PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIAN
MINISTRY OF HIGHER EDUCATION & SCIENTIFIC RESEARCH
UNIVERSITY OF MOHAMED BOUDIAF - M'SILA

FACULTY OF TECHNOLOGY
DEPARTMENT OF ELECTRICAL ENGENERING
N°: ER-07

DOMAIN: SCIENCE AND TECHNOLOGY
STREAM: RENEWABLE ENERGY
OPTION: RENEWABLE ENERGIES IN ELECTRICAL ENGINEERING

Project Report Presented in Partial Fulfillment of the Requirements of the Degree Master

Presented by:
MIRA Aya

Title

Study and Performance Evaluation of a Large-Scale Grid-Tied PV Plant: Case Study Ain El-Melh, Algeria

Defended in front of the jury composed of:

First and last name	Grade	Establishment	Quality
Dr. CHOUDER Aissa	Professor	University of M'sila	President
Dr. BENGUESMIA Hani	Associate Professor 'A'	University of M'sila	Supervisor
Dr. BAKRI Badis	Associate Professor 'A'	University of M'sila	Co- Supervisor
Dr. BOUAFIA Saber	Assistant professor 'B'	University of M'sila	Examiner

Academic year: 2023/ 2024

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Dr. DJERIOUI Ali	Professor	University of M'sila	Representative of the incubator/CATI
Mr. ZEROUGUI Abdelkarim	Engineer	SAIEG-M'sila	Socio-economic partner

Academic year: 2023/ 2024

إهـــــــداء

وأولا وقبل كل شيء الحمد لله رب العالمين الذي أعطاني القوة والإرادة والشجاعة لإكمال هادا العمل

هدي شكري الى والداي العزيزان : أبي الحبيب وأمي الغالية اللذان شجعاني

وأعطياني كل الحب ومنحاني عزيمة صلبة من اجل السير في هدا الطريق الطويل

الى أخر اللحظات اليوم

الى اخواتي الأربعة : دنيا، بشرى،غفران، سجود على مسندتي في الفرح والحزن

ووقوفهم معي قلبا وقالبا

الى أخي الوحيد : سندي ومسندي وضلعي الثابت الذي لا يميل الذي أحبه كثيرا

الى جدتي وخالاتي على اهتمامهم بي كل سنواتي الجامعية

الى أصدقائي الأعزاء :رفيق ,يوسف, سهام,وكل زملاء قسمي على العموم اسأل الله

ان يحفظهم ويديم صداقتنا مدى الحياة

الى أستاذي العزيز على بذله كل هدا المجهود معي، لك مني أسمى عبارات الشكر

والامتنان لأستاذي العزيز أدام الله صحتك وعافيتك ان شاء الله

اتمنا لكم جميعا اللحظات السعيدة والصحة والعافية.

Dedication

First of all thank God the Lord of the two worlds who gave me the strength, will and courage to complete the work.

Give my thanks to my dear parents: my beloved father and my dear mother, who encouraged me and gave me all the love and resolve to walk the long way to the last moments of today

To my four sisters: Dounia, Bouchra, Ghofran, Soudjoud on my support in joy and sadness and standing with me heart and mold

To my only brother Akram: My steady, inclined shade, which I don't tend to love very much.

My grandmother and aunts are interested in me all my college years.

To my dear friends: Rafik, Yousef, Saham, and all my colleagues generally ask God to save them and perpetuate our friendship for life

To my dear Professor for making every effort with me, I am grateful and grateful to you.

We hope you all happy moments, health and wellness

Aya Mira

Acknowledgement

First and foremost, we thank God Allah, who gave us the courage, patience, strength, serenity, and will to complete this modest work during all these years of study.

The success of any project depends largely on the encouragement and guidance of many others. We take this opportunity to express our gratitude to the people who have been instrumental in the successful completion of this project.

*Secondly, we would like to express our greatest appreciation to our supervisors, **Mr. Hani Benguesmia,** Associate Professor at the University of M'sila, and **Mr. Badis Bakri**, Associate Professor at the University of M'sila.*

We can't say thank you enough for his tremendous support and help. We feel motivated and encouraged every time we attend his meetings. Without his encouragement and guidance, this Master's thesis would not have materialized

*I would like to thank the president of the jury, **Mr. Aissa Chouder**, Professor at the University of M'sila, and the member of the jury, **Mr. Bouafia Saber**, Associate Professor at the University of M'sila, for having participated in the jury and for taking the time to examine my Master's thesis.*

*Finally, I thank all those who contributed directly or indirectly to the development of this work especially **Mrs. Razika Ihaddadene,** Professor at the University of M'sila, **Mr. Kichene Moadh**, Phd student, and engineer in the SKTM group-Sinelgaz- Ain Mleh.*

ملخص

يقدم هذا العمل دراسة أداء محطة الطاقة الشمسية الكهروضوئية طبقاً للمواصفة **IEC 61724** ويهدف إلى تحليل وتقييم أداء محطة كهروضوئية بقدرة 20 ميجاوات متصلة بالشبكة بعين الملح بالمسيلة. الهدف الرئيسي هو دراسة تأثير البيئة على الإنتاج لضمان التشغيل الفعال، وتحسين إنتاج الطاقة، والمساهمة في التحول إلى مصادر الطاقة المتجددة مع تلبية الطلب المحلي على الطاقة.

استخدمنا برنامجًا مبتكرًا بعنوان PVPA ، والذي يهدف إلى تحليل أداء التركيبات الكهروضوئية بطريقة بسيطة وسريعة باستخدام البيانات المسجلة من التثبيت وفقًا لمعيار **IEC 61724** تم في هذه الدراسة عرض تحليل أداء محطة توليد الكهرباء بعين الملح بالمسيلة.

الكلمات المفتاحية: المواصفة**IEC 61724** ، التركيبات الكهروضوئية، الأداء، التقييم، الناتج النهائي.

Abstract

This work presents the performance study of the solar PV plant according to the IEC 61724 standard. It aims to analyze and evaluate the performance of a 20-megawatt photovoltaic plant connected to the grid in Ain El-Melh, M'sila. The main objective is to examine the influence of the environment on production to ensure efficient operation, optimize energy production, and contribute to the transition to renewable energy sources while meeting local energy demand. We used innovative software entitled PVPA, which aims to analyze the performance of PV installations in a simple and rapid manner using recorded data from the installation according to the IEC 61724 standard. The performance analysis of the power plant in Ain El-Melh, M'sila, is presented in this study.

Keyword: IEC 61724 standard, photovoltaic installations, performance, evaluation, final yield.

"List of Acronyms and Symbols"

List of Acronyms and Symbols

Acronyms

PV	solar photovoltaic
IEC	International Electrotechnical Commission
PVPA	Photovoltaic performance analyzer
IEA	International Energy Agency
STC	normal sunlight conditions
SKTM	Shariket KahrabawaTakat Moutadjadida
SPE	Electricity Production Company
MPPT	Maximum Power Point Tracking
AC	Alternating current
DC	Direct current

Symbols

I	Current (A)
V	Voltage(V)
I_{cc}	Short circuit current (A)
P_c	Peak power (W_c)
η	Efficiency (%)
S	The cell area in m^2
E_{dc}	Energy generated by photovoltaic panel system (Wh)
P_{dc}	The power in direct current (W)
T_r	The recording time interval
T_{rp}	The recording period
E_{ac}	Alternative energy (Wh)
P_{ac}	The AC alternative power (W)
Y_r	The reference efficiency
H_t	the ratio between the total energy from solar radiation (kWh/m^2)
G_0	Reference radiation energy (1 kW/m^2)
Y_a	The yield of the field
P_0	The peak power (W)

N	The number of operating days of the plant in a month
Y_f	The system efficiency
$P_{pv(rate)}$	
P_R	performance ratio
η_{sys}	The efficiency of the photovoltaic system (%)
A_t	The total surface modules
η_{inv}	Inverter Efficiency
CF	The capacity factor
L_S	System losses by conversion
L_c	Losses per field capture
β	The orientation of the panels
P_0	Rated power of the PV array (W).

"List of Figures and Tables"

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Chapter II: ″Presentation of the Aïn El Melh photovoltaic solar power plant″

Chapter III: ″ Performance Investigation of a Large-Scale Grid-Tied PV Plant: Case Study Ain El-Melh″

"General Introduction"

General Introduction

The share of renewable energy in meeting global energy demand is expected to increase by 20% to 12.4% of global production in 2023. These green energy production systems will experience the fastest growth in the electricity sector, providing up to 30% of electricity demand in 2023, compared to 24% in 2017. For this period to come, renewable energy is expected to account for more than 70% of the world's electricity generation growth, thanks to solar photovoltaic (PV) energy [1-2]. In 2017, the cumulative solar photovoltaic capacity reached nearly 398 GW and generated more than 460 TWh corresponding to about 2% of global production. In 2021, 183 GW of photovoltaic capacity was installed worldwide, nearly 40 GW more than in 2020. [3]

Among all renewable energies, solar photovoltaic (PV) is of particular interest to Africa, as it has a large solar field. For example, Mauritania has a good solar potential varying between 1900 and 2200 KWh/m²/year [2]. This country depends mainly on fossil fuels to meet its domestic energy demand. Fossil fuels account for about 66% of primary energy consumption, while the remaining 34% comes from biomass, which is mainly used for cooking and heating. Electricity is mainly generated by diesel-powered thermal generators.

Due to increased domestic energy demand and insufficient installed capacity, total energy consumption exceeds domestic energy production by about 35%, leading to the import of fossil fuels. The country is seeking to meet its growing energy demand with fewer fuel imports by integrating renewable energy as a source of energy. Electricity demand increases by 10% per year, mainly due to industry needs and partly due to higher domestic demand. In a "high growth" scenario for the electricity sector, grid-connected demand (excluding mining activities) is expected to increase by 450% between 2010 and 2030. This underscores the need for sound policies to drive future capacity expansion. Planned investments in national electricity capacity, including several new wind and solar projects, would bring the contribution of renewable energy to 36% of capacity in 2020 and 41% in 2030. [4]

To study the efficiency of a photovoltaic power generation system, the European standard 61724 of the International Electrotechnical Commission (IEC) presents guidelines for measurements, data exchange and analysis for electrical performance monitoring and determination [5]. It does not describe the performance of discrete components, but rather focuses on evaluating the performance of a generator as part of a system, providing a summary of performance suitable for comparison of photovoltaic installations of different sizes operating in different climates. [6-7]

The aim of this master's thesis is to study the performance of the Ain El-Melh-M'sila photovoltaic power plant. This work is organized as follows:

Chapter I: we present a bibliographic part that contains general information on photovoltaic modules, their components, their operating principle and a presentation of the IEC 61724 standard and some studies that follow this standard.

Chapter II: a description of the Aïn El-Melh photovoltaic power plant of M'sila is presented, namely: its geographical location, its development, its composition (solar fields, junction boxes, inverters, control room, load communication cabinet and environmental measurement device),..etc.

Chapter III which aims: to analyze in a simple and fast way the performance of PV installations from the recorded data of these installations according to IEC 61724. Ain El-Melh uses innovative software called PVPA (Photovoltaic performance analyzer).

And let us conclude our work with a general conclusion that represents a global synthesis of our work.

<u>Chapter I</u>

″State of the art"PV modules and the IEC 61724standard″″

I.1. Introduction

Solar energy can be used by photo thermal and photovoltaic approaches. The photo-electrochemical conversion of solar energy into chemical energy and fuels, could allow the application of solar energy in many fields [2]. This chapter presents a literature search on photovoltaic modules, describing their constituents, their principle of operation, their technologies, their modes of degradation, presentation of IEC 61724 and some studies already carried out according to this standard.

I.2. Components of a PV module

A photovoltaic solar module is composed of photovoltaic cells, an encapsulant, by pass diodes, connectors, junction box, cables, protective glass on the front side, a glass or polymer film on the back side and an aluminum frame. The components of a PV module change according to the manufacturing technologies (see Figure I.1).

The assembly of these components can defend the photovoltaic cells against different mechanical constraints that may appear during transport or installation and the different environmental conditions such as rain, temperature, exposure to UV rays and humidity. A PV solar module is essentially composed of the strata shown in figure I.1.

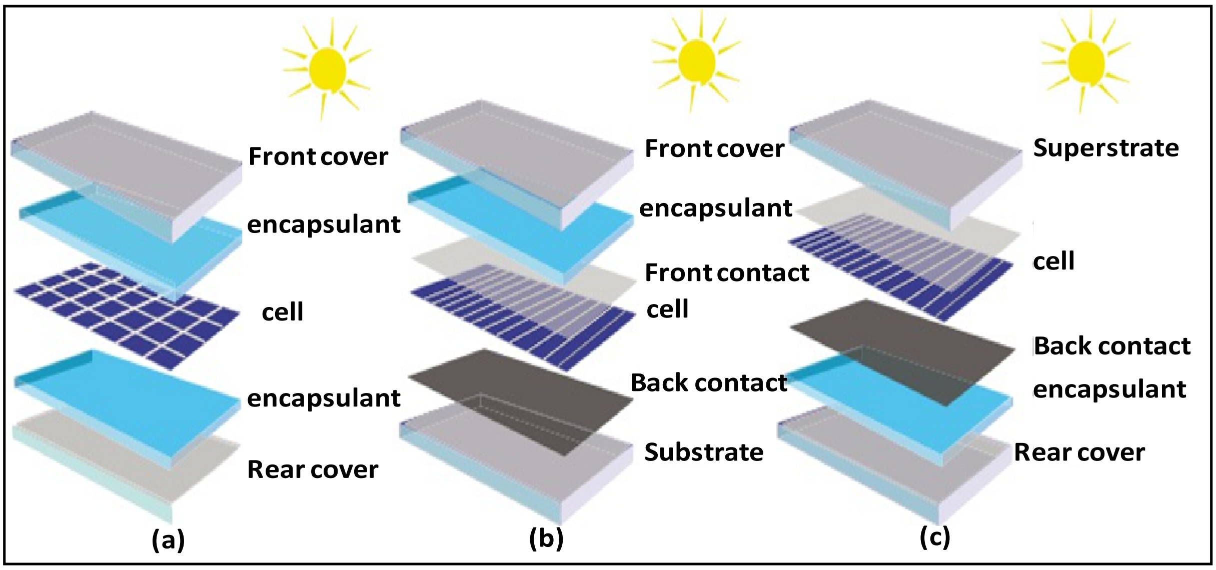

Figure I.1. PV solar module is essentially composed of the strata shown.
(a) Crystalline Si PV module, (b) Substrate Type Thin Film PV Module, (c) Superstrate type thin film PV module.

