table 2.6: The optimal inclination angles for each month.

In Figure 2.7, we note that the solar energy received is at a maximum using the optimal angle values presented in Table 2.6.

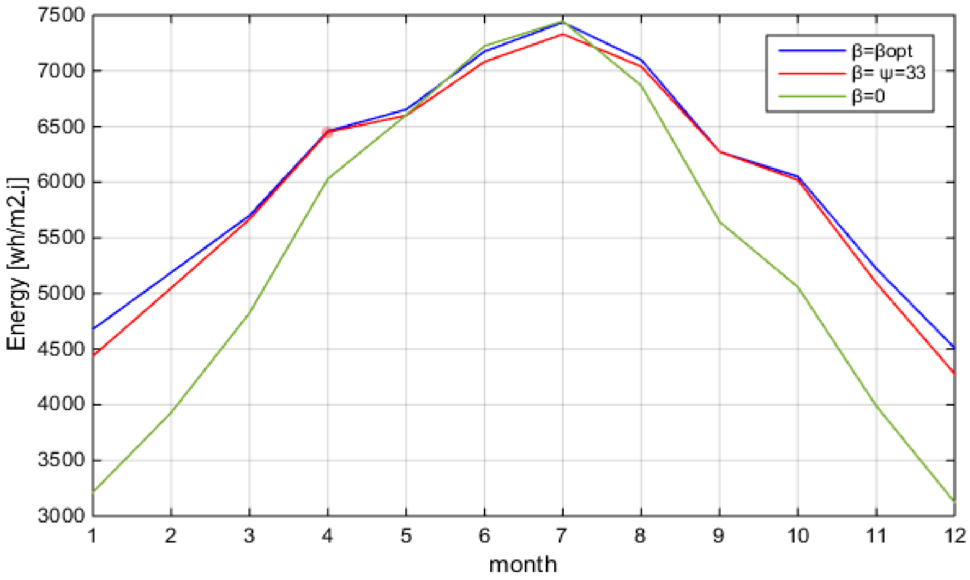


Figure 2.7: Monthly total daily irradiation for the three cases.

Table 1.9 below shows the different annual energy values for different inclination angle values. We find that the energy is at its best for an optimal monthly angle.

β	**β = ψ = 33**	**β = 0**	**β = β_{opt}**
$\bar{H}$ [kwh/m^2.years]	2169.3	1945.2	2203.5

Table 2.7: The energy acquired annually for different inclinations.

2.7 Conclusion

The global solar radiation incident on a horizontal or inclined surface is estimated by establishing the sky conditions. Monthly variation of clearness index (K_T), diffuse ratio (K_d) and Temperature were presented in this chapter. Klein and Jordan model were used in this study to examine the variation of diffuse solar radiation.

The improvement of the capture efficiency by the orientation of the surface of the modules of the

Photovoltaic field makes it possible to obtain a rational sum of solar radiation. In other words, achieving a good yield,. In reality and for financial reasons, the solar panels are usually oriented with a fixed inclination angle $\boldsymbol{\beta}$.In this work we found that we can improve the efficiency of the system and receive the maximum of photovoltaic energy, by optimally choosing the monthly angle of inclination. Therefore, solar panels can capture the most solar radiation at a low cost by changing the inclination angle only four times a year (seasonally).

3.1 Introduction

In a photovoltaic system, the light energy is converted directly into electrical energy. This conversion uses sensors made of semi-conductor materials sensitive to visible wavelengths, called "Photovoltaic" "PV" cells. The association of several PV cells in series and / or parallel, gives rise to a photovoltaic generator (PVG)[17].

The GPV has a nonlinear static current-voltage (I -V) characteristic. This characteristic depends on the level of illumination and the temperature of the cell as well as the aging of the equipment [17]. The determination of the operating point of the photovoltaic generator depends directly on the load to which it is connected to. This point of operation is more or less distant from the PPM which is characterized by the optimal current and voltage. In order to improve the conversion of photovoltaic energy in terms of efficiency, a PPM tracking mechanism called Maximum Power Point Tracking (MPPT) is needed so that the maximum power is generated continuously. These techniques include classical methods (Perturb and Observe ...) and new techniques of artificial intelligence.

3.2 Photovoltaic system

A photovoltaic system, also PV system or solar power system, is a power system designed to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the electric current from DC to AC, as well as mounting, cabling, and other electrical accessories to set up a working system. It may also use a solar tracking system, to improve the system's overall performance, and an integrated battery solution for energy storage application.

PV systems range from small, rooftop-mounted or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts. Nowadays, most PV systems are grid-connected, while off-grid or stand-alone systems only account for a small portion of the market.

PV system operates silently and without any moving parts or environmental emissions, it has developed from being a mere market applications into a mature technology used for mainstream electricity generation. A rooftop system recoups the invested energy for its manufacturing and installation within 0.7 to 2 years and produces about 95 percent of net clean renewable energy over a 30-year service lifetime[17].

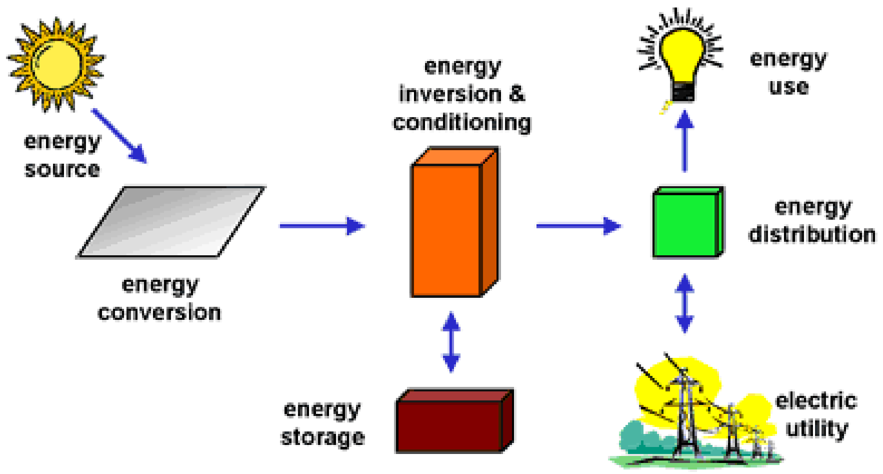


Figure 3.1: A simple photovoltaic system.

3.2.1 The semiconductors

A semiconductor material has an electrical conductivity value falling between that of a conductor such as copper, gold etc. and an insulator, such as glass. Their resistance decreases as their temperature increases, which is behavior opposite to that of a metal. A Semiconductor can be defined as a material that has the characteristics and ability to conduct a small amount of electrical current. Semiconductors have much lower resistance to the flow of electrical current in one direction than in another. Electronic Components such as Diodes, transistors, and many photovoltaic cells contain semi-conductive materials. The electrical conductivity of a semiconductor device can be controlled over a wide range, either permanently or dynamically.

3.2.2 Operating principle of semiconductor

Every material has an energy band gap. This band gap represents the energy difference of the valence and conduction electrons. The valence band is a band of all energy levels that the typical valence electrons. The conduction band is the band of the energy levels in which the electrons can conduct electricity. The difference being the conduction band electrons are not bound to a single atom and free to move around. An analogy is the valence electrons are in a relationship with an atom, (doesn't have to be a monogamous relationship, since a single electron can orbit multiple atom) and conduction band electrons are single. In metals the valence and conduction band overlap which is why metals are conductors. Insulators have a large energy gap between the two bands, which makes it more difficult (not impossible) for them conduct electricity. Semi-conductors have a small energy band gap so even though they don't conduct electricity like metals, they are able to if you apply a voltage/energy potential which corresponds to the band gap energy. This happens because the voltage/energy potential energizes the electron enough for it to make the jump from the valence band to the conduction band [19]. The band gap in the descending order is as follows:

1. Insulators.
2. Semiconductors.
3. Conductors.

The energy band of gap of silicon corresponds roughly to the energy levels of photons, so when a photon hits the solar panel, it's absorbed by and electron orbiting the silicon atom, the electron then has enough energy to make the jump to the conduction band(breaks up with the silicon atoms). Combine that with the fact that solar panels are composed of two layers of silicon doped with positive and negative ions(one layer has a net positive charge, the other a net negative charge) the electron in the conduction band(the newly single electron) then flows from the negative terminal to the positive terminal, which creates an electric current [20].

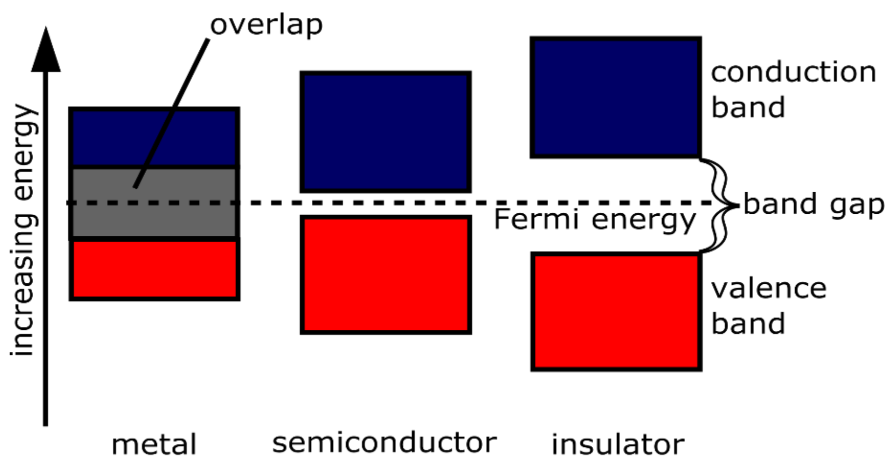


Figure 3.2: Band gap comparison.

3.3 Composition of a photovoltaic installation

The photovoltaic installation is composed by:

- The photovoltaic cells
- The photovoltaic module
- photovoltaic generator

3.3.1 The photovoltaic cells

A single PV cell is a thin semiconductor wafer made of two layers generally made of highly purified silicon (PV cells can be made of many different semiconductors but crystalline silicon is the most widely used). The layers have been doped with boron on one side and phosphorous on the other side, producing surplus of electrons on one side and a deficit of electrons on the other side. When the wafer is bombarded by sunlight, photons in the sunlight knock off some of excess electrons; this makes a voltage difference between the two sides as the excess electrons try to move to the deficit side. In silicon this voltage is 5 volt[19].

Metallic contacts are made to both sides of the semiconductor. With an external circuit attached to the contacts, the electrons can get back to where they came from and current flows through the circuit. This PV cell has no storage capacity; it simply acts as an electron pump.

The amount of current is determined by the number of electrons that the solar photons knock off. Bigger cells, more efficient cells, or cells exposed to more intense sunlight will deliver more electrons.

3.3.1.1 The different types of photovoltaic cells

- **Mono-crystalline cells**

Mono-crystalline silicon (also called "single-crystal silicon", "single-crystal Si", "mono c-Si", or mono-Si) is the base material for silicon chips used in virtually all electronic equipment. today[21]. Mono-Si also serves as a photovoltaic, light-absorbing material in the manufacture of solar cells. They have the best performance (from 12 to 18% up to 24.7% in the laboratory) [21]. However, they are too expensive due to their complex manufacturing.

Figure 3.3: Mono-crystalline solar cell**.**

Poly-crystalline cells

Polycrystalline Silicon (also called**:** polysilicon, poly crystal, poly-Si or also: multi-Si, mc-Si) are manufactured from cast square ingots**,** produced by cooling and solidifying molten silicon. The liquid silicon is poured into blocks which are cut into thin plates. Their design is easier and their cost of
manufacturing is less important. However, their yield is lower: 11% to 15% up to 19.8% in the laboratory [22].

Figure 3.4: Polycrystalline solar cell**.**

The amorphous cells

Amorphous silicon (a-Si) is the non-crystalline form of silicon used for solar cells and thin-film transistors in LCDs. Used as semiconductor material for a-Si solar cells, or thin-film silicon solar cells, it is deposited in thin films onto a variety of flexible substrates, such as glass, metal and plastic. They are considered one of the most environmentally friendly photovoltaic technologies, since they do not use any toxic heavy metals such as cadmium or lead. They have a low efficiency (5% to 8%, 13% in laboratory) [22], but only require very low silicon thicknesses and have a low cost. They are commonly used in small products of consumption such as solar calculators or watches. The advantage of this latter type is that it operates with low illumination (even on a cloudy day or inside a building).

Figure 3.5: Amorphous solar cell**.**

3.3.2 The photovoltaic module

A PV module consists of many PV cells wired in parallel to increase current and in series to produce a higher voltage. 36 cell modules are the industry standard for large power production.

The module is encapsulated with tempered glass (or some other transparent material) on the front surface, and with a protective and waterproof material on the back surface. The edges are sealed for weatherproofing, and there is often an aluminum frame holding everything together in a mountable unit. In the back of the module there is a junction box, or wire leads, providing electrical connections[23].

Figure 3.6: Photovoltaic modules.

3.3.3 The photovoltaic generator

The basic unit of a PV generator is the PV cell. An individual PV cell typically produces from 1 to 2 W. To increase the power, cells are electrically connected to form larger units, called PV modules. In practice, a PV module consists of PV cells connected in series. Modules, in turns, can be connected in series and parallel to form larger units called PV panels. Panels connected in series constitute a PV array. Arrays connected in parallel constitute a PV generator [17].

The photovoltaic generator system consists of several modules and a set of components that help in energy generation and conversion.

Figure 3.7: Photovoltaic generator.

3.4 Mathematical modeling of photovoltaic module

The number of unknown parameters increases when the equivalent circuit of the chosen model becomes more convenient and far from being the ideal form. But most of the manufacturers' data sheets do not give enough information about the parameters which depend on weather conditions (irradiance and temperature). So, some assumptions with respect to the physical nature of the cell behavior are necessary to establish a mathematical model of the PV cell and the PV module, in addition of course, to the use of that information given by the constructors.

3.4.1 Ideal model of photovoltaic cell

The photovoltaic cell can be studied from equivalent circuit given by the figure (3.8) composed of a current generator and a diode in parallel.

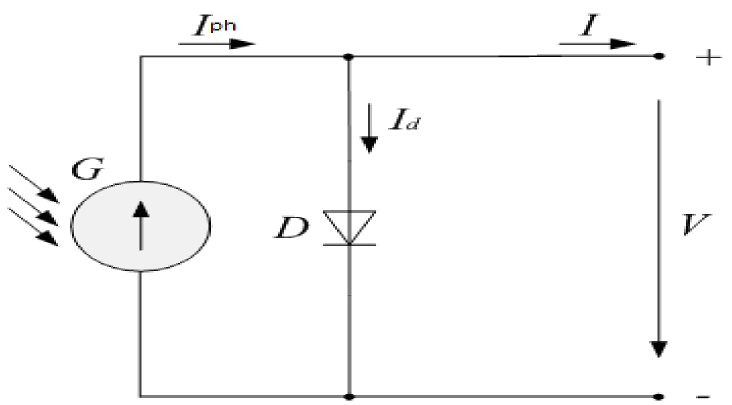


Figure 3.8: Electrical circuit of an Ideal photovoltaic cell**.**

The characteristic equation is deduced directly from the Kirchhoff law [24]:

$$I = I_{ph} - I_d \qquad [3.1]$$

Where:

I : Current produced by the PV cell.

I_{ph} : The current generated by the incident light.

I_d : The diode current.

$$I_d = I_0 \left[exp.\left(\frac{V}{V_T}\right) - 1\right] \qquad [3.2]$$

With:

$$V_T = \frac{kT}{e}$$

So the equation of the current delivered by a photovoltaic cell is described as follows:

$$I = I_{ph} - I_0[\exp\left(\frac{V}{\propto V_T}\right) - 1] \qquad [3.3]$$

I_0 : The diode reverse bias saturation current [A].

V_T : The thermal tension [V].

$\propto$: The ideality factor of the diode.

k : The Boltzmann constant [$1.3806503.10^{-23}$ J/K].

e : The electron charge [$1.60217646\ .10^{-19}$ C].

T : The temperature of the PN junction in Kelvin [K].

V : The terminal voltage [V].

V_{oc} : Open circuit voltage [V].

I_{sc} : Short circuit current [I].

If we draw the current (I) according to the voltage (V) at a subtraction of two curves:

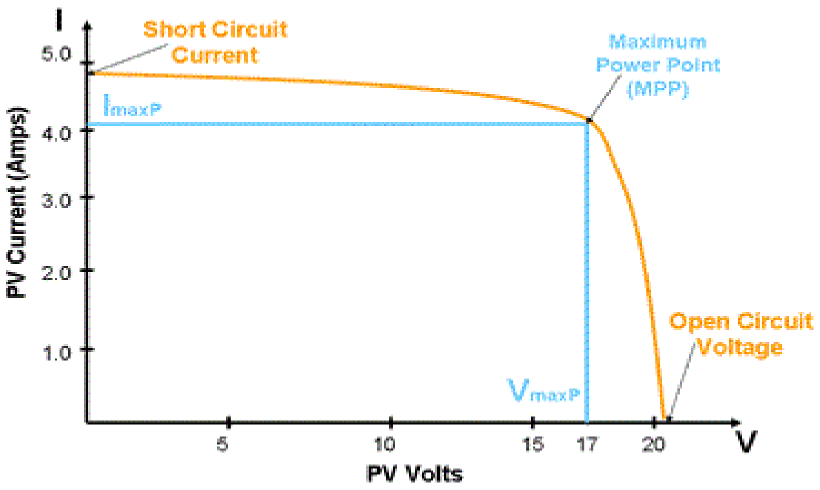


Figure 3.9: The (I-V) characteristic of a photovoltaic cell.

3.4.2 Real model of photovoltaic cell

In the case of a real photovoltaic cell, other parameters must be taken into consideration like the resistive effects, recombination, leaks towards the edges,

The mathematical model of the photovoltaic generator is based on the equivalent circuit.

This circuit is represented in figure (3.9) by a current generator, a diode and two resistors R_s and R_{sh} [25]

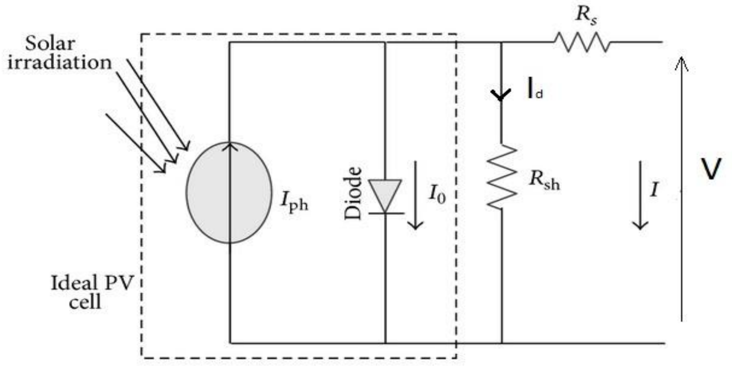


Figure 3.10: Electrical circuit of a real photovoltaic cell.

