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Techno-economic comparative study of grid-connected PV power systems in three climate zones, Algeria

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Thanks

We reach with our thanks to ALLAH all mighty for blessing us with the courage,

will and motivation to successfully complete this work.

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We also reach our thanks to our parents, friends who helped or contributed in the achievement of this work from close or afar.

Dedication

First of all, I would like to dedicate this work my hero my father who pushed me all the time tirelessly and my beloved mother for her sacrifices to see me successful

My classmate aymen the best partner I have ever had, without you brother, I wouldn't done this work alone.

Mourad

Dedication

Thank you ALLAH...

At first I dedicate this work to my parents who sacrificed their life for me, and who have never stopped encourage and support me.

To my brother imad who helped me a lot with this work.

To my partner my colleague my brother SKENDER Mourad who without him this work and this year would never have been possible.

Aymene

ملخص

يعالج المشروع ادناه دراسة تقنية اقتصادية مقارنة لأنظمة الطاقة الكهروضوئية المتصلة بالشبكة في ثلاث مناطق مناخية ، الجزائر (المدية ، غرداية و تمنراست) و ذلك بغية تركيب نظام كهروضوئي لتغذية فندق،على مستوى المناطق المذكورة اعلاه .

الكلمات المحورية : كهروضوئية , شبكة كهرباء , لوح شمسي , طاقة متجددة , نظام هجين , محول , حمولة كهربائية , تغذية كهربائية.

Abstract

This study presents a comparative techno-economic analysis of grid-connected photovoltaic (PV) power systems for a rooftop solar PV hotel building. The techno-economic performance of grid-connected PV system in the three regions was evaluated using the HOMER software. The system comprising of the photovoltaic array to capture solar energy, a power converter to change over between AC and DC, and grid connection.Monthly average electric production, economic considerations, and sensitivity analyses were all considered. For the grid/PV systems of the three climate zones, Among the three regions (Medea, Ghardaia and Tamenrast), Tamenrast was the one that came with the best results in terms of energy production and material profit, where the value of the NPC was -1230000 DA, which is the lowest among the three regions.

Key words: photovoltaic, electricity grid, solar panel, renewable energy, hybrid system, transformer, electric load, electric feed

Résumé

Le projet ci-dessous porte sur une étude technico-économique de systèmes photovoltaïques connectés au réseau dans trois régions climatiques, l'Algérie (Medea, Ghardaïa et Tamanrasset) en vue d'installer un système photovoltaïque pour alimenter un hôtel, au niveau des Régions. Cette étude présente une analyse comparative technico-économique des systèmes d'alimentation photovoltaïque (PV) connectés au réseau La performance technico-économique du système PV connecté au réseau dans les trois régions a été évaluée à l'aide du logiciel HOMER. Le système comprend le réseau photovoltaïque pour capter l'énergie solaire,

un convertisseur de puissance pour basculer entre le courant alternatif et le courant continu et la connexion au réseau.La production électrique moyenne mensuelle, les considérations économiques et les analyses de sensibilité ont toutes été prises en compte. Pour les systèmes réseau/PV des trois zones climatiques, parmi les trois régions (Médéa, Ghardaïa et Tamenrast), Tamenrast est celle qui a obtenu les meilleurs résultats en termes de production d'énergie et de profit matériel, où la valeur du NPC était -1230000 DA, qui est le plus bas parmi les trois régions.

Mots clés : photovoltaïque, réseau électrique, panneau solaire, énergie renouvelable, système hybride, transformateur, charge électrique, alimentation électrique

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List of Abbreviations

Sign	Nominal sign meaning	Unit
Δ	Declination	°
Ω	Hour angle	°
Γ	Surface azimuthal angle	°
Θ	Angle of Incidence	°
$\boldsymbol{\varphi}$	Latitude	°
B	Slope of the surface	°
FF	fill factor of solar cell	%
I_{mp}	current at maximum power point	A
V_{mp}	voltage at maximum power point	V
I_{sc}	short circuit current of solar cell	A
V_{oc}	open circuit voltage of solar cell	V
H	efficiency of solar cell	%
G	the radiation power on the earth	KW/m²
S	the exposed surface area of the cell	m²
T_{cell}	the cell temperature	°C
T_{amb}	the ambient temperature	°C
NOCT	nominal operating cell temperature given by manufacturers	°C
S_V	salvage value	DA
C_{rep}	replacement cost of the component	DA
R_{rem}	remaining life of the component	Year
R_{comp}	the lifetime of the component	Year
C_{npc}	total net present cost	DA
$C_{ann,tot}$	total annualized cost	DA
$CRF_{(i,R_{proj})}$	capital recovery factor	DA
COE	cost of energy	DA
E_{prim}	total amounts of primary load	KW/Year
E_{def}	total amounts of deferrable load	KW/Year
$E_{grid,sales}$	amount of energy sold to the grid	KW/Year
P_{PV}	power output of the PV array	KW
f_{PV}	PV derating factor	%
Y_{PV}	rated capacity of the PV array	KW
I_T	global solar radiation	KW/m²
I_S	standard amount of radiation	KW/m²
$P_{PV-rated}$	PV rated power at standard test conditions	KW
K_C	temperature coefficient of the PV array	%/°C
T_C	PV cell temperature	°C
T_{ref}	PV cell temperature under standard test conditions	°C
η_{inv}	inverter efficiency	%
$P_{inv,out}$	output power of the inverter	KW
$P_{inv,in}$	input power of the inverter	KW

Introduction

There are nine major areas of energy resources. They fall into two categories: nonrenewable and renewable. Nonrenewable energy resources, like coal, nuclear, oil, and natural gas, are available in limited supplies. This is usually due to the long time it takes for them to be replenished. Renewable resources are replenished naturally and over relatively short periods of time. The five major renewable energy resources are solar, wind, water (hydro), biomass, and geothermal.

Since the dawn of humanity people have used renewable sources of energy to survive, wood for cooking and heating, wind and water for milling grain, and solar for lighting fires. A little more than 150 years ago people created the technology to extract energy from the ancient fossilized remains of plants and animals. These super-rich but limited sources of energy (coal, oil, and natural gas) quickly replaced wood, wind, solar, and water as the main sources of fuel.

Fossil fuels make up a large portion of today’s energy market, although promising new renewable technologies are emerging. Careers in both the renewable and nonrenewable energy industries are growing; however, there are differences between the two sectors. They each have benefits and challenges, and relate to unique technologies that play a role in our current energy system. For a range of reasons, from the limited amount of fossil fuels available to their effects on the environment, there is increased interest in using renewable forms of energy and developing technologies to increase their efficiency. This growing industry calls for a new workforce.

Algeria's energy consumption:

Compared to other developing countries with a similar development level, Algeria's consumption is high (1.3 toe per capita), partly because of consumption and losses in the energy sector (oil & gas production and LNG plants, mainly). Electricity consumption per capita reaches 1 500 kWh (2020).

In the framework of the new Program for the Development of Renewable Energy, adopted in 2015, the Government raised the target for renewables to 22 GW by 2030;

they will represent 37% of installed capacity and should cover 27% of the country's electricity supply. The bulk of this new capacity should come from solar PV (13.6 GW), followed by wind (5GW), solar CSP (2 GW), and biomass (1 GW). This development of renewables should save 300 bcm of gas by 2030 (or 8 times the 2014 gas consumption).

This master's dissertation project will discuss a techno-economic comparative study of grid-connected PV system in three climate zone of Algeria (Medea, Ghardaia and Tamenrast), By using HOMER PRO we will take a hotel as an electrical loud and try to feed it from a grid-connected PV system and see the best combination for our project in the three sites, the best system according to this thesis will be decided depending on the results that will be casted along the study.

This academic work will be divided into three chapters which each tackling:

Chapter 1 - Solar energy:

Being a general introduction of sun position and geometry as well as the photovoltaic technology and working principle.

Chapter 2 - electrical energy in Algeria:

Contain the electrical and renewable energy in Algeria and The different types of photovoltaic systems.

Chapter 3 - HOMER modeling and simulation:

Taking a glimp of HOMER PRO and how its functioning then use it to discuss our study and get our results.

Chapter I: Solar energy

I-1 Introduction:

solar energy, radiation from the Sun capable of producing heat, causing chemical reactions, or generating electricity. The total amount of solar energy incident on Earth is vastly in excess of the world's current and anticipated energy requirements. If suitably harnessed, this highly diffused source has the potential to satisfy all future energy needs. In the 21st century solar energy is expected to become increasingly attractive as a renewable energy source because of its inexhaustible supply and its nonpolluting character, in stark contrast to the finite fossil fuels coal, petroleum, and natural gas.

The Sun is an extremely powerful energy source, and sunlight is by far the largest source of energy received by Earth, but its intensity at Earth's surface is actually quite low. This is essentially because of the enormous radial spreading of radiation from the distant Sun. A relatively minor additional loss is due to Earth's atmosphere and clouds, which absorb or scatter as much as 54 percent of the incoming sunlight. The sunlight that reaches the ground consists of nearly 50 percent visible light, 45 percent infrared radiation, and smaller amounts of ultraviolet and other forms of electromagnetic radiation.

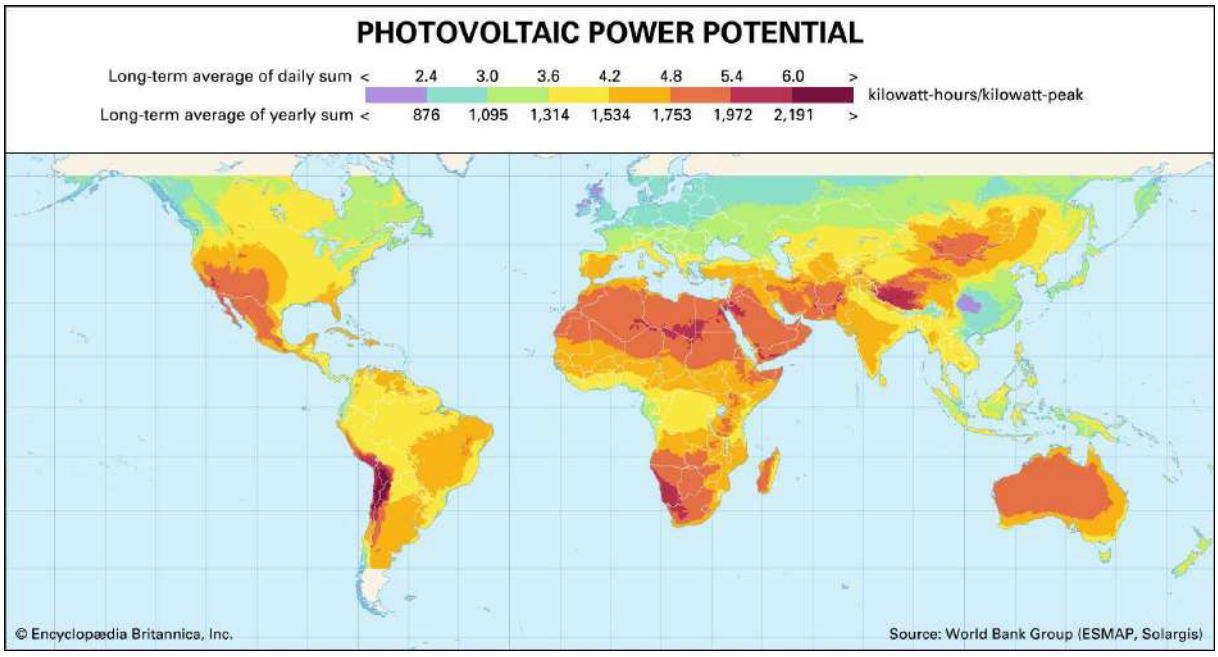


Figure I- 1 world photovoltaic power potential.

The potential for solar energy is enormous, since about 200,000 times the world's total daily electric-generating capacity is received by Earth every day in the form of solar energy. Unfortunately, though solar energy itself is free, the high cost of its collection, conversion, and storage still limits its exploitation in many places. Solar radiation can be converted either into thermal energy (heat) or into electrical energy, though the former is easier to accomplish.

I-2 the Position of the Sun:

For planning a PV system, it is crucial to know the position of the sun in the sky at the location of the solar system at a given time. In this section we explain how this position can be calculated. Since celestial objects like the sun, the moon and the stars are very far away from the earth it is convenient to describe their motion projected on a sphere with arbitrary radius and concentric to the earth. This sphere is called the celestial sphere. The position of every celestial object thus can be parameterized by two angles. For photovoltaic applications it is most convenient to use the horizontal coordinate system, where the horizon of the observer constitutes the fundamental plane. In this coordinate system, the position of the sun is expressed by two angles that are illustrated in below: The altitude a that is the angular elevation of the center of the solar disc above the horizontal plane. Its angular range is $a \in [-90^\circ, 90^\circ]$, where negative angles correspond to the object being below the horizon and thus not visible. The azimuth A that is the angle between the line of sight projected on the horizontal plane and due North. It is usually counted eastward, such that $A = 0^\circ, 90^\circ, 180^\circ, 270^\circ$ correspond to due North, East, South and West, respectively. Its angular range is $A \in [0^\circ, 360^\circ]$. In a different convention also used by the PV community, due South corresponds to 0° and is counted westward, the angles then are in between -180° and 180°. Figure below also shows the meridian, which is great circle on the celestial sphere passing through the celestial North and South poles as well as the zenith.

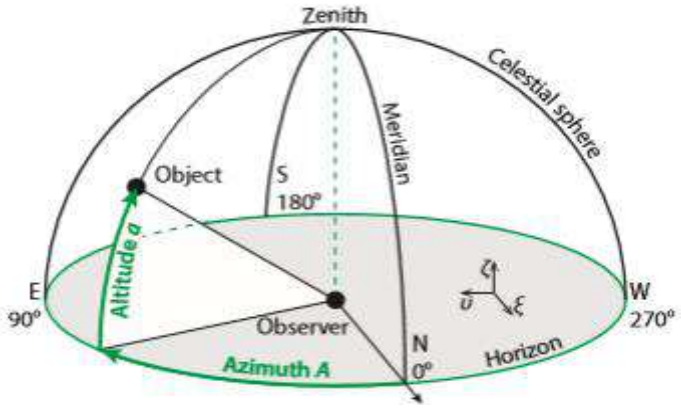


Figure I- 2 the altitude a and the azimuth A in the horizontal coordinate system.

I-3 Sun Geometry:

Because of the Earth's orbit and rotation, the position of the sun relative to a solar array is constantly changing. Designers use several geometrical techniques to design an array that will capture the most solar energy possible. The location of the sun is specified by two angles which vary both daily and annually. The geometry of the sun-earth relationships is shown schematically in Figure I-3 The distance between the sun and earth varies by 1.7 % due to the elliptic orbit of the earth around the sun. The mean earth distance is 1.495 x 10^{11} m. The sun subtends an angle of 32' with the earth. The diameter of the sun is 1.39x 10^{9}m and that of the earth is 1.27 x 10^{7} m.

The distance between the earth and the sun determines the intensity of solar radiation that can be received by the earth, notwithstanding the atmospheric attenuation. The elliptic motion of the earth around the sun causes the seasonal variation in the solar radiation as received by the earth. In addition to these geometric or "regular" variations, variation as actually received at any location is due to the position of the location on the earth, day and time during the day and the climatic conditions such as cloudy, bright, or rainy etc.