I.2.1. Front facing glass

The front of the module includes a tempered solar glass that requires transmittance high, high transparency, low iron content and low reflectivity. Glass forms the previous termination of the photovoltaic module and protects the components sheltered inside laminate against weather and mechanical stress. Similarly, it helps support in the rolling process. High transmittance increases the efficiency of photovoltaic cells and therefore has a direct return on the power and performance of the final module. Low iron content in the glass composition and anti-reflective coating decrease the absorption of radiant energy. They have a hydrophobic anti-reflective layer that increases the absorption of light and minimal dust accumulation on the surface. They achieve good resistance mechanical stress and temperature changes in favour of the manufacturer's preload. The glass thickness can be selected in the range of 2.5 to 10 mm. [3]

I.2.2. Encapsulant

The protection of photovoltaic energy production cells (fungi, humidity, oxidation) is the main factor of stable energy efficiency [4]. In the composition of solar panel, the encapsulant guarantees this protection. Encapsulation materials can be divided into:

- Elastomeric materials;
- Thermoplastic materials or thermoplastic elastomers (TPE) not cross-linking,

The characteristics of encapsulating PV modules in terms of optimization of the efficiency of the modules can be divided into five categories: reliability, cost, efficiency.

❖ The encapsulant must show low light absorption and refractive index adapted to minimize the reflectance of the interface.

❖ High thermal conductivity reduces operating temperatures and progresses thus the electrical efficiency,

❖ Only very low leakage currents are allowed by the standard approval tests (for electrical safety) in accordance with IEC 61215. [5]

❖ In terms of PV module reliability, the properties of the encapsulant are critical in this that looks at UV irradiation, humidity, temperature cycles, temperatures exceptionally low or high ambient, mechanical loads, potential electrical in relation to earth, etc.

❖ The encapsulant must keep a strong adhesion to other components of the module and defend the cell and impact metallization exteriors,

❖ A module manufacturer will also take into account the cost of materials, cost and processing time, retention time and quality assurance issues.

I.2.3. The photovoltaic cells

A cell is defined as the smallest piece of semiconductor with a voltage associated with a single junction. In polycrystalline or mono-crystalline silicon modules, each cell consists of a single piece of silicon. In thin-film modules, the semiconductor material is deposited on large surfaces and the cells are defined by scrapingthe material to create electrically isolated areas.

A "chain" of cells represents a set of cells electrically connected in series, usually 10 or 12 cells for wafer-based modules and about 60 to 100 cells for thin-film modules. Two or more cell chains can be connected in parallel with diodes of bypass to create electrically independent "sub-modules". The functionality of this sub-module is separated from cells or strings that are not part of the sub-module. Up to four levels of metallization and electrical connections are possible. Grid lines» (also known as “fingers”) are the thinnest metallization level placed directly on and consist of a network of lines less than 0.4 mm thick. The current of grid lines are collected in a “busbar” that is placed directly on the cell. The figure I.2 shows a diagram of grid lines and omnibus "bus bars" on cells in mono-crystalline or polycrystalline silicon. [8]

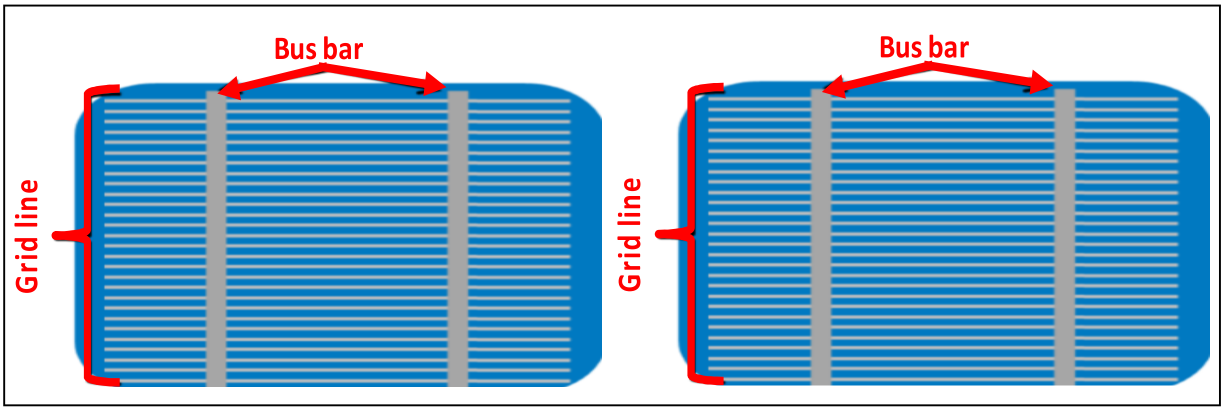

Figure I.2. Metallization on a silicon cell.

The cells connected in series are connected in chain by a "connecting strip of cell". Note that the cell mounting tape directly covers the bus bars of silicon cell, which often obscures bus bar inspection. Several chains are connected by a "chain interconnect". This is usually near the edge of the module and can be hidden by the module frame or facade. Figure I.3 shows a diagram showing the cell connection strips and chain connections. The layouts of metallization and/or connection may be less standardized in thin-film modules only in mono-crystalline and polycrystalline silicon modules. A thin-film module can omit four levels of metallization and electrical connections. Conventions of name of these modules follow their respective connection level functions above. [8]

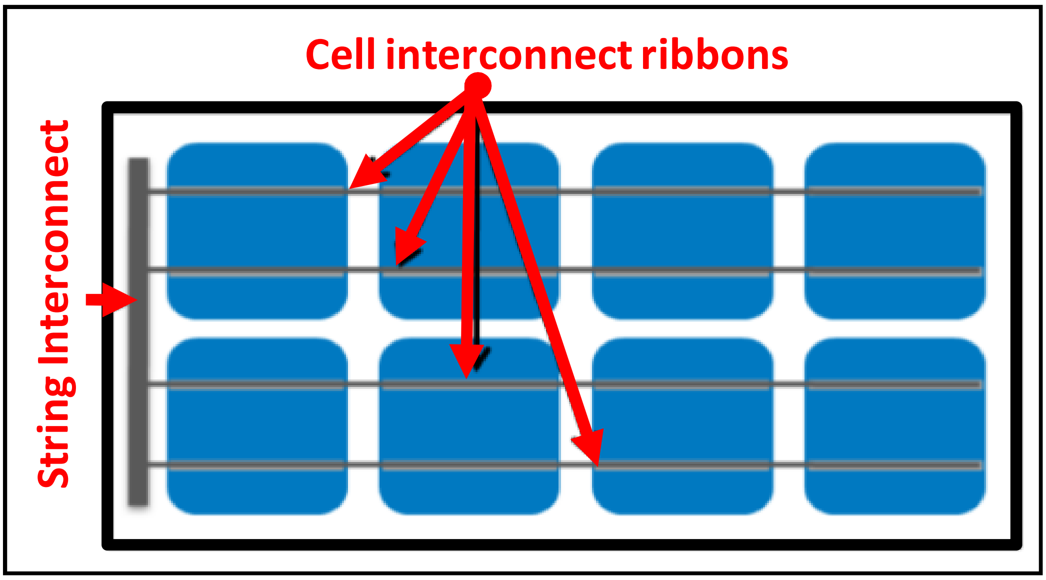

Figure I.3. Chain electrical connections of photovoltaic cells.

I.2.4. Back panel (backsheet)

The backsides of PV modules are usually a multi-layered construction (usually three layers) where each layer performs a specific function. The layer in contact with the packaging must have durable adhesion and chemical compatibility with packaging and be stable to direct sunlight filtered through glass layers and packing. [9]

The central layer or core is generally thicker and provides the mechanical and electrical properties required for the entire mixture.

This layer is generally, consists of poly (ethylene terephthalate) (PET), while some types of support pads have polyamide or polyolefin as the center layer. The layer external must be very strong and stable as it ensures the environmental protection of others layers and is subject to direct environmental influences, including short UV indirect (reflected, soil, depending on the albedo) of the soil. This is why it is generally composed of PET, vinylidene fluoride (PVDF) or vinyl fluoride (PVF). [10-11]

These layers are usually laminated with the addition of an adhesive. Only certain combinations materials can be co-extruded into laminated panels. Given that each of the layers of the inverted sheet is subjected to a different set of stresses when outdoor exposure, their individual performance will affect the performance of the entire inverted sheet, and finally the entire inverse expression of the PV module. [11]

I.2.5. Frame and junction box

The frame of photovoltaic solar panels has no percussion on the hermeticity and its address to be produced before to the external data. Its strength is related to its mechanical characteristics that have multiple benefits [12]:

- Transport,
- Storage,
- Grounding,
- Fixation,
- Resistance to environmental conditions loads.

Much of the cost of the solar module is in the cell, and therefore in the material of the silicon. Of all the remaining components, the frame holds an important place. Therefore, it is not surprising to see the thickness of the frame gradually decrease over the years. They are generally made of aluminum and their cost depends on the weight of the material and the price of the material first.

Therefore, reducing the thickness of the frame has a direct impact on costs because less material is needed. For the installer, there is also an advantage because the module will be a slightly lighter. That said, over the years, we have not seen a major breakthrough in technology development is slow and tends to cap. Indeed, the reduction in costs goes through the search for a compromise between the design and the weight of aluminum to ensure the reliability of the mechanical properties of photovoltaic solar modules. But as always, it is not about applying a magic formula.

Two modules with the same thickness frame may behave differently due to design choices. The box junction of photovoltaic modules is the device that ensures the connection between the assembly of photovoltaic cells of photovoltaic panels and load control device solar. It represents a comprehensive multi-domain design that incorporates electrical design, mechanical design and materials science.

The junction box of solar panels occupies an important place in the structure of solar panels. It mainly connects the energy generated by the solar cell to the lines The junction box is attached to the back of the panel with silica gel, and the cables output components are connected to the inside cables of the junction box, and the cables are connected to the outside cables to allow the components to cut and the outside of the conductor cable. The diode in the junction box helps the elements to work correctly when obscured by light. [13]

Junction boxes for photovoltaic solar modules connect and protect the solar panels, drive the energy generated by solar cells to external cables and conduct the current generated by the solar panels.

The function of the solar junction box PV is checked under Standard Test Conditions (STC) of 25°C, AM: 1.5, = 1000W/m^2.

I.3. Principle of operation of a PV module

Matter, in all its states, consists of molecules that are groups of atoms. Usually, atoms are represented as electrons in orbit around the nucleus, like satellites around the Earth. The nucleus is composed of protons and neutrons. The charge of a neutron is zero. A proton with a positive charge is the absolute value of a negatively charged electron. In the normal state, an atom is electrically neutral, the number of electrons is similar to the number of protons.

Electrons, which carry a negative charge, are in layers. Any shell may have only a defined or limited number of electrons. By example, the layer K closest to the nucleus is saturated with 2 electrons. It is in the layer the more external (valence layer) than electrons have the least attraction to the nucleus, which allows bonds with neighboring atoms to create the cohesion of matter. The valence of most atoms is incomplete (except for noble gases), so it can (temporarily) gain or lose electrons. This is the case when ionizing an atom. The 14 electrons of a silicon atom revolve around the nucleus composed of 14 protons and 14 neutrons. Atoms can charge by gaining or losing one or more electrons: one then speaks of ions.

If an atom gains one or more electrons, the charge of the atom becomes negative (anion), and if it loses some, the charge of the atom is positive (cation). In a crystal of silicon, each atom is attached to four neighboring atoms that distribute the four electrons of the layer M. above this tetrahedron. A semiconductor is an object whose resistivity is averaged between the resistivity of the conductor and the resistivity of the insulator. Silicon is a semi-silicon conductor. Intrinsic conduction: When the temperature rises, due to fluctuations thermal, electrons spontaneously escape and participate in the conduction process. The electrons located in the outermost shell of the nucleus participate in covalent bonds.

In crystals, these electrons are located on energy levels called valence bands. The electrons that can contribute to conduction have energy levels in the conduction. Between the valence band and the conduction band may be a band prohibited. To overcome this band gap, the electron must gain energy (heat, photons...). For insulators, the gap is almost impassable, for conductors, it doesn't exist. Semiconductors have a fairly narrow frequency band.

The atom that gave an electron becomes a positive ion and the hole formed can participate in the formation of an electric current as it moves. If the free electron is blocked by an atom, then there is recombination. For a given temperature, ionization and recombination balance; the resistivity decreases as temperature increases. A semiconductor with electrical conductivity free is said to be intrinsic. On the other hand, by adding impurities (doping), the conductivity of semi-freedriver is foreign. [14]

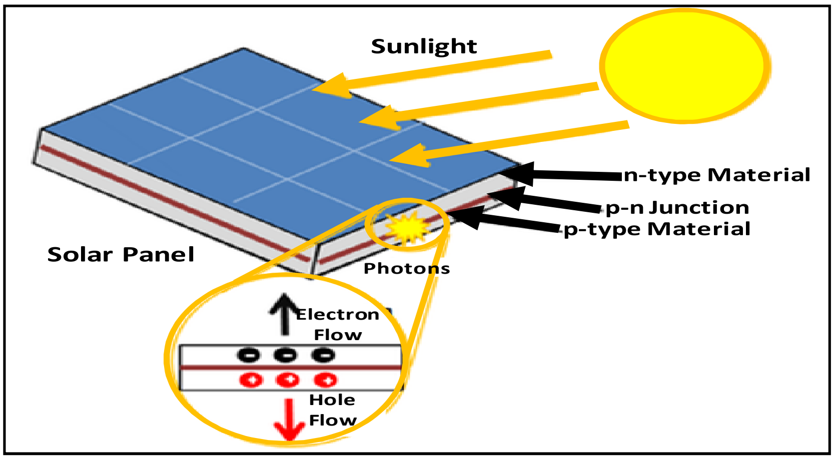

Figure I.4. PN junction.