• R_s: is a series resistor related to volume resistivity and impedance of electrodes and materials.

• R_{sh}: is a shunt resistance related to edge effects and volume recombination.

One recognizes the symbol of the diode (crossed by the current I_d), in parallel with the generator of current I_{CC}, which corresponds to the flow of electrons generated by the flow of photons from the light (solar or otherwise) within the junction of the diode. Also in parallel to the diode there is the resistance R_{sh} (shunt resistance), which corresponds to the direct losses through the junction. In series towards the V_p and I_P usage, is the resistance R_s (series resistance) that corresponds, amongst other things, to the Joule losses in the wires. The characteristic equation can be deduced directly by using the Kirchhoff law:

$$I = I_{ph} - I_d - I_{sh} \qquad [3.4]$$

Where:

I : Current produced by the PV cell.

I_{sh} : The shunt resistance current which is equal to $I_{sh} = \frac{V+R_S.I}{R_{sh}}$

I_d : The diode current equal to $I_d = I_0(e^{\frac{e(V+R_S.I)}{\propto.KT}} - 1)$

The relationship between the PV cell output current and terminal voltage according to the single-diode model is governed by equation:

$$I = I_{ph} - I_0 \left(e^{\frac{e(V+R_S.I)}{\propto.KT}} - 1 \right) - \frac{V+R_S.I}{R_{sh}} \quad [3.5]$$

3.4.3 Photovoltaic cell panel model

The equivalent circuit for PV array is shown in Fig 3.11:

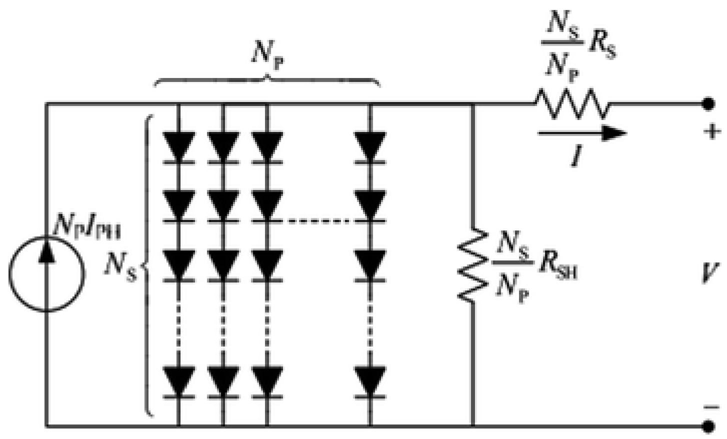


Figure 3.11: Equivalent circuit of solar array.

Module reverse saturation current I_{rs}

$$I_{rs} = \frac{I_{sc}}{\exp\left(e.\frac{V_{oc}}{N_S}.\propto KT\right)} \quad [3.6]$$

Where:

N_s : number of PV modules connected in series.

N_p : Number of PV modules connected in parallel.

The module saturation current I_0 varies with the cell temperature, which is given by

$$I_0 = I_{rs} \left[\frac{T}{T_r}\right]^3 \exp\left[\frac{e.E_{g0}}{\propto K}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \quad [3.7]$$

Here:

T_r: Nominal temperature [298.15 K].

E_{g0}: Band gap energy of the semiconductor [1.1 eV].

The current output of PV module is[26]:

$$I = N_p . I_{ph} - N_p . I_0 . \left[exp\left(\frac{V/_{N_s} + I . \frac{R_S}{N_p}}{\propto . V_t} \right) - 1 \right] - I_{sh} \qquad [3.8]$$

With:

N_p : Number of PV modules connected in parallel.

N_s : Number of PV modules connected in series.

V_t : The diode thermal voltage (V). Which is equal to:

$$V_t = \frac{K.T}{e}$$

And

$$I_{sh} = \frac{V\frac{N_p}{N_s} + 1.R_s}{R_{sh}} \qquad [3.9]$$

3.5 Characteristics of Photovoltaic Module under different weather conditions.

3.5.1 Case of variable solar irradiance

The PN junction reacts differently according to the energy it receives. The more energy it receives, the more it returns, but always with a very low efficiency coefficient of the order of 15%. The variation in characteristics is represented on the curves of figure 3.12. For different levels of irradiation, the optimal current change is very important. This confirms the approximation made typically on the optimal current delivered by a PV generator, which is globally proportional to the level of irradiation. We can see it also in Figure 3.13. According to weather conditions, we get different curves with different maximum powers during the same day. We also note the slight decrease in open circuit voltage at a drop in light flow [27].

By examining the actual characteristics obtained, we can conclude that strong variations in the level of irradiation cause relatively large variations in optimal current. While, the relative variations of the optimal voltage remain low. In the three models the temperature is maintained constant at 25°C and by varying the irradiation (250W/m^2, 500W/m^2, 750W/m^2, and 1000W/m^2).

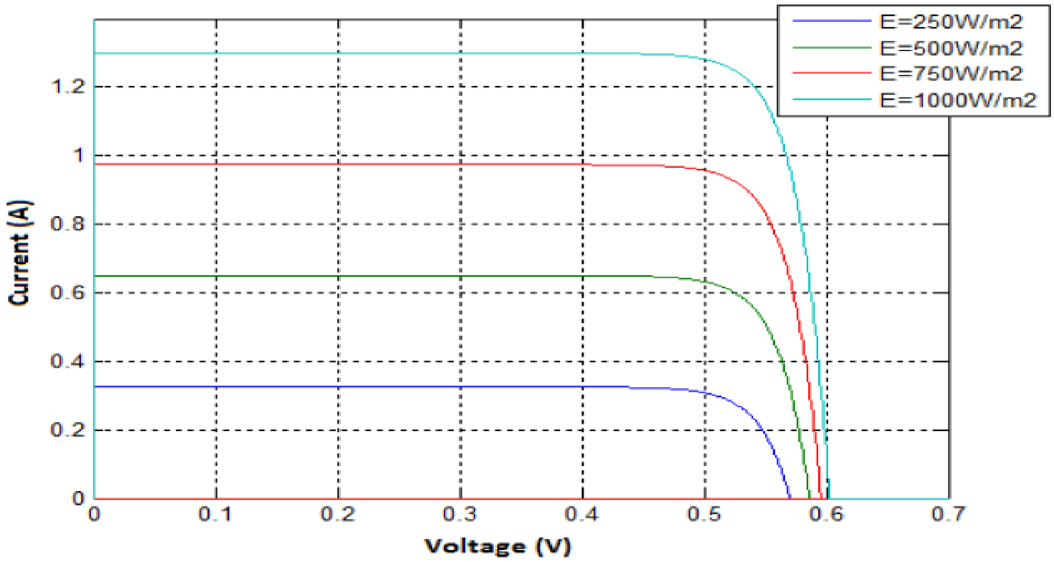


Figure 3.12: Influence of irradiation on I-V characteristics.

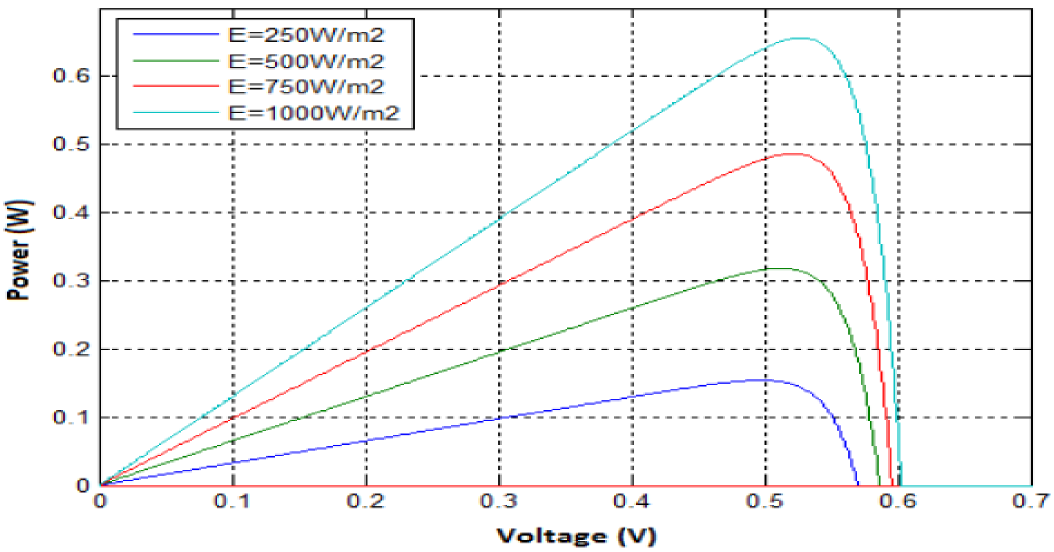


Figure 3.13: Influence of irradiation on P-V characteristics.

3.5.1 Case of variable temperature

As explained above, the base of photovoltaic cells is a PN junction. This lets us think that its performance will vary according to the temperature from the junction. Figure 3.14 below shows that the open circuit voltage of a solar cell decreases with the increase of the temperature of the cell by 2.3 mV / per degree Celsius / per cell. The short-circuit current, on the other hand, slightly increases with the temperature of the cell (about 0.05% per degree Celsius). The irradiation is maintained constant at1000W/m^2 and varying temperature (0°C, 25°C, 50°C, and 75°C) will generate the characteristic curves:

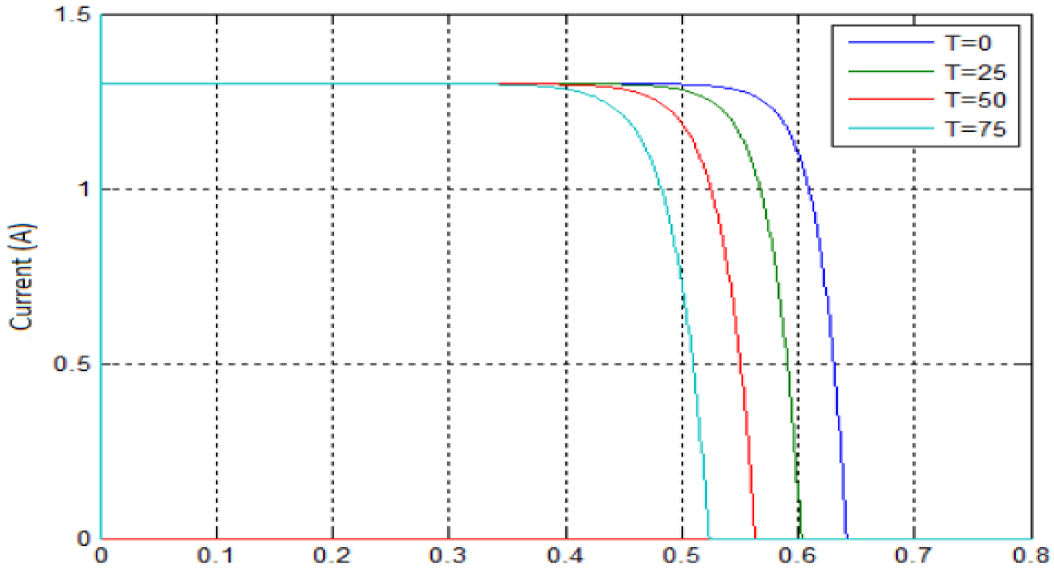


Figure 3.14: Influence of temperature on I-V characteristics.

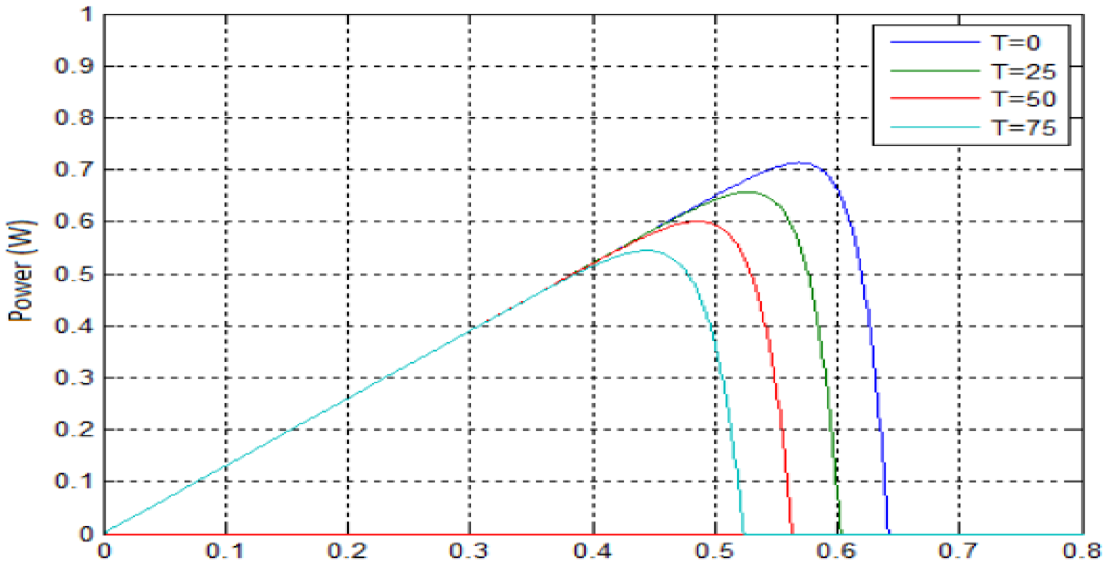


Figure 3.15: Influence of temperature on P-V characteristics.

3.6 Connection of PV generator to a load

The photovoltaic system can operate according to two main modes:

- Connected directly to the load.

- Connected through an adaptation stage.

3.6.1 Connection of PV system directly to the load

This is the simplest one that can be conceived. It consists of a PV generator connected directly to the DC load. This choice is mainly related to the simplicity of the operation and the high degree of reliability and that is mainly due to the lack of electronics as shown in Figure 3.16, without forgetting the low cost of this option.

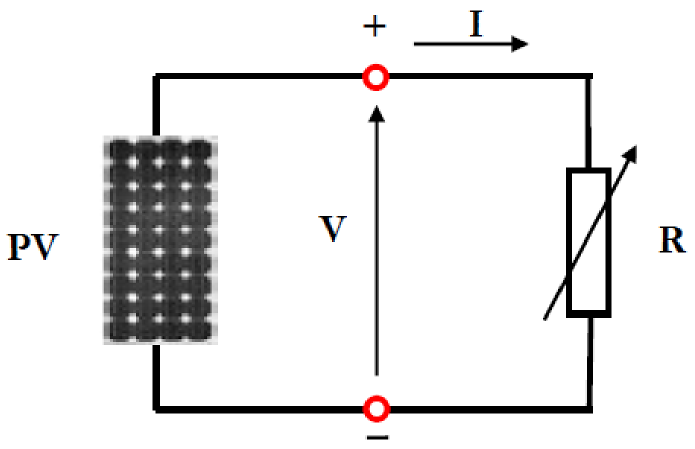


Figure 3.16: direct-coupled PV system.

The major disadvantage of this configuration is that it offers no type of limitation and / or adjusting the voltage across the load. The transfer of maximum power available from the PVG to the load is also not guaranteed Indeed.

3.6.2 Connection of PV system to the load through an adaptation stage.

The output of power varies greatly depending on the irradiation, the temperature, but also the overall aging of the system. In addition, depending on the characteristics of the load on which the PV generator is powering, we can find a very large difference between the potential power of the generator and that actually being transferred to the load in direct connection mode. In order to extract at each moment the maximum power available at the terminals of the PV generator and transfer it to the load, the technique applied is to use a mediator between the PV generator and the load as described in Figure 3.17 below. This element plays the role of a mediator between the two elements by ensuring, through an action of control, the transfer of the maximum power supplied by the generator[28].

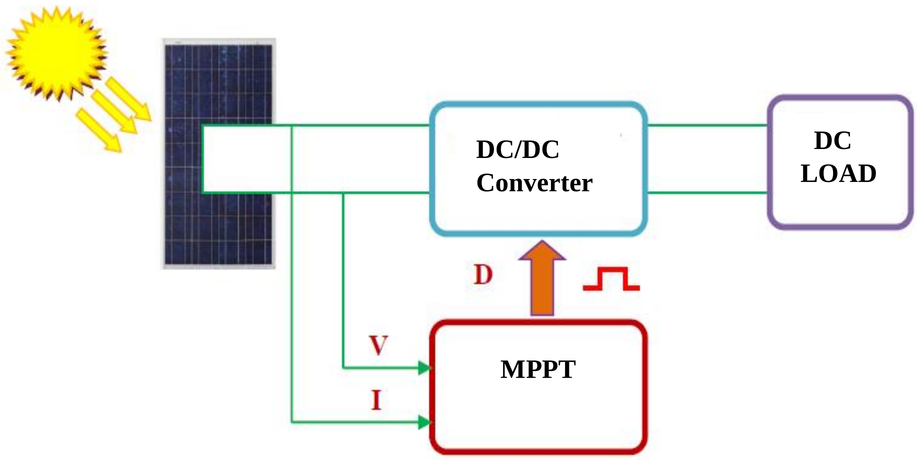


Figure 3.17: PV generator controlled by MPPT.

- **The DC/DC converter (chopper)**

A chopper is a static device that converts fixed dc input voltage to a variable dc output voltage directly. A chopper is a high-speed on/off semiconductor switch. It connects source to load and disconnects the load from source at high-speed. Also known as DC-to-DC converter. Widely used for motor control.

a) Step-down chopper (buck)

In step down chopper output voltage is less than input voltage as presented in figure3.18:

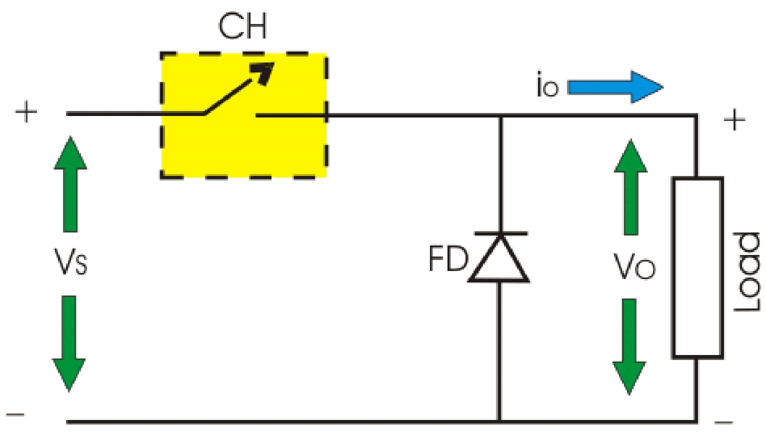


Figure 3.18: Equivalent circuit of a buck chopper.