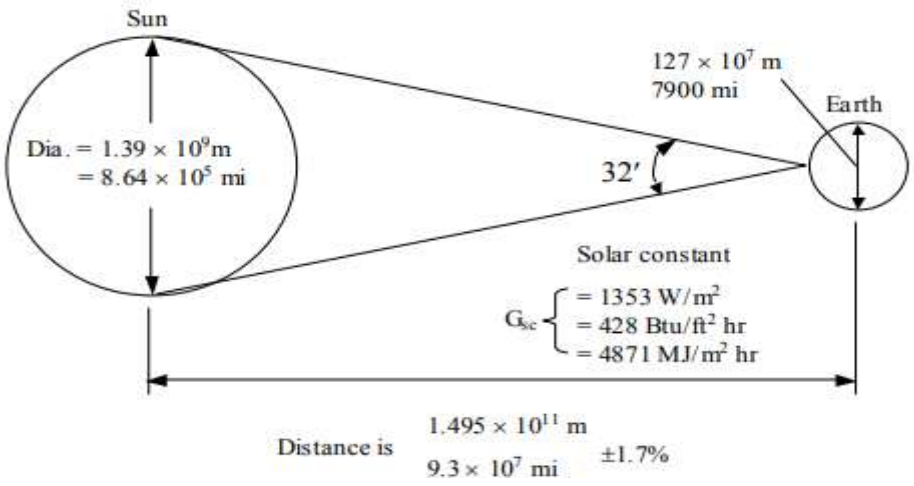


Figure I- 3 Sun-earth relationships.

I-4 Different Angels:

Latitude and Longitude are the coordinates of a point (location) on the earth's surface. A location on the earth's surface may be specified by latitude, longitude and elevation. Elevation does not directly enter into the calculation of different angles though may affect solar radiation received. The constant latitude and longitude lines, north pole, south pole, and the equatorial plane are shown in Figure I-4 (Latitude, φ, is reckoned positive in the northern hemisphere and negative in the southern hemisphere. Longitudes, λ, is described along with "east" or "west", meaning that the location is situated to the east or to the west of the Greenwich meridian). Thus, the latitude varies from – 900 to + 900 and the longitude varies from 00 to 1800 E or 00 to 1800.

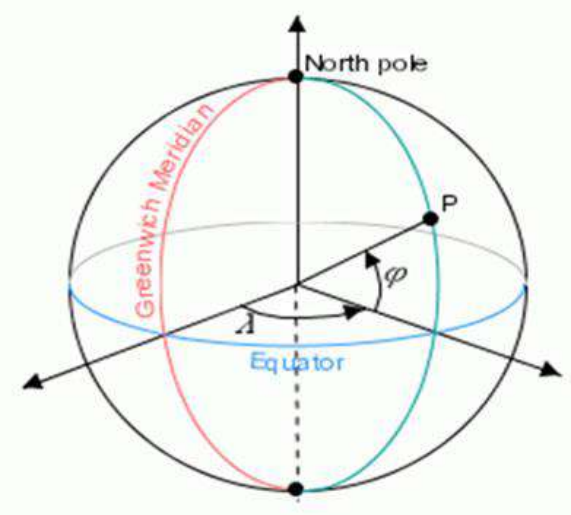


Figure I- 4 Concept of latitude, φ and longitude λ.

The latitude of a point on the earth's surface is the angle between the equatorial plane and a line that passes through that point and is normal to the surface. The north pole is 90° N; the south pole is 90° S. The 0° parallel of latitude has designated the equator, the fundamental plane of all geographic coordinate systems.

The Longitude λ, of a point on the earth's surface, is the angle east or west from a reference meridian to another meridian that passes through that point Declination, δ is the angular position of the sun at solar noon with respect to the place of the equator. Declination varies from - 23.450 to 23.450, in degrees, for the day, n, of the year (counting Jan. 1 as 1), can be calculated from,

$$\delta = 23.45 \sin\left(\frac{360\,(284+n)}{365}\right) \qquad (1\text{-}1)$$

Hour angle ω, is the angular displacement of the sun east or west of the local meridian due to rotation of earth on its axis at 150 per hour. ω= 0, at solar noon and is reckoned negative in the forenoon and positive in the afternoon.

Surface azimuthal angle γ, is defined as the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative and west positive, -1800 <γ< 1800

Angle of Incidence θ, is defined as the angle between the sun's ray and the outer normal to a surface.

The angle of incidence is related to the latitude, $\boldsymbol{\varphi}$, declination, δ, the hour angle, ω, slope of the surface, β, and the azimuthal angle of the surface, γ by:

$$cos\theta = \sin\delta \sin\varphi \sin\beta - \sin\delta \cos\varphi \sin\beta \cos\gamma + \cos\delta \cos\varphi \cos\beta \cos\omega + \cos\delta \sin\varphi \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega \quad (1\text{-}2)$$

The different angles can be clearly understood from Figure I-5.

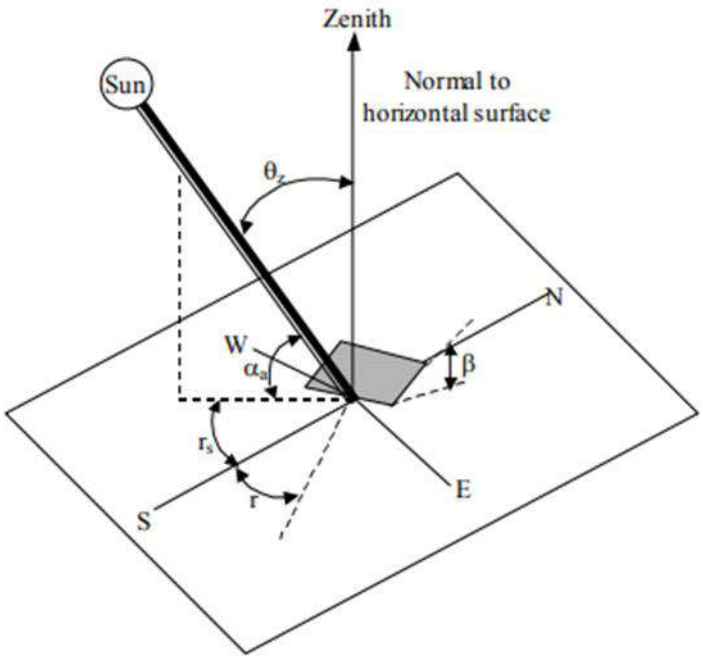


Figure I- 5 Different angles.

I-5 Solar radiation:

Irradiance is a combination of direct and diffuse radiation and will depend on the albedo (reflected solar radiation) of that particular location. That proportion of solar radiation which is scattered, absorbed or re-emitted in the atmosphere is diffuse radiation. Understandably on a sunny day, this scattered diffuse radiation will contribute only to 10 per cent of visible light, but on a cloudy day there will be much more scattering of the solar radiation reaching the Earth's surface which means the amount of diffuse radiation will be much greater

Direct or beam radiation is the solar radiation that travels down to the surface of the earth on a straight line without any atmospheric losses due to scattering or absorption.

Diffuse radiation is the solar radiation which reaches the surface of the earth after being scattered or absorbed by molecules in the atmosphere.

Reflected radiation is reflected from surface features.

Global Horizontal Irradiation (GHI) is the total of direct horizontal irradiation (DHI) and diffuse horizontal irradiation (DIF).

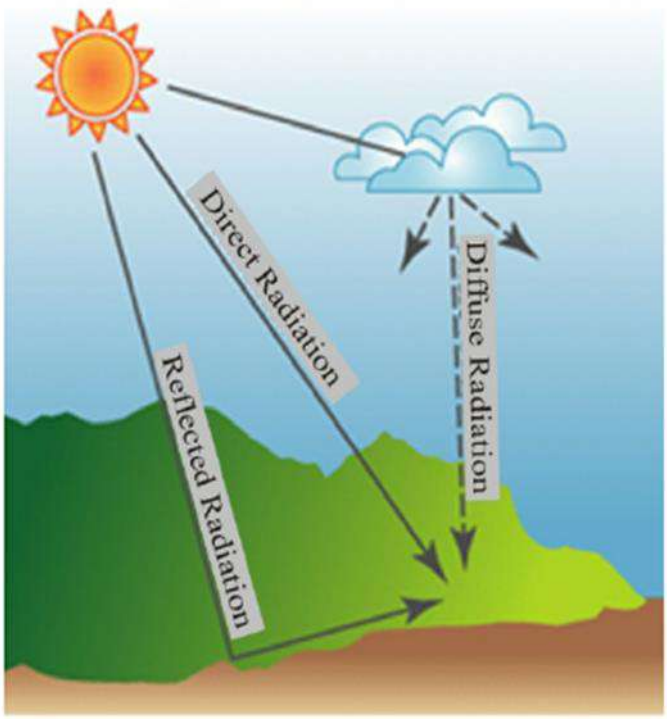


Figure I- 6 The three main components of solar radiation.

I-6 Photovoltaics (PV) Technologies:

PV materials and devices convert sunlight into electrical energy. A single PV device is known as a cell. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. These cells are made of different semiconductor materials and are often less than the thickness of four human hairs. In order to withstand the outdoors for many years, cells are sandwiched between protective materials in a combination of glass and/or plastics.

To boost the power output of PV cells, they are connected together in chains to form larger units known as modules or panels. Modules can be used individually, or several can be connected to form arrays. One or more arrays is then connected to the electrical grid as part of a complete PV system. Because of this modular structure, PV systems can be built to meet almost any electric power need, small or large.

PV modules and arrays are just one part of a PV system. Systems also include mounting structures that point panels toward the sun, along with the components that take the direct-current (DC) electricity produced by modules and convert it to the alternating-current (AC) electricity used to power all of the appliances in your home.

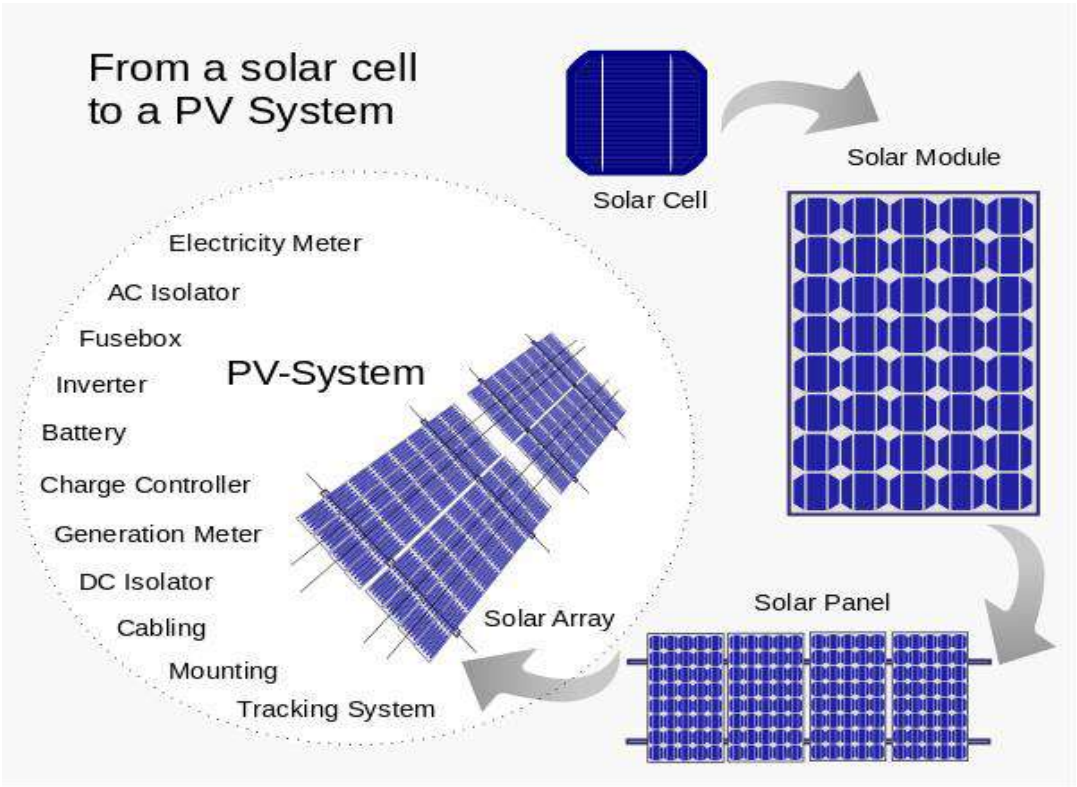


Figure I- 7 from a solar cell to a pv system.

Small photovoltaic cells that operate on sunlight or artificial light have found major use in low-power applications as power sources for calculators and watches, for example. Larger units have been used to provide power for water pumps and communications systems in remote areas and for weather and communications satellites. Classic crystalline silicon panels and emerging technologies using thin-film solar cells, including building-integrated photovoltaics, can be installed by homeowners and businesses on their rooftops to replace or augment the conventional electric supply.

I-7 Solar Cell:

A solar cell is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.

Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. By itself this isn't much – but remember these solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated.

I-7-1 Construction of Solar Cell:

A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer.

These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the solar cell from any mechanical shock.

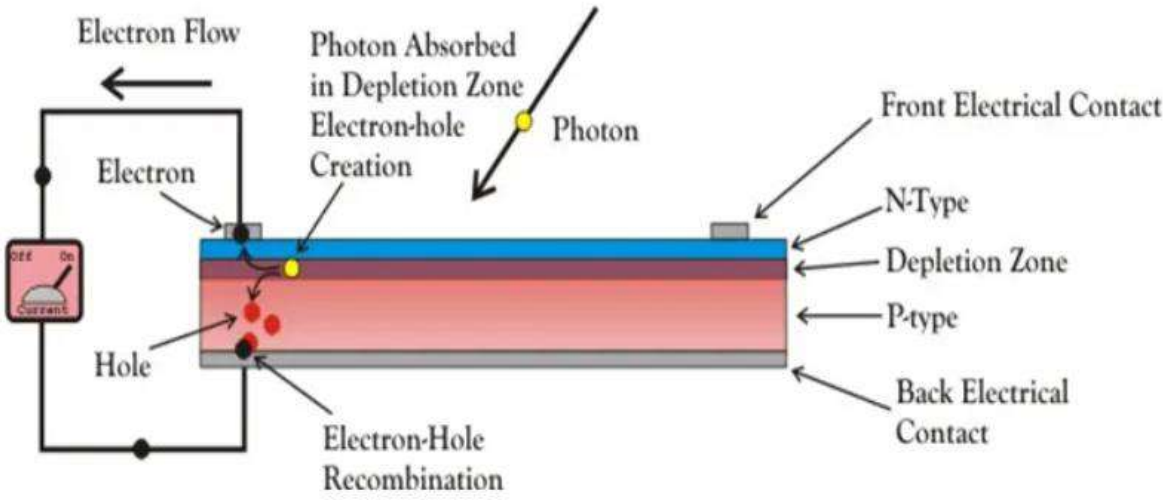


Figure I- 8 construction of solar cell.

I-7-2 Working Principle of Solar Cell:

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction.

Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.

Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

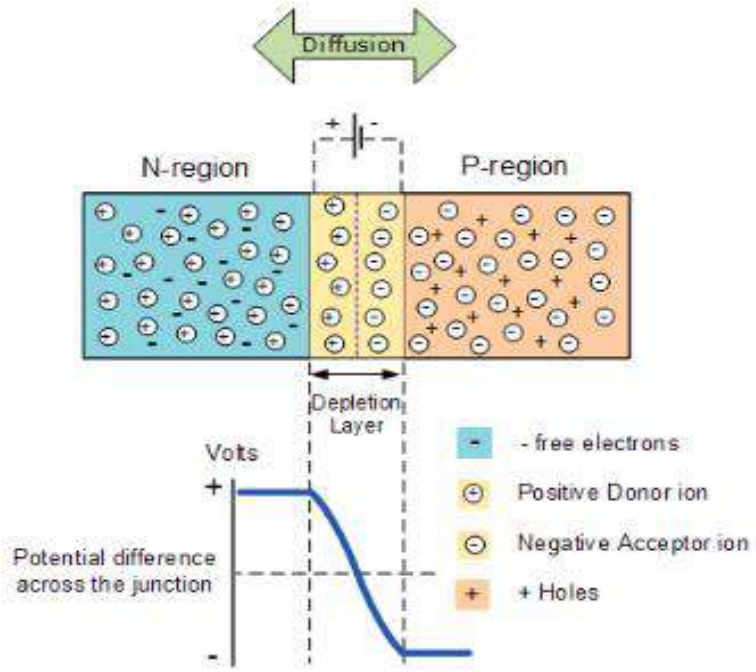


Figure I- 9 Working Principle of Solar Cell.