The photovoltaic effect used in the solar cell directly converts the energy light from solar rays into electricity through production and transport in the material semiconductor of negative and negative charges under the influence of sunlight. This material has two parts, an excess of electrons and a lack of electrons, known as of type n and type p. When the first object is in contact with the second, the excess electrons in the material n will diffuse into the material p. The nth doped region initially becomes positively charged, and the initial doped region p becomes charged negatively. Thus, an electric field is created between them which tends to push the electrons towards region n and holes towards region p. A PN junction has formed (see Figure I.4).

If the material is exposed to sunlight, the atoms exposed to solar radiation will be bombarded by photons; under the effect of this bombardment, the electrons of the layers higher electronics may be ripped/dissected: if the electron returns to its state of origin, the excitation of the electron acts by heating of matter. The kinetic energy of the photon is converted into heat. On the other hand, in the cell photovoltaic, some electrons do not return to their original state. Inactive electrons produce a low continuous voltage. Thus, part of the kinetic energy of photons is immediately transformed into electrical energy: this is the photoelectric effect. [14]

I.4. Electrical characteristics of a photovoltaic panel

Understanding the electrical characteristics of a photovoltaic (PV) panel is crucial for designing and optimizing solar power systems. Here are the key electrical parameters and characteristics of PV panels:

I.4.1. I-V Characteristics Curves

A plot of current (I) versus voltage (V) for a PV panel. The shape of the I-V curve helps determine the performance of the panel under different conditions.

A photovoltaic cell flows a certain current, under a potential difference. This relationship is described in figure I.5 which ensures the electrical operation of a PV cell and its coupling with a receiver [15].

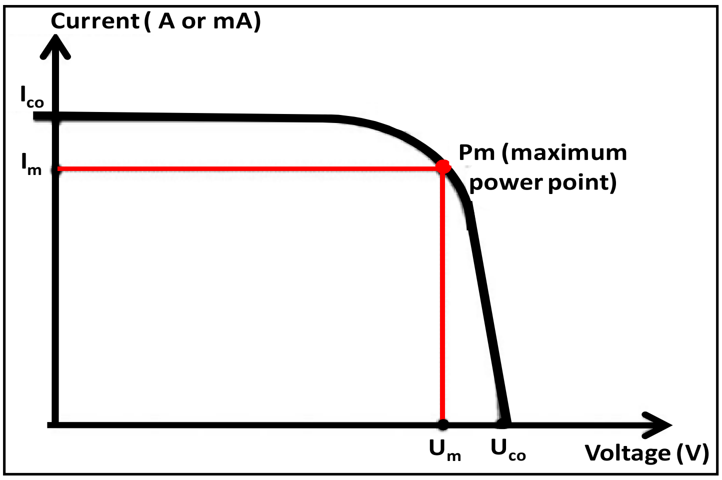

Figure I.5. Curve of a PV cell.

Open Circuit Voltage

If a cell is placed under a constant light source, without any load, it will produce a maximum direct voltage at its terminals, the open circuit voltage or so-called open circuit voltage U_{co}.

Short Circuit Current

Unlike the open circuit point, when the cell is shorted it gives a peak current, but no voltage.

This is the current that can be directly measured with an ammeter. It is the short-circuit current. (I_{cc}: Short circuit current).

Maximum power point

The optimal use of the cell is to supply the load at maximum peak voltage and current. This should be in conditions where the voltage-current product is maximum: this is the ideal operating point of the cell, or the peak power point as shown in Figure I.5. The voltage and current corresponding to this operating point are usually called $\mathbf{U_m}$ and $\mathbf{I_m}$.

Peak power (P_c)

The maximum power depends on the lighting. When it comes to maximum power in Standard Test Conditions STC (1000 W/m^2), 25°C, AM solar spectrum: 1.5, we then mean peak Watt (W_c) or peak power.

Efficiency of a cell

The efficiency of the cell is the ratio between the electrical power generated by the PC and the light power received by the cell G_0. It is defined as:

$$\eta = \frac{P_c}{G_0 S} \quad \text{(I.1)}$$

Where:

S is the cell area in m^2,

The operation of the PV cell is proportional to sunlight and temperature ambient.

I.5 Technology of a PV module

Many photovoltaic cell technologies are currently on the market with variable returns. The most commonly used technologies with their efficiencies are presented in Table I.1.

Table I.1. Maximum declared efficiency of PV technologies.[16]

Technology and Material	Better efficiency (%) at laboratory scale		Technology and Material	Better efficiency (%) at laboratory scale
Crystalline silicon			**Emerging PV**	
Monocrystalline silicon (s-Si)	26.7		Dye Sensitised Cells (liquid electrolyte)	13
Multicrystalline silicon (m-Si)	22.3		Inorganic Cells (CZTSSe)	12.6
Silicon heterostructures (HIT)	26.7		Organic cells	16.5
Thin film lens	21.2		Organic Tandem Cells	14.2
Single Junction Gallium Arsenide (GaAs)			Perovskite Cells	25.2
monocrystal	27.8		Perovskite/ Si Tandem Cells	28
Thin-film crystal	29.1		Quantum Dot Cells	16.6
Multi-junction cells			Carbon Nano Tube (Single-walled)/ Si Heterojunction	12
Two junctions	32.8		Carbon Nano Tube (Multi-walled)/ Si Heterojunction	10
Three junctions	37.9		**Thin Film**	
Four or more junctions	39.2		Amorphous Silicon (a-Si)	14
Thin layer			Cadmium Telluride (CdTe)	22.1
Amorphous silicon (a-Si)	14		Copper indium gallium selenide (CIGS)	23.4
Cadmium telluride (CdTe)	22.1		**Multi-junction Cells**	
Copper, indium and gallium selenide (CIGS)	23.4		Two Junction	32.8
Inorganic cells (CZTSSe)	12.6		**Single-Junction Gallium Arsenide (GaAs)**	
organic cells	16.5		Single Crystal	27.8
Tandem organic cells	14.2		Thin-film Crystal	29.1
Perovskite cells	25.2		**Crystalline Silicon**	
Tandem/perovskite cells	28		Silicium cristallin unique (s-Si)	26.7
Quantum dot cells	16.6		Silicium multi cristallin (m-Si)	22.3
Carbon nano-tube (single wall) / Si Heterojunction	12		Silicon Heterostructures (HIT)	26.7
Carbon nano-tube (multi-wall) / Si Heterojunction	10		Thin Film Crystal	21.2

I.6. Degradation modes of a PV module and its components

Degradation modes have the potential to irreversibly degrade the performance of PV modules/systems or can lead to safety issues. [17]

I.7. Performance evaluation methodology

To analyze the performance of a solar energy system, the performance parameters have been regulated by the International Energy Agency (IEA) and described in the standards of standardization (International Electrotechnical Commission) IEC 61724 (IEC, 1998) [18], and updated in 2017 [50]. Such as reference yield, final output of PV system and performance report. These parameters are used to determine the performance of the entire system with regard to energy production, insulation and the overall effect of PV system losses. The search parameters of IEC 61724 that will be used in the chapters of this master thesis are presented in this section. [16,18-20].

I.7.1. Energy generated by photovoltaic panel system

The total value of the continuous power output (DC) monitored daily is given by thefollowing equation:

$$E_{dc,d} = \sum_{t=1}^{t=Trp} P_{dc} T_r \tag{I.2}$$

The monthly generated DC continuous energy is noted as follows:

$$E_{dc,m} = \sum_{d=1}^{N} P_{dc,d} \tag{I.3}$$

Where:

T_r:is the recording time interval;

Trp: is the recording period;

N: the number of operating days of the plant in a month.

P_{dc}: is the power in direct current, it is given by:

$$P_{dc} = V_{dc} I_{dc} \tag{I.4}$$

I.7.2. Alternative energy or energy supplied to the grid

The energy generated by the PV system (E_{ac}) is the measurement of the energy at the output terminals of the inverter. [16]

The total value of the AC output power monitored daily ($E_{ac,d}$) is calculated by this equation:

$$E_{ac,d} = \sum_{t=1}^{t=Trp} P_{ac} T_r \tag{I.5}$$

the AC alternative power is given by:

$$P_{ac} = V_{ac}\, I_{ac} \tag{I.6}$$

I.7.3. Benchmark Performance

The reference efficiency (Y_r) is the ratio between the total energy from solar radiation Ht (kWh/m^2) intercepted by the extent (area) of the PV modules and the reference radiation energy G_0 ($1\ kW/m^2$) (see equation I.3). It evokes the hours whose radiation is similar to the reference. Yr represents the resource from the sun of the studied PV system, it is made by: [16]

$$Y_r = \left(\frac{H_t}{G_0}\right) \text{ (KWh/kW}_c\text{)} \tag{I.7}$$

I.7.4. Photovoltaic field efficiency

The yield of the field (Y_a) is determined by the ratio of the energy produced E_{dc} (kWh) by the installed PV for a well-defined period of time (daily, monthly or annual) and the peak power P_0 (kWp) of the fields under Standard Test Conditions (STC: irradiation: 1000 W/m^2, 25°C temperature). The daily yield of the PV field ($Y_{a,d}$) is given by the following equation:

$$Y_{a,d} = \frac{E_{dc,d}}{P_{pv\,(rated)}} \tag{I.8}$$

The monthly yield of the PV field ($Y_{a,m}$) is given by the following equation:

$$Y_{a,m} = (\frac{1}{N})\sum_{d=1}^{N} Y_{a,d} \tag{I.9}$$

I.7.5. Final System Performance

The system efficiency (Y_f) is the energy generated by the PV installation, E_{ac} (kWh) at the power peak of the P_0 system (kWp). This refers to the operating hours where the installation PV must operate at its peak power. The daily system output corresponds ($Y_{f,d}$) and the monthly final yield ($Y_{f,m}$) are given by:

$$Y_{f,d} = \frac{E_{ac,d}}{P_{pv\,(rated)}} \tag{I.10}$$

$$Y_{f,m} = (\frac{1}{N})\sum_{d=1}^{N} Y_{f,d} \tag{I.11}$$

I.7.6. Performance Report

The performance ratio (P_R) refers to the entire consequence of losses in production energy of PV systems.

The values of the latter indicate to what extent an installation PV combines the ideal performance under real operating conditions. The ratio of performance is the ratio of system performance to baseline performance, it is a dimensionless size:

$$P_R = \frac{Y_f}{Y_r} \tag{I.12}$$

I.7.7. Efficiency of photovoltaic system

The efficiency of the photovoltaic system η_{sys} represents the efficiency of the solar system photovoltaic or efficiency, it is the ratio of E_{ac} to their radiation H_t on the total surface Modules (A_t):

$$\eta_{sys} = \left(\frac{E_{ac}}{H_t\, A_t}\right) \tag{I.13}$$

I.7.8. Inverter Efficiency

The efficiency of the η_{inv} inverters represents the efficiency of the conversion of the continuous power or continuous energy in alternating power or alternating power. One can express it as the quotient between alternative energy (E_{ac}) and continuous energy (E_{dc}).

$$\eta_{inv} = \left(\frac{E_{ac}}{E_{dc}}\right) \tag{I.14}$$

I.7.9. Capacity Factor

The capacity factor (CF) is a methodology for energy presentation delivered by a electrical power distribution system.

If the system continuously delivers its full nominal power, its CF will be equal to the unit. It is defined as the ratio between production actual annual energy and the amount of energy the PV system can provide at its capacity Nominal for 24 hours per day in a year:

$$CF = \left(\frac{Y_f}{8760}\right) = \left(\frac{E_{ac}}{8760 P_0}\right)(\%) \tag{I.15}$$

I.7.10. System losses per conversion

System losses by conversion (L_S) are due to inverter conversion losses (DC-AC current) and are defined by the difference between the yield of the PV field Y_a and the final yield Y_f. They are given by:[16]

$$L_s = Y_a - Y_f \tag{I.16}$$

I.7.11. Losses per field capture

Panel capture loss (L_c) is defined by the diversity between the reference yield and solar field. They evoke losses at: panel temperature, wiring, partial shading, fouling, spectral losses, power point determination maximum, continuous to alternative conversions, etc. They are noted as:

$$L_c = Y_r - Y_a \tag{I.17}$$

I.8. Some studies that follow IEC 61724

The efficiency of photovoltaic installations is significantly related to the conditions weather determined by irradiance, humidity, ambient temperature and speed of wind [21]. It is also affected by other environmental factors such as dirt [22], shadow, DC ohmic losses, AC ohmic losses, inverter losses, the orientation of the modules and similarly the technology used [60]. In addition, this standard inspired the development of techniques to estimate the performance of PV installations or for watch over.

L.C. de Lima et al. (2017) presented a performance study of a photovoltaic installation 2.2 kWp installed at Ceará State University, Fortaleza, Brazil (latitude 3.40°S, longitude 38.33°W and 31 m above sea level).The system was monitored from June 2013 to May 2014. Over the period measured, the average daily network and The final value of the system was 5.6 kWh/kWp, 4.9 kWh/kWp and 4.6 kWh/kWp, respectively. The average annual daily losses of the generator and system were 1.05 kWh/kWp and the average annual yields of the solar field, system after conversion and inverter were respectively 13.3%, 12.6% and 94.6%. The performance ratio and also the factor capacity are 82.9% and 19.2% respectively [23].