The average value of the tension $\overline{V_{out}}$ can be adjusted by adjusting the value of the duty cycle α. When one varies α from 0 to 1, $\overline{V_{out}}$ varies linearly from 0 to V_{in}.

$$\overline{V_{out}} = \alpha V_{in} \qquad [3.10]$$

$$I_{out} = \frac{I_{in}}{\alpha} \qquad [3.11]$$

With:

V_{out}: The output voltage.

V_{in}: The input voltage.

$\overline{V_{out}}$: The average value of output voltage.

α: The duty cycle.

From Equations (3.10) and (3.11), we can deduce the resistance at the output of the PV panel (Rpv):

$$R_{pv} = \frac{1}{\alpha^2} R_{Load} \qquad [3.12]$$

Under optimal conditions and for a given load, the optimum resistance of the PV generator (Rpv = $Ropt$) is calculated by the following equation:

$$R_{opt} = \frac{1}{\alpha_{opt}^2} R_{Load} \qquad [3.13]$$

b) Step-up chopper (boost)

In step up chopper output voltage is more than input voltage. See figure (3.19):

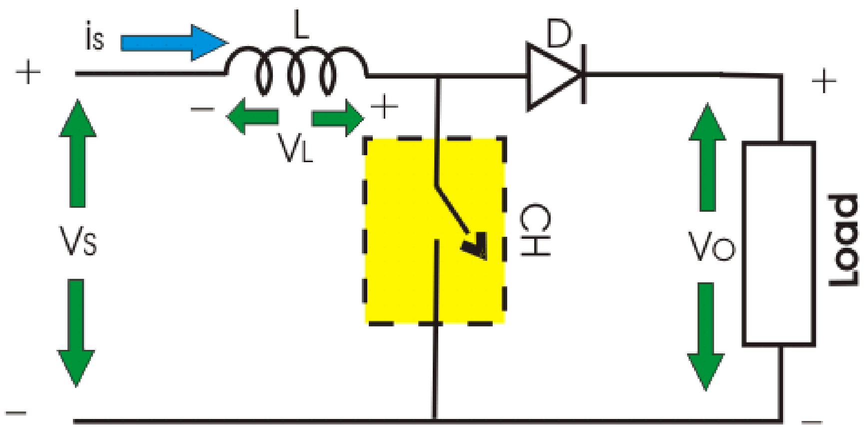


Figure 3.19: Equivalent circuit of a boost chopper.

The average value of the voltage $\overline{V_{out}}$ is calculated by:

$$\overline{V_{out}} = \frac{V_{in}}{(1-\alpha)} \qquad [3.14]$$

$$I_{out} = (1-\alpha)I_{in} \qquad [3.15]$$

From equations (3.14) and (3.15), we can deduce the resistance at the output of the PV array (R_{pv}):

$$R_{pv} = R_{load}(1-\alpha)^2 \qquad [3.16]$$

Under optimal conditions and for a given load, the optimum resistance of the PV generator is calculated by the following equation:

$$R_{opt} = R_{load}(1-\alpha_{opt})^2 \qquad [3.17]$$

The DC / AC converter (inverter)

Inverters are devices which can convert electrical energy of DC form into that of AC. They come in all shapes and sizes, from low power functions such as powering a car radio to that of backing up a building in case of power outage. Inverters can come in many different varieties, differing in price, power, efficiency and purpose. The purpose of a DC/AC power inverter is typically to take DC power supplied by a battery, and transform it into an AC power source operating at 50 Hz.

a)- Single phase inverter

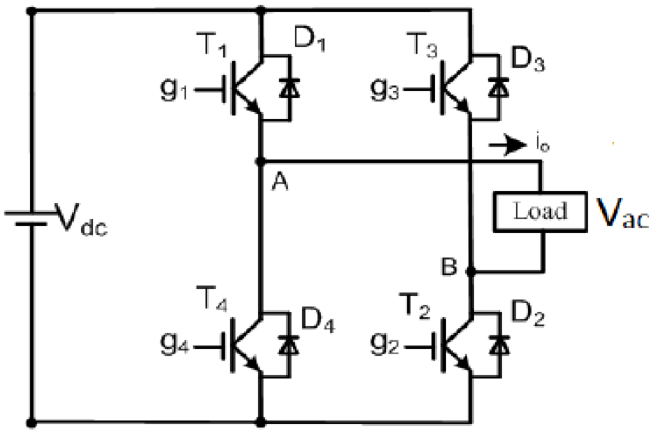


Figure 3.20: The equivalent circuit of a single-phase inverter.

The single-phase voltage source half-bridge inverters, are meant for lower voltage applications and are commonly used in power supplies.[29]. Figure (3.20) shows the circuit schematic of this inverter. Low-order current harmonics get injected back to the source voltage by the operation of the inverter. This means that two large capacitors are needed for filtering purposes in this design.[29] As Figure (3.20) illustrates, only one switch can be on at time in each leg of the inverter. If both switches in a leg were on, at the same time, the DC source will be shorted out.

b)- Three-phase inverter

Three-phase VSI (Voltage Source Inverter) cover both medium and high power range applications.[29] Figure (3.21) shows the circuit schematic for a three-phase VSI. Switches in any of the three legs of the inverter cannot be switched off simultaneously due to this resulting in the voltages being dependent on the respective line current's polarity. States 7 and 8 produce zero AC line voltages, which result in AC line currents freewheeling through either the upper or the lower components. However, the line voltages for states 1 through 6 produce an AC line voltage consisting of the discrete values of V_{in}, 0 or - V_{in}.[4]

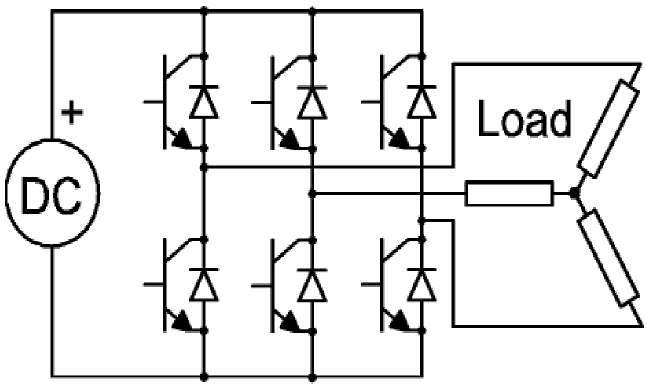


Figure 3.21: The equivalent circuit of a three-phase inverter.

3.7 Security of photovoltaic panels

When designing a photovoltaic system, we must provide an electrical protection for this installation in order to increase its service life, and that by avoiding destructive malfunctions related to the assembly of cells and their function in the event of shades. For this, two types of protection are conventionally used in PV installations:

- **Blocking Diodes**

The diagram below shows a simple setup with two panels charging a battery (for simplicity no controller is shown) with a blocking diode in series with the two panels, which are also wired in series. When the sun shines, as long as the voltage produced by the two panels is greater than that of the battery, charging will take place. However, in the dark, when no voltage is being produced by the panels, the voltage of the battery would cause a current to flow in the opposite direction through the panels, discharging the battery, if it was not for the blocking diode in the circuit. Blocking diodes will be of benefit in any system using solar panels to charge a battery. Blocking diodes are usually included in the construction of solar panels so further blocking diodes are not required[30].

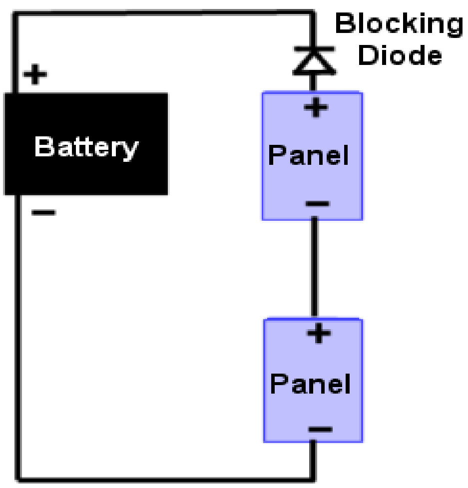


Figure 3.22: Protection of PV panels via blocking diodes.

- **By-Pass Diodes**

Now let's consider what happens if one of the panels in the above diagram is shaded. Not only will that panel not be producing any significant power, but it will also have a high resistance, blocking the flow of power produced by the unshaded panel. This is where by-pass diodes come into play as shown in the diagram below. Now, if one panel is shaded, the current produced by the unshaded panel can flow through a by-pass diode to avoid the high resistance of the shaded panel.

By-pass diodes will not be of use unless panels are connected in series to produce a higher voltage. They are most likely to be of benefit where an MPPT Controller or String Inverter involves panels connected in series to produce voltages well above that items minimum input voltage[30].

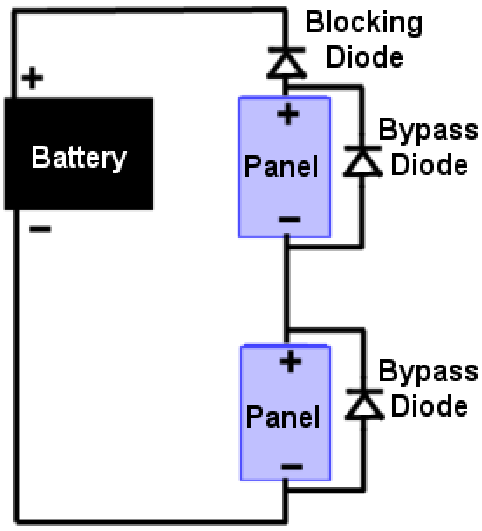


Figure 3.23: Protection of PV panels via by-pass diodes.

3.8 The maximum power point tracking (MPPT)

3.8.1 Introduction

The power delivered by a PV system of one or more photovoltaic cells is dependent on the irradiance, temperature, and the current drawn from the cells as well as the connected load. Maximum Power Point Tracking (MPPT) is used to obtain the maximum power from these systems. Such applications as putting power on the grid, charging batteries, or powering an electric motor benefit from MPPT. In these applications, the load can demand more power than the PV system can deliver. In this case, a power conversion system is used to maximize the power from the PV system.

There are many different approaches to maximizing the power from a PV system, this range from using simple voltage relationships to more complex multiple sample based analysis. Depending on the end application and the dynamics of the irradiance, the power conversion engineer needs to evaluate the various options.

3.8.2 Operating principle of MPPT

The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point). That is to say:

MPPT checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get maximum current into battery. It can also supply power to a DC load, which is connected directly to the battery.

- Cold weather, cloudy or hazy days: Normally, PV module works better at cold temperatures and MPPT is utilized to extract maximum power available from them.
- When battery is deeply discharged: MPPT can extract more current and charge the battery if the state of charge in the battery is lowers.

3.8.3 Perturb and Observe algorithm

The P&O algorithm is also called “hill-climbing”, while both names refer to the same algorithm depending on how it is implemented. Hill-climbing consist of a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, perturb the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both name refer to the same technique. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what is the next perturbation should be on the left of the MPP incrementing the voltage increases the power whereas on the right decrementing the voltage increases the power.

If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented [31]. The process is repeated until the MPP is reached. Then the operating point oscillates around the MPP. The flowchart of P& O algorithm is shown in Figure 3.24.

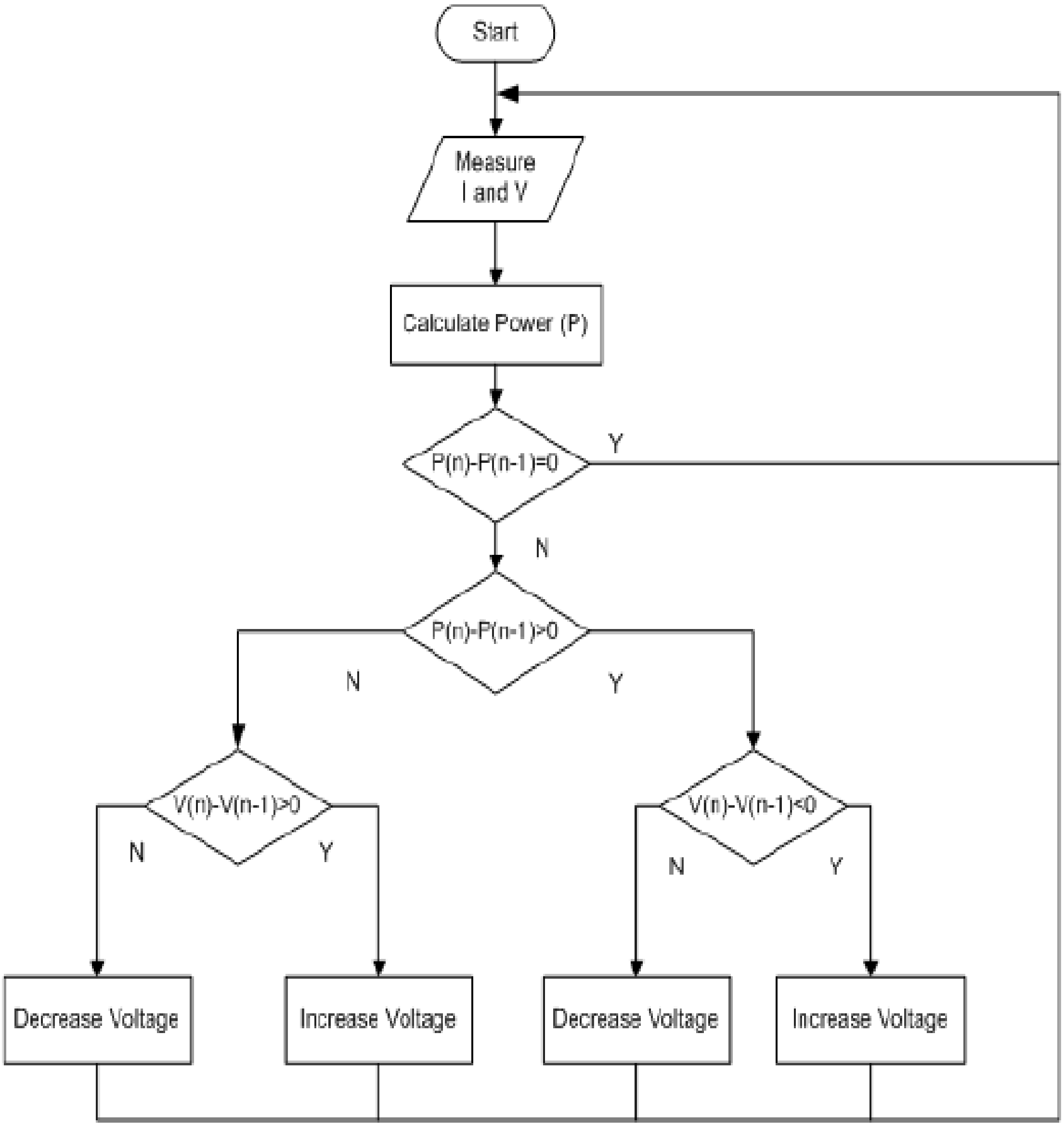


Figure 3.24: Perturb & Observe flowchart.

3.9 Conclusion

In this chapter, we have presented the main features and components of a PV generator. We were able to show the implications on the conversion efficiency of solar energy into electrical energy of a PV installation. We have noticed that the yield of this conversion is still very low, often less than 15%. This performance has led us to search for a way to get most of the electrical power available at the PV generator. We also showed how we could optimize the power provided by the PVG through an adaptation stage with MPPT.

4.1 Introduction

Nowadays, the demand for water is becoming more and more important, especially in rural areas and isolated sites where access to conventional energy is difficult or practically impossible. This phenomenon has led to a growing interest in the use of photovoltaic generators as a new source of energy. The realization of an independent, reliable and efficient photovoltaic pumping system provides a practical and economical solution to the problem of water shortage, particularly in desert regions. Indeed, a photovoltaic is easy to install, with acceptable autonomy and excellent service reliability. This chapter details more specifically with the theoretical elements that allow us to determine the sizing and dimensions of pumping stations.

4.2. Hydraulic Terms And Concepts

The pumping stations consist of one or more pumps that suck up volumes of water and push them back under a certain pressure in the pipes of the network. The parameters needed to size the solar pump are the operating flow and the height at which the pump will pump back.

4.2.1. The Flow Rate (Q)

Water travels downhill from points of higher energy to points of lower energy in a specified time. The flow rate provided by a pump is the amount of water it delivers during a given time interval. In solar pumping, the flow is often expressed in m^3 per day.

4.2.2. Total Dynamic Head (TDH)

Total Dynamic Head is the amount of pressure differential created by a pump as it operates. The TDH developed by a pump is the difference between the suction pressure and discharge pressure of the pump while in operation. The TDH is calculated as such [32]:

$$TDH = V_R + \Delta H \qquad [4.1]$$

With:

V_R: Elevation head - is the vertical distance which the water must be pumped. It is the elevation difference in feet between the pumping level in the well and the pressure tank.

ΔH: Friction head loss is the loss of pressure due to the flow of water through pipe and fittings.

Determine diameter, length, and type of pipe material through which the water flows from the well to the pressure tank.

4.3. Photovoltaic Water-Pumping Technology

To pump water with a photovoltaic system, two techniques are possible:
in the first technique, solar energy is consumed in "real time", we are talking then of a "pumping over the sun". This solution requires storage of water in a reservoir (the pumped water during the day is stored for later use in the evening, for example).
The second method is to use energy storage, this time via batteries. Energy stored during the day can be used later to pump water.

4.3.1. Water Pumping Over The Sun

As we will see, the method of pumping "over the sun" allows to have a simpler, more reliable and less expensive photovoltaic system than a system which uses batteries to store energy first. In this first technique, it is the water itself which is pumped and stored when there is enough sunlight. The water is stored in a tank at a height above soil so that it is, if necessary afterwards, distributed by gravity. It must be pointed out here that the water reservoir can often be built locally. In addition, it does not require a complex maintenance and can be repaired easily. The water's storage capacity may vary from one to several days depending on the model and consumption.