I-7-3 Characteristics of a Photovoltaic Cell:

The Solar Cell I-V Characteristic Curves shows the current and voltage (I-V) characteristics of a particular photovoltaic (PV) cell, module or array. It gives a detailed description of its solar energy conversion ability and efficiency. Knowing the electrical I-V characteristics (more importantly P_{max}) of a solar cell, or panel is critical in determining the device's output performance and solar efficiency.

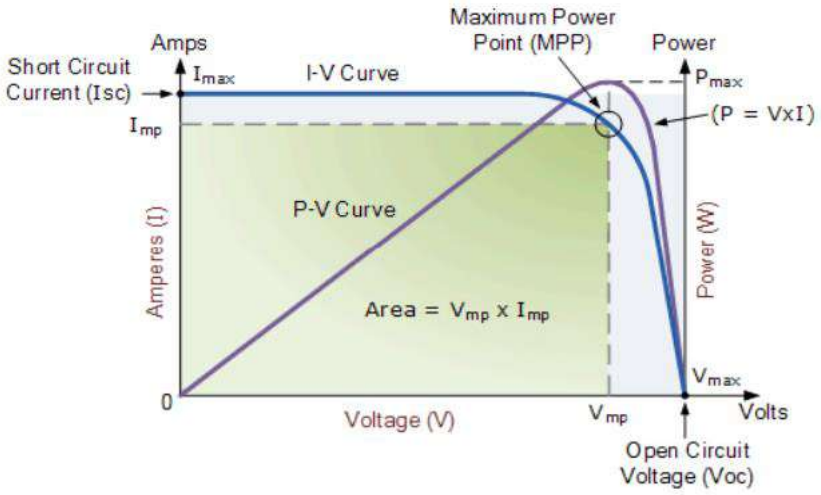


Figure I- 10 Solar Cell I-V Characteristic Curve.

The fill factor of a solar cell is the ratio between product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage of the solar cell as in equation (1-3):

$$FF = \frac{I_{mp}V_{mp}}{I_{sc}V_{oc}} \quad (1\text{-}3)$$

I_{mp}: current at maximum power point,

V_{mp}: voltage at maximum power point,

I_{sc}: short circuit current of solar cell,

V_{co}: open circuit voltage of solar cell.

The efficiency $\boldsymbol{\eta}$ of solar cell defined as the ratio of maximum electrical power output to the radiation power input to the cell and it is expressed in percentage as in equation (1-4):

$$\eta = \frac{I_{mp}V_{mp}}{G\ S} \quad (1\text{-}4)$$

G: the radiation power on the earth,

S: the exposed surface area of the cell.

Photovoltaic panels can be wired or connected together in either series or parallel combinations, or both to increase the voltage or current capacity of the solar array. If the array panels are connected together in a series combination, then the voltage increases and if connected together in parallel then the current increases.

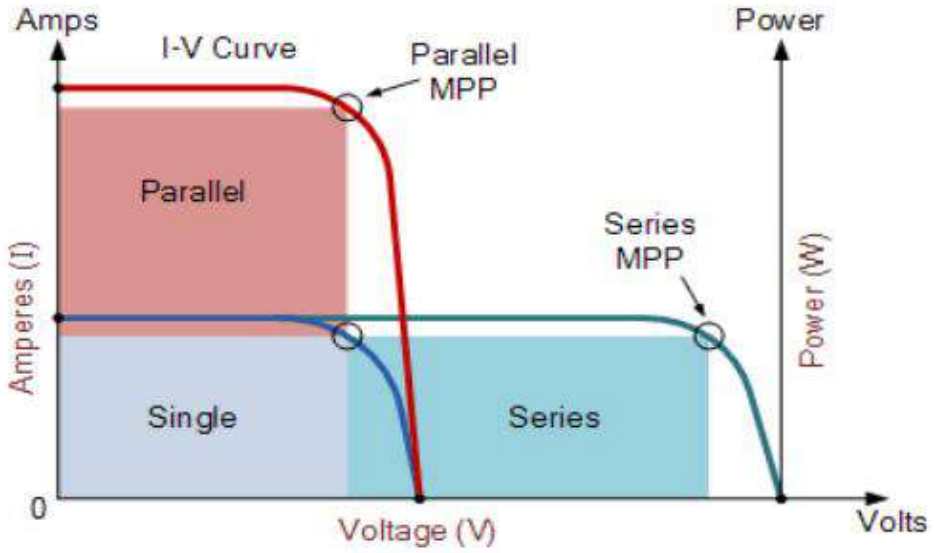


Figure I- 11 series / parallel I-V Characteristic Curve.

The electrical power in Watts, generated by these different photovoltaic combinations will still be the product of the voltage times the current, (P = V x I). However, the solar panels are connected together, the upper right hand corner will always be the maximum power point (MPP) of the array.

I-7-4 Temperature and Solar Irradiation Effects:

Factors such as ambient air temperature, the material of PV module characteristics and solar irradiance determine the operating temperature for the solar cells. As stated previously, the effect of the temperature on PV cells will decrease the output voltage, which directly will affect the output power of the cells. This operating temperature for the solar cells is determined through equation (1-5):

$$T_{cell} = T_{amb} + \left[\frac{NOCT - 20^{\circ}}{0.8}\right] G \qquad (1\text{-}5)$$

T_{cell}: the cell temperature [C°],

T_{amb}: the ambient temperature [C°],

NOCT: the nominal operating cell temperature given by manufacturers,

G: the solar insolation [kW/m2].

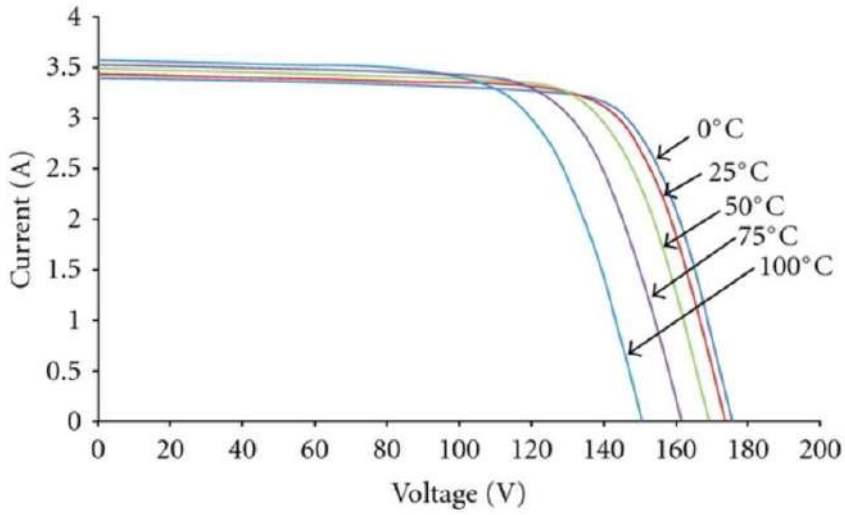


Figure I- 12 I-V curve of voltage affected with diverse operating temperatures.

Solar cells must receive as much solar irradiation as possible from a sun whose position in the sky depends on the time of day and the time of year. For solar cells to track the movement of the sun, PV cells have to hold equipment trackers that allow them to receive as much solar irradiation as possible. However, these trackers are expensive and need regular maintenance, hence, most PV cells are installed in a specific position. Usually, the PV modules are installed at a fixed angle determined by the local latitude and characteristics of the demand. This prescribed installation assists in optimizing the received amount of solar irradiations.

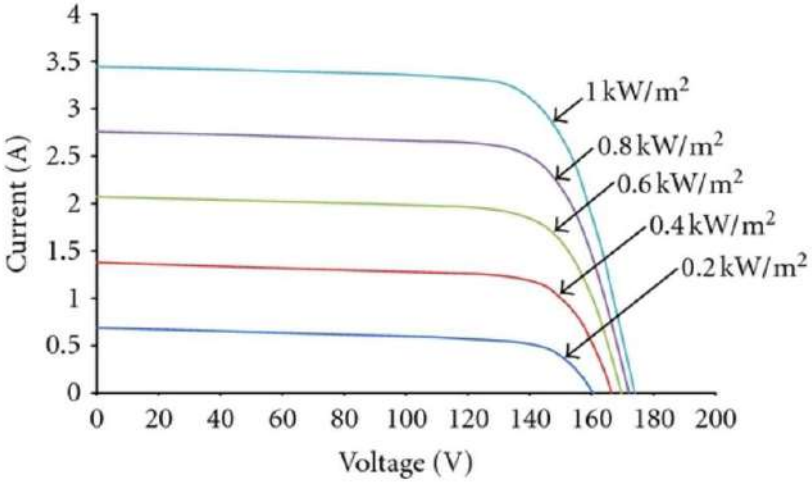


Figure I- 13 I-V curve of voltage affected with diverse operating solar irradiation.

I-8 Conclusion:

To conclude, a brief history of the discovery of solar energy as well as the PV technologies is discussed. Next, solar cells are covered and the different ways of connection that the solar cells can be organized in parallel and series are detailed with showing the effects of these connections on the output voltages and currents of solar cells depending on which connection method is used. As parallel connection is used when higher output currents needed and series method for higher voltages. Furthermore, the factors that have an impact on the efficiency of PV modules are provided with displaying their effects on the output voltages and currents, thus the output power. These factors are the cell temperature and solar irradiation.

Chapter II: Types and configurations of PV systems

II-1 Introduction:

Algeria is located in North Africa and borders Tunisia and Libya in the east, Niger and Mali in the south, and Mauritania, Western Sahara, and Morocco in the west. In the north, Algeria's vast coast of over 1,200 km extends to the Mediterranean Sea. With its more than two million km² of national territory, Algeria is by far the largest North African country. However, most of its national territory is occupied by the Sahara, which explains the arrangement of population density: 90% of the population is located in the north. The mild Mediterranean climate coming from the coast is replaced by a dry desert climate further south.

Algeria has the highest technical and economical potential for solar power exploitation in the MENA region, with about 170 TW/h per year. First industrial scale solar thermal power project has been initiated by inauguration of Hassi R'Mel power station in 2011. This new hybrid power plant combines a 25-megawatt (MW) concentrating solar power array in conjunction with a 130 MW combined cycle gas turbine plant. In addition, Algeria has launched in 2011 a national program to develop renewable energy based on photovoltaics (PV), concentrated solar power (CSP) and wind power, and to promote energy efficiency. The program consists of installing up to 12 GW of power generating capacity from renewable sources to meet the domestic electricity demand by 2030.

II-2 Algeria's Energy Consumption:

Algeria's total final consumption (TFC) has been steadily increasing in recent years. While in 2010 the energy consumption added up to around 31,500 ktoe, in 2013 it had increased to 38,543 ktoe, which means that the country has seen an increase of 22% in just three years.

Taking a closer look at various sectors, the residential sector (including agriculture) is the one which consumes the most energy (43%), followed by the transport sector

(36%) and the industry sector (21%). More detailed figures are outlined in the table Bellow.

Table II- 1 Final energy consumption in Algeria in 2012 and 2013 by sector (ktoe).

Sector	2012	2013	Change in %
Industry	7,939	8,229	+3.7
Transport	13,371	13,889	+3.9
Residential	15,068	16,425	+9.0
Total	36,377	38,543	+6.0

At the end of 2013, the installed capacity of electricity generation reached 15.1 GW. This is an increase of about 18% compared to the precedent year and due to the new power plants being installed and starting operations.

Between 2001 and 2013, electricity production rose from 26,250 GWh to 57,397 GWh. As table 2 below shows, the main source for the production of electricity is gas with a relative percentage to the total amount produced of over 92%. Although there are other sources of electricity, namely oil and hydro-power, these play only a minor role.

Table II- 2 Electricity production by source (2012).

Production from	**in GWh**	**in %**
Oil	3,727	6.49
Gas	53,048	92.42
Hydro	622	1.08
Total Production	57,397	100

The residential sector is the biggest consumer in Algeria, representing 38.1% of the nationally consumed energy. Other important sectors are the tertiary sector (20.93%) and the manufacturing industry (17.83%). The details are outlined in table 3.

Table II- 3 Electricity consumption by sector (2012) in (ktoe).

Sector/ Product	in ktoe	in %
Agriculture	89,865	2.42
Public works	17,742	0.48
Hydraulics	468,786	12.63
Mines and quarries	27,365	0.74
Manufacturing industry	661,555	17.83
Gas and oil industry	273,239	7.36
Residential	1,413,960	38.10
Tertiary	776,735	20.93
Transport	11,670	0.31
Total	3,710,917	100

II-3 Renewable Energy in Algeria:

Although there is a high potential for the use of solar energy in Algeria, there are hardly any solar power plants so far. According to the MENA Renewables status report 2013 by REN21 the installed capacity of Photovoltaics (PV) was 7.1 MW in 2010 and 25 MW in 2012 of Concentrated Solar Power (CSP). The report also gives estimates for capacity of renewable energy projects in the pipeline. For solar power, a capacity of 175 MW in the pipeline was estimated as well as 20 MW of wind power. However, the figures issued by the Regional Centre for Renewable Energy and Energy Efficiency (RCREE) are higher: They state an estimated capacity of 370 MW of solar power in the pipeline (all CSP) and 210 MW of wind power.

Although there is some installed capacity of hydro power (228 MW), this energy source only plays a marginal role due to limited precipitation and high evaporation.

In February 2015, the Algerian Government adopted an ambitious Renewable Energy program. It envisions the installation of 22 GW of RE by 2030, which is almost double

than what was set as a target before (12 GW) and equals a share of about 27% RE in total electricity production. Of these 22 GW, about 4.5 GW are supposed to be installed by 2020. The targets per technology are set according to two phases as outlined in the table below:

Table II- 4 The Algerian RE target.

Source	1st phase 2015-2020 [MW]	2nd phase 2021-2030 Mw]	Total [MW]
Solar PV	3,000	10,575	13,575
Wind	1,010	4,000	5,010
CSP	-	2,000	2,000
Cogeneration	150	250	400
Biomass	360	640	1,000
Geothermal	5	10	15
Total	4,525	17,475	22,000

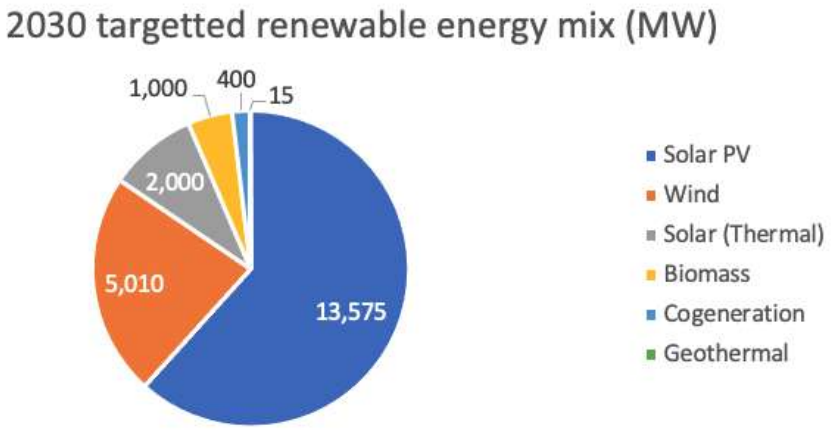


Figure II- 1 The Algerian RE target.

II-4 Energy Efficiency:

Also in February 2015, the Algerian government announced a new national program on energy efficiency (EE) for the years 2015 to 2030. The EE program mainly targets three sectors: the building sector, transport and industry.