J. Taylor et al. (2015) presented the results of the analysis of energy production and performance of more than 2500 distributed PV systems in the UK, monitored for 7 years, and provides an overview of the state of the art. We have mapped the annual energy performance of all PV systems in the database according to the regions of the United Kingdom. The Average annual system performance reported for PV in the UK in 2013 was 910 kWh/kWp, and we estimated the corresponding long-term value at 886 kWh/kWp. The value The average annual integrated PR for 2012-14 was 84%. [24]

D.H. Daher et al. (2018) presented an empirical study of the performance of grid-connected photovoltaic power plants operating in environmental, desert and dusty, as well as maritime conditions, using data from major equipment of this type in Djibouti. The first 4 years of operation were evaluated according to the IEC measurement standard 61724, and the influence of climate parameters was estimated using a technical analysis of manoeuvring performance. The average monthly daily network performance and final performance were 5.1 kWh/kWp and 4.7 kWh/kWp, respectively. Average daily yields of 12.6% and 11.7% per month for photovoltaic modules and systems.

The efficiency of solar PV modules follows a funnel shape with a marked minimum centered on the month of July. The influence of temperature and leakage due to fouling was evaluated, showing a decrease in the ratio of 0.70% with each daily increase of 1°C of the ambient temperature. Fouling losses varied by 0.03% due to events 14.23% for dry and sandy intervals. At the end, to maintain the performance loss of the moldy panel by 5%, a cleaning program is recommended every 15 days. [25]

A. Necaibia et al. (2018) presented a detailed system evaluation analysis Solar 2.5 kWp located in Algeria to the south has been realized in this article in order to support the growth in the implementation of grid-connected photovoltaic plants in the environment This analysis was carried out by carrying out an accurate assessment of different impacts of environmental parameters on the operational performance of the system grid-connected photovoltaics. The data set covers 12 months of operation, the experimental data collected show that variation in environmental parameters has a direct effect on energy conversion efficiency and system losses.

The network has been powered with a power of 4322.65 kWh during the year 2015, where the temperature annual average was 28.30°C. A significant change in performance parameters was observed for the various months. The daily reference yield values Average monthly max/min, table and final were; 7.68/5.7 kWh/kWp/day, 6.07/4.24 kWh/kWp/day and 5.75/3.98 kWh/kWp/day, respectively. The efficiency of the PV module, of the overall inverter and system reached 14.19/11.10%, 95.34/93.94% and 13.53/10.50%, The experimental results indicate that the performance ratio (P_R) varies from 66.66% to 85.93% and the annual average capacity factor was 7.91%.[26]

I.9. Conclusion

This bibliographic chapter presents general information on PV modules, showing their components, their characteristics, the principle of operation, the semiconductors and the PN junction. The different technologies developed are highlighted with their efficiencies.

An overview of the IEC 61724 standard parameters such as reference efficiency, field efficiency, system efficiency, field efficiency, system efficiency, capacity factor and performance ratio.

A presentation of performance studies already carried out that follow the IEC 61724 standard in different regions and continents.

Chapter II

″Presentation of the Aïn El-Melh photovoltaic solar power plant″

II.1. Introduction

The Ain El-Melh photovoltaic power plant, located in the M'sila region, is a major solar energy production facility in Algeria. It is part of the initiatives to develop and exploit renewable energy resources in the country.

The Ain El-Melh photovoltaic plant is equipped with solar panels that capture sunlight and convert it into electricity. It uses a clean and renewable energy source, helping to reduce greenhouse gas emissions and preserve the environment.

The plant, with a significant production capacity, provides a considerable amount of electricity to the M'sila region and helps meet the country's growing energy needs. It also represents an important step towards diversifying Algeria's energy mix by integrating more renewable energies into its electricity grid.

The inauguration of the Ain El-Melh photovoltaic power plant marked an important step in Algeria's energy transition, demonstrating the country's commitment to clean and sustainable energy. It also symbolizes ongoing efforts to harness the region's solar potential and promote the use of renewable energy sources in the country.

In this chapter we present the company SKTM (Shariket KahrabawaTakat Moutadjadida) and we give characteristics of the photovoltaic power plant in (Ain El M'elh).

II.2. Presentation of the SKTM Company

- Shariket Kahrabawa Takat Moutadjadida, abbreviated SKTM, is a company producing conventional electricity for isolated networks in the south and Renewable Energies for the national territory.
- SKTM is a joint stock company with capital subscribed entirely by Sonelgaz and whose head office is located in Ghardaïa.
- Shareholders: 100% subsidiary of SONELGAZ Holding.
- Creation of the company: 07/04/2013

The electricity and renewable energy company "SKTM" in Algeria is a company engaged in the production and distribution of electricity, as well as the development and operation of renewable energy sources. SKTM aims to meet the country's growing electricity needs while adopting a sustainable and environmentally friendly approach.

SKTM is involved in large-scale projects for the construction of power plants using renewable energy sources, including solar, wind and hydro. The company focuses on using innovative and efficient technologies to maximize electricity generation while minimizing environmental impact.

As an electricity company, SKTM also focuses on modernizing and optimizing the existing electricity grid, setting up advanced infrastructure for efficient and reliable electricity distribution across the country.

Through its renewable energy initiatives, SKTM contributes to Algeria's energy transition by reducing dependence on fossil fuels and promoting the use of clean and sustainable energy resources.

The company plays a key role in promoting and implementing energy policies aimed at ensuring a reliable and environmentally friendly electricity supply for the country's socio-economic development.[27]

II.3. Reasons for creation

The Production Company in charge of isolated networks in the south and Renewable Energies, SKTM, is a new joint stock company with capital subscribed entirely by Sonelgaz and whose head office is located in Ghardaïa. The statutes of SKTM were signed on February 25, 2012.

- The specificities of managing the RIS Diesel production park (isolated network in the south) The considerable expectations of the populations of the south in terms of continuity and quality of service.
- The desire to realize the ambitious national Renewable Energy development program. These are all reasons justifying the creation of a specific management company (100% subsidiary of Sonelgaz) with its own management and legal and economic autonomy.
- This option also has the advantage of enabling the Electricity Production Company (SPE) to concentrate on the major challenges specific to the interconnected network. [27]

II.4. Fields of Activities

- SKTM is mainly responsible for operating isolated electrical energy networks in the south (conventional electricity production) and renewable energies.

- The development of the park's electrical infrastructure, production of the Southern Isolated Networks, Engineering, maintenance and management of power plants falling within its field of competence.
- SKTM is responsible for ensuring the marketing of the energy produced for the two Distribution subsidiaries SDO and SDC, and soon for SDE and SDA after the deployment of En.R on the interconnected networks.
- SKTM may undertake any operations of any nature whatsoever, whether financial, commercial, industrial, civil or real estate, relating to this corporate purpose and likely to promote its development, in particular through the acquisition of all equipment, materials, parts or technical installations linked to its activity and to all processes and know-how that may be linked to the corporate purpose.
- SKTM is responsible for compliance with public service obligations in terms of regularity and quality of electricity supply.
- Figure II.1 and table II.1 presents photovoltaic power plants in Algeria under the management of SKTM.

Table II.1. Table of photovoltaic power plants in Algeria. [27]

Rang	Location	Installation Manager	Installed power in (MW)	Geographic coordinates
1	Oued Nechou PV(Ghardaïa)	SKTM	01.1	32°29′ N, 3°40′ E
2	Sedret Leghzel (Naama)	SKTM	20	33°16′ N, 0°19′ E
3	Oued Elkebrit (SoukAhras)	SKTM	15	35°56′ 00″ nord, 7°55′00″est
4	Ain Shouna (Saïda)	SKTM	30	34°30′ 20″ nord, 0°50′59″est
5	Ain El Bel(Djelfa)	SKTM	20	34°21′ 17″ nord,3°13′22″ est
6	Lekhneg (Laghouat)	SKTM	20	33°44′ 41″ nord,2°47′39″ est
7	Télagh (Sidi-Bel-Abbès)	SKTM	12	34°47′ 06″ nord,0°34′23″ ouest
8	Labiodh Sidi Chikh (El-Bayadh)	SKTM	23	32°53′ 55″ nord,0°32′40″ est
9	El Hdjira (Ouargla)	SKTM	30	32°36′ 48″ nord,5°30′44″ est

10	**Ain-El-Melh(M'Sila)**	**SKTM**	**20**	**34°50′54″nord,4°09′40″est**
11	Oued El Ma (Batna)	SKTM	02	35°38′ 43″ nord,5°59′41″ est
12	Adrar	SKTM	20	27°52′ 00″ nord,0°17′00″ ouest
14	Àine Salah	SKTM	05	27°15′ nord,2°31′ est
13	Kaberténe	SKTM	03	28°27'0"N0°4'0"W
15	Timimoune	SKTM	09	29°15′ nord,0°15′ est
16	Reggane	SKTM	05	26°43′ 12″ nord,0°10′16″ est
17	Zaouiat Kounta	SKTM	06	27°13′ 00″ nord,0°12′00″ ouest
18	Aoulef	SKTM	05	26°58′ 00″ nord,1°05′00″ est
19	Tamanrasset	SKTM	13	22°47′ 13″ nord,5°31′38″ est
20	Djanet	SKTM	03	24°33′ 18″ nord,9°29′06″ est
21	Tindouf	SKTM	09	27°40′ 00″ nord,8°09′00″ ouest
		Total Power (MW)	**270**	

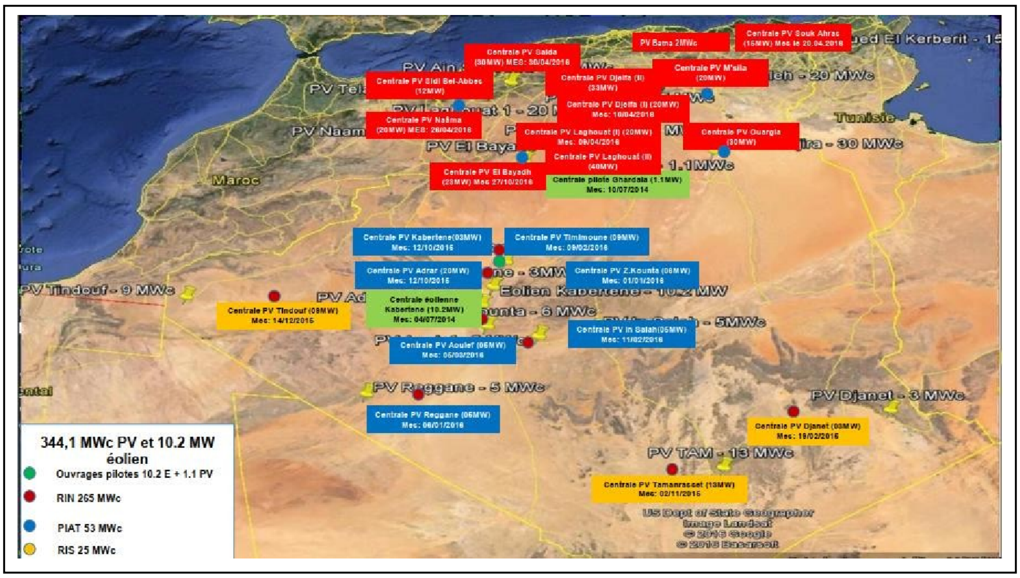

Figure II.1. The distribution of PV power plants in Algeria.

II.5. Ain El-Melh solar photovoltaic power plant is operational

The photovoltaic power plant in Ain El-M'elh in the wilaya of M'sila is part of the SKTM's 400 MW project. Sonelgaz sector responsible for the development of renewable energies, SKTM plans to finalize all 23 power plants planned by the end of 2015. In the Hauts Plateaux Center region, four installations are planned. Their cumulative power will be 90 MW.

On Sunday, September 24, 2017; The Minister of Energy, **Mustapha Guitouni**, carried out on Sunday in the wilaya of M'sila the commissioning of the photovoltaic solar power plant in the commune of Ain El-Melh, located 120 km to the south -west of the wilaya capital.

With a capacity of 20 megawatts, and the surface area of this plant is 40 hectares, this photovoltaic solar power plant for the production of electrical energy is the first of its kind in the capital of Hodna and whose construction required the mobilization of an investment of nearly 3.9 billion dinars.

The Minister called to master the various aspects related to renewable energies including the aspects of management and implementation "The management of renewable energy is reflected in the control of the cost of realization of the installations and the successful interconnection between the different sources of electric energy," considered the minister.

He called, in the same context, to encourage investment in renewable energy and to introduce training related to the trades of this energy stressing that Algeria has 'a solar field estimated at 5 billion gigawatts with a sunshine duration in the Highlands and South of nearly3000hours/year'.