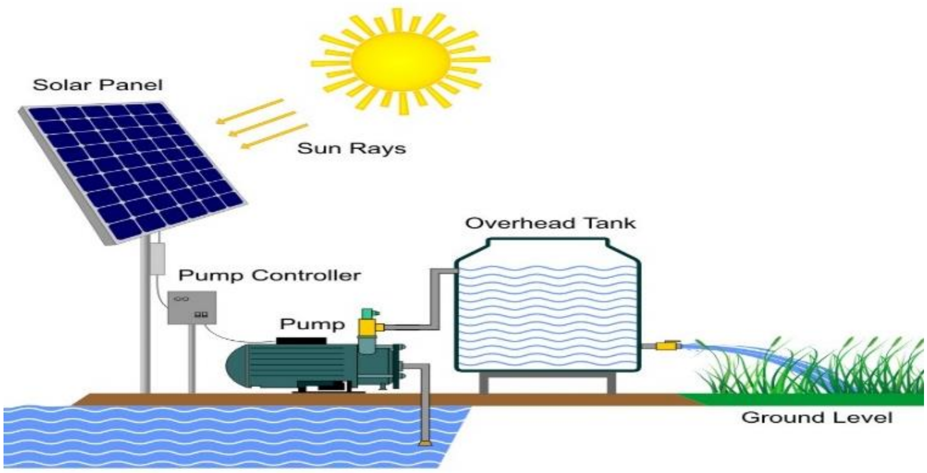


Figure 4.1: Over-the-Sun Water Pumping.

4.3.2. Water Pumping With Batteries

The method of pumping water using energy stored on batteries may have the advantage of guaranteeing a stable supply of power to the equipment (the possibility of pumping when the sun is absent). Energy is stored to be used for other future needs as well. The major inconvenience in this technique is that it has several components that negatively influence the reliability and overall cost of the system. For example, the batteries are fragile and are often the first elements that need to be changed. In addition, the controllers used to regulate the charge and discharge of batteries age quickly and may be unreliable. Batteries also introduce a degree of loss in efficiency about 20% to 30% of energy production.

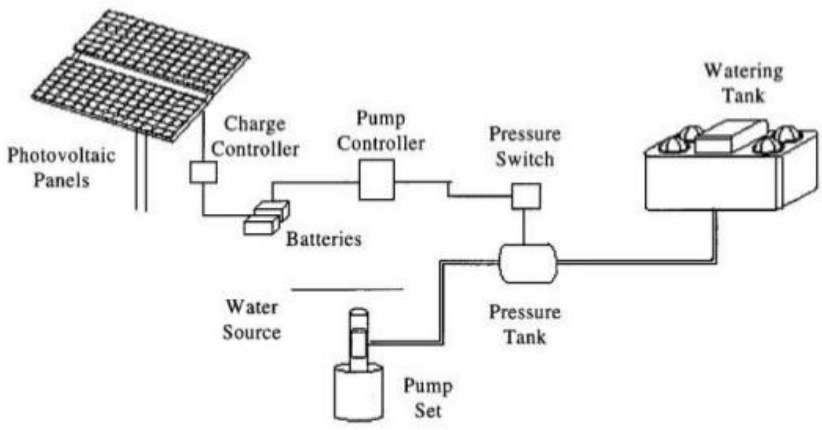


Figure 4.2: Water Pumping with Batteries.

4.4. The Components of a PV Pumping System

A solar pumping system usually consists of [32]:

- The photovoltaic generator (PVG).
- The electric pump group.
- Command and control electronics.
- The storage unit.

4.4.1. The Photovoltaic Generator (PVG)

PV panels are made up of a series of solar cells. Each solar cell has two or more specially prepared layers of semiconductor material that produce DC electricity when exposed to sunlight. A single, typical solar cell can generate approximately 3 watts of energy in full sunlight. To obtain higher powers, it is necessary to associate in series and in parallel several modules. PV generators are grouped in a field of several modules (a few hundred).

4.4.2. The Electric Pump Set

1) The Pumps

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. It is a device for aspirating and repressing. There are two large types of pumps: centrifugal pumps and positive displacement pumps. These last are suitable for raising low flow rates at high pressures.

1.2) Centrifugal Pumps

Centrifugal water pumps use centrifugal force to pressurize and move water from the inlet to the outlet. A rotating set of vanes (called an 'impeller') is spun by the pump shaft. As water is forced through the impeller, rotational energy is transferred from the impeller to the water, which gains velocity and pressure through the centrifugal force applied and is flung from the impeller. The volute (a spiral-shaped case) funnels the now-pressurized water to the outlet. Image below shows clockwise rotation as viewed from the motor mound.

Figure 4.3: Centrifugal Pump.

1.3) The Advantages Of Centrifugal Pump

- They do not require any valves, or many moving parts. This makes them easy to produce with many different materials. It also allows them to move at high speeds with minimal maintenance.
- Their output is very steady and consistent. Most of all, they are very small compared to other types of pumps that create the same output.
- They can deal with large volumes of water.

1.4) The Volumetric Pump (Positive Displacement Pump)

A positive displacement pump makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe. Some positive displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant through each cycle of operation.

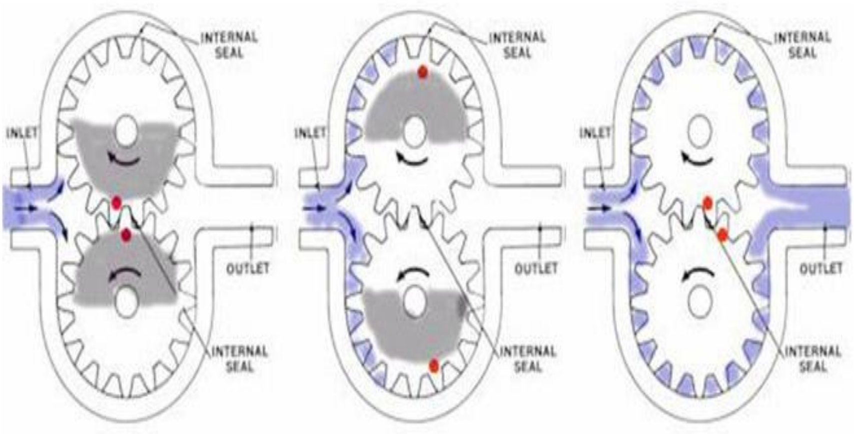


Figure 4.4: Volumetric Pump.

1.5) The Advantages Of The Volumetric Pump

- PD pumps can move fluids that are not only higher in viscosity, but also those that range from liquefied gases to water-like fluids (sliding vane) and medium to very-viscous fluids (eccentric disc and sliding vane).
- PD technologies have a comparable history of operating successful in chemical plants**.**
- Initial costs can be similar to those of centrifugal pumps when all equipment, accessories and controllers are included, with oftentimes a lower total cost of ownership over the life of the pump**.**

2) Electric Motors

An electric motor is an electromechanical device for converting electrical energy into mechanical energy. Most electrical machines work thanks to magnetism; there are two types of motors: DC and AC [33].

2.1) Direct Current Motors

A DC motor is any of a class of rotary electrical machines that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic; to periodically change the direction of current flow in part of the motor.

2.1.1) Brushed DC Motor

A brushed DC motor is an internally commutated electric motor designed to be run from a direct current power source. Brushed motors were the first commercially important application of electric power to driving mechanical energy, and DC distribution systems were used for more than 100 years to operate motors in commercial and industrial buildings. Brushed DC motors can be varied in speed by changing the operating voltage or the strength of the magnetic field. Depending on the connections of the field to the power supply, the speed and torque characteristics of a brushed motor can be altered to provide steady speed or speed inversely proportional to the mechanical load.

2.1.2) Brushless DC Motor

Brushless DC electric motor (BLDC motors, BL motors) also known as electronically commutated motors (ECMs, EC motors), or synchronous DC motors, are synchronous motors powered by DC electricity via an inverter or switching power supply which produces an AC electric current to drive each phase of the motor via a closed loop controller. The controller provides pulses of current to the motor windings that control the speed and torque of the motor.

2.2) Alternating Current Motors

An AC motor is an electric motor driven by an alternating current (AC). The AC motor commonly consists of two basic parts, an outside stator having coils supplied with alternating current to produce a rotating magnetic field, and an inside rotor attached to the output shaft producing a second rotating magnetic field. The rotor magnetic field may be produced by permanent magnets, reluctance saliency, or DC or AC electrical windings.

Less common, AC linear motors operate on similar principles as rotating motors but have their stationary and moving parts arranged in a straight-line configuration, producing linear motion instead of rotation.

2.2.1) Single Phase Asynchronous Motors

The single-phase asynchronous motor is an electric motor that is operated using single-phase current. The rotor winding is of a squirrel-cage type and the stator winding comprises a main and an auxiliary winding whose magnetic axes are electrically offset by one half of a pole pitch (90°). The auxiliary winding is used to generate a rotary field component in the air gap of the machine so that the machine can self-start.

2.2.2) Three-phase Asynchronous Motors

Three-phase asynchronous motors can be considered among the most reliable electrical machines: they carry out their function for many years with reduced maintenance and adapt themselves to different performances according to the requirements of both production as well as service applications. And with the presence of inverters, we are able to use this type of motors in solar pumping.

3) Types of Electro Pump Set

3.1) Surface Pumps

Surface pumps are designed to pump water from surface sources like springs, ponds, tanks, or shallow wells. Most of our surface pumps are either diaphragm pumps or rotary vane pumps and can run solar-direct for simple and inexpensive operation. These pumps can be:

- ✓ With horizontal axis.

Figure 4.5: Surface Pumps with Horizontal Axis.

- ✓ With vertical axis.

Figure 4.6: Surface Pumps with Vertical Axis.

3.2) Submersible Pumps

Submersible pumps are a type of centrifugal pumps designed to function with the pump and motor submerged in the fluid to be pumped. A submersible pump (or sub pump, electric submersible pump (ESP)) is a device which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of this type of pump is that it prevents pump cavitation, a problem associated with a high elevation difference between pump and the fluid surface**.** We find different types of ESP such as:

- ✓ Submersible drilling pumps**.**

Figure 4.7: Submersible Drilling Pumps.

✓ Submersible pumps in dry pit.

Figure 4.8: Submersible Pumps in Dry Pit.

4.4.3 Command and Control Electronics

❖ The DC / DC converter (chopper):

A chopper is a device that converts fixed DC input to a variable DC output voltage directly. Essentially, a chopper is an electronic switch that is used to interrupt one signal under the control of another. In other words, it extracts at each moment the maximum power available from the PV generator and transfers it to the load (pump powered by DC motor),

❖ The DC / AC converter (inverter):

The main function of the inverter is to transform the DC current, produced by the solar panels in a three-phase alternating current to operate the pump motor unit. The inverter obviously operates with a PWM signal generation circuit controlled by a control and protection circuit. The DC / AC converter ensures optimal power transfer from the solar generator to the pump motor unit.

4.4.4 The Storage Unit

Energy storage can be done in two ways: the storage of electrical energy or the storage of water. The latter method is often used because it is more convenient to store water in tanks that storing electrical energy into expensive and fragile batteries. Also, the battery storage system generates additional cost, like: battery maintenance problems and the obligation to replace it after 3 to 5 years of use. The reservoir can often be built locally and the storage capacity can vary from one to several days. This tank does not require complex maintenance and is easy to repair.

4.5 Sizing and Determining of Photovoltaic Water Pumping System Parameters

The different steps for sizing a pumping system are:

- Calculation of Water supply needed.
- Calculation of the hydraulic energy needed.
- Determination of available solar energy.
- Size of photovoltaic generator.
- Sizing of the pump.

4.5.1 Calculation of Water Supply Needed

The determination of the water needs for the consumption of a given population depends essentially on its way of life, its environment and the climatic conditions of each region. The water requirements for irrigation depend on the type of crop, meteorological factors such as temperature, humidity, wind speed, soil and the method of irrigation. However, it is important to rely on local practice and experience. For a tropical region, water requirements can be defined using the values in the following table [34]:

Humans
Per person 5 to 10 liters/day minimum Normal living conditions 30 liters/day
Animals
Sheep and goats 5 liters/day
Horse 40 liters/day
Donkey 20 liters/day
Camel 20 liters/day
Irrigation
Market farming 60m^3/hectare/day
Rice 100 m^3/hectare/day
Sugar cane 65 m^3/hectare/day
Cotton 55 m^3/hectare/day

Table 4.1: Estimation of Water Requirements by Humans, Animals and Irrigation.

4.5.2 Calculation of the Hydraulic Energy Needed

Once the necessary water volume requirements for each month of the year and the characteristics of the well are defined, we can calculate the average daily and monthly hydraulic energy required from the relationship [35]:

$$E_h = C_h . Q_a . THD \qquad [4.2]$$

$$C_h = g . \rho_a / 3600$$

Where:

g: is acceleration of gravity [9.81 m.s^{-2}];

E_h: is the needed hydraulic energy [Kwh/ day];

C_h: is a hydraulic constant [Kg.h.s/m^2];

ρ_a: is water density [1000 kg/m^3];

Q_a: is daily water needs [m^3/day];

THD: is the total dynamic head [m];

The tank capacity is determined by the daily water needs and the autonomy of the system.

4.5.3 Calculation of the Daily Electrical Energy Required

The energy needed to lift a certain amount of water over a certain height given for one day is calculated using the following equation [36]:

$$E_e = E_h / (\eta_{MP} \times \eta_{Ond}) \qquad [4.3]$$

Where:

E_e: Electrical energy [Kwh/ day]

η_{MP} : The efficiency of the pump set, usually between 30% and 60%.

η_{Ond} : The efficiency of the inverter.

4.5.4 Determination of Available Solar Energy

The sizing method used is based on the calculations of the monthly average of/and daily values of the solar irradiation available at the inclination β of the photovoltaic modules (PV). It must be done in such a way as to optimize the conversion of solar energy into electricity. The methods of calculation have been explained in the second chapter.

4.5.5 Size of Photovoltaic Generator

Two methods are used for sizing photovoltaic pumping systems: an analytical method and a graphical method. These methods make it possible to size a photovoltaic pumping installation to satisfy the water needs of a well-defined consumption.

4.5.5.1 Analytical Method

Once the daily volume V [m^3 / day], total dynamic head TDH and the average daily irradiation incident on the generator plane are known, the corresponding nominal power of the photovoltaic generator is calculated by the following expression [37]:
The power supplied by the PV generator under the standard conditions of measurement SCM (illumination of [1000w / m^2] and the temperature 25 °C).

$$P_{pv} = \eta_g \times A_{pv} \times G_t \qquad [4.4]$$

Where:

P_{pv}: The hourly output of the PV generator under SCM [w].
η_g: Represents the PV generator efficiency under the reference temperature of 25 °C.
A_{pv}: The active surface of the generator [m^2].
G_t: illumination rate under SCM.

Daily electrical energy is given by the equation [38]:

$$E_e = \eta_{PV} \times A_{pv} \times G_d(\beta) \qquad [4.5]$$

Where:

η_{pv}: The average daily efficiency of the generator under operating conditions.
$G_d(\beta)$: The average daily irradiation incident on the module surface by the inclination β [kwh/m^2/day].

The efficiency η_{pv} is calculated by the following formula [39]:

$$\eta_{pv} = F_m \cdot [1 - \gamma(T_c - T_{cref})] \qquad [4.6]$$

Where:

F_m : is the power conditioning efficiency which is equal to 1 if a perfect maximum power tracker (MPPT) is used.

γ: is the generator efficiency temperature coefficient, it is assumed to be a constant and for silicon cells the range of γ is 0.004–0.006 per (°C).

T_{cref} : is the reference cell temperature (°C).

T_c : The cell temperature (°C) and can be calculated as follows [40]:

$$T_c = T_a + \left(\frac{NOCT-20}{800}\right) . G_d \qquad [4.7]$$

Where:

T_a: is the ambient temperature (°C).

NOCT: is the nominal cell operating temperature (°C).

β , NOCT and A_{pv}, are parameters that depend upon the type of module used. The data are obtained from the PV module manufacturers.

Calculation of Peak Power, in Watts, that the field must obtain, by substituting equations [4.3], [4.5] and [4.6] in [4.4], we obtain the peak power of the generator:

$$P_{pv} = \frac{G}{F_m[1-\gamma(T_c-T_{cref})]G_d(\beta)} . \frac{E_h}{\eta_{MP}.\eta_{Ond}} \qquad [4.8]$$

4.5.5.2 Graphical Method

The calculation of the power of the photovoltaic generator can be done in two ways: either by analytical expressions like the one given above, or by using the pump performance charts provided by the manufacturer. To summarize the performance of different pumps according to conditions of their use[41].

The charts:

These are direct reading graphs that facilitate numerical calculations. Graphics are used to spontaneously determine results that are obtained by calculations in a test system.

Equipment manufacturers develop such diagrams based on data calculated or measured. This type of graphs gives the possible configuration of a pump. For example, Figure 4.5 shows the characteristics of the electric pump SP14A-3 given by the manufacturer GRANDFOS.

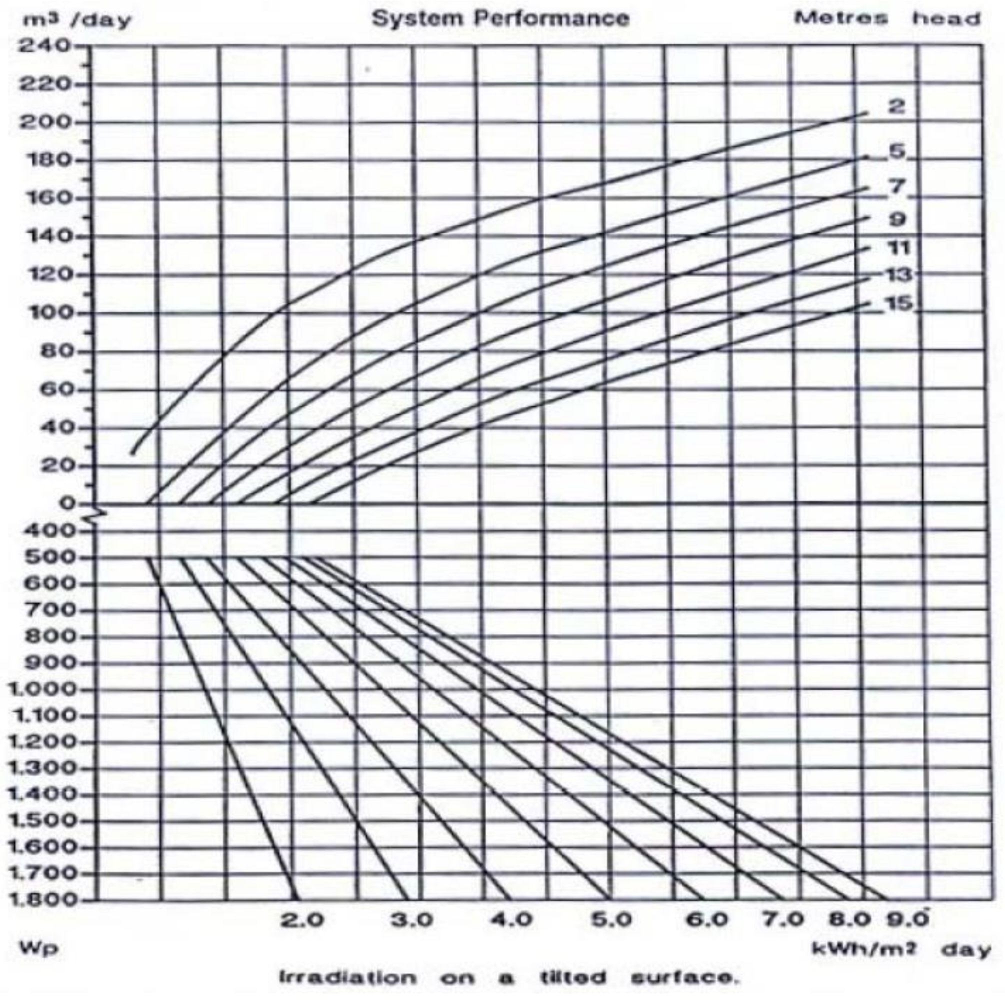


Figure 4.9: Typical Curve of the Performance of a Pump under Conditions of Use.