In the building sector, more than 30 million toe are supposed to be saved by 2030. This will be achieved through innovative technologies and thermal insulation of constructions. Also, economic lamps and solar water heaters will contribute. In the transport sector, the target is to save more than 15 million toe. The government aims to use fuels which are widely available and least polluting, like LNG and natural gas, in order to reduce the use of gasoline. The industry sector is supposed to contribute 34 million toe by 2030.

II-5 The different types of photovoltaic systems:

Photovoltaic systems are currently divided into two large categories: stand-alone systems (not connected to the network) and grid-connected systems.

II-5-1 Review of Standalone Solar Energy Systems:

The system which utilizes only solar electric energy as main source of energy is referred as standalone solar electrical system. There are many locations on this earth where no source of electricity is available. At these locations standalone solar electrical system can be the ideal source of electricity. The main advantage of this system is that it does not depend on grid or any other source of electricity.

As it does not have any connection with grid or other electric supply line, it is also known as off-grid Photovoltaic system. As the sun is the only source of energy in this system it should have some means to make it active even in night times. A storage battery system does the job. Therefore, a storage battery system is an essential component of standalone solar system. But, often this battery system can be omitted from the system if the system is dedicated for the load which to be operated in day times only. Popular examples of standalone solar system are solar lanterns, solar home lighting systems, solar water pumping systems, etc.

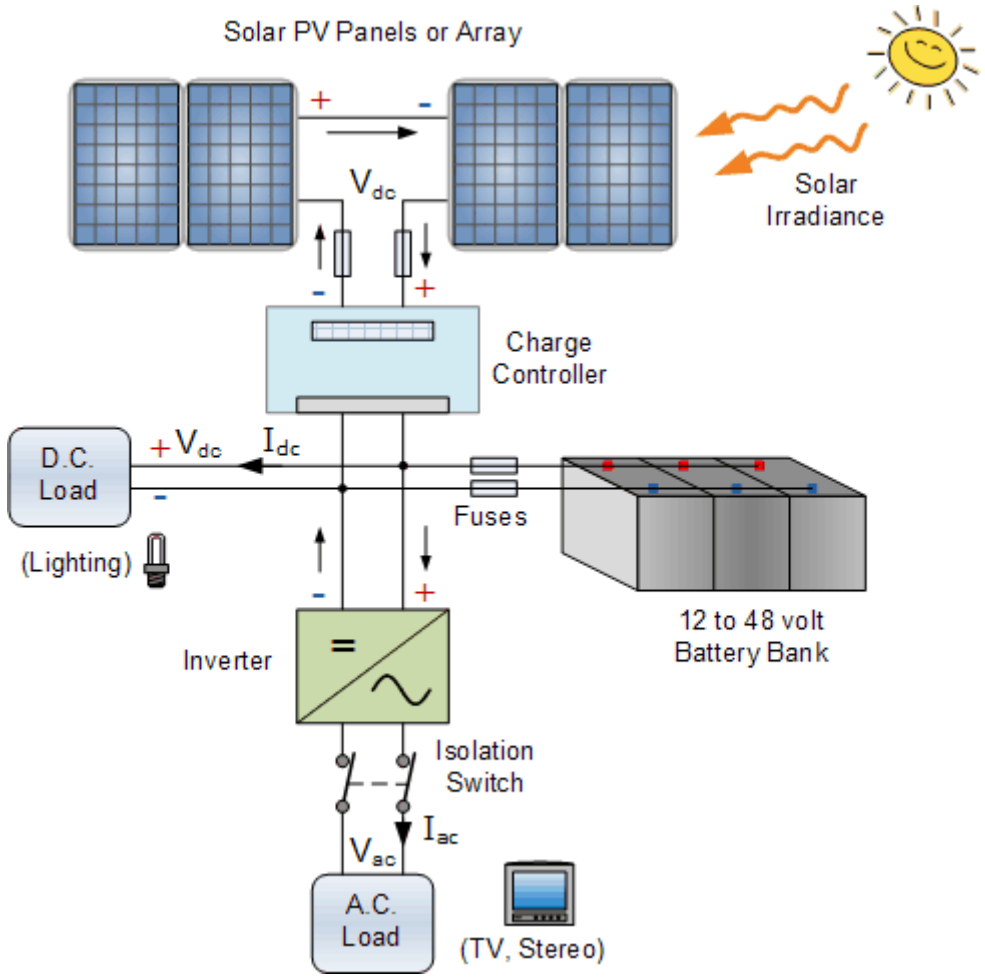


Figure II- 2 Standalone Solar Energy Systems.

The maximum numbers of equipment we use in our daily life are AC operated so some means is required to attach with the solar energy system so that we can run AC equipment as well with standalone solar system. Inverter is a device which converts DC to AC of specified voltage and frequency. Inverter is basically a DC to AC converter whose input is DC and output is AC of desired voltage and frequency. So if we connect an inverter across the DC output terminals of electronic control device along with the DC load then the system becomes able to run AC equipments as well. As this system can operate both DC and AC load, the system becomes most popular version of standalone solar energy system. Nearly all kinds of DC and AC load can be operated by this system such as AC/DC fan, computer, TV, tube lights, CFL, LED lamps etc. This system is most suitable as alternative of grid electric supply where limited grid electric supply is available.

II-5-2 Grid-Connected PV System:

A grid-connected PV system is one where the photovoltaic panels or array are connected to the utility grid through a power inverter unit allowing them to operate in parallel with the electric utility grid. In recent years, however, the number of solar-powered homes connected to the local electricity grid has increased dramatically. These Grid Connected PV Systems have solar panels that provide some or even most of their power needs during the daytime, while still being connected to the local electrical grid network during the night-time.

Solar-powered PV systems can sometimes produce more electricity than is actually needed or consumed, especially during the long hot summer months. This extra or surplus electricity is either stored in batteries or as in most grid-connected PV systems, fed directly back into the electrical grid network. In other words, homes, and buildings that use a grid-connected PV system can use a portion or all of their energy needs with solar energy, and still use power from the normal electrical mains grid during the night or on cloudy dull, and rainy days, giving the best of both worlds. Then in grid-connected PV systems, electricity flows back and forth to and from the mains grid according to sunlight conditions and the actual electrical demand at that time.

In a grid-connected PV system, also known as a “grid-tied”, or “on-grid” solar system, the PV solar panels or array are electrically connected or “tied” to the local mains electricity grid which feeds electrical energy back into the grid.

The main advantage of a grid-connected PV system is its simplicity, relatively low operating and maintenance costs as well as reduced electricity bills. The disadvantage however is that a sufficient number of solar panels need to be installed to generate the required amount of excess power.

Since grid-tied systems feed their solar energy directly back into the grid, expensive backup batteries are not necessary and can be omitted from most grid-connected designs.

II-5-2.1 Solar Power Integration to Grid:

The solar power fed to the grid will need to possess certain characteristics when it comes to frequency, voltage level, and power quality. The process of converting the raw power produced by the PV array into electricity for the grid takes measures in

maximizing the amount of power extracted at all levels of irradiation while using strategies for mitigating problems arising from differential shading of the modules. For a traditional grid-connected PV system, the conversion from raw DC power to refined AC power is carried out in two main steps. The first step usually involves boosting the DC power from the PV array by using a DC-DC converter in addition to applying maximum power point tracking (MPPT) techniques to trace the most optimal operating point on the IV curve. The next step is to transfer this power into AC power, with the right requirements for the grid, using DC-AC inverters.

II-5-2.2 Configurations of grid-connected PV systems:

The configurations used for the grid-connected PV systems are summarized as follows.

Centralized configuration: The dominant configuration for utility-scale PV systems. The array consists of parallel-connected strings that are all connected to the same inverter that converts the DC power from the array into AC power to be fed directly into the grid. Notice that the DC-DC stage is omitted which means that the module configuration itself needs to provide high enough voltage for grid integration without being boosted. Since the system do not include a DC-DC converter, the MPPT must be carried out by the DC-AC inverter. This is usually a configuration used for high-power PV arrays. If the voltage is not sufficiently high, the configuration must be modified to include a DC-DC converter on the DC side of the inverter or use a transformer on the AC side to increase the voltage. this configuration is shown in FigureII-3.

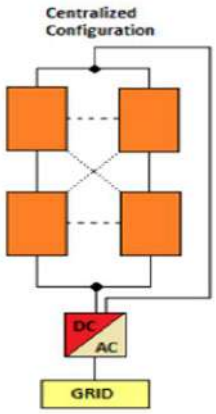


Figure II- 3 Centralized configuration.

String configuration: Instead of having all of the power created by the array going through the same inverter, all the strings are connected to their own DC-AC inverter. The MPPT system is carried out individually for each string, which could reduce mismatch losses. The AC power from each string is collected and fed to the grid. This is in effect the same configuration as the centralized configuration, except that more converters are needed. Just like for the centralized configuration, if the voltage is too low, a DC-DC converter can be introduced on the DC side, or a transformer can be added on the AC side. A model of this configuration is shown in Figure II-4.

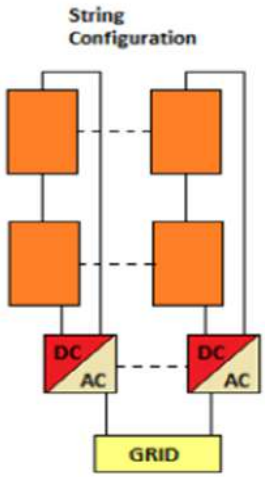


Figure II- 4 String configuration.

Multi string configuration: Each string is connected to its own DC-DC boost converter. The MPPT is implemented in the DC-DC converters, and the tracking is therefore conducted for each string. The DC boosted power produced by each string is then collected into one single DC-AC inverter that is connected to the three-phase grid. This is a configuration of high efficiency. A figure of this configuration is shown in Figure II-5.

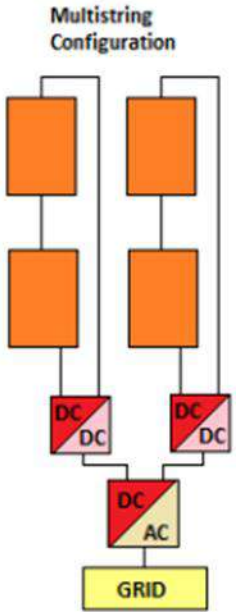


Figure II- 5 Multi string configuration.

AC module configuration: Each module is MPPT controlled by inserting DC-AC converters on each of them. By having each module individually MPPT-tracked, mismatch losses are reduced. This configuration is more expensive than the others but can be the right choice if the array is exposed to partial shading A model of the configuration can be seen in Figure II-6.

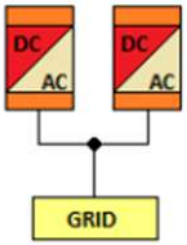


Figure II- 6 AC module configuration.

Modular Configuration: Each string has its own DC-DC converter that also conducts MPPT. The boosted DC power from all the converters is collected on a DC bus. From the DC bus, many DC-AC inverters are connected which produces the necessary power for grid connection. The configuration can be seen in Figure II-7.

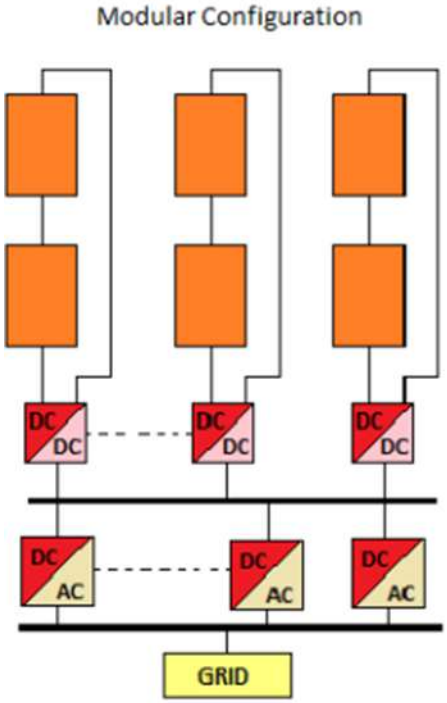


Figure II- 7 Modular Configuration.

II-5-2-3 Components of grid-connected PV system:

Grid-connected PV systems always have a connection to the public electricity grid via a suitable inverter because a photovoltaic panel or array (multiple PV panels) only deliver DC power. As well as the solar panels, the additional components that make up a grid-connected PV system compared to a stand-alone PV system are:

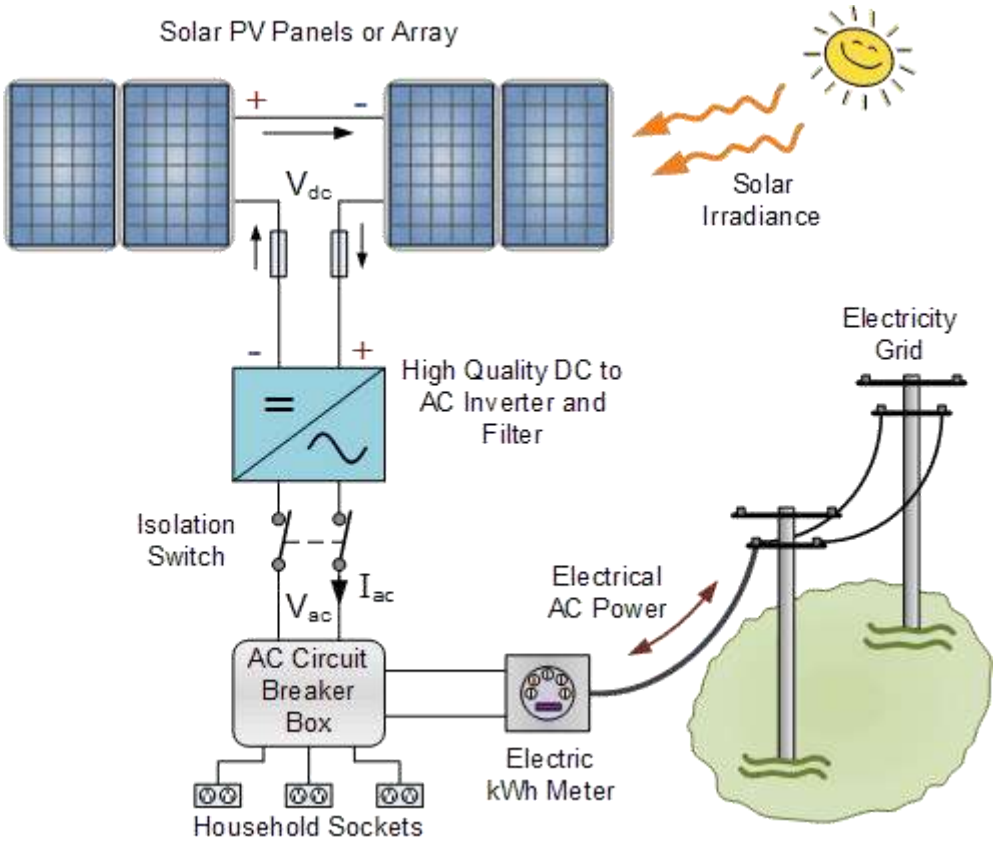


Figure II- 8 components of grid-connected system.

Inverter: The inverter is the most important part of any grid-connected system. The inverter extracts as much DC (direct current) electricity as possible from the PV array and converts it into clean mains AC (alternating current) electricity at the right voltage and frequency for feeding into the grid or for supplying domestic loads. It is important to choose the best quality inverter possible for the budget allowed as the main considerations in grid-connected inverter choice are: Power – Maximum high and low voltage power the inverter can handle and Efficiency – How efficiently does the inverter convert solar power to AC power.

Electricity Meter: The electricity meter also called a Kilowatt-hour (kWh) meter is used to record the flow of electricity to and from the grid. Twin kWh meters can be used, one to indicate the electrical energy being consumed and the other to record the solar electricity being sent to the grid.