Figure II.2. Ain El-Melh solar photovoltaic power plant

II.6. Characteristics of the Ain El-Melh PV plant

The Aïn El-Melh Photovoltaic (PV) plant, being a significant renewable energy project, likely possesses several key characteristics that contribute to its effectiveness and impact. Here are some characteristics commonly associated with such PV plants:

- Country: Algeria – W: M'sila – Locality: Ain El-Melh,
- Geometric Coordinates: 32o35'N and 05o50' E,

- Area: Forty (40) Hectares,
- Power: 20000KWcrete,
- Injection voltage: 60Kv,
- Project manager: The electricity and renewable energy company "SKTM",
- Project manager:Yingli Solar,
- Technology: Polycrystalline,
- The number of photovoltaic panels in this plant is 80,080 of the polycrystalline type with a power P = 250 W_C,
- It also includes 40 inverters: 20 inverters on side A made up of 2002 PV panels and 20 inverters on side B also made up of 2002 panels and the voltage output is V=315V AC. Each one of P= 500 KW,
- It is made up of 20 transformers 315V AC to 30 kV AC (step-up and step-down),
- The angle of inclination of the PV panels is β= 33° and the orientation of the panels faces south,
- The maximum power reached to date is P max =21.7 MW but it is instantaneous,
- A Diesel Generator.
- A meteorological station to measure (global radiation, temperature, wind speed, humidity, pressure and duration of sunshine), see figure II.3,
- An evacuation station (electricity sending station),
- A pumping chamber for cleaning PV panels and a small part of water for other uses,
- Level 01 junction boxes: the output cable section is 70 mm,
- Parallel boxes levels 02: the output cable section is 240 mm,
- The number of solar public lighting poles is 68 pots for the power plant fence of 4.7 m height and for interior lighting 10 poles of 7 m height. Each of them (is an autonomous system) and is composed of:
    - Mono-crystalline panels with a power of around 140 Wp,
    - Two batteries (flat plate) of 12 Volt and capacity 120,
    - A charge controller 10A-12A,
    - An LED lamp 24V/30W,
- Each 1 MW it has 24 junction boxes and 8 parallel boxes, a 5 kW inverter and a transformer,
- Maximum production takes place in **March and April**,

- **1MW is obtained by placing 22 panels in series in each string and 182 branches in parallel, so, 22x182 = 4004 panels x 20 = 80080 panels (to produce the 20MW of the power plant).**
- The efficiency of the inverter and η= 97%,
- A truck for cleaning photovoltaic panels,
- A truck for maintenance,
- A water heater for washing dishes, showering, etc.

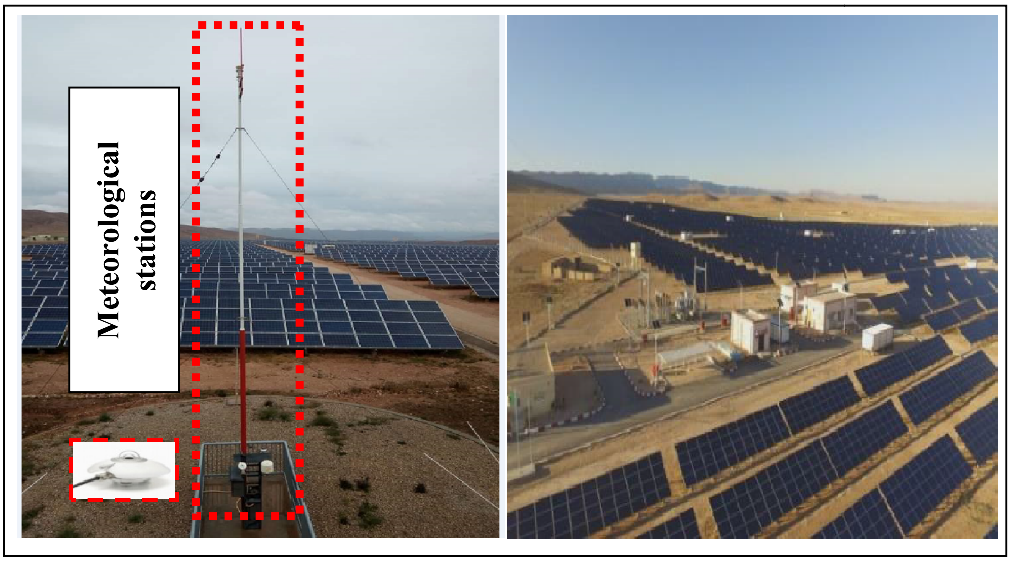

Figure II.3. Photovoltaic panel and meteorological stations.

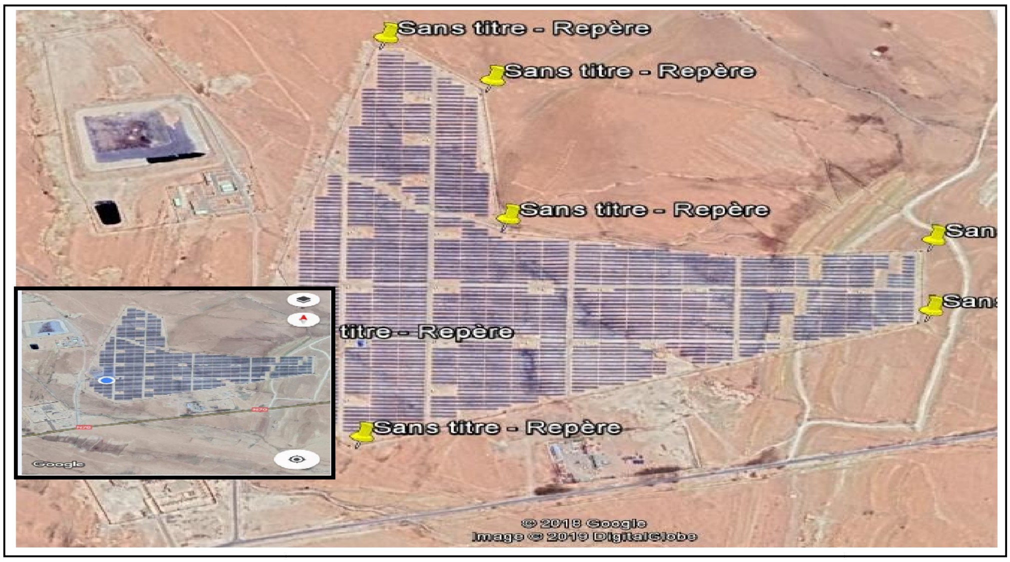

Figure II.4. Solar power plant at Ain El-Melh.

II.7. Photovoltaic systems

Photovoltaic (PV) systems, often referred to as solar power systems, are technology setups that convert sunlight directly into electricity. These systems are composed of various components working together to capture, convert, and distribute solar energy. Here's an overview of the key elements and workings of photovoltaic systems: [28]

II.7.1. Photovoltaic effect

The term «photovoltaic» often abbreviated by the acronym «PV», was formed from the words «photo» a Greek word meaning light and «Volta» the name of the Italian physicist Alessandro Volta who gave birth to the electrochemical battery in 1800. The photovoltaic effect is the direct conversion of energy into electricity.

The photovoltaic effect occurs when a photon is absorbed into a material composed of doped semiconductors p (positive) and n (negative), referred to as junction p-n (or np). Under the effect of this doping, an electric field is present in the material permanently (like a magnet has a permanent magnetic field). When an incident photon (light grain) interacts with the electrons of the material, it cedes its energy to the electron that is released from its valence band and thus undergoes the intrinsic electric field. Under the effect of this field, the electron migrates towards the upper face leaving room for a hole that migrates in the opposite direction. Electrodes placed on the upper and lower faces make it possible to collect the electrons and to make them realize an electric work to join the hole of the front face. [29]

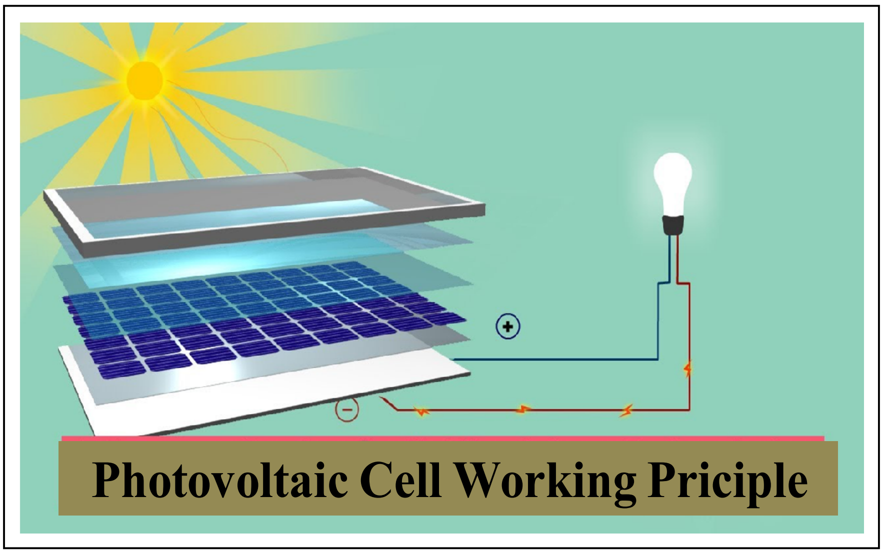

Figure II.5. Photovoltaic cell.

II.7.2. Different types of photovoltaic systems

There are usually three types of photovoltaic systems, stand-alone systems, hybrid systems and grid-connected systems. The first two are independent of the electricity distribution system, often found in remote areas.

- **Stand-alone systems**

These photovoltaic systems are installed to ensure autonomous operation without the need for other energy sources. Typically, these systems are used in isolated and remote areas of the grid.

The different types of autonomous photovoltaic systems have the possibilities of direct coupling to a suitable load or coupling with MPPT (Maximum Power Point Tracking) impedance adapter, operation over the sun or with electrical energy storage. Direct coupling involves operation over the sun, therefore at essentially variable power throughout the day. Typical direct current loads that can meet the criterion (constant voltage at variable power) are electrochemical accumulators. The alternative loads are the water pumps, it is pumping over the sun, the storage is nevertheless present in the form of stored water (in a reservoir).

In most cases, impedance adaptation must be carried out by inserting an electronic device between the generator and its electrical load which forces the system to operate at its maximum power. [29]

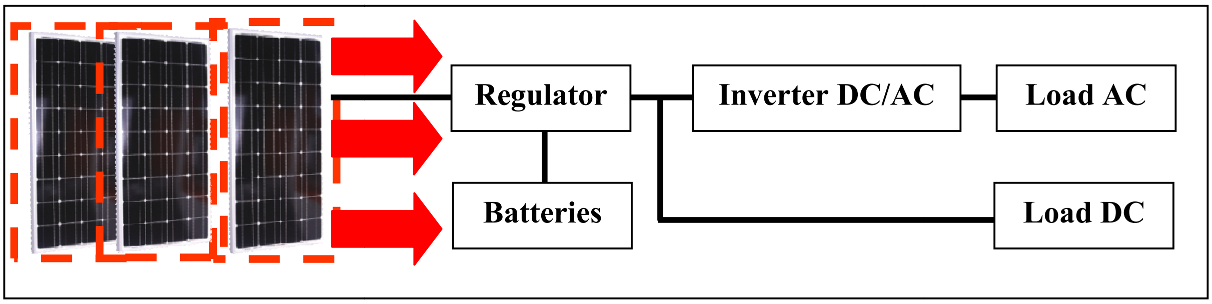

Figure II.6. Stand-lone systems.

- **Hybrid systems**

Hybrid energy systems combine at least two renewable energy sources and one or more conventional energy sources. Renewable energy sources, such as photovoltaic and wind turbines, do not deliver constant power, but given their complementarities, their combination allows continuous electricity production. Hybrid energy systems are generally self-sustaining from large interconnected grids and are often used in isolated regions.

The different sources in a hybrid system can be connected in two configurations, DC bus architecture and AC bus architecture. In the first configuration, the power supplied by each source is centralized on a DC bus. Thus, alternating current (AC) power conversion systems first supply their power to a rectifier and then convert it to direct current (DC).

The generators are connected in series with the inverter to power the AC loads. The inverter must supply the AC loads from the DC bus and must follow the setpoint set for amplitude and frequency.

The specific function of the supervision system is the start and stop control of the generators and the storage system. The advantage of this topology is ease of control. In the second configuration all the components of the hybrid system are connected to the AC load.

II.8. System connected to the network

Grid-connected photovoltaic energy production systems are a result of the trend toward decentralization of the electrical grid. Energy is produced closer to places of Energy is produced closer to places of consumption. Grid-connected systems reduce the need to increase the capacity of transmission and distribution lines. It generates its own electricity and sends its excess energy to the grid, from which it draws supplies as needed; these transfers eliminate the need to purchase and maintain a battery. It is always possible to use these systems to act as backup power when a network outage occurs. [30]

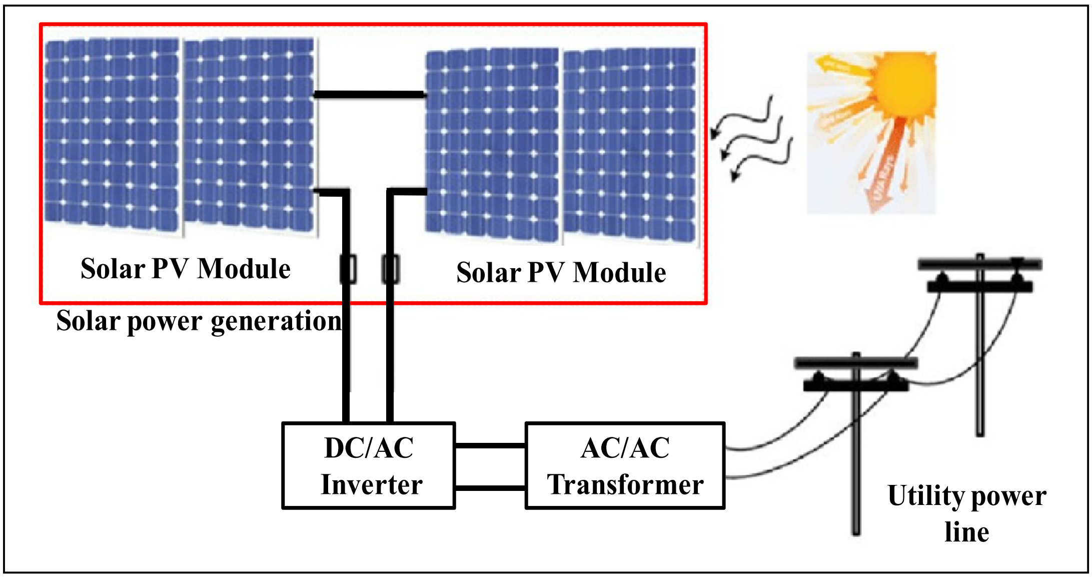

Figure II.7. Grid-connected photovoltaic systems.

NB: The solar photovoltaic plant of ain El-Melh is dependent on the third type Photovoltaic systems connected to the grid.