4.5.6 Sizing of the Pump

The choice of pump is based on two factors:

- Total Dynamic Head TDH
- The hourly flow rate Q_h

$$Q_h = \frac{Q[m^3/day]}{h} \quad [4.9]$$

h: is the maximum number of hours of sunshine at [1000 w/m^2].

4.7 Dimensioning and Sizing of Solar Pumping Stations

To define the power of used for the operation of the pump provided by the solar panels, the minimum data are:

- ❖ The geographical location to determine global solar irradiation.
- ❖ The flow rate to determine daily water requirements during the period of need.
- ❖ The total dynamic head to measure the static level, the height of the tank and the pressure drops due to the piping.

We proceed as follows:

1- Define the total monthly and daily irradiation in [wh/m^2/day] in relation to the latitude of the work area.

2- Select a pump based on flow rate and total dynamic head values.

3- Select the inverter suitable for the pump (voltage and power).

4- Determine the peak power necessary to operate the pump by the analytical or graphical method.

5- Choose the type of solar panel (defined by their nominal power).

6- Determine the number of PV panels.

7- Check the nominal voltage for the inverter to operate (according to the panels).

8- Determine the number of serial / parallel panels (the connection form).

4.8 Conclusion

In this chapter, we presented the results of a study that led to the sizing of a photovoltaic pumping system. We discussed the various elements of this photovoltaic system. Two PV pumping techniques were tackled: over the sun pumping and battery pumping. We have shown the benefits of pumping over the sun. We have also been able to conclude that the most common photovoltaic pumping systems, according to the current state of the art, consist of a centrifugal pump of a three-phase induction motor. The motor is powered by a photovoltaic generator without batteries, via a three-phase inverter with variable frequency designed specifically for this application. We have also given the important and necessary definitions for the understanding of the practical study to be presented in the next chapter.

5.1 Introduction

In the previous part of this work, we have detailed the study and the sizing of the photovoltaic pumping system. And then, we applied the techniques studied on a real site to validate the chosen method and draw a conclusion from the obtained results.
For this practical study, we have chosen the wilaya of El Oued. El Oued is a city in the south-east of Algeria. It is characterized by a Saharan climate, with energy of sunshine more than 5 kWh / m^2 per day and significant water resources underground [43].

5.2 Geographic Setting

The region of El Oued is located in the Algerian Sahara, it became a Wilaya in 1984 and covers a total space of 77 km^2. El Oued is located about 700 km south-east of Algiers (Figure 5.1) and 350 km west of Gabes (Tunisia)[16]. It is boarded by:

- The wilayas of Biskra, Khenchela and Tebessa to the north.
- Tunisia to the east.
- The wilayas of Biskra, Djelfa and Ouargla to the west.
- The Wilaya of Ouargla to the south.

The study zone that we selected is the Souf Valley at 7 ° E and 33 ° 5N.

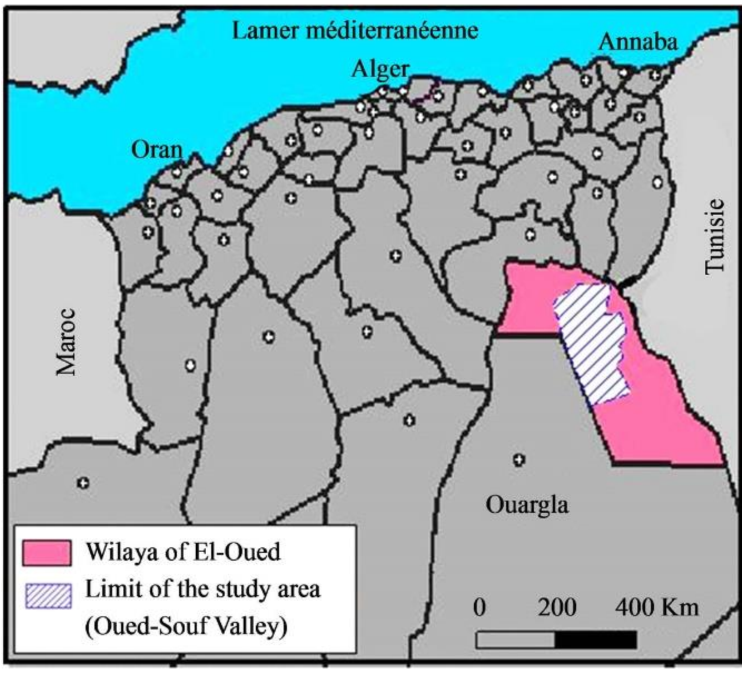


Figure 5.1: Geographical Location of El Oued.

5.3 Physical Environment

5.3.1 Climate Settings of El Oued Region

The Algerian climate is characterized by its great variability in rainfall and annual temperatures, this variation is mainly due to the topographic irregularities and the opposite influences of the Mediterranean and the Sahara.

To analyze the climatic parameters, the weather station of the ONM (National Meteorological Office) of Guemar airport, which represents the only existing station in the study zone, was selected. These data are taken through a period of 32 years (1976-2008). The geographical characteristics of this station are [16]:

- Code A.N.R.H: 13 04 14
- Altitude: 64m
- Longitude: 06 ° 47'E
- Latitude: 33 ° 30 '
- Albedo (Convention factor): 0.2

5.3.1.1 Pluviometer (Rain gauge)

Precipitation is very low throughout the province, but somewhat more rain does fall in the north, particularly during the winter and adjacent months. The average monthly inter-annual precipitation estimates over a 32-year observation period (1976-2008) are summarized in the following table:

Month	JA	FE	MR	AP	MY	JU	JUL	AU	SE	OC	NO	DE	Total
P(mm)	13.78	6.97	7.72	6.8	4.57	1.38	0.51	1.96	5.04	7.48	9.03	6.8	72.04

Table 5.1: The Monthly Average of Inter-annual Precipitation Estimates

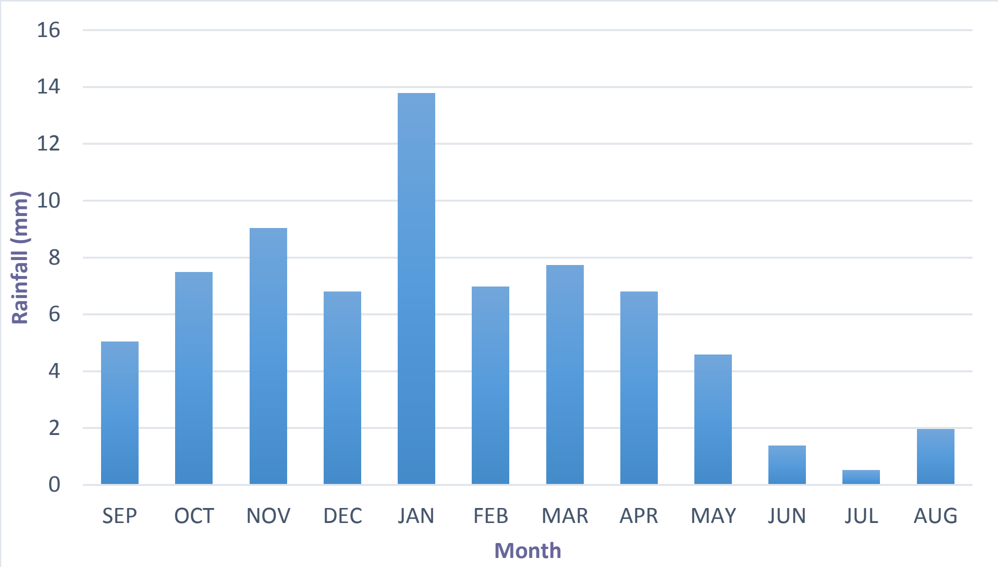


Figure 5.2: Monthly Rainfall Distribution at El Oued.

5.3.1.2 Temperature

Average temperatures in El Oued vary drastically. Considering humidity, temperatures feel very agreeable most of the year, but hot in the summer and cold in the winter with a very low chance of rain or snow throughout the year. EL Oued Province experiences a hot desert climate. Winters are mild, with average temperatures around 11 °C in January, but summers are hot with average temperatures around 32 °C, average maxima around 40 °C and the hottest days approaching 50 °C. The region is characterized by temperature differences, both at the diurnal and monthly scale, Table 5.2 below shows the average monthly distribution of temperature:

Month	JA	FE	MR	AP	MY	JU	JUL	AU	SE	OC	NO	DE	AVG
T (°C)	10.71	13.16	17.16	20.76	26.33	31.03	34.18	33.89	29.22	22.85	16.2	11.33	21.51

Table 5.2: The Monthly Average of Temperature in El Oued.

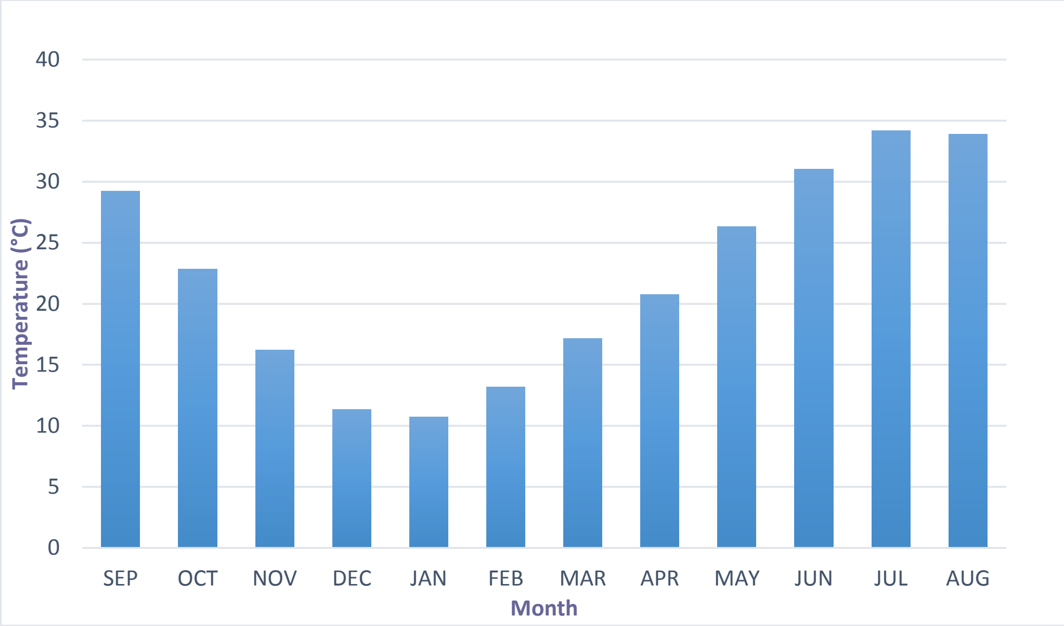


Figure 5.3: Monthly Average of Temperature Distribution in El Oued.

5.3.1.3 Evapotranspiration

Evapotranspiration (ET) is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves. Evapotranspiration is an important part of the water cycle. Table 5.3 shows the average monthly distribution of evapotranspiration:

Month	JAV	FEB	MA	APR	MY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
ET (mm)	10.4	16.8	38.5	64.8	126.3	190.1	244.7	255.9	140.98	72.9	28.59	11.6	1171.93

Table 5.3: Monthly Average of Evapotranspiration in El Oued.

5.3.1.4 Wind Speed

Wind in El Oued is usually extremely calm and very frequent. The windiest month is June, followed by April and May. We must also talk about the sand winds that have their favorite seasons between February and April (during the spring). But, real storms are very rare. The average wind speed for the period 1976-2008 is shown in Table 5.4:

Month	JAV	FEB	MR	APR	MY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
Wind speed (m /S)	2,25	2,64	3,37	4,12	4,29	3,79	3,58	3,17	3,24	2,42	2,40	2,54	3.15

Table 5.4: Monthly wind speed distribution at El Oued**.**

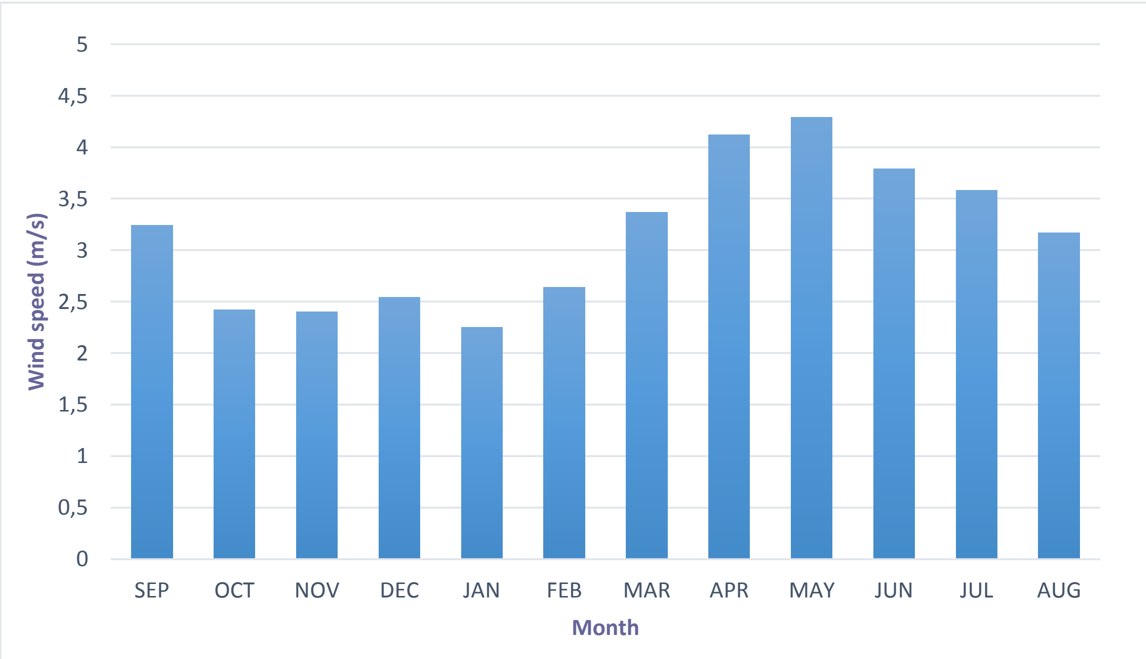


Figure 5.4: Monthly Wind Speed Distribution at El Oued**.**

5.3.1.5 Solar Insolation

Insolation is the solar radiation that reaches the earth's surface. It is measured by the amount of solar energy received per square centimeter per minute. Insolation affects temperature. The more the insolation, the higher the temperature. It is determined by direct measurements. From El Oued weather station (Guemar Airport), a series of data have been obtained from 1976 to 2008:

Month	JAV	FEB	MAR	APR	MY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
Inso(h)	214	231	251	274	279	335	357	330	278	283	249	209	282.5

Table 5.5: Monthly Average of Insolation in El Oued.

The average annual solar radiation duration is 282 hours; the maximum is recorded in July with 351.9 hours; and the minimum appears in December with 228 hours.

The climatic analysis of the experiment zone revealed the following results:

- The monthly inter-annual precipitation is of the degree of 72.04 mm.
- The monthly average temperature is about 21.51 ° C.
- The region of El Oued has a hyper arid climate.
- The most humid month is December (66.65% inter-annual average) and with low solar radiation (228 hours average).
- The driest month is July, with low humidity (average 31.37%).
- The brightness of the sun is very high (average 282 hours) which reflects an excessive evaporative power.

5.3.2 Availability of Water Resources

Despite the absence of surface water resources, El Oued has a very important hydraulic reserve, presented in the form of three underground aquifers:

1- The CI Aquifer

The CI aquifer is composed by fluvio-deltaic continental deposits produced intercalations of detrital levels with of clay silts and frequent gypsum layers. The CI aquifer is located within a succession of clastic sediment of Mesozoic age, the thickness and lithology of which vary laterally. The aquifer is continuous from north to south from the Saharan Atlas to the Tassilis of the Hoggar (Algeria) and west to east from western Algeria to the Libyan Desert through southern Tunisia [44]. It can be found at depths of 800-2,500 m with a thickness of around300-1,200 m. The groundwater of the CI is mainly paleo ground water which dates back to the Pleistocene and early Holocene under a cooler and humid climate regime. The CI has its recharge source in the Algerian and Tunisian Atlas Mountains (270 mm^3/year). It is mainly confined and discharges in the Chotts (Fejej, Djerid, El Gharssa, GaratDouza and El Guettar) of Tunisia and in the Gabes gulf. Recent recharge is observed at the periphery of the Sahara basin. The water is geothermal with temperatures between 45 and 70˚C.

1.1- CI 1st Layer (The Albian)

The Albian is characterized by a massive return of terrigenous sedimentation. This floor includes the mass of sands and clays between the bar and the underlying clay attributed to the Cenomanian. The Albian sandstone is formed from fine sandstone with some carbonate intercalations [45]. Towards the edges of the basin (Tinrhert and Tademait) sediments become coarser.

1.2- CI 2nd Layer (The Aptian)

It is represented in most of the Lower Sahara, with an average of 20 to 30 m, of dolomites alternating with beds of anhydrite, clays and lignite (lagoon sedimentation). The sandy formations of the Aptian are located on the edges of the basin. On the atlasic borders and towards the south of Tunisia,[45] the Aptian dolomite passes, laterally over a short distance, to orbitlines and algae limestones. Generally, the Aptian is characterized, in the Algerian Sahara, by a very large homogeneity of facies and thickness. It seems to coincide with a slowdown terrigenous inputs and subsidence. It is a period of stability of the platform.