A single bidirectional kWh meter can also be used to indicate the net amount of electricity taken from the grid. A grid connected PV system will slow down or halt the

aluminum disc in the electric meter and may cause it to spin backwards. This is generally referred to as net metering.

AC Breaker Panel and Fuses: The breaker panel or fuse box is the normal type of fuse box provided with a domestic electricity supply and installation with the exception of additional breakers for inverter and/or filter connections.

Safety Switches and Cabling: A photovoltaic array will always produce a voltage output in sunlight so it must be possible to disconnect it from the inverter for maintenance or testing. Isolator switches rated for the maximum DC voltage and current of the array and inverter safety switches must be provided separately with easy access to disconnect the system.

Other safety features demanded by the electrical company may include earthing and fuses. The electrical cables used to connect the various components must also be correctly rated and sized.

The Electricity Grid: Finally, the electricity grid itself connects too because without the utility grid it is not a Grid-Connected PV System.

A grid-connected system without batteries is the simplest and cheapest solar power setup available, and by not having to charge and maintain batteries they are also more efficient. It is important to note that a grid-connected solar power system is not an independent power source, unlike a stand-alone system. Should the mains supply from the electrical grid be interrupted, the lights may go out, even if the sun is shining. One way to overcome this is to have some form of short-term energy storage built into the design.

II-5-3 Hybrid PV Systems:

A hybrid PV system is a combination of multiple sources of power to enhance the availability and usage of power. Such a system can leverage energy from sources such as wind, sun, or even hydrocarbons. Furthermore, hybrid PV systems are often backed up with a battery to maximize the efficiency of the system. There are various advantages of using a hybrid system. Multiple sources of energy mean that the system is not dependent on any particular energy source. For instance, if the weather is not conducive to generating enough solar energy, the PV array can charge the battery. Similarly, if it’s windy or cloudy, a wind turbine can address the charging

requirements of the battery. Hybrid PV systems are best suited for isolated places with limited grid connections.

Despite the above advantages, there are a few challenges associated with a hybrid system. For instance, it involves a complex design and installation process. Moreover, multiple sources of energy can increase the upfront costs.

II-7 Conclusion:

In summation, the reviewed studies focusing on standalone solar energy systems and hybrid renewable energy systems show that solar energy source play an important role in electrical energy generation. To add, Algeria is focusing on the usage of renewable energy resources, especially solar energy, and this is shown by the projects that Algeria has already done by using solar energy. In addition, the environmental and health issues of conventional energy sources have been discussed. What's more, the economics of solar energy is provided, and some studies suggest that the price of this energy will decrease in the future. Lastly, with reviewing the last conducted studies about the renewable energy potentials for Algeria, it is clear that Algeria has high potential to utilize renewable energy resources, especially solar and wind energy, to reduce dependency on conventional energy sources, depending on the location in Algeria.

Chapter III: HOMER modeling and simulation

III-1 Homer modeling:

III-1-1 Introduction:

The HOMER Micro Power Optimization Model is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist in the design of micro power systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER allows the modeler to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs.

A micro power system is a system that generates electricity, and possibly heat, to serve a nearby load. Such a system may employ any combination of electrical generation and storage technologies and may be grid-connected or autonomous, meaning separate from any transmission grid. Some examples of micro power systems are a solar–battery system serving a remote load, a wind–diesel system serving an isolated village, and a grid-connected natural gas micro turbine providing electricity and heat to a factory. Power plants that supply electricity to a high-voltage transmission system do not qualify as micro power systems because they are not dedicated to a particular load. HOMER can model grid-connected and off-grid micropower systems serving electric and thermal loads, and comprising any combination of photovoltaic (PV) modules, wind turbines, small hydro, biomass power, reciprocating engine generators, micro turbines, fuel cells, batteries, and hydrogen storage.

The analysis and design of micro power systems can be challenging, due to the large number of design options and the uncertainty in key parameters, such as load size and future fuel price. Renewable power sources add further complexity because their power output may be intermittent, seasonal, and non-dispatchable, and the availability of renewable resources may be uncertain. HOMER was designed to overcome these challenges.

HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis. In the simulation process, HOMER models the performance of a particular micro power system configuration each hour of the year to determine its technical feasibility and life-cycle cost. In the optimization process, HOMER simulates many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, HOMER performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs. Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each. Sensitivity analysis helps assess the effects of uncertainty or changes in the variables over which the designer has no control, such as the average wind speed or the future fuel price.

Figure III.1 illustrates the relationship between simulation, optimization, and sensitivity analysis. The optimization oval encloses the simulation oval to represent the fact that a single optimization consists of multiple simulations. Similarly, the sensitivity analysis oval encompasses the optimization oval because a single sensitivity analysis consists of multiple optimizations.

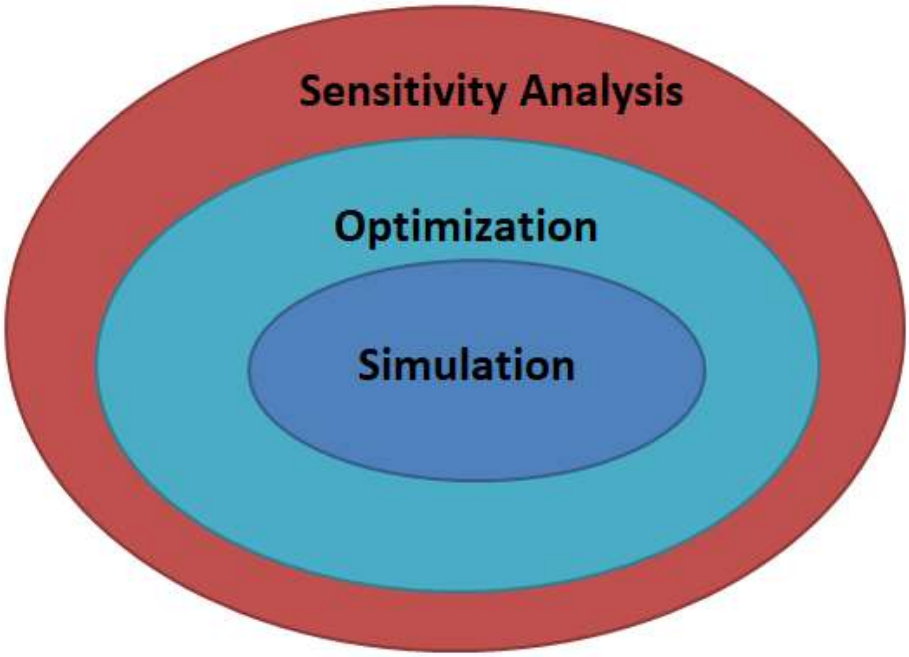


Figure III- 1 relationship between simulation, optimization, and sensitivity analysis.

To limit input complexity, and to permit fast enough computation to make optimization and sensitivity analysis practical, HOMER's simulation logic is less detailed than that of several other time-series simulation models for micropower systems, such as Hybrid2. On the other hand, HOMER is more detailed than statistical models such as RET Screen, which do not perform time-series simulations. Of all these models, HOMER is the most flexible in terms of the diversity of systems it can simulate.

III-1-2 Simulation:

HOMER's fundamental capability is simulating the long-term operation of a micro power system. Its higher-level capabilities, optimization and sensitivity analysis, rely on this simulation capability. The simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period of time.

HOMER can simulate a wide variety of micro power system configurations, comprising any combination of a PV array, one or more wind turbines, a run-of-river hydro-turbine, and up to three generators, a battery bank, an ac–dc converter, an electrolyzer, and a hydrogen storage tank. The system can be grid-connected or autonomous and can serve ac and dc electric loads and a thermal load. The simulation process serves two purposes. First, it determines whether the system is feasible. HOMER considers the system to be feasible if it can adequately serve the electric and thermal loads and satisfy any other constraints imposed by the user. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. The life-cycle cost is a convenient metric for comparing the economics of various system configurations. Such comparisons are the basis of HOMER's optimization process.

HOMER models a particular system configuration by performing an hourly time series simulation of its operation over one year. HOMER steps through the year 58 one hour at a time, calculating the available renewable power, comparing it to the electric load, and deciding what to do with surplus renewable power in times of excess, or how best to generate (or purchase from the grid) additional power in times of deficit. When it has completed one year's worth of calculations, HOMER determines whether the system satisfies the constraints imposed by the user on such quantities as the

fraction of the total electrical demand served, the proportion of power generated by renewable sources, or the emissions of certain pollutants. HOMER also computes the quantities required to calculate the system's life-cycle cost, such as the annual fuel consumption, annual generator operating hours, expected battery life, or the quantity of power purchased annually from the grid.

The quantity HOMER uses to represent the life-cycle cost of the system is the total net present cost (NPC). This single value includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. The total net present cost includes the initial capital cost of the system components, the cost of any component replacements that occur within the project lifetime, the cost of maintenance and fuel, and the cost of purchasing power from the grid. Any revenue from the sale of power to the grid reduces the total NPC. In Section 3.1.4 we describe in greater detail how HOMER calculates the total NPC. For many types of micro power systems, particularly those involving intermittent renewable power sources, a one-hour time step is necessary to model the behavior of the system with acceptable accuracy.

III-1-3 Optimization and Sensitivity Analysis:

Whereas the simulation process models a particular system configuration, the optimization process determines the best possible system configuration. In HOMER, the best possible, or optimal, system configuration is the one that satisfies the user specified constraints at the lowest total net present cost. Finding the optimal system configuration may involve deciding on the mix of components that the system should contain, the size or quantity of each component, and the dispatch strategy the system should use. In the optimization process, HOMER simulates many different system configurations, discards the infeasible ones (those that do not satisfy the user specified constraints), ranks the feasible ones according to total net present cost, and presents the feasible one with the lowest total net present cost as the optimal system configuration.

The goal of the optimization process is to determine the optimal value of each decision variable that interests the modeler. A decision variable is a variable over which the system designer has control and for which HOMER can consider multiple possible values in its optimization process. Possible decision variables in HOMER include:

- The size of the PV array
- The number of wind turbines
- The presence of the hydro system The size of each generator
- The number of batteries
- The size of the ac-dc converter
- The dispatch strategy (the set of rules governing how the system operates)

Optimization can help the modeler find the optimal system configuration out of many possibilities. Consider, for example, the task of retrofitting an existing diesel power system with wind turbines and batteries. In analyzing the options for redesigning the system, the modeler may want to consider the arrangement of components shown in Figure 3.2, but would not know in advance what number of PV panel, what number of batteries, and what size of converter minimize the lifecycle cost. These three variables would therefore be decision variables in this analysis. HOMER allows the modeler to enter multiple values for each decision variable.

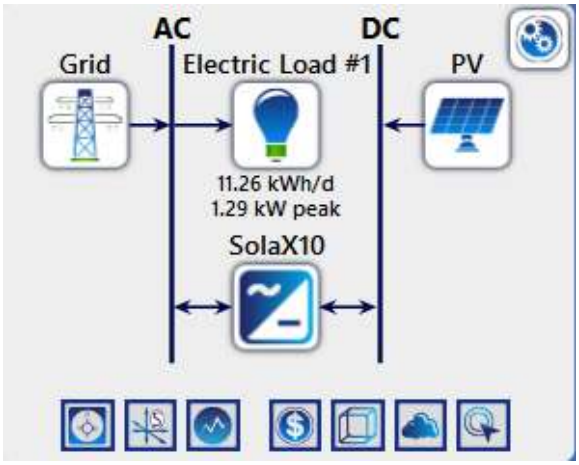


Figure III- 2 Hybrid PV-Grid system.

The optimization results tables allow this kind of comparison because they display more than just the optimal system configuration. The overall optimization results table in particular tends to show many system configurations whose total net present cost is

only slightly higher than that of the optimal configuration. The modeler may decide that one of these suboptimal configurations is preferable in some way to the configuration that HOMER presents as optimal.

Architecture				Cost					System		PV	
PV (kW)	PV-MPPT (kW)	Grid (kW)	SolaX10 (kW)	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
12.0	10.0	999,999	6.00	-$517,648	-$2.13	-$93,109	$814,000	-$95,831	90.5	0	760,000	18,077
12.0	10.0	999,999	6.00	-$517,648	-$2.13	-$93,109	$814,000	-$95,831	90.5	0	760,000	18,077
11.9	10.0	999,999	6.00	-$515,716	-$2.14	-$92,494	$807,125	-$95,215	90.5	0	753,125	17,897
11.9	10.0	999,999	6.00	-$515,716	-$2.14	-$92,494	$807,125	-$95,215	90.5	0	753,125	17,897
11.8	10.0	999,999	6.00	-$513,329	-$2.14	-$91,846	$800,250	-$94,567	90.4	0	746,250	17,715
11.8	10.0	999,999	6.00	-$513,329	-$2.14	-$91,846	$800,250	-$94,567	90.4	0	746,250	17,715
11.9	10.0	999,999	5.98	-$508,894	-$2.11	-$92,243	$810,356	-$94,964	90.5	0	756,562	17,987
11.9	10.0	999,999	5.98	-$508,894	-$2.11	-$92,243	$810,356	-$94,964	90.5	0	756,562	17,987
11.5	10.0	999,999	6.00	-$507,112	-$2.13	-$90,450	$786,500	-$93,171	90.3	0	732,500	17,348
11.5	10.0	999,999	6.00	-$507,112	-$2.13	-$90,450	$786,500	-$93,171	90.3	0	732,500	17,348
12.0	10.0	999,999	5.95	-$501,801	-$2.08	-$91,972	$813,588	-$94,694	90.5	0	760,000	18,077
12.0	10.0	999,999	5.95	-$501,801	-$2.08	-$91,972	$813,588	-$94,694	90.5	0	760,000	18,077

Figure III- 3 Categorized Optimization results table.

HOMER finds the system configuration that is optimal under a particular set of input assumptions. In this section we describe the sensitivity analysis process, in which HOMER performs multiple optimizations, each using a different set of input assumptions. A sensitivity analysis reveals how sensitive the outputs are to changes in the inputs. In a sensitivity analysis, the HOMER user enters a range of values for a single input variable. A variable for which the user has entered multiple values is called a sensitivity variable. Almost every numerical input variable in HOMER that is not a decision variable can be a sensitivity variable. Examples include the grid power price, the fuel price, the interest rate, or the lifetime of the PV array. The magnitude of an hourly data set, such as load and renewable resource data, can also be a sensitivity variable.

III-1-4 Economic Modelling:

Economics play an integral role both in HOMER's simulation process, wherein it operates the system so as to minimize total net present cost, and in its optimization process, wherein it searches for the system configuration with the lowest total net present cost. This section describes why life-cycle cost is the appropriate metric with

which to compare the economics of different system configurations, why HOMER uses the total net present cost as the economic figure of merit, and how HOMER calculates total net present cost. Renewable and non-renewable energy sources typically have dramatically different cost characteristics. Renewable sources tend to have high initial capital costs and low operating costs, whereas conventional non-renewable sources tend to have low capital and high operating costs. In its optimization process, HOMER must often compare the economics of a wide range of system configurations comprising varying amounts of renewable and non-renewable energy sources. To be equitable, such comparisons must account for both capital and operating costs. Life-cycle cost analysis does so by including all costs that occur within the life span of the system.

HOMER uses the total net present cost (NPC) to represent the life-cycle cost of a system. The total NPC condenses all the costs and revenues that occur within the project lifetime into one lump sum in today's dollars, with future cash flows discounted back to the present using the discount rate. The modeler specifies the discount rate and the project lifetime. The NPC includes the costs of initial 64 constructions, component replacements, maintenance, fuel, plus the cost of buying power from the grid and miscellaneous costs such as penalties resulting from pollutant emissions. Revenues include income from selling power to the grid, plus any salvage value that occurs at the end of the project lifetime. With the NPC, costs are positive and revenues are negative. This is the opposite of the net present value. As a result, the net present cost is different from net present value only in sign.