II.9. Equipment of the Aine El-Melh PV plant

The equipment used in the Aïn El-Melh PV plant includes various components necessary for the generation, conversion, and distribution of solar energy. While specific details may vary depending on the plant's design and specifications, here's an overview of the equipment commonly found in photovoltaic solar power plants like Aïn El-Melh: [27]

II.9.1. Solar Panels (Photovoltaic Modules)

High-efficiency solar panels made of photovoltaic cells, typically composed of silicon or other semiconductor materials.

These panels are arranged in arrays across the plant's site to capture sunlight and convert it into electricity. [28]

II.9.2. Inverters

Grid-tied inverters convert the direct current (DC) electricity generated by the solar panels into alternating current (AC) electricity compatible with the local electrical grid.Inverters also optimize power output and ensure system efficiency. [29]

II.9.3. Mounting Structures

Racking systems or mounting structures support and secure the solar panels in place.These structures may include fixed, adjustable, or tracking systems designed to maximize sunlight exposure and energy production. [27]

II.9.4. Transformer

Transformers are used to step up the voltage of the electricity generated by the PV system before it is transmitted to the grid.They also facilitate the integration of solar power into the existing electrical infrastructure. [30]

II.9.5. Monitoring and Control Systems

Monitoring equipment tracks the performance of the PV plant in real-time, including energy production, system efficiency, and potential issues.

Control systems may include software or hardware solutions to optimize energy production, manage grid interaction, and ensure safety and reliability. [30]

II.9.6. Switchgear and Protection Devices

Switchgear, circuit breakers, and protection devices are essential for the safe operation of the PV plant and to protect against electrical faults or overloads.These devices help isolate and disconnect specific components or sections of the system as needed. [27]

II.9.7. Power Conditioning Units

Power conditioning units, such as voltage regulators or power factor correction equipment, may be used to improve the quality of electricity generated by the PV system. [28]

II.9.8. Meteorological Stations

Weather monitoring stations or meteorological sensors may be installed onsite to collect data on sunlight intensity, temperature, wind speed, and other environmental factors.This data helps optimize system performance and predict energy output. [29]

II.9.9. Communication Systems

Communication equipment enables remote monitoring, control, and management of the PV plant.It facilitates communication between onsite equipment, control centers, and grid operators. [30]

II.9.10. Security and Surveillance Systems

Security cameras, sensors, and access control systems may be deployed to safeguard the PV plant against theft, vandalism, or unauthorized access.

II.9.11. Auxiliary Power Systems (optional)

Backup generators or battery storage systems may be installed to provide auxiliary power for critical equipment or during periods of low sunlight.

II.9.12. Civil Works and Infrastructure

Civil works and infrastructure, including foundations, roads, fencing, and drainage systems, are essential for the construction and operation of the PV plant. [27-30]

Each component plays a crucial role in the generation, conversion, and distribution of solar energy, contributing to the plant's overall efficiency, reliability, and performance.[27-29]

II.9.13. Photos of equipment of the Ain El-Melh PV plant [27-29]

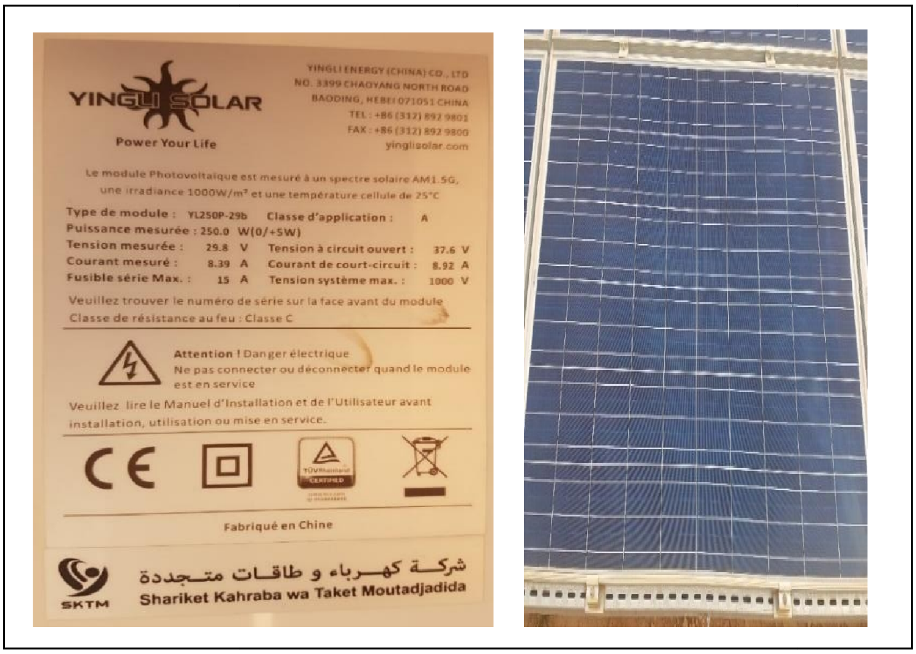

Figure II.8. The technical sheet of the PV panel and the PV module.

Figure II.9. Solarinvreter500KW.

(a) Transformer 30KV.

(b) Transformer 400V.

(b) Transformer 60kV.

FigureII.10. DifferentsTransformer.

Figure II.11. Diesel Generator.

FigureII.12. Meteorological Station.

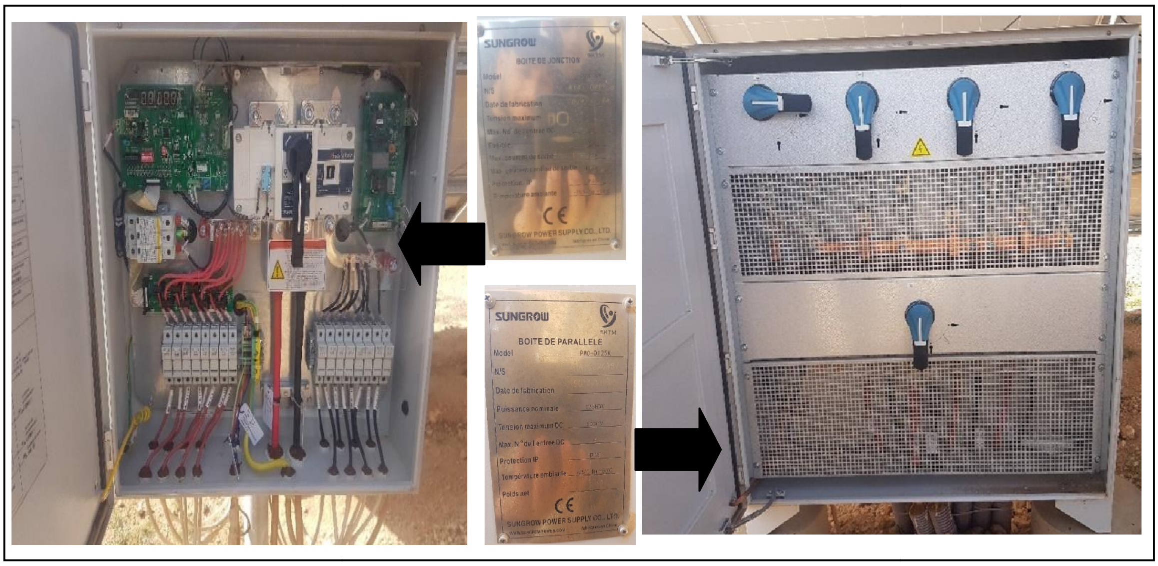

Figure II.13. Junction box.**Figure II.14.**Parallel box.

Figure II.15. The arrivals and departure.

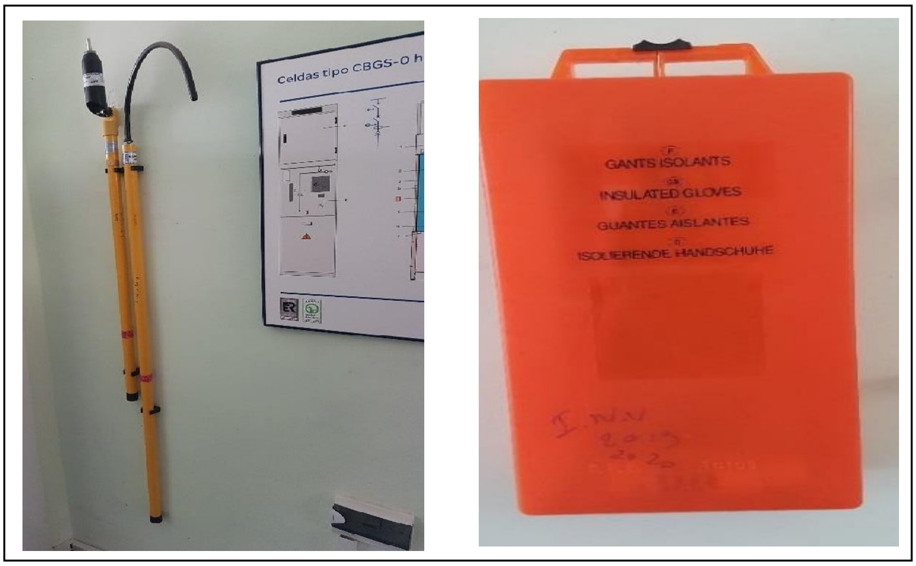

Figure II.16. Protective equipment found in the evacuation station.

Figure II.17. Equipment for maintaining and cleaning panels and the photovoltaic power plant.

Figure II.18. Photos aériennes de la centrale photovoltaïque de Aine El-Melh.

Figure II.19. Solar public lighting.

II.10. Conclusion

The Aïn El-Melh photovoltaic solar power plant stands as a testament to sustainable energy innovation, harnessing the abundant power of the sun to generate clean electricity. Situated in a region blessed with ample sunlight, this cutting-edge facility epitomizes the shift towards renewable energy sources, contributing significantly to the reduction of carbon emissions and environmental impact.

By following this presentation structure in this chapter, we were able to effectively showcase the features, benefits and contributions of the Ain El-Melh solar PV plant to the renewable energy landscape.

Chapter III

″ Performance Investigation of a Large-Scale Grid-Tied PV Plant: Case Study Ain El-Melh″

III.1. Introduction

Photovoltaic (PV) technology has emerged as a leading solution for harnessing renewable energy, contributing significantly to the global transition towards sustainable energy systems.

Large-scale grid-tied PV plants play a crucial role in this transition by providing substantial amounts of clean electricity to the grid. This study focuses on the performance investigation of a large-scale grid-tied PV plant located in Ain El-Melh. [29]

This chapter aims to analyze the operational efficiency, energy yield, and overall effectiveness of the Ain El-Melh PV plant. By examining various performance metrics and identifying potential areas for optimization, the study seeks to enhance the understanding of large-scale PV plant operations in similar climatic and geographical conditions.

The findings will provide valuable insights for improving the design, implementation, and management of future PV installations.

III.2. PV plant description

A photovoltaic (PV) plant, also known as a solar power plant or solar farm, is a large-scale solar installation where photovoltaic panels are used to generate electricity. Below is a detailed description of a PV plant: [1,27]

III.2.1. Site description

The grid-connected, ground-mounted photovoltaic system examined in this last chapter is situated in Ain El-Melh, Algeria, at the edge of the Algerian highlands and the gateway to the great desert.

Additionally, its proximity to a 60 kV substation, crucial for efficient electricity transmission to the national grid, was a key factor. The availability of suitable land at Ain El-Melh also played a significant role, providing ample space for a large-scale photovoltaic system.

Environmental and social considerations were addressed through assessments aimed at minimizing ecological impacts and promoting positive interactions with the local community.

Overall, these factors made Ain El-Melh the optimal location for the photovoltaic power plant, enabling efficient electricity transmission, optimal land use, and positive community integration.

The site's coordinates are 34°51′ N latitude and 04°11′ E longitude, with an elevation of 910 meters above sea level. Climatically, the PV plant installation site is characterized by:

- Moderate temperatures in winter and spring, rising to high temperatures in summer and autumn,
- High solar potential, with an annual average of 7 kWh/m²,
- Low relative humidity,
- A high number of clear sky days,
- Numerous days with dust storms, particularly in spring.

The construction and commissioning of the Ain El-Melh photovoltaic power plant involved a comprehensive planning process. This included procuring equipment, preparing the site, installing system components, connecting to the power grid, and conducting performance testing. Challenges were addressed through effective project management and close collaboration with stakeholders. This meticulous approach resulted in the successful implementation of the photovoltaic power plant.[1]

III.2.2. PV power plant

The photovoltaic power plant connected to the medium voltage network in Ain El-Melh is part of a larger 400 MW project managed by the SKTM Company. The Ain El-Melh plant, a solar PV facility with a total capacity of 20 MWp, spans 40 hectares.

Figure III.1. 20 MWp grid-connected ground-mounted PV plant system at Ain El-Melh.

Figure III.1, a drone-captured image, provides an aerial view of the photovoltaic installation. The general layout, equipment, components, and the photovoltaic field—including solar panels, supporting structures, mounting boxes, cabling, converter stations, and transformer stations are detailed below. The design parameters of the 20 MWp PV plant are summarized in Table III.1.

Table III.1. Ain El-Melh PV power plant design parameters (20 MWp)

Parameters	Characteristics
Type of module	Poly-crystalline silicon
Efficiency of PV module	15%
Tilt and Orientation	33° South
Type of installation	Fixed structure
PV rows distance	5 meters
Inverter nominal power	500 KW
Characteristics of transformers	1250 kVA, 47−52 Hz, 315 V/31.5kV

The grid-tied PV park comprises 80,080 polycrystalline silicon modules, each with a rated power of 250 Wp. The park is segmented into 40 sub-fields, each with a capacity of 500 kW and connected to a 500 kW SUNGROW inverter. Every two sub-fields (1 MWp) are linked to a step-up transformer with an apparent power of 1250 VA. Each sub-field includes:

- 1936 polycrystalline silicon modules of 250 Wp each and inclined at 33° to the south,
- 88 PV strings (each string consists of 22 modules connected in series),
- 1 inverter of 500 kW type SUNGROW (input 500-850 V_{DC} - output 315 V_{AC}),
- 11 level 1 junction boxes,
- 3 level 2 junction boxes,
- 1 level 3 junction box.