1.3- CI 3rd Layer (The Barremien)

These formations are in the form of fine or coarse sandstone and clays from apparently the south (Hoggar). In Touggourt area, surveys have crossed arkosic sandstones. The carbonate banks are few and confined to the North-East of the Algerian Sahara, in the region of the Daïas and the North Mzab [45]. Overall, Barremian corresponds to sedimentation incontinental fluviatile, lacustrine, over most of the Lower Sahara. Towards the North-East, this sedimentation is mixed, deltaic, with somemarine influences. Sediment thickness varies significantly from one point to the other. It is strong in the subsidiary areas of the Lower Sahara (Laghoua: 800-1100m), weak on the moles (El Abiod, GassiTouil, El Baguel Rh: 100-300m) and the eastern and south-western border areas.

2- The CT Aquifer

The term CT describes a multi-layer aquifer which consists of the Upper Cretaceous formations in the northern Saharan basin, i.e. the Upper and Lower Senonian and sandy formations of the Eocene and the Mio-Pliocene. The CT formations are relatively heterogeneous and are composed of three main aquifer horizons separated by semi-permeable to impermeable strata. The main productive levels are located either in the carbonates levels of the Upper Cenomanian Zebbag Formation and Upper Senonian Abiod Formation, Beglia and Segui Formations in the mining region[45].

2.1-CT1st Layer

It is composed of clay, and sand. This layer is characterized by its relatively salty water. It has an average depth of 70 to 100 meters. Recently, a lot of prospecting have taken place in this layer, especially in the Oued Reig area and this is due to the increase of consumption rates.

2.2-CT2nd Layer

This layer is considered the most exploited one in both Oued Reig and El Oued, where it is specifically used in watering crops. This layer is characterized by its flow rate which can reach to 30 L/s using a pump, and 2 L/s without the need for pumps. It has an average depth of 140 to 280 meters.

2.3-CT3rd Layer

This one is unexploited by both Oued rig and Oued souf due to its salty waters. This layer consists of limestones and crust.

3- The Shallowest Aquifer

The shallowest aquifer, which is an unconfined superficial unit and occurs within the MPQ aquifers. It is constituted by coarse sand with thin levels of red clays and quartz, which indicate clearly a humid paleoclimate and a paleogeography dominated by perennial fluvial system. This aquifer is essentially recharged by the excess of irrigation water coming from CI and CT deep aquifers, in oasis area.

Region	Layer	Flow rate	Temperature	Depth	Residue
El Oued area	The Complexe Terminal CT	25 TO 35 L/S	_	200 TO 300m	2-3 g/L
	The Continental Intercalaire CI	200 L/S	60	1900m	2-3 g/L
Oued Reig area	The Complexe Terminal CT	25 TO 45 L/S	_	250 TO 400 m	6g/L
	The Continental Intercalaire CI	150 TO 180 L/S	60	1800 TO 2100 m	1.8-2 g/L

Table5.6: Groundwater in El Oued Region.

5.4 Agricultural Activity in EL Oued Area

The wilaya of El Oued has witnessed significant changes in many sectors including agriculture, tourism and investment in the industrial field, which enabled it to turn into a major economical pole during these past years. This area is well known for many crops, but mainly palms, potatoes, peanuts and tobacco. And that is due to the availability of arable lands and human resources.

- **Palm cultivation**

  The community of El Oued is well known for this practice across the country. There are many types of dates cultivated there such as: DEGLAT NOUR and GHARES. El Oued is currently considered the top provider of this product with 34727 Ha of land used for farming it.

- **Potatoes cultivation**

  Despite all the difficult conditions in the region, this crop has become a primary product in El Oued region; with massive quantity, enough to provide for the entire country of Algeria.

- **Olive cultivation**

  Olive is considered one of the most promising agricultural products in the area. The olive plantations cover almost 2913 Ha, with revenue of 152.2 tons a year (90.2 tons of olive and 62.2 tons of olive oil).

5.5 Solar Pumping System

We have pointed out in the paragraphs above, that the implantation of palms and olives represents the main agricultural activity of the population of El Oued. The need for water is very strong. In addition, the valley of El Oued is in far south with a quite high solar radiation. For these reasons, we have chosen to study a system of pumping applied to the irrigation of 2.5 hectare of palm and olive trees in this region.

5.5.1 Estimation of Water Requirements

The water requirements for irrigation depend on the type of crop, the irrigation method and weather factors (temperature, humidity, wind speed, evapotranspiration of the soil, and the season of the year in question). However, the practice and experience are still very much needed for a proper evaluation. The water requirements of palms for the region of El Oued are given in the next table:

❖ **Palms Trees**

Season	Winter	Spring	Summer	Fall
Amount of water [L/day]	90	320	400	220

Table 5.7: Average Daily Water Requirements for Palm Trees.

❖ **Olive Trees**

Age [years]	Amount of water [L/day]				
	January and February	March	April to September	October	November and December
1	10	20	30	20	10
2	20	30	40	30	20
3	25	40	50	40	25
4	30	50	60	50	30
5	35	60	70	60	35
6	40	70	80	70	40
More than 6	50	80	100	80	50

Table 5.8: Average Daily Water Requirements for Olive Trees.

5.5.2 Solar Radiation

The table below gives the daily global radiation values calculated on the monthly average for incident rays on an inclined plane with an angle equal to latitude on the El Oued site:

Month	JA	FE	MR	AP	MY	JU	JUL	AU	SE	OC	NO	DE
$\overline{H}$ [wh/m² day]	4437.9	5049.8	5668.1	6449.7	6599.3	7081.9	7329.1	7038.4	6273.3	6018	5094.3	4278.1

Table 5.9: The Values of the Monthly Daily Global Solar Irradiation for a Slope Equal to the Altitude.

Given the specific location of the study area in relation to the movement of the sun, the orientation of the PV modules should be facing south with an inclination equal to the latitude.

5.5.3 Total Dynamic Head

For our pumping station, we have decided to choose a total head of 35 m. This depth corresponds to the CI aquifer which is used to water these crops.

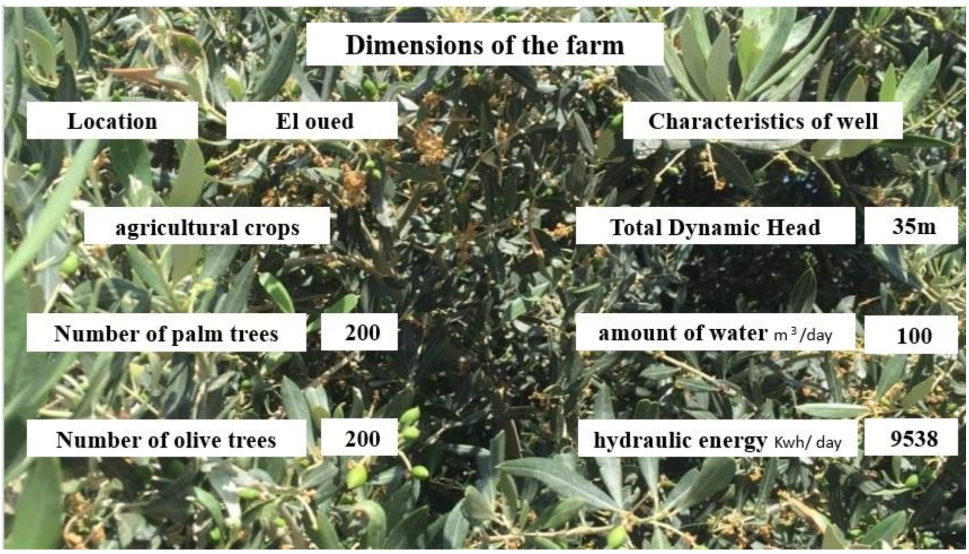


Figure 5.5: The Daily Water Needs in the Study

5.6 Sizing of the Pumping Station

The design of the PV pumping system concerns: the calculation of the peak power of the photovoltaic generator, choosing the adequate pump and proper inverter responding to the tasks required under the reference conditions. This dimensioning takes into consideration the following two conditions [46]:

- ✓ Determination of the daily water requirements during the highest time of need.
- ✓ Choosing the month with the lowest solar irradiation.

To size the pumping station, we follow these steps:

For our example, the maximum daily flow required is $0.4m^3$ / day for Palm and $0.1m^3$ / day for Olive during Summer. And the lowest solar radiation energy in the summer season is 6273.3 wh /m^2.day during September.

To size the pumping station, we follow these steps below:

5.6.1 Choosing the Pump

We choose the pump according to the flow rate and the total head [47]. Hourly rate which is calculated by the following formula:

$$Q_h = \frac{Q[m^3/d]}{h} \qquad [5.1]$$

With:

Q_h: The number of hours of sunshine during a day.

In our case, we have:

Q=100m^3/day

h= 7.74

Therefore, the hourly rate is as follows:

Q_h= 13 m^3 /h.

For our study, the choice of the motor pump used is 140 PR N, FLOATING IMPELLER manufactured from PANELLI.

Motor Features at 2900 RPM			Flow rate [m^3/h]					
Type	η=77% P [kw]	m^3/h	0	4.8	8.4	12	13.8	18
140PR9 N/04	2.2	TDH [m]	64	62	56	45	37	26
140PR9 N/06	3		96	93	84	68	56	39
140PR9 N/08	54		128	124	112	90	74	52
140PR9 N/11	5.5		176	171	154	124	102	72
140PR9 N/15	7.5		240	233	210	169	139	98
140PR9 N/18	9.2		288	279	252	203	167	117
140PR9 N/22	11		352	341	308	284	204	143
140PR9 N/26	13		416	403	364	293	241	169
140PR9 N/30	15		480	465	420	338	378	195

Table 5.10: Electrical Characteristics of a Couple of PANELLI Pumps.

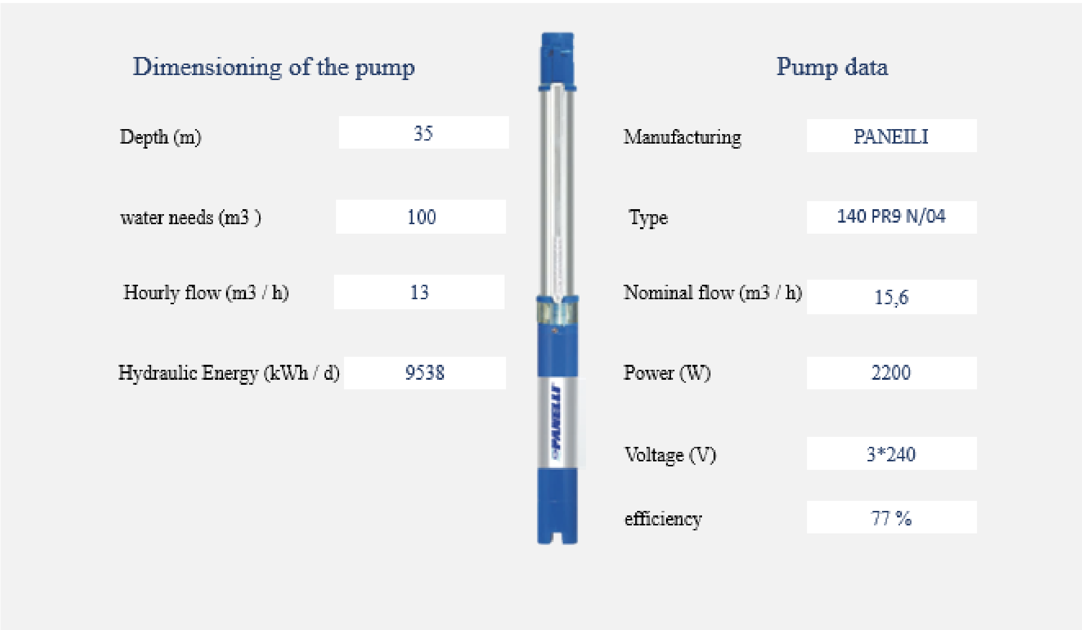


Figure 5.6: Electrical Characteristics of a PANELLI140PR9 N/04.

5.6.2 Reservoir Capacity

One must bear in mind that the pumping technique chosen for our case is called "over the sun". The storage of water is carried out in a tank. The capacity of the latter is calculated to meet the need for water during cloudy days. It varies from one to several days. For our example, the storage capacity is calculated to ensure a day of water supply.

5.6.3 The DC / AC Converter (inverter)

Its main role is to convert the direct current produced by the solar panels into alternating current identical to that of the network. It is therefore essential for the supplied of AC loads. The choice of the inverter depends on the electrical characteristics of the pump supplied (power, voltage).

5.6.4 The Size of PV Generator

Depending on the power required by the motor-pump unit and the daily irradiation incident on the generator panels, the nominal power that the PV generator must supply is calculated by the following expression [47]:

$$P_C = \frac{G}{F_m[1-\gamma(T_c-T_{cref})]G_d(\beta)} \cdot \frac{E_h}{\eta_{MP}.\eta_{Ond}} \quad [5.2]$$

After calculating the power of the PV generator, we determine the number of modules constituting the generator according to the power of the chosen PV module.

5.6.4.1 The Number of Modules

The total number of modules N_M constituting the generator PV is calculated by the following formula:

$$N_M = \frac{P_C}{P_M} \quad [5.3]$$

Where:

P_C: The peak power of the generator.

P_M: The power of the PV module.

a) - The Number of Modules in Series

In order to find the correct voltage for the power supply of a given load by putting several PV modules in series, the number of these modules is calculated by the following expression:

$$N_{MS} = \frac{V_{Ch}}{V_M}$$

With:

V_{Ch}: The nominal voltage of the load (the inverter).

V_M: The nominal voltage of the PV module.

b) - The Number of Modules in Parallel

The use of parallel wiring of modules gives the necessary current intensity for the load. The number of branches is calculated by the following equation:

$$N_{MP} = \frac{N_M}{N_{MS}}$$

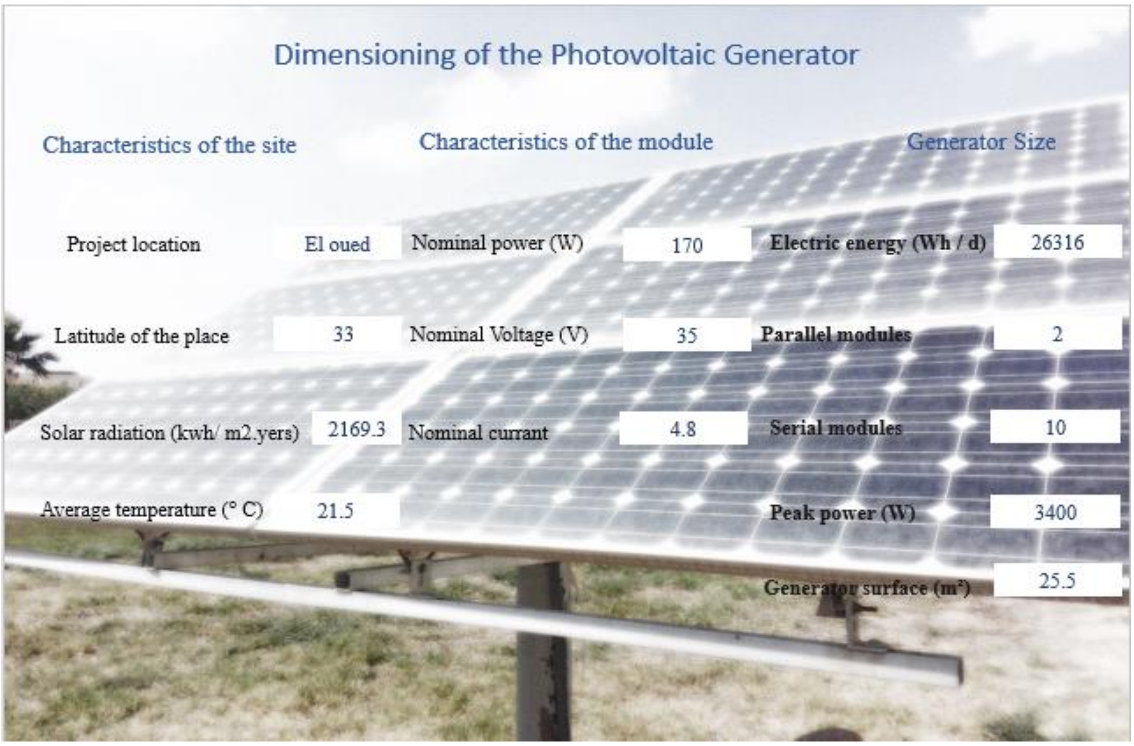


Figure 5.7: Dimensioning of the Photovoltaic Generator.

5.7 Optimization of PV Water Pumping System by MPPT Regulator

In this part, we will present the main characteristic of the photovoltaic system which is pumping water with solar energy by studying the importance of the maximization of the MPPT on the performances of the system (the quantity of the water pumped).

5.7.1 Simulation of PV System Using MPPT with AC Pump Motor

Simulink of the MATLAB environment is chosen for this purpose, because it offers a tool called "SimPowerSystems" that facilitates the modeling of AC motors with its toolbox of the AC machine. The model is later used in the MATLAB simulation. Figure 5.8 shows a block diagram of the pumping system. The latter includes photovoltaic panels connected to a DC-AC converter with MLI command equipped with a MPPT controller and a pump motor with a passive filter.

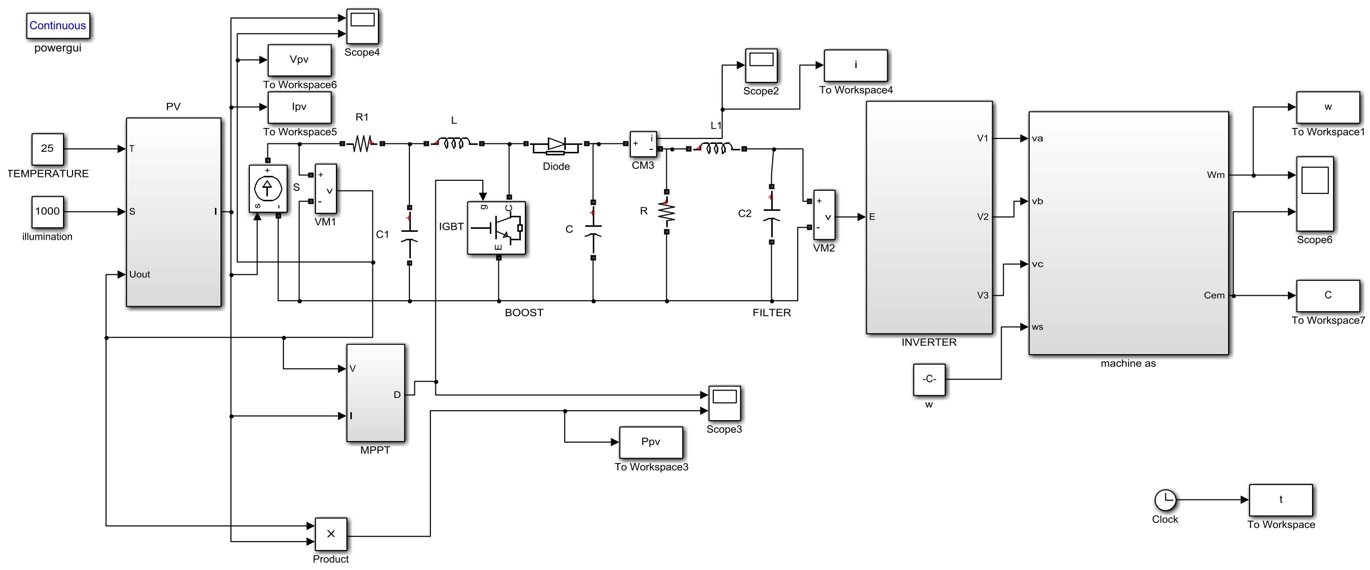


Figure 5.8: The Simulation Block Diagram of PV Panel, Buck Booster, MLI Inverter and Asynchronous Machine.