HOMER assumes that all prices escalate at the same rate over the project lifetime. With that assumption, inflation can be factored out of the analysis simply by using the real (inflation-adjusted) interest rate rather than the nominal interest rate when discounting future cash flows to the present. The HOMER user therefore enters the real interest rate, which is roughly equal to the nominal interest rate minus the inflation rate. All costs in HOMER are real costs, meaning that they are defined in terms of constant dollars. Life-cycle cost analysis does so by including all costs that occur within the life span of the system.

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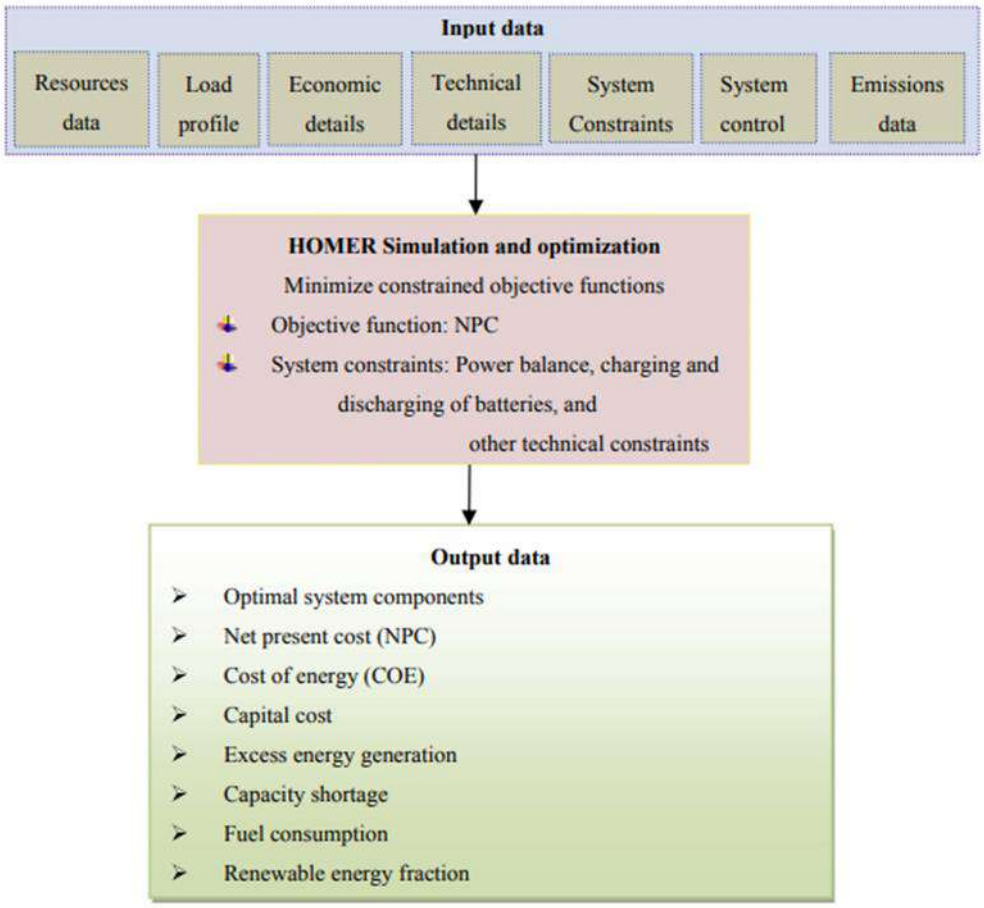


Figure III- 4 Schematic representation of HOMER software.

To calculate the salvage value of each component at the end of the project lifetime, HOMER uses the equation:

$$S_V = C_{rep}\left(\frac{R_{rem}}{R_{comp}}\right) \tag{3.1}$$

where S_V is the salvage value, Crep the replacement cost of the component, Rrem the remaining life of the component, and Rcomp the lifetime of the component. For example, if the project lifetime is 20 years and the PVarray lifetime is also 20 years, the salvage value of the PV array at the end of the project lifetime will be zero because it has no remaining life. On the other hand, if the PV array lifetime is 30 years, at the

end of the 20-year project lifetime its salvage value will be one-third of its replacement cost.

For each component, HOMER combines the capital, replacement, maintenance, and fuel costs, along with the salvage value and any other costs or revenues, to find the component's annualized cost. This is the hypothetical annual cost that if it occurred each year of the project lifetime would yield a net present cost equivalent to that of all the individual costs and revenues associated with that component over the project lifetime. HOMER sums the annualized costs of each component, along with any miscellaneous costs, such as penalties for pollutant emissions, to find the total annualized cost of the system. This value is an important one because HOMER uses it to calculate the two principal economic figures of merit for the system: the total net present cost and the levelized cost of energy.

HOMER uses the following equation to calculate the total net present cost:

$$C_{npc} = \frac{C_{ann,tot}}{CRF_{(i,R_{proj})}} \tag{3.2}$$

where $C_{ann,\,tot}$ is the total annualized cost, i the annual real interest rate (the discount rate), R_{proj} the project lifetime, and CRF(.) is the capital recovery factor.

III-1-4-1 Levelized cost of energy (COE) (DA/kWh):

COE is defined by the HOMER program as the following. «To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served". COE is calculated by Equation (3.3)

$$COE = \frac{C_{ann,tot}}{E_{prim}+E_{def}+E_{grid,sales}} \tag{3.3}$$

where $C_{ann,\,tot}$ is the total annualized cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively, that the system serves per year, and $E_{grid,sales}$

is the amount of energy sold to the grid per year. The denominator in equation (3.3) is an expression of the total amount of useful energy that the system produces per year. The levelized cost of energy is therefore the average cost per kilowatt-hour of useful electrical energy produced by the system. Although the levelized cost of energy is often a convenient metric with which to compare the costs of different systems, HOMER uses the total NPC instead as its primary economic figure of merit. In its optimization process, for example, HOMER ranks the system configurations according to NPC rather than levelized cost of energy. This is because the definition of the levelized cost of energy is disputable in a way that the definition of the total NPC is not. In developing the formula that HOMER uses for the levelized cost of energy, we decided to divide by the amount of electrical load that the system actually serves rather than the total electrical demand, which may be different if the user allows some unmet load.

III-1-4-2 Assessment Criteria for Optimization:

In this study, the assessment criteria such as the net present cost, Levelized cost of energy,

The operating cost, and initial capital cost, are taken into consideration during the optimization phase. The detailed description of each criterion is defined in the sub-headings below.

III-1-4-3 Net present cost (DA):

The cost term "NPC" is defined by the HOMER program as the following. "The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating the component over the project lifetime, minus the present value of all the revenues that earns over the project lifetime. HOMER calculates the net present cost of each component in the system and of the system as a whole.

III-1-4-4 Operating Cost:

Operating cost is defined by the HOMER program as the following. “The operating cost is the annualized value of all costs and revenues other than initial capital costs. Operating cost is calculated using Equation 2

$$C_{operating} = C_{ann,tot} - C_{ann,cap} \tag{3.4}$$

where:

$C_{operating}$ is the total annualized cost of the system (DA/yr),

$C_{ann,cap}$ is the total annualized capital cost (DA/yr).

III-1-4-5 Initial capital cost:

The initial capital cost of a component is the total installed cost of that component at the beginning of the project.

III-1-5 Micro Sources:

The term resource applies to anything coming from outside the system that is used by the system to generate electric or thermal power. That includes the four renewable resources (solar, wind, hydro, and biomass) as well as any fuel used by the components of the system. Renewable resources vary enormously by location. The 67 solar resource depends strongly on latitude and climate, the wind resource on largescale atmospheric circulation patterns and geographic influences, the hydro resource on local rainfall patterns and topography, and the biomass resource on local biological productivity. Moreover, at any one location a renewable resource may exhibit strong seasonal and hour-to-hour variability. The nature of the available renewable resources affects the behavior and economics of renewable power systems, since the resource determines the quantity and the timing of renewable power production. The careful modelling of the renewable resources is therefore an essential element of system modelling. In this section we describe how HOMER models the solar and wind renewable resources and the fuel.



Figure III- 5 HOMER Resources.

In HOMER, a component is any part of a micro power system that generates, delivers, converts, or stores energy. HOMER models 10 types of components. Three generate electricity from intermittent renewable sources: photovoltaic modules, wind turbines, and hydro turbines. PV modules convert solar radiation into dc electricity. Wind turbines convert wind energy into ac or dc electricity. Hydro turbines convert the energy of flowing water into ac or dc electricity. HOMER can only model run-ofriver hydro installations, meaning those that do not comprise a storage reservoir.



Figure III- 6 HOMER Components.

Another three types of components, generators, the grid, and boilers, are dispatchable energy sources, meaning that the system can control them as needed. Generators consume fuel to produce ac or dc electricity. A generator may also produce thermal power via waste heat recovery. The grid delivers ac electricity to a grid-connected system and may also accept surplus electricity from the system. Boilers consume fuel to produce thermal power

Two types of components, converters and electrolyzes, convert electrical energy into another form. Converters convert electricity from ac to dc or from dc to ac. Electrolyzes convert surplus ac or dc electricity into hydrogen via the electrolysis of water. The system can store the hydrogen and use it as fuel for one or more generators. Finally, two types of components store energy: batteries and hydrogen storage tanks. Batteries store dc electricity. Hydrogen tanks store hydrogen from the electrolyzer to fuel one or more generators. In this section we explain how HOMER models each of these components and discuss the physical and economic properties that the user can use to describe each.

III-1-5-1 Photovoltaic:

Solar Resource data: To model a system containing a PV array, the HOMER user must provide solar resource data for the location of interest. Solar resource data indicate the amount of global solar radiation (beam radiation coming directly from the sun, plus diffuse radiation coming from all parts of the sky) that strikes Earth's surface in a typical year. The data can be in one of three forms: hourly average global solar radiation on the horizontal surface (kW/m^2), monthly average global solar radiation on the horizontal surface (kWh/m2 *day), or monthly average clearness index. The clearness index is the ratio of the solar radiation striking Earth's surface to the solar radiation striking the top of the atmosphere. A number between zero and 1, the clearness index is a measure of the clearness of the atmosphere.

If the user chooses to provide monthly solar resource data, HOMER generates synthetic hourly global solar radiation data using an algorithm developed by Graham and Hollands. The inputs to this algorithm are the monthly average solar radiation values and the latitude. The output is an 8760-hour data set with statistical characteristics similar to those of real measured data sets. One of those statistical properties is autocorrelation, which is the tendency for one day to be similar to the preceding day, and for one hour to be similar to the preceding hour.



Figure III- 7 average monthly temperature data for the location.

PV Array: HOMER models the PV array as a device that produces dc electricity in direct proportion to the global solar radiation incident upon it, independent of its temperature and the voltage to which it is exposed. HOMER calculates the power output of the PV array using the equation (3.5):

$$P_{PV} = f_{PV}.Y_{PV}.\frac{I_T}{I_S} \quad (3.5)$$

Where, f_{PV} is the PV derating factor, Y_{PV} the rated capacity of the PV array (kW), I_T the global solar radiation (beam plus diffuse) incident on the surface of the PV array (kW/m^2), and I_S is 1 kW/m^{2,} which is the standard amount of radiation used to rate the capacity of the PV array. In the following paragraphs we describe these variables in more detail.

The rated capacity (sometimes called the peak capacity) of a PV array is the amount of power it would produce under standard test conditions of 1 kW/m2 irradiance and a panel temperature of 25^{0}C. In HOMER, the size of a PV array is always specified in terms of rated capacity. The rated capacity accounts for both the area and the efficiency of the PV module, so neither of those parameters appears explicitly in HOMER. A 40-W module made of amorphous silicon (which has a relatively low efficiency) will be larger than a 40-W module made of polycrystalline silicon (which has a relatively high efficiency), but that size difference is of no consequence to HOMER.

Each hour of the year, HOMER calculates the global solar radiation incident on the PV array using the model of Duffie and Beckmann. This model takes into account the current value of the solar resource (the global solar radiation incident on a horizontal surface), the orientation of the PV array, the location on Earth's surface, the time of year, and the time of day. The orientation of the array may be fixed or may vary according to one of several tracking schemes. The derating factor is a scaling factor meant to account for effects of dust on the panel, wire losses, elevated temperature, or anything else that would cause the output of the PV array to deviate from that expected under ideal conditions. HOMER does not account for the fact that the power output of a PV array decreases with increasing panel temperature, but the HOMER user can reduce the derating factor to (crudely) correct for this effect when modelling systems for hot climates.

In reality, the output of a PV array does depend strongly and nonlinearly on the voltage to which it is exposed. The maximum power point (the voltage at which the power output is maximized) depends on the solar radiation and the temperature. If the PV array is connected directly to a dc load or a battery bank, it will often be exposed

to a voltage different from the maximum power point, and performance will suffer. A maximum power point tracker (MPPT) is a solid-state device placed between the PV array and the rest of the dc components of the system that decouples the array voltage from that of the rest of the system, and ensures that the array voltage is always equal to the maximum power point. By ignoring the effect of the voltage to which the PV array is exposed, HOMER effectively assumes that a maximum power point tracker is present in the system.

To describe the cost of the PV array, the user specifies its initial capital cost in dollars, replacement cost in dollars, and operating and maintenance (O&M) cost in 70 dollars per year. The replacement cost is the cost of replacing the PV array at the end of its useful lifetime, which the user specifies in years. By default, the replacement cost is equal to the capital cost, but the two can differ for several reasons. For example, a donor organization may cover some or all of the initial capital cost but none of the replacement cost.

III-1-5-2 Converter:

A converter is a device that converts electric power from dc to ac in a process called inversion, and/or from ac to dc in a process called rectification. HOMER can model the two common types of converters: solid-state and rotary. The converter size, which is a decision variable, refers to the inverter capacity, meaning the maximum amount of ac power that the device can produce by inverting dc power. The user specifies the rectifier capacity, which is the maximum amount of dc power that the device can produce by rectifying ac power, as a percentage of the inverter capacity. The rectifier capacity is therefore not a separate decision variable. HOMER assumes that the inverter and rectifier capacities are not surge capacities that the device can withstand for only short periods of time, but rather, continuous capacities that the device can withstand for as long as necessary.

The HOMER user indicates whether the inverter can operate in parallel with another ac power source such as a generator or the grid. Doing so requires the inverter to synchronize to the ac frequency, an ability that some inverters do not have. The final physical properties of the converter are its inversion and rectification efficiencies; which HOMER assumes to be constant. The economic properties of the converter are its

capital and replacement cost in dollars, its annual O&M cost in dollars per year, and its expected lifetime in years.

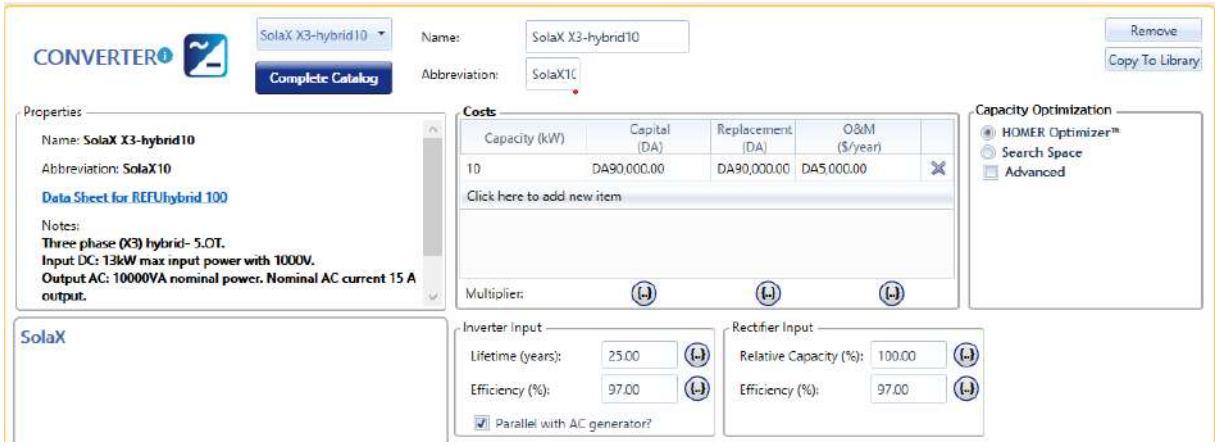


Figure III- 8 homer converter.