As shown in figure III.2, the 60 kV overhead lines connected to the national grid are used to evacuate the produced electricity.

Therefore, the photovoltaic modules are connected to the 500 kW inverter cabinets via junction boxes (level 1), parallel boxes (level 2), and general boxes (level 3) included in the shelters.

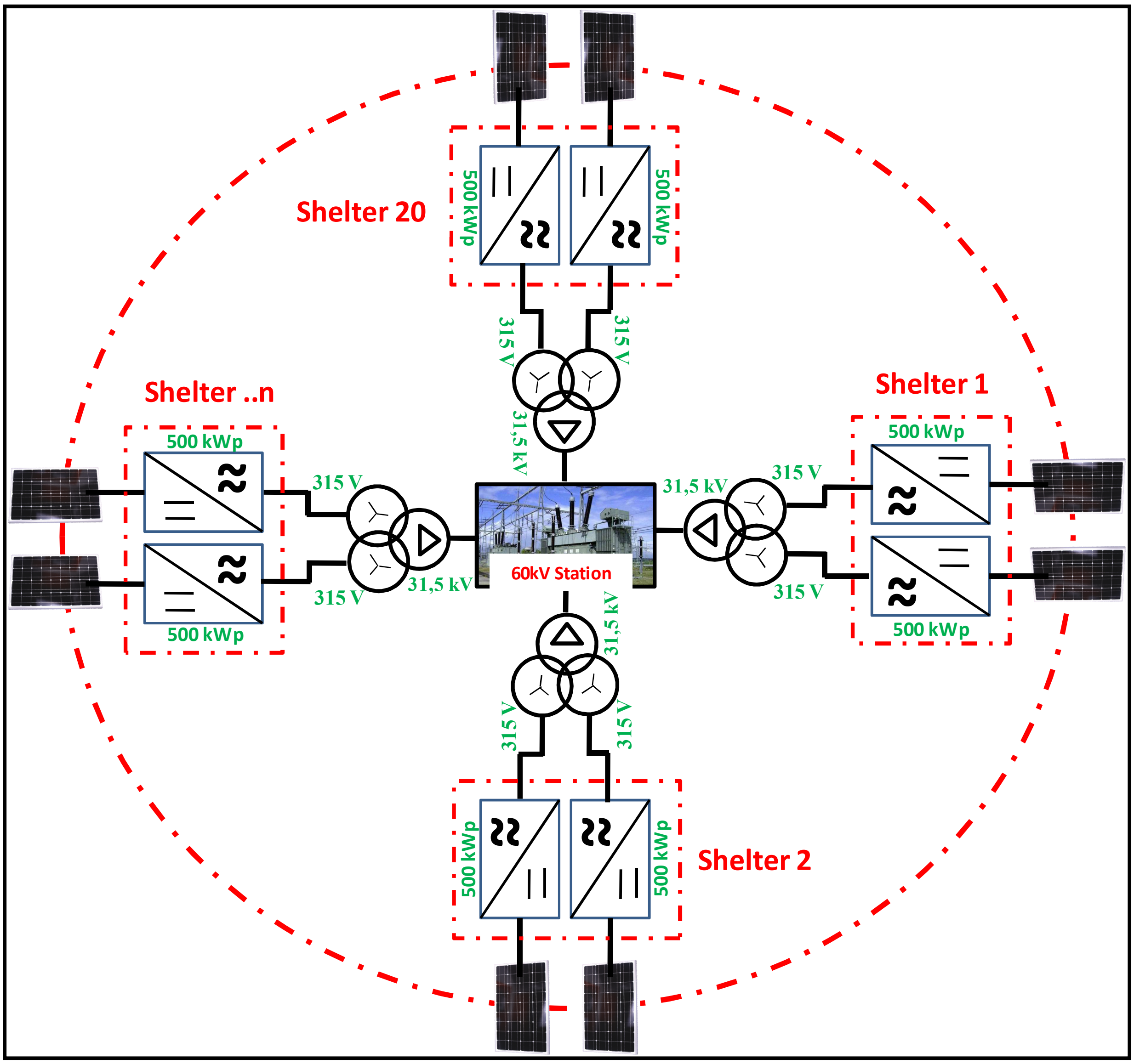

Figure III.2. Overview of the 20 MW Ain El-Melh grid connected power plant.

III.3. Analysis of real performance of the Ain El-Mleh PV plant

This section discusses the performance monitoring of the Ain El-Mleh photovoltaic solar field, boasting a power capacity of 20 MWp, and its connection to the national grid throughout January 2019. The performance metrics analyzed in this study adhere to the standards set forth by the International Energy Agency (IEA) and are detailed in the standardized guidelines of IEC 61724 [3]. The chapter is structured into two main parts: the first part focuses on the analysis of meteorological data collected at the Ain El-Mleh site, while the second part delves into the daily performance analysis of the Ain El-Mleh field.

III.3.1. Analysis of meteorological data from the Ain El-Mleh site

The primary external factors constraining the optimal performance of a photovoltaic installation during its production phase are the environmental conditions within which it operates. Solar radiation, or irradiation, stands out as the most significant factor influencing the system's efficiency.

Additionally, temperature variations impact the performance of key components, while factors such as wind speed and direction play less prominent roles. These elements collectively shape the environmental context that dictates the actual operation of the photovoltaic plant at a specific site.

To analyze the climatic parameters specific to the Ain El-Mleh area, data from various sensors were collected and interpreted for the month of January 2019.

III.3.1.1. Evolution of daily insolation

To understand the environmental conditions impacting the Ain El-Mleh photovoltaic solar power plant and its performance, we initiated our analysis by examining the evolution of daily solar radiation on the module inclination plane (I_{POA}) throughout January 2019, depicted in Figure III.3.

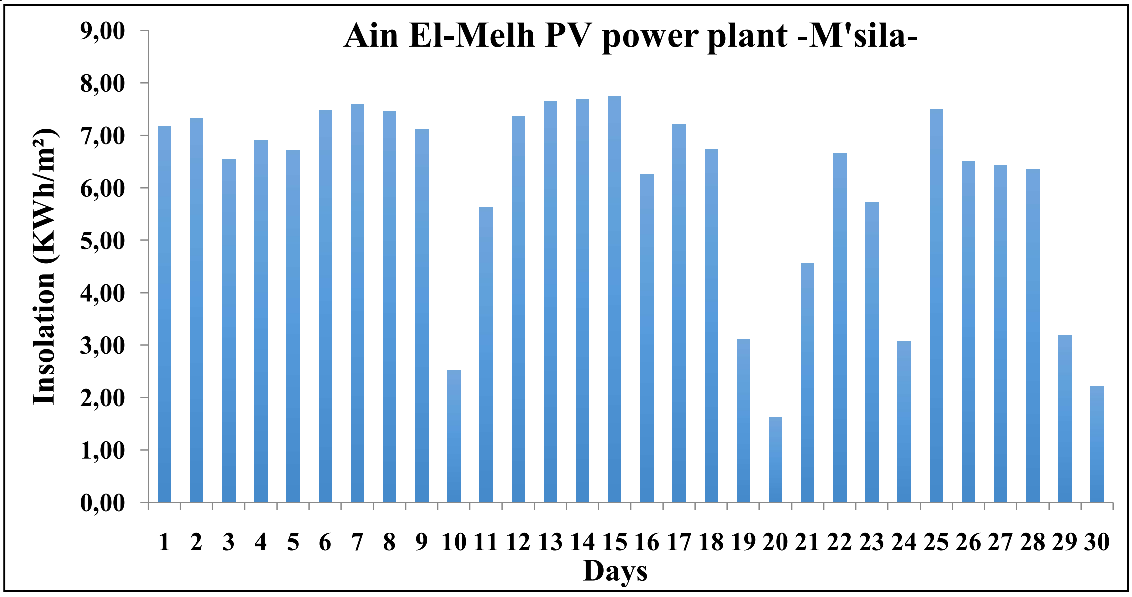

Figure III.3. Evolution of daily insolation of the Ain Mleh PV power plant, (January 2019).

Observations reveal a fluctuation in daily insolation levels throughout the month. The maximum insolation, reaching 7.745 kWh/m², was recorded on the 15th day of January, while the minimum insolation, 1.618 kWh/m², was recorded on the 20th day of the same month. On average, the insolation for January amounted to 6.002 kWh/m²/day.

III.3.1.2. Evolution of daily temperatures

Figure III.4 depicts the fluctuations in daily temperatures (ambient and module) throughout January 2019. It's notable that these temperatures exhibit daily variations. Ambient temperature ranges between 9.80°C and 2.31°C, with an average of 6.73°C.

Meanwhile, module temperature fluctuates between 18.41°C and 9.71°C, averaging at 13.55°C. Notably, both temperatures show a consistent trend, with the module temperature consistently higher than the ambient temperature. This disparity can be attributed to the generation of thermal losses inherent in energy production processes.

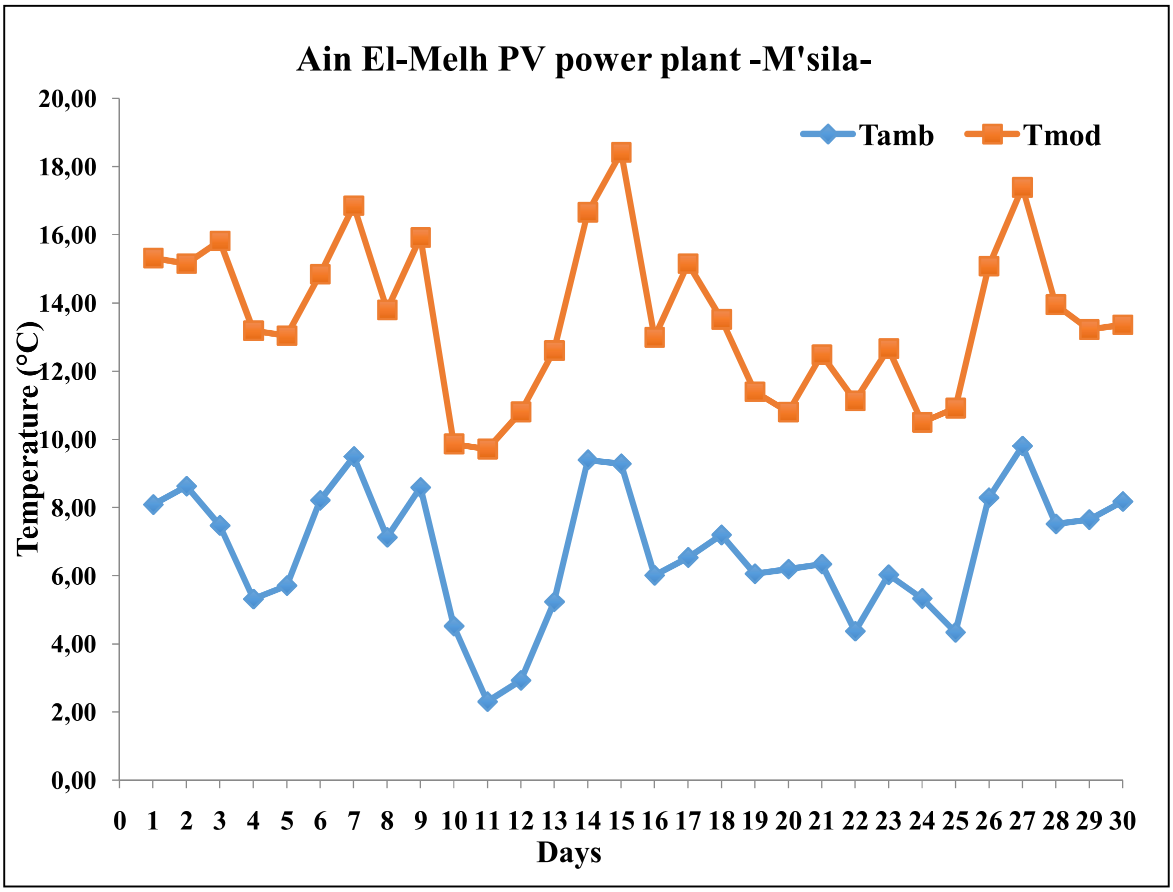

Figure III.4. Evolution of daily temperatures at the Ain Mleh PV plant.

III.3.2. Analysis of the evolution of the performances of the Ain El-Mleh PV power plant

Our performance analysis covers the month of January 2019 of the photovoltaic field (Ain Mleh1), with a capacity of 20 MWp connected to the grid, of the Ain mleh power plant in the wilaya of M'sila.

III.3.2.1. Energy generated and energy delivered

Figure III.5 depicts the daily progression of energy generation by the photovoltaic field (E_{DC}) alongside the energy supplied to the distribution network (E_{AC}) for January.

It's evident that both E_{DC} and E_{AC} energies exhibit a parallel trajectory, with the energy generated by the photovoltaic field (E_{DC}) surpassing that supplied to the distribution network (E_{AC}).

The daily energy output from the photovoltaic field (E_{DC}) reaches its peak at 3.044 kWh on the 13th day of the month, while its lowest point is recorded at 0.654 MWh on the 20th day. On average for the month, the energy generated amounts to 2,384 kWh.