5.7.2 The analysis of results

After testing the effectiveness of the proposed method, a comparative study was conducted on the two systems: directly coupled or optimized.

We chose different levels of solar insolation to be sure that even in the event of a rapid change in atmospheric conditions such as radiation or temperature, the PV array is able to operate around the optimum value. Figures (5.9 and 5.10) show the characteristics of system operation with and without optimization for 1000 and 400 W / m^2 irradiation.

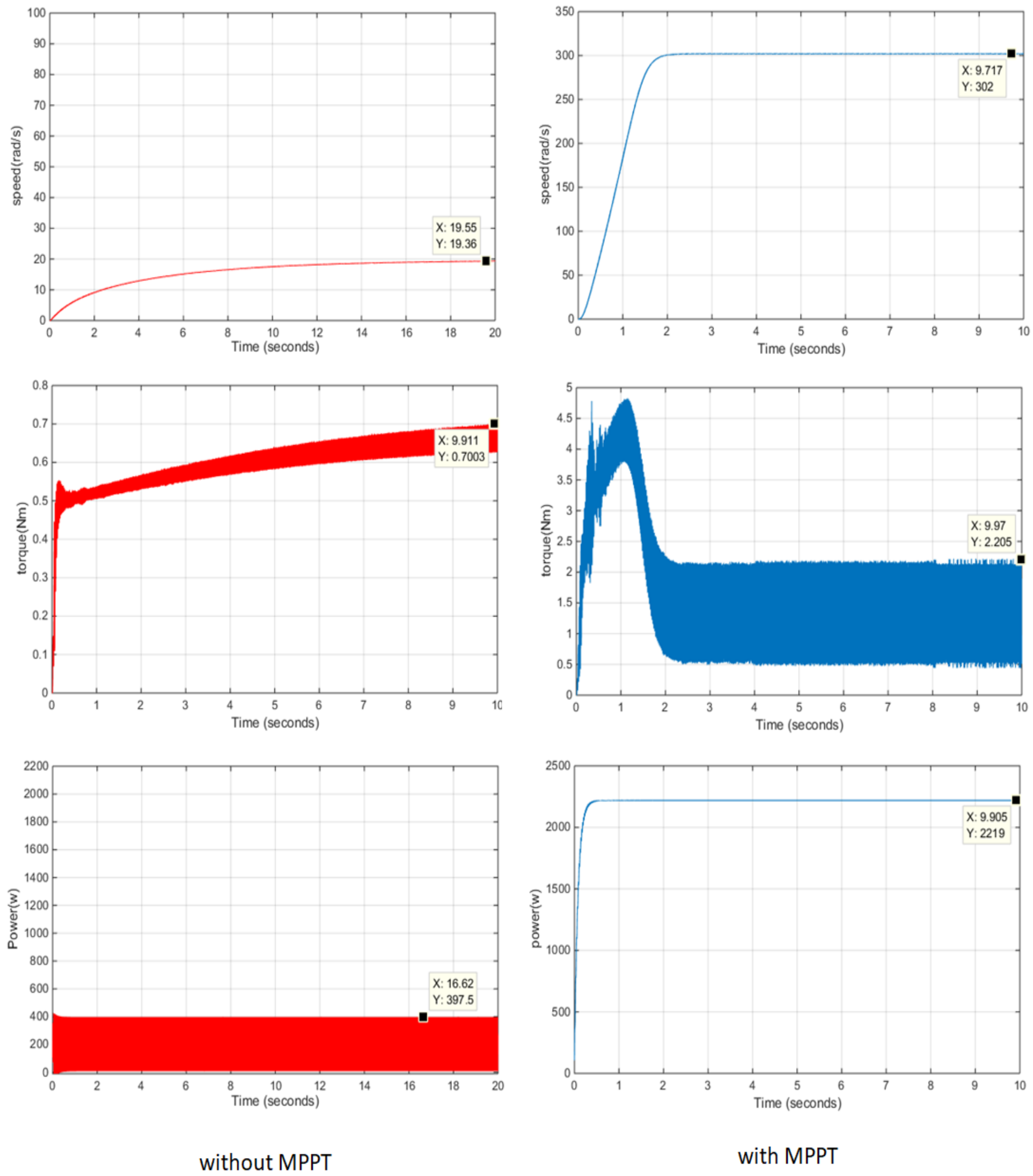


Figure 5.9: Characteristics of the PV Pumping System With and Without MPPT at (1000 W / m^2) and 25 ° C.

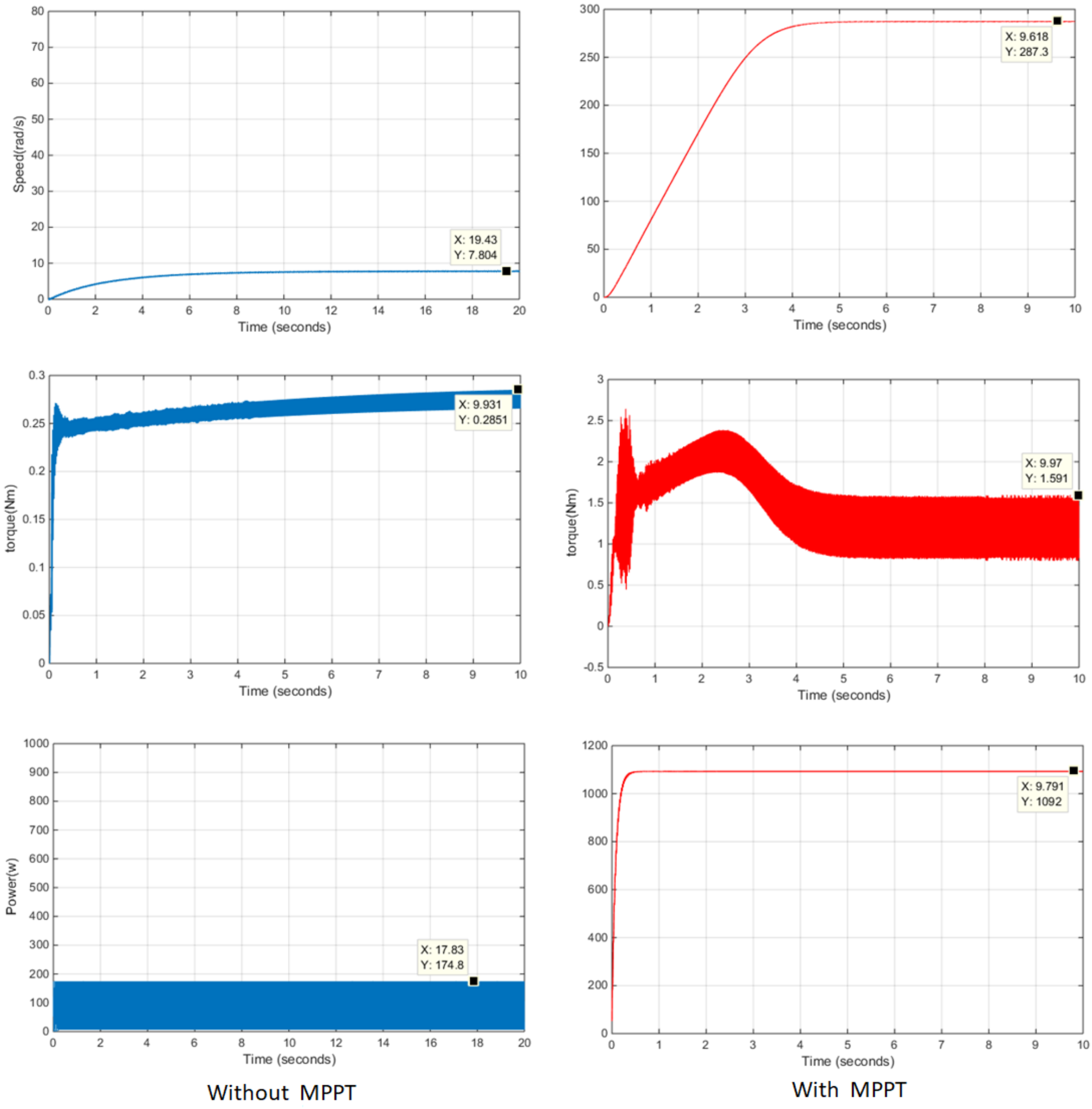


Figure 5.10: Characteristics of the PV Pumping System With and Without MPPT at (400 W / m^2) and 25 ° C.

5.7.3 Comparison between the Two Photovoltaic Systems with and Without MPPT

We have shown below the comparison of the operation of a photovoltaic pumping system with and without MPPT optimization. The optimization of the system by MPPT directly influences the efficiency of the engine.

The results of the MPPT effect and the system parameters for different irradiations before and after the optimization are shown in Table 11:

	With MPPT		Without MPPT	
G [W/m²]	**P [W]**	**Ω [rad/s]**	**P [W]**	**Ω [rad/s]**
1000	2219	302	608.4	146
400	1092	287	300.2	63

Table 5.11: The MPPT Effect and the System Parameters for Different Irradiations Before and After the Optimization.

From the results obtained from Table 5.11, we can notice that it is very important to optimize the performance of the system. Optimization methods have an important effect on the system studied especially when the photovoltaic system works far from the nominal value of insolation (at low light levels). On the other hand, in the case of a very high level of irradiation (1000W / m^2), optimization has no effect on the system (Table 5.11). In the case of low irradiation (400W / m^2), optimization by MPPT is clearly visible.

5.8 The Study of a Solar Water Pumping System in the Laboratory of Renewable Energies at the University of Mohamed Khider Biskra

5.8.1 The System's Definition

The method of pumping "over the sun" allows having a simpler, more reliable and less expensive photovoltaic system than a system which uses batteries to store energy first. In this first technique, it is the water itself which is pumped and stored when there is enough sunlight. The water is stored in a tank at a height above soil so that it is, if necessary afterwards, distributed by gravity.

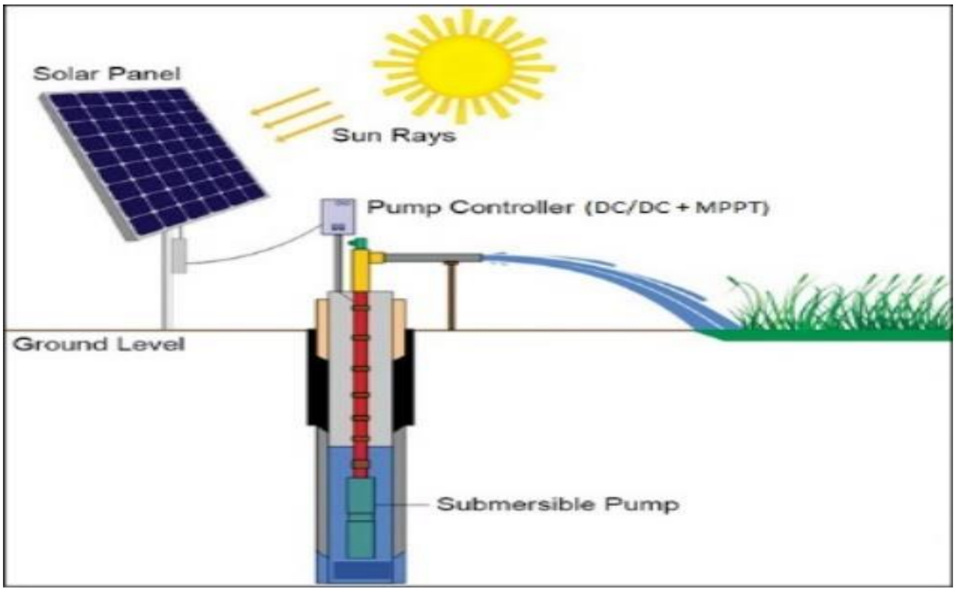


Figure 5.12: Over the Sun Water Pumping in the University of Mohamed Khider Biskra.

5.8.2 The System's Components

This photovoltaic solar powered pump system has three parts:

- Solar panels.
- The controller.
- The pump.

The solar panels make up most (up to 80%) of the systems cost. The size of the PV-system is directly dependent on the size of the pump, the amount of water that is required (m^3/d) and the solar irradiance available.

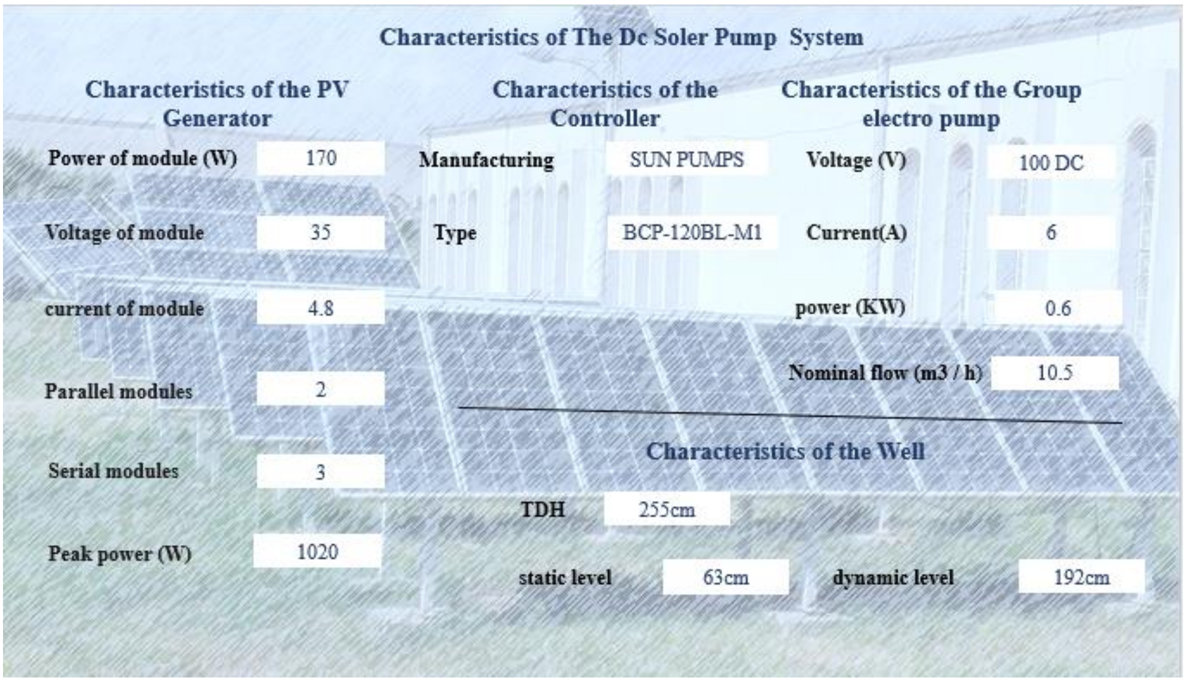


Figure 5.13: Characteristics of the DC Solar Pumping at the Laboratory of Renewable Energies in the University of Mohamed Khider Biskra.

5.8.3 Results of the Experiment

G	V_{OC}	I_C	V	Q
887 W/m^2	120 V	5.98 A	94.1 V	10.2 m^3/h

Table 5.12: The Results of the Experiment at the University of Mohamed Khider Biskra.

5.9 The Set Up Pump System in El Oued

5.9.1 The System's Definition

The method of pumping water using energy stored on batteries may have the advantage of guaranteeing a stable supply of power to the equipment (the possibility of pumping when the sun is absent). Energy is stored to be used for other future needs as well. The major inconvenience in this technique is that it has several components that negatively influence the reliability and overall cost of the system**.**

5.9.2 The System's Components

This photovoltaic solar powered pump system has three parts:

- Solar panels.
- The controller.
- The pump.
- Storage batteries.

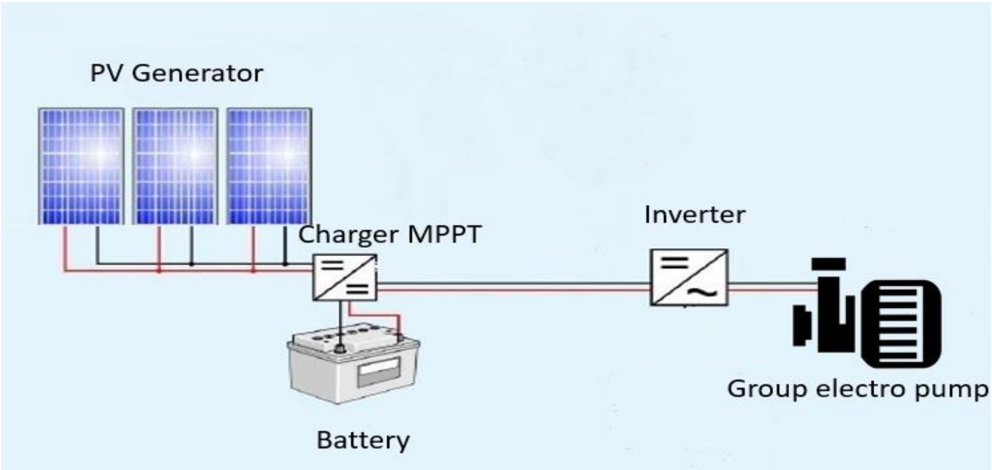


Figure 5.14: Water Pumping System with Batteries at the Laboratory of Renewable Energies in the University of El Oued.