III-1-5-3 Load:

In HOMER, the term load refers to a demand for electric or thermal energy. Serving loads is the reason for the existence of micro power systems, so the modelling of a micro power system begins with the modelling of the load or loads that the system must serve. HOMER models three types of loads. Primary load is electric demand that must be served according to a particular schedule. Deferrable load is electric demand 79 that can be served at any time within a certain time span. Thermal load is demande for heat.



Figure III- 9 HOMER Loads.

Primary Load:

Primary load is electrical demand that the power system must meet at a specific time. Electrical demand associated with lights, radio, TV, household appliances, computers, and industrial processes is typically modelled as primary load. When a consumer switches on a light, the power system must supply electricity to that light immediately—the load cannot be deferred until later. If electrical demand exceeds supply, there is a shortfall that HOMER records as unmet load.

The HOMER user specifies an amount of primary load in kilowatts for each hour of the year, either by importing a file containing hourly data or by allowing HOMER to synthesize hourly data from average daily load profiles. When synthesizing load data, HOMER creates hourly load values based on user-specified daily load profiles. The modeler can specify a single 24-hour profile that applies throughout the year, or can specify different profiles for different months and different profiles for weekdays and weekends. HOMER adds a user-specified amount of randomness to synthesized load data so that every day's load pattern is unique. HOMER can model two separate primary loads, each of which can be ac or dc.

Among the three types of loads modelled in HOMER, primary load receives special treatment in that it requires a user-specified amount of operating reserve. Operating reserve is surplus electrical generating capacity that is operating and can respond instantly to a sudden increase in the electric load or a sudden decrease in the renewable power output. Although it has the same meaning as the more common term spinning reserve, we call it operating reserve because batteries, fuel cells, and the grid can provide it, but they do not spin. When simulating the operation of the system, HOMER attempts to ensure that the system's operating capacity is always sufficient to supply the primary load and the required operating reserve.



Figure III- 10 homer electric load **.**

III-1-5-4 Grid:

HOMER models the grid as a component from which the micro power system can purchase ac electricity and to which the system can sell ac electricity. The cost of purchasing power from the grid can comprise an energy charge based on the amount of energy purchased in a billing period and a demand charge based on the peak demand within the billing period. HOMER uses the term grid power price for the price (in dollars per kilowatt-hour) that the electric utility charges for energy purchased from the grid, and the demand rate for the price (in dollars per kilowatt per month) the utility charges for the peak grid demand. A third term, the sell back rate, refers to the price (in dollars per kilowatt-hour) that the utility pays for power sold to the grid.

The HOMER user can define and schedule up to 16 different rates, each of which can have different values of grid power price, demand rate, and sellback rate. The schedule of the rates can vary according to month, time of day, and weekday/ weekend. For example, HOMER could model a situation where an expensive rate applies during weekday afternoons in July and August, an intermediate rate applies during weekday afternoons in June and September and weekend afternoons from June to September, and an inexpensive rate applies at all other times.

HOMER can also model net metering, a billing arrangement whereby the utility charges the customer based on the net grid purchases (purchases minus sales) over the billing period. Under net metering, if purchases exceed sales over the billing 81 period, the consumer pays the utility an amount equal to the net grid purchases times the grid power cost. If sales exceed purchases over the billing period, the utility pays the consumer an amount equal to the net grid sales (sales minus purchases) times the sellback rate, which is typically less than the grid power price, and often zero. The billing period may be one month or one year. In the unusual situation where net metering applies to multiple rates, HOMER tracks the net grid purchases separately for each rate.

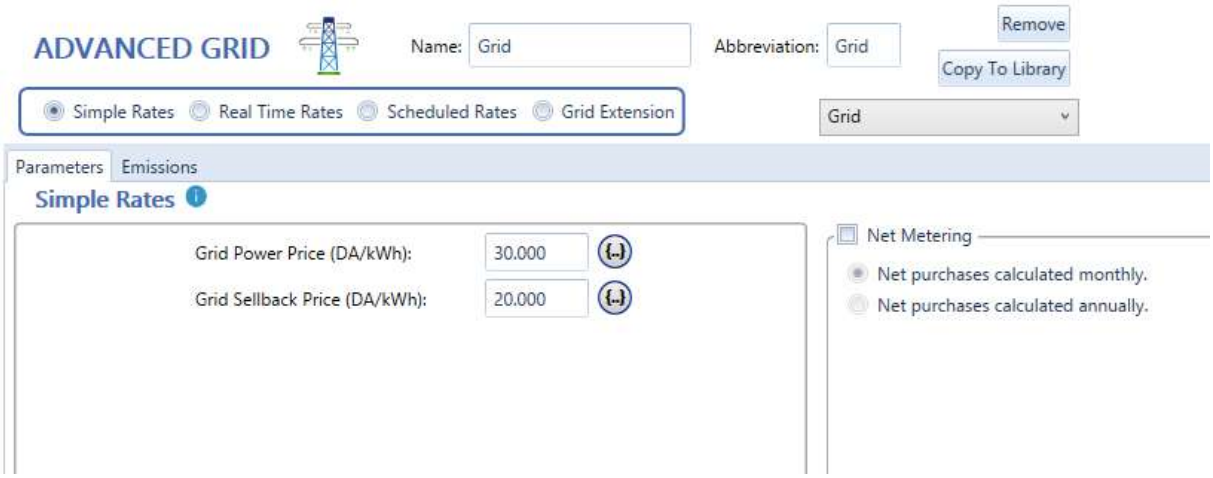


Figure III- 11 homer grid.

Two variables describe the grid's capacity to deliver and accept power. The maximum power sale is the maximum rate at which the power system can sell power to the grid. The user should set this value to zero if the utility does not allow sellback. The maximum grid demand is the maximum amount of power that can be drawn from the grid. It is a decision variable because of the effect of demand charges. HOMER does not explicitly consider the demand rate in its hour-by-hour decisions as to how to control the power system; it simply calculates the demand charge at the end of each simulation. As a result, when modelling a grid-connected generator, HOMER will not turn on the generator simply to save demand charges. But it will turn on a generator whenever the load exceeds the maximum grid demand. The maximum grid demand therefore acts as a control parameter that affects the operation and economics of the

system. Because it is a decision variable, the user can enter multiple values and HOMER can find the optimal one.

The user also enters the grid emissions coefficients, which HOMER uses to calculate the emissions of six pollutants associated with buying power from the grid, as well as the avoided emissions resulting from the sale of power to the grid. Each emissions coefficient has units of grams of pollutant emitted per kilowatt-hour consumed. Because it is a dispatchable power source, HOMER calculates the grid's fixed and marginal cost of energy. The fixed cost is zero, and the marginal cost is equal to the current grid power price plus any cost resulting from emissions penalties. Since the grid power price can change from hour to hour as the applicable rate changes, the grid's marginal cost of energy can also change from hour to hour. This can have important effects on HOMER's simulation of the system's behavior. For example, HOMER may choose to run a generator only during times of high grid power price, when the cost of grid power exceeds the cost of generator power.

III-2 HOMER Simulation:

III-2-1 introduction:

The aim of this work is to evaluate and compare the techno-economic performance of grid-connected photovoltaic (PV) power systems for a rooftop solar PV hotel in three climate zones in Algeria. The techno-economic performance of grid-connected PV system in the three regions was evaluated using the HOMER software. Monthly average electric production, economic and environmental considerations, and sensitivity analyses were all considered. The results show that the pollutants from grid-only and grid/PV systems come mainly in the form of CO2 emissions. In addition, this study concludes that grid/PV systems are technically, economically and environmentally feasible for all three climate zones. The excess electricity, NPC, and COE values of the grid/PV systems for all three climate zones increased with PV penetration increased, whereas the CO2 emissions for these climate zones decreased due to the increasing PV sizes. For the grid/PV systems of three climate zones, Tamenrast is the most economical with the least NPC (-1.23M DA) and COE (-4.35 DA). From an economic perspective, Tamenrast, with its hot climate conditions, may be especially suitable for grid/PV power generation.

III-2-3 Climatic:

Data for the climate zones under study The solar radiation data used in this study were obtained from the NASA Surface Meteorology and Solar Energy database. Figures.III-12 and III-13 show the monthly average global solar radiation and clearness index data for the proposed sites. The solar radiation values in Medea, Ghardaia and Tamenrast range between 2.26 kWh/m2 /d in December and 7.26 kWh/m2 /day in june-july (Medea), 2.56 kWh/m2 /day in December and 7.85 kWh/m2 /day in July (Ghardaia) and 4.64 kWh/m2 /day in December and 7.12 kWh/m2 /day in July (Tamenrast). The average solar radiation values over the year for Medea, Ghardaia and Tamenrasset were 4.84, 5.36 and 6.16 kWh/m2 /day respectively. Solar irradiance is high from April to September for Medea, Ghardaia and Tamenrasset.

Atmospheric cleanliness is defined by the clearness index, which was determined as 0.57, 0.61 and 0.66 for Medea, Ghardaia and Tamenrasset respectively.

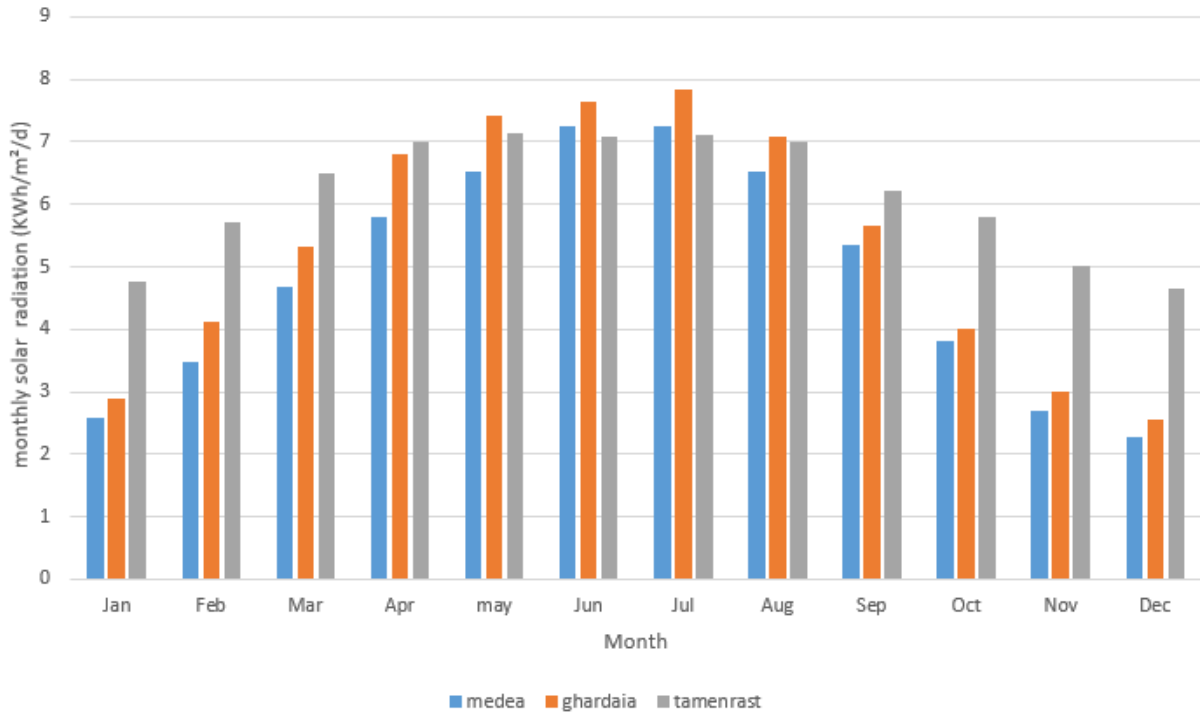


Figure III- 12 Monthly average global solar radiation for the proposed sites.

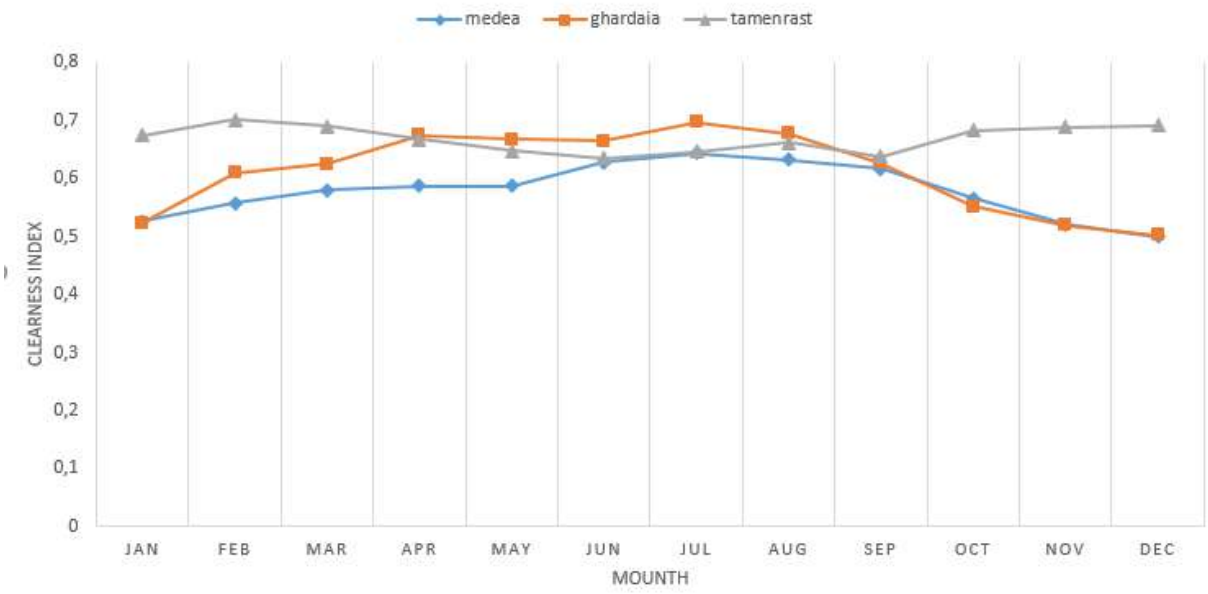


Figure III- 13 Monthly average clearness index for the proposed sites.

Ambient temperature data are important for defining the actual output power of the PV modules. Figure III-14 shows monthly average ambient temperature data. The minimum and maximum ambient temperatures were 8.04°C, 8.44°C and 11.46°C (January) and 27.2°C, 33.11°C and 29.2°C (August, July and June) for Medea, Ghardaia and Tamenrast respectively.

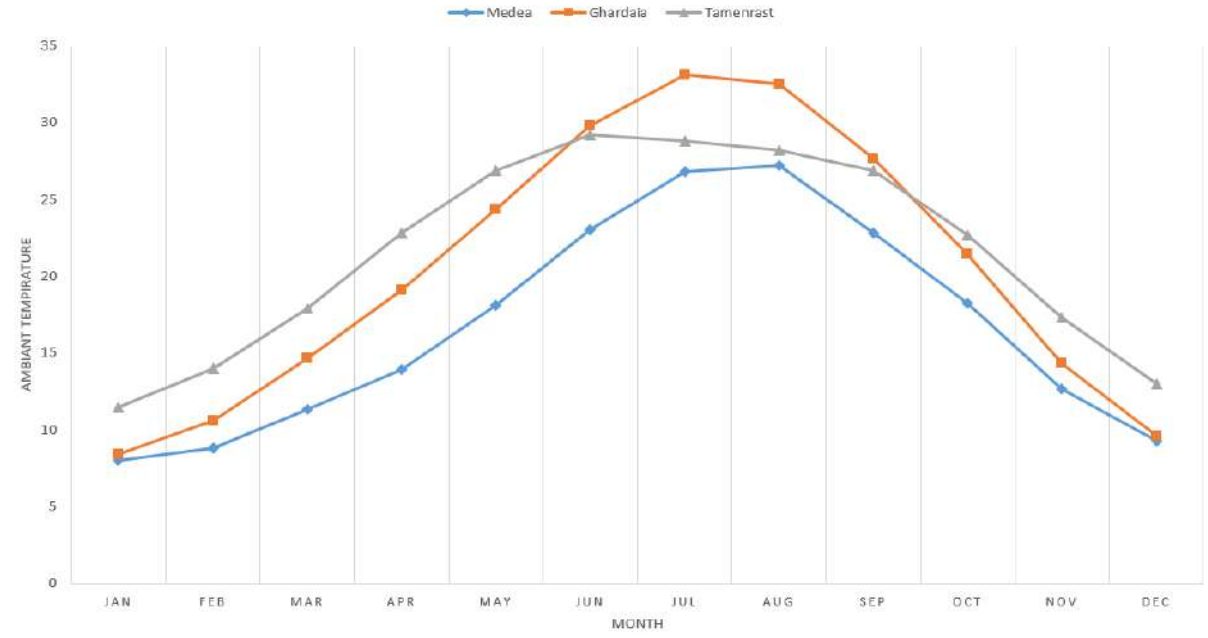


Figure III- 14 Monthly ambient temperature data for the study locations.

III-2-4 Description of the grid-connected PV power system:

A grid-connected PV power system is a PV array power system connected to a central grid. Figure III-15 shows a schematic diagram of the proposed grid-connected PV system. The total system consists of PV arrays, a DC/AC bi-directional converter, a, charge controller, DC and AC buses, load, and other accessory devices. The PV arrays act as the basic load power source and ensure a continuous power supply. Any excess power from the PV array can be fed to the utility grid. In this study, a grid-connected PV system was designed for a rooftop solar PV building containing a HOTEL in the three climate zones of Algeria considering meteorological and load data for these areas. The meteorological data consisted of monthly solar irradiation, clearness index, average ambient temperature, etc …

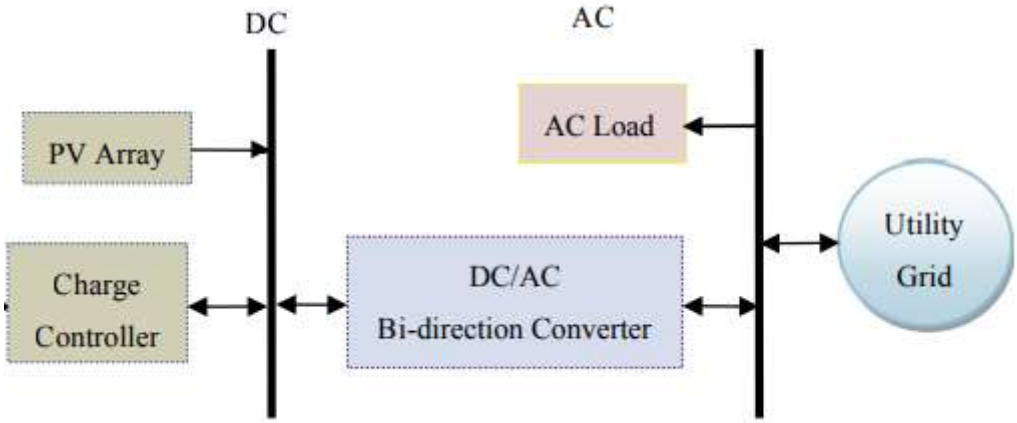


Figure III- 15 Schematic block diagram of the grid/PV system.

PV arrays PV array output is highly dependent on environmental conditions such as temperature and solar irradiance and can be calculated from the following equation (3.6):

$$P_{PV} = P_{PV-rated} f_{PV} \frac{I_T}{I_S} \left[1 + K_C \left(T_C - T_{ref}\right)\right] \qquad (3.6)$$

where P_{PV}-rated is the PV rated power at standard test conditions (kW), f_{PV} is the PV derating factor (%), I_T is global solar radiation incident on the surface of the PV array (kW/m^2), I_S is the solar radiation at standard temperature conditions (IS ¼ 1 kW/m^2), Kc is the temperature coefficient of the PV array (%/°C), Tc is the PV cell temperature (°C), and T_{ref} is the PV cell temperature under standard test conditions (25 °C).

In this analysis, the OP590M60-P4 mono-crystalline silicon (p-Si) PV modules were selected due to their relatively lower cost and high efficiency. The derating factor to compensate for reduction in efficiency due to temperature, dust, and wiring losses was 0.8. The lifetime of the PV arrays was assumed to be 25 years. The tracking mode of the PV panels was assumed to be horizontal-axis with daily adjustment.

Table III- 1 Technical and cost data of PV module.

Parameter	Specification
Model No	OP590M60-P4
PV type	Monocristallin
Panel dimension (H/W/D)	2172x1303x35 mm
Weight	30.9 kg
Derating factor	0.80
Temperature coefficient of power	-36 %/°C
Efficiency at standard test conditions	21.2 %
Capital cost	34,000.00 DA
Replacement cost	29,000.00 DA
O&M cost	5,000.00DA
Lifetime	25 years

III-2-5 Converter:

Two types of energy conversion occur in the system, AC to DC and DC to AC power. Hence, both a rectifier and an inverter are essential. The selected inverter must be able to maintain capability at maximum expected monitoring of the simulated AC

loads. The inverter efficiency is defined as the ratio of the AC power produced by the inverter (output power) to the DC power generated by the PV arrays or battery unit (input power), as shown in the following equation (3.7):

$$\eta_{inv} = \frac{P_{inv,out}}{P_{inv,in}} \quad (3.7)$$

where $P_{inv,out}$ is the output power of the inverter (kW) and $P_{inv,in}$ is the input power of the inverter (kW). In this study, the inverter efficiency was assumed to be 90%, and its lifetime was 25 years. On the other hand, the rectifier had 100% capacity relative to the inverter, and its efficiency was 97%. The initial capital, replacement and O&M costs of the converter considered in this analysis were assumed to be DA 90,000.00/kW, DA 5,000.00/kW, and 0, respectively. The inverter sizes of the grid-connected PV systems are often lower than or the same as the rated sizes of PV.

Table III- 2 Technical and cost data of converter.

Parameter	Specification
Efficiency	97%
Capital cost	90,000.00 DA
Replacement cost	90,000.00 DA
O&M cost	5,000.00DA
Lifetime	25 year

III-2-7 Results and discussion:

HOMER can simulate all the feasible energy system configurations that can meet the required power loads for the study regions under locally available energy resources. Techno-economic and environment evaluations of the various power system were carried out using this software. Among this configuration, grid/ PV system in the three climate regions were categorized depending on economic and emissions considerations to find the optimal energy configuration.

In a grid/PV power system, electricity supply comes from PV arrays and grid purchases. In this study, the effect of temperature on PV array power was considered. Table 7 shows the outputs associated with economic and environmental consideration of optimal grid/PV systems in the study regions. For Medea, the NPC (DA-497,648) and COE (DA-2.05/kWh) of the grid/PV system were the highest due to this city's having the highest OC (DA-93,109/yr); this means that Medea's grid/PV system is the least economically viable. In contrast, the NPC (DA -1,23M) and COE (DA-4,35) of the grid/PV system for Tamenrast were the lowest among the three regions, meaning that Tamenrast's grid/PV system was the most economically viable.

Table 8 shows the monthly average electric production of the optimal grid/PV systems in the study regions. The minimum monthly power acquisition from grid purchases for Medea (0,05 kW) occurred in March, whereas the maximum monthly power acquisition from grid purchases for Medea (0,41 kW) occurred in September. The minimum monthly power generation from the PV system for Ghardaia (0.05 kW) occurred in March, whereas the maximum monthly power generation from the PV system for Ghardaia (0,41 kW) occurred in august. and The minimum monthly power generation from the PV system for Tamenrast (0.05 kW) occurred in March, whereas the maximum monthly power generation from the PV system for Tamenrast (0,42 kW) occurred in august.

Table 9 shows the electrical production and consumption of optimal grid/PV systems in the study regions. The minimum annual generating capacity acquired from grid purchases for Medea was 2,19 kWh/yr. whereas the minimum power generation from Medea's PV system was 24,75 kWh/yr. The maximum annual generating capacity represented by grid purchases for Tamenrast was 2,24 kWh/yr. whereas the maximum power generation from Tamenrast's PV system was 30,07 kWh/yr. due to the city's high solar radiation values. In addition, the electric power was supplied from the pv mainly and the electric power sold was valuable. It is obvious that the electric power from the grid/PV systems in the study regions can meet the load demand.

Table III- 3 All outputs associated with certain economic parameters.

Regions	Grid (KW)	PV(KW)	Converter(KW)	IC (DA)	OC (DA/yr)	NPC (DA)	COE(DA/KWh)	RF (%)
Medea	999	12	6	834,000	-93,109	-497,648	-2,05	90,5

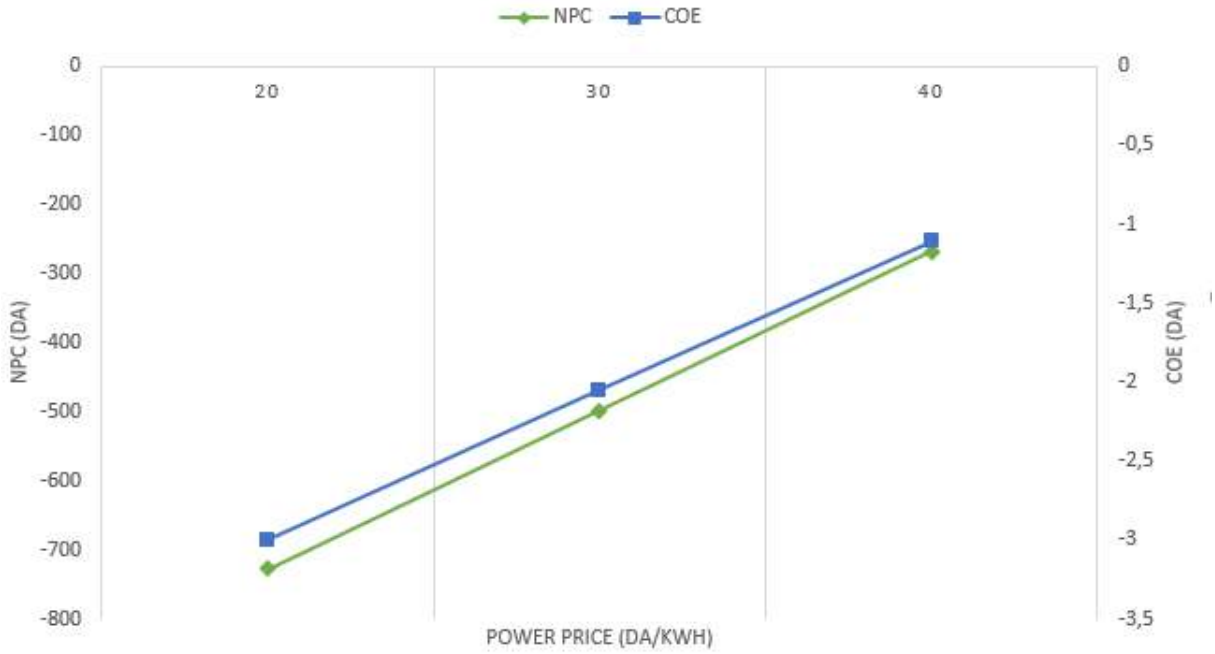
Ghardaia	999	12	6	854,000	-110,255	-722,836	-2.84	91
Tamenrast	999	12	6	874,000	-146,798	-1,230,000	-4,35	91,7

Table III- 4 Monthly average electric production in the study regions.

Month	Medea		Ghardaia		Tamenrast	
	PV(KW)	Grid(KW)	PV(KW)	Grid(KW)	PV(KW)	Grid(KW)
Jan	1.64	0.07	1.66	0.07	2.39	0.06
Feb	1.87	0.07	2.13	0.06	2.65	0.06
Mar	2.18	0.05	2.40	0.05	2.71	0.05
Apr	2.28	0.05	2.65	0.05	2.62	0.05
May	2.27	0.10	2.56	0.11	2.47	0.12
Jun	2.39	0.36	2.51	0.37	2.37	0.39
Jul	2.46	0.38	2.64	0.38	2.43	0.41
Aug	2.42	0.40	2.60	0.41	2.54	0.42
Sep	2.31	0.41	2.37	0.41	2.46	0.42
Oct	1.92	0.16	1.90	0.16	2.56	0.14
Nov	1.57	0.07	1.64	0.06	2.45	0.06
Dec	1.44	0.07	1.51	0.07	2.42	0.06

Table III- 5 Electrical production and consumption in the study regions.

Capacity (KWh/yr)	Medea	Ghardaia	Tamenrast
PV array production	24.75	26.57	30.07
Grid purchases	2.19	2.2	2.24
Total production	26.94	28.77	32.31
AC primary load	5.59	5.59	5.59
Grid sales	17.6	18.82	21.37
Total consumption	23.19	24.41	26.96



MEDEA



Ghardaia



Tamenrasset

Figure III- 16 Effect of power price on the NPC and COE for the study regions.

III-3 Conclusions:

In this study, the techno-economic performance of grid-connected PV power systems for a rooftop solar PV building containing a HOTEL in the three climate zones of Algeria was examined. The main conclusions can be stated as follows:

- The average solar radiation in a typical year for Medea, Ghardaia and Tamenrast was 4.84, 5.36 and 6.16 kWh/m2 /day respectively. The average clearness indices for Medea, Ghardaia and Tamenrast were 0.57, 0.61 and 0.66 respectively. The minimum and maximum ambient temperatures were 8.04°C, 8.44°C and 11.46°C (January) and 27.2°C, 33.11°C and 29.2°C for Medea, Ghardaia and Tamenrast respectively.
- The NPC and COE values of the grid/PV systems for all three climate zones increased with inverter rating increased. The excess electricity, NPC, and COE values of the grid/PV systems for all three climate zones increased with PV penetration increased.
- From an economic and environmental perspective, tamenrast, with its mild climate conditions, may be especially suitable for grid/PV power generation in the considered zones.

- The NPC and COE values of grid/PV systems for all three climate zones increased as power price increased. The NPC values of grid/PV systems for all three climate zones increased as load demand increased.

General conclusion

During this study, we neglected the support provided by Sonalgaz in the electricity prices of the network, because the results were dispensing with solar panels, so we decided to calculate the prices without the support, so we got the following results:

The best combination, which was the same in all regions, is 20 solar panels with a capacity of 600W, or 12KW in general, they are connected to the electrical network, which will be located on the roof of the hotel.

The panels produce the largest possible amount of energy all the time, as they give all the energy they produce with the electrical network to the LOAD during the days of high consumption in the summer period, while feeding the LOAD and giving the rest of the energy to the electrical network during the days of low consumption in the winter period.

Among the three regions (Medea, Ghardaia and Tamenrast), Tamenrast was the one that came with the best results in terms of energy production and material profit, where the value of the NPC was -1230000 DA, which is the lowest among the three regions, and this is due to the high solar radiation, which caused a high energy production.

The latter led to an energy surplus, which is sold to the electricity company through the grid, so there is a high financial profit compared to the rest of the regions.

This profit is more in the winter, despite the low solar radiation and the turbidity of the weather, and this is due to the low energy requirements in the hotel in the winter period, as the largest energy consumption is in the summer because of the air conditioners, which in turn require a large capacity.

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