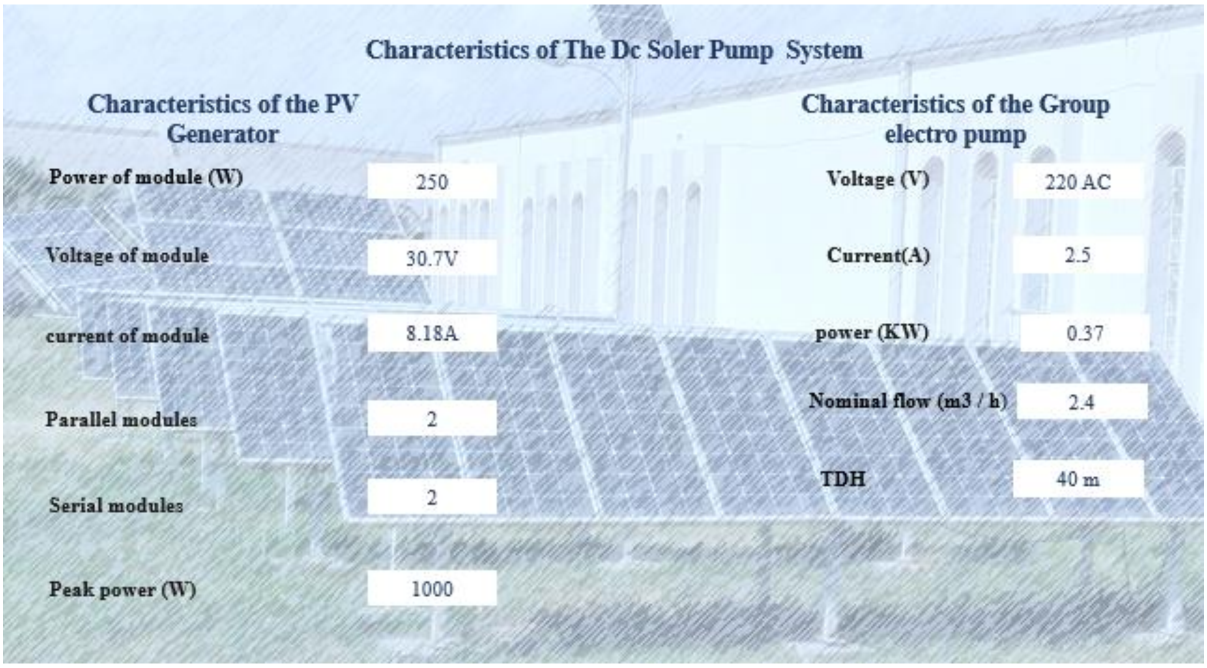


Figure 5.15: Characteristics of the AC Solar Pumping at the Laboratory of Renewable Energies at the University of El Oued.

5.9.3 Results of the Experiment

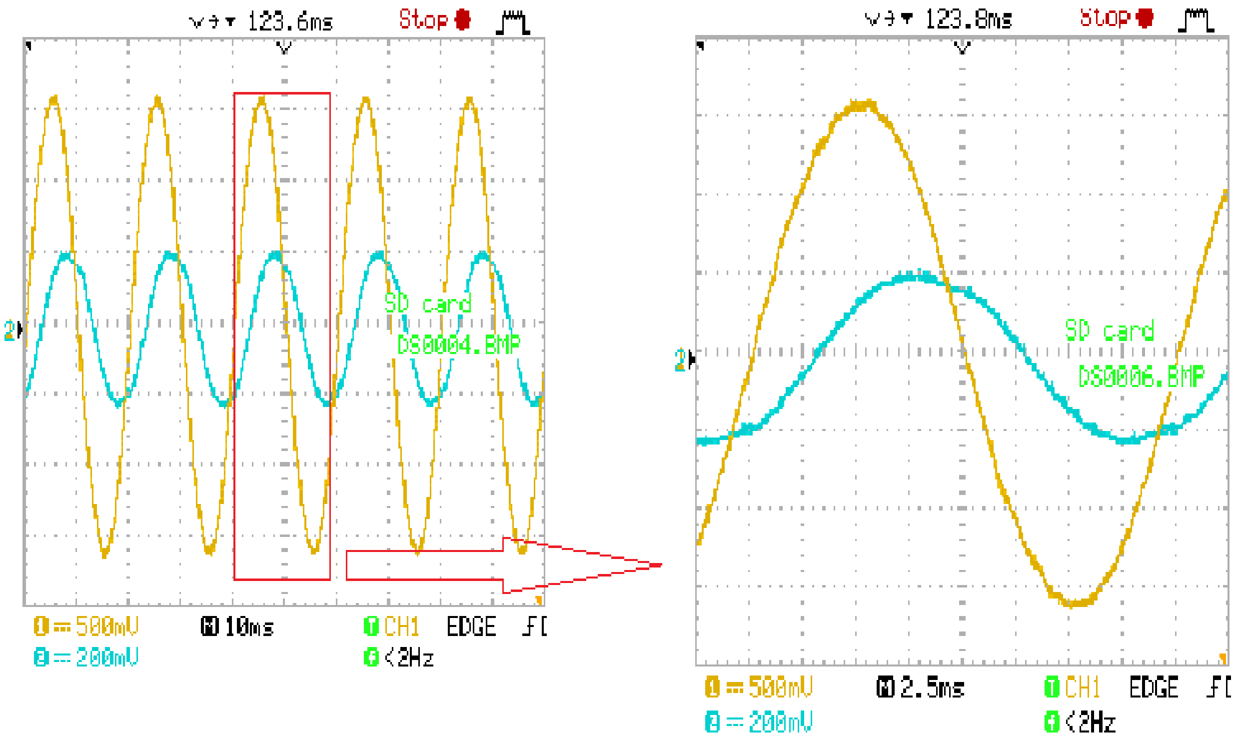


Figure 5.16: Voltage and Current Curves Obtained from the Pump.

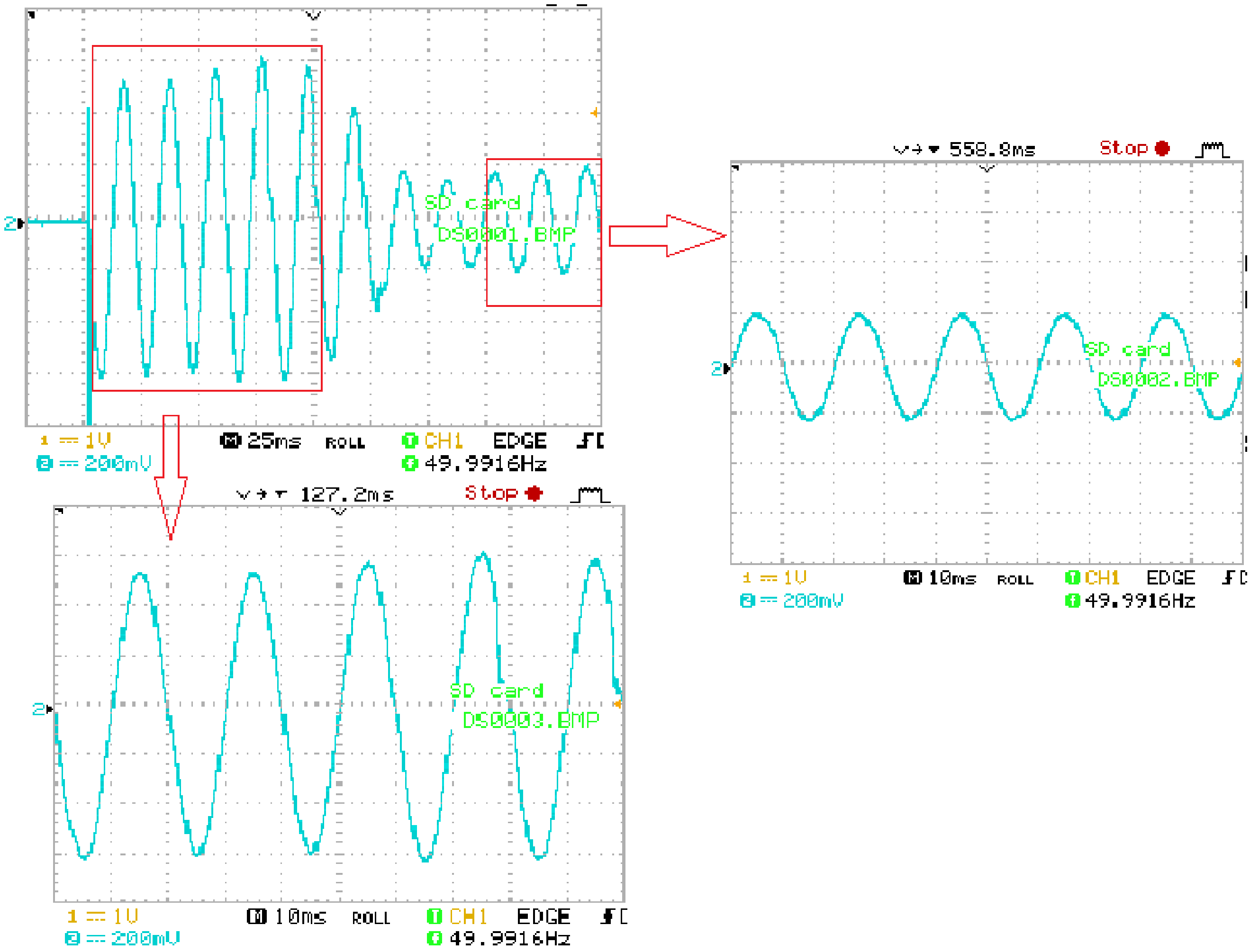


Figure 5.17: Startup Current of the Pump.

Startup current	Current	Voltage	Flow rate Q	ϕ	COS ϕ
6A	2A	220 V	2.4m^3/h	0.078°	0.71

Table 5.13: The Results of the Experiment at the University of El Oued.

5.10 Conclusion

In this chapter, we presented the results of a study that led to the sizing of a photovoltaic pumping system to irrigate 2.5 hectare of palm and olive trees located on the valley of El Oued. We presented the different elements of this photovoltaic system which are: a photovoltaic generator, an electric pump and an inverter. According to the study, the adequate photovoltaic generator consists of 12 photovoltaic modules with a peak power of 150 W each. So, the Peak power of the PV generator is 3400 W. It is important to note, however, that often calculating the size of the generator has a certain degree of uncertainty. This uncertainty is mainly due to two reasons: the first is related to the random nature of the solar radiation that is often little known. The second is related to the difficult estimate of the water requirements. It is therefore advisable to take precautions when choosing the type of pump and the size of the generator.

This chapter was devoted to a detailed comparative study between the two techniques of pumping water, pumping through an optimized photovoltaic system and pumping using an ordinary system. After a thorough analysis of each technique, we compared the two pumping techniques by a comparative study of the peak power used for irrigation of the same surface.

General Conclusion

Solar energy is the most abundant energy source; it is available almost everywhere as well as it is a clean and free. These advantages have led to faster growth for solar energy demand.

On the other hand, the demand of electrical energy for water pumping, mainly in rural and isolated areas is an interesting subject. Usually in this type of situation, conventional energy is used to power generator. However, this energy has several constraints, such as fuel transportation and Periodic maintenance for diesel engines. This work is devoted to a technical study of a water pumping system using photovoltaic energy in the region of El-Oued.

There were many problems that were raised during the design of a solar pumping system, such as the elevated initial cost of the cubic meter of pumped water and the low efficiency of the system. This research aims ~~at~~ to realize a powerful pumping system for irrigation needs. To achieve this goal and to extract the maximum power from the PV generator, three axes have been studied:

- The improvement of the solar radiation captation by an optimal choice of the inclination angle for solar panels.,
- The addition of an adaptation stage between the load and the PV generator.
- Controlled use of the pumped water by an appropriate irrigation technique.

The obtained results demonstrate the importance of inclination angle of solar panels in increasing the received solar radiation. The optimal choice of the inclination angle makes the PV panels collect the maximum solar radiation. This would increase the power of the PV generator and therefore increase the amount of pumped water. The simulation results obtained by our calculation code developed especially for this have confirmed that the best inclination of photovoltaic solar panels for year-round use is that of the latitude of the place where the PV panels are installed. However, an optimum monthly tilt is the best solution even it is more practical and suitable.

In a second axis, the energy gain from adding an adaptation stage controlled by an MPPT algorithm has been confirmed. The DC load can get the most electrical power available in the PV generator during sunshine duration by using this adaptation stage.

For the sake of simplification and cost minimization, the global design for water pumping system has been optimized. It is more suitable to use water storage in hydraulic tanks

instead of storing electrical energy in batteries. Hence, the system will be more reliable and the cost has been reduced. This type of solar pumping is called "over the sun".
To better analyze the constraints of the operation of a water pumping system, we presented in this research, comparative results of two different PV pumping systems used to irrigate 2.5 hectare of palm and olives trees located in El-Oued. The first system is optimized by the proposed-optimized techniques while the second is non-optimized system.
The obtained results show that the use of the optimized system for the irrigation of the same surface brings an average energy gain between 30% and 40%.
According to our results, it is clearly seen that an optimized PV pumping system can be an interesting alternative to conventional ones. Therefore, the development of this type of decentralized energy, especially in the south of our country, is highly recommended since it allows access to water supplies easily and cheaply in any place. Another very important coincidence that favors the use of this type of energy for water pumping in El-Oued is that the demand for water, especially in agriculture, which reaches its maximum in hot and dry weather. And that is precisely the moment when we have access to the maximum of solar energy.

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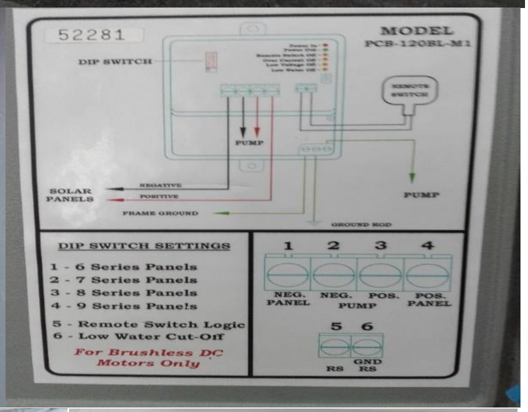
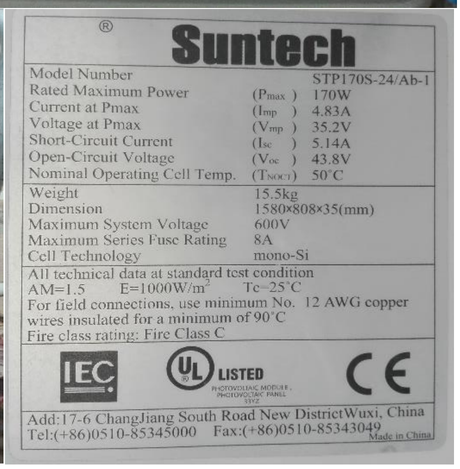
Calculation of the Monthly Total Daily Irradiation and the Optimal Inclination of a Solar Panel on an Inclined Surface - Chapter 2

```
clear all
clc
n=[1 36 65 101 138 173 184 220 258 280 306 343];% The typical
day number of the month.
S=[7.74 8.17 8.36 9.13 9.3 10.8 11.5 10.64 9.26 9.43 8.3
7.35];%The duration
% average daily insolation (measured)
for k=1:1:12
q=0.2;% Albédo DU SOLE
Hil_max=0;
G=1367;% The solar constant
L=33*pi/180; % Latitude deloued
c=1+0.034*cos(2*pi*(n-2)/365);
g=23.45*sin(2*pi*(284+n)/365); % The declination IN DEGREE
g1=g*pi/180; % The declination RAD
w1=acos(-tan(L)*tan(g1));% Solar angle
H0=(24*c*G/pi).*(cos(L).*cos(g1).*sin(w1)+w1.*sin(g1).*sin(L))
;
% H0 Daily average daily irradiation outside atmosphere
S0=(2/15)*w1*180/pi;% The astronomical duration of the day
Q=S./S0;% The rate of insolation
K=0.3+0.43*Q; %
H=K.*H0; %
Hannuelle=(365/12)*sum(H);
Kd=0.91-0.98*K;%
Hd=(0.91-0.98*K).*H;% The diffuse component
   for B=-10:1:90;
        Bl=B*pi/180;
        w2l=acos(-tan(L-Bl).*tan(g1));
        V=[w1; w2l];
        w3l=min(V);
        %R :The conversion invoice
        R=(cos(L-
Bl).*cos(g1).*sin(w3l)+w3l.*sin(L*Bl).*sin(g1))./(cos(L).*cos(
g1).*sin(w1)+w1.*sin(L).*sin(g1));
        Hil=(H-Hd).*R+Hd.*(1+cos(Bl))/2+H*q.*(1-cos(Bl))/2;
        if Hil > Hil_max;
            Hil_max =Hil;
            B_op=Bl*180/pi;
        end
    end
Hio=Hil_max
Bopt=B_op
end
```

The Solar Water Pumping System in the Laboratory of Renewable Energies at the University of Mohamed Khider Biskra - Chapter 5





The Pump System in El Oued - Chapter 5

Used Measuring Instruments

Solar Pump systems Installed in El Oued

Town	Location	Characteristic of the well				
		Depth(m)	Flow	Ns(m)	Nd(m)	Tupage
Djamaa	Chemora	180	30	22.5	33	PVC 315mm
Hamraia	Megatla	180	12	0	19.5	PVC 315mm
Bengacha	Bengacha	150	6	18	135	PVC 315mm
Bengacha	Douilette1	180	3	0	116	PVC 315mm
Magrane	Besser	30	3	0.3	8	PVC 315mm
Hassi Khalifa	Mafssel	33	3	6	16	PVC 315mm
Guemar	Guemar	35	3	13	21	PVC 315mm

Résumée

L'eau et l'énergie sont parmi les plus importants éléments essentiels et indispensables à la vie. Ce travail de recherche est une étude technique sur la réalisation de stations d'irrigation dans les zones sahariennes-El oued fonctionnant à l'énergie solaire (photovoltaïque). Cette dernière s'entend sur une grande superficie de 54.573km^2. La wilaya d'EL Oued dispose également d'une grande réserve d'eau souterraine à quelques mètres du sol. Aussi l'énergie solaire annuelle dépasse les 2100kWh au m^2 par an. L'utilisation de ce type d'énergie propre et décentralisée contribue au développement de l'économie de la zone Les possibilités de production de l'énergie et du pompage de l'eau sur le Sahara de la wilaya encourage l'Agriculteur à développer leur activité.

Mots Clés: Energie renouvelable, Panneau solaire, Pompage Photovoltaïque d'eau, Onduleur, Batterie.

Abstract

Water and energy are among the most important and essential elements of life. This research work is a technical study on the realization of irrigation stations in Saharan-El Oued areas powered by solar energy (photovoltaic). The latter covers a large area of 54,573km^2. The wilaya of EL Oued also has a large reserve of groundwater a few meters above the ground. Also annual solar energy exceeds 2100kWh per m^2 per year. The use of this type of clean and decentralized energy contributes to the development of the economy of the area. The possibility of energy production and water pumping over the Sahara of the wilaya encourages the Farmer to develop their activities.

Key Words: Renewable energies, Solar panel, Photovoltaic Water Pumping, inverter, Batteries.