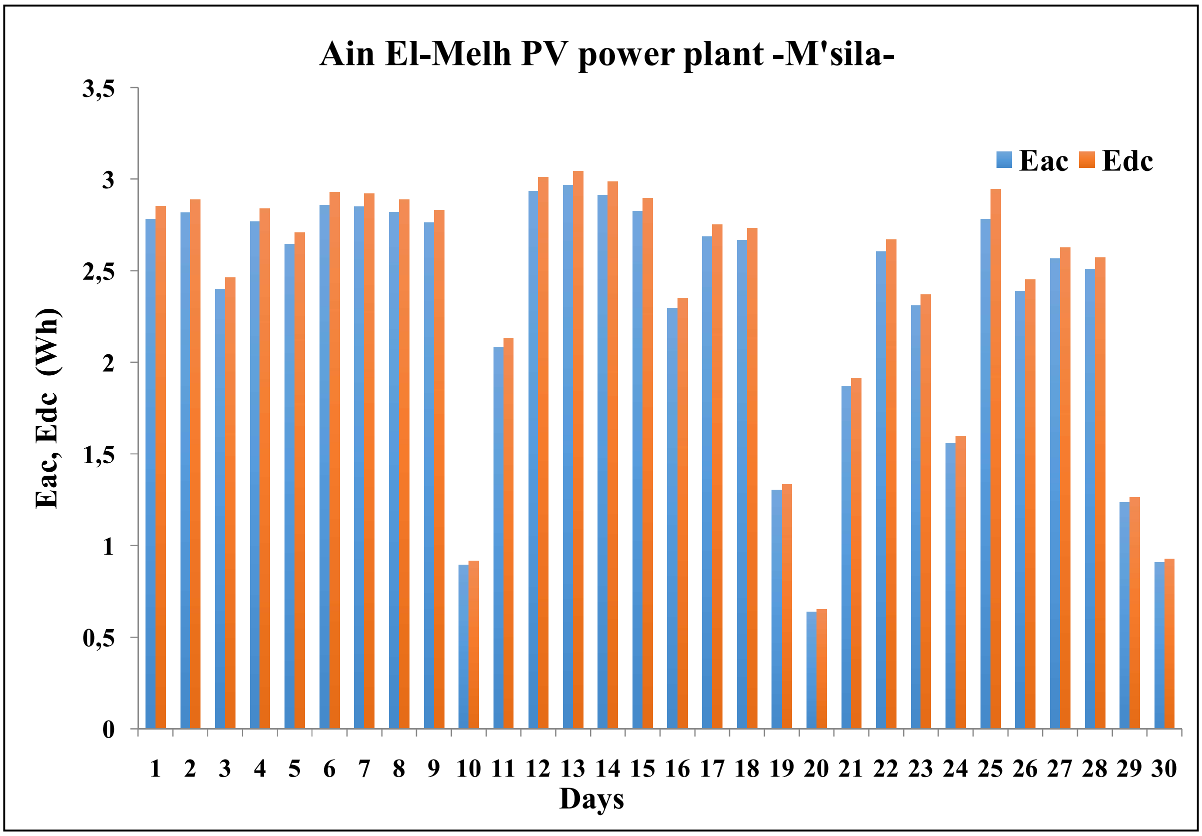

Figure III.5. Daily evolution of the energies of the Ain El-Mleh PV plant.

The daily energy supplied to the network (E_{AC}) has a maximum value of 2,970 KWh recorded during the 13th day of the month and also has a minimum value of 0.638 KWh recorded during the 20th day of the month. The monthly average of energy supplied to the network is 2,323 KWh.

We note that these energies (generated by the photovoltaic field (E_{DC}) and supplied to the network (E_{AC}) follow the same pace as the daily insolation (H_t) as illustrated in figure III.3. They are proportional to the insolation; they present high values for high insolation and low values for low insolation values.

III.3.2.2. Reference yields, PV field efficiency and final yield

Reference efficiency, or reference yield (Y_r), is the ratio of the total incident solar radiation on the plane of the PV modules to the reference radiation. It is typically measured in hours per day (h/d) and represents the ideal yield under standard test conditions.

$$Y_r = \frac{H_t}{G_{stc}} \quad \text{(III.1)}$$

- *Ht* : Total incident solar radiation (kWh/m^2)
- G_{stc} : Reference solar radiation under standard test conditions (typically 1 kW/m²)

Photovoltaic field efficiency, or array yield (Y_a), is the actual energy output from the photovoltaic array per day, normalized by the rated power of the PV modules. It measures how effectively the PV array converts sunlight into electrical energy.

$$Y_a = \frac{E_{dc}}{P_0} \quad \text{(III.2)}$$

- E_{dc} : Actual DC energy output from the PV array (kWh),
- P_0 : Rated power of the PV array (kW).

Final efficiency, or final yield (Y_f), is the actual energy delivered to the grid per day, normalized by the rated power of the PV system.

It encompasses all losses in the system, including those from inverters, wiring, and other components, reflecting the overall performance of the entire photovoltaic system.

$$Y_f = \frac{E_{ac}}{P_0} \quad \text{(III.3)}$$

- E_{ac}: Actual AC energy output delivered to the grid (kWh),

- P_0: Rated power of the PV system (kW).

Figure III.6 illustrates the daily evolution of yields for January, including the reference efficiency (Y_r), the photovoltaic field efficiency (Y_a), and the final efficiency (Y_f) of the photovoltaic system.

We observe that all these yields follow a similar trend. The reference yield (Y_r) ranges from 1.62 h/d on the 20th day to 7.75 h/d on the 15th day, with the monthly average reference yield for January being 6.00 h/d.

The yield of the photovoltaic field (Y_a) peaks at 6.29 h/d on the 13th day and drops to a minimum of 1.35 h/d on the 20th day. The average yield for the photovoltaic field in January is 4.93 h/d.

The final yield reaches a maximum of 6.14 h/d on the 13th day and a minimum of 1.32 h/d on the 20th day of the month. For January, the average final yield of the photovoltaic field is 4.80 h/d.

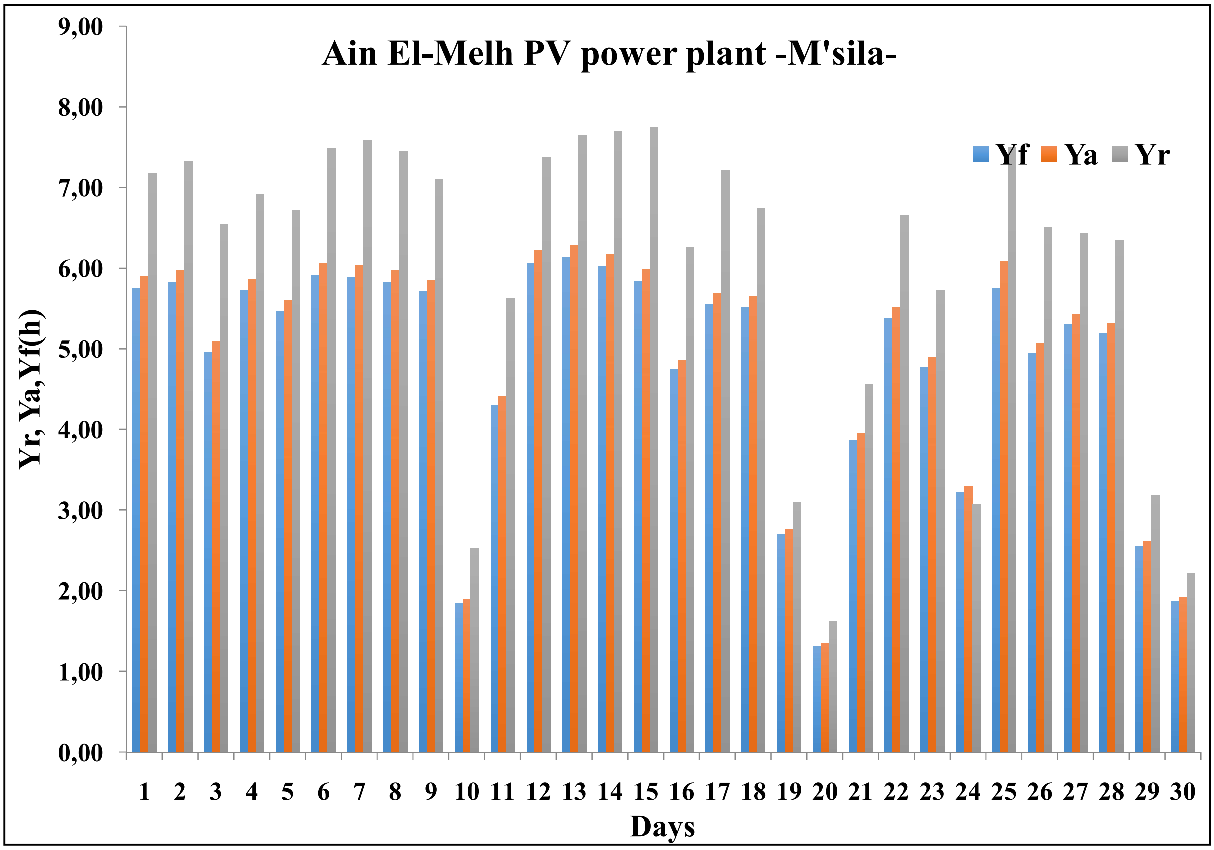

Figure III.6. Daily evolution of yields from the Ain El-Mleh PV plant.

We observe that all these yields are proportional to the insolation, which explains the similar patterns seen among the reference yield, the yield of the photovoltaic field, the final yield, and the insolation, as illustrated in Figure III.6.

III.3.2.3. Performance ratio

The daily evolution of the performance ratio (P_R) for January is shown in Figure III.7. Throughout the month, the performance ratio remains relatively stable, ranging from 73.28% on the 10th day to 104.93% on the 24th day, with a monthly average of 80.66%. A performance ratio exceeding 80% indicates a system performing close to its optimal efficiency under standard test conditions (STC). Notably, the Ain Mleh power plant achieved this level on 18 days, demonstrating a very favorable performance ratio that confirms its excellent operational condition with no signs of degradation.

Note: On the twenty-fourth day, the PR factor exceeds 100%, which is an illogical value, possibly a measurement error.

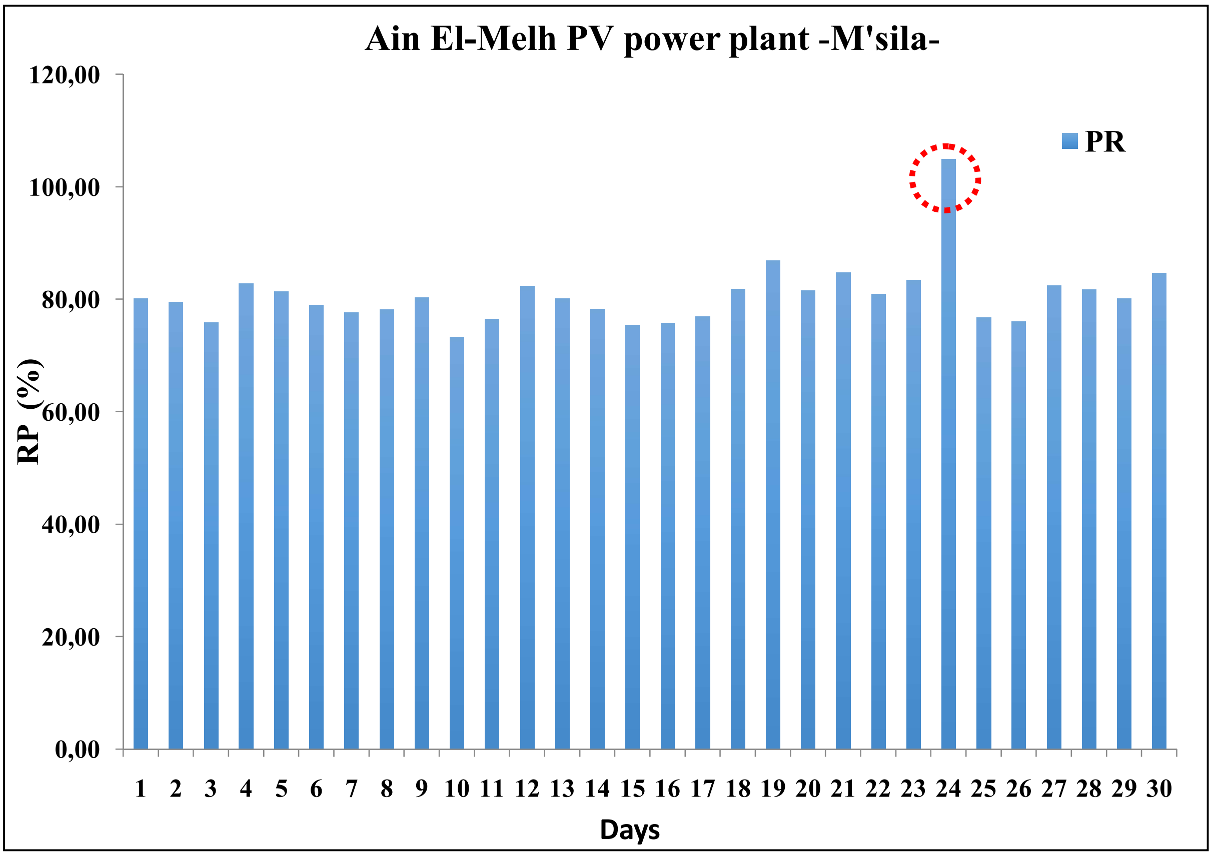

Figure III.7. Daily evolution of the performance index of the Ain Mleh PV plant.

III.3.2.4. Conversion losses and other losses

The daily evolution of system losses due to conversion (L_S) and miscellaneous losses (L_C) is illustrated in Figure III.8. The daily conversion losses are relatively stable, averaging 0.13 h/day, with a minimum of 0.11 h on the 20th day and a maximum of 0.335 h on the 25th day. This indicates that the inverter (A) of the shelter 1 subfield is efficient in terms of DC-AC conversion.

Miscellaneous daily losses exhibit more variability, ranging from a minimum of 0.23 h/day to a maximum of 1.76 h/day. Negative values, noted as minus capture loss, suggest that less time is required for the PV system to produce DC power at its rated capacity. The average value of daily miscellaneous losses is 1.08 h/day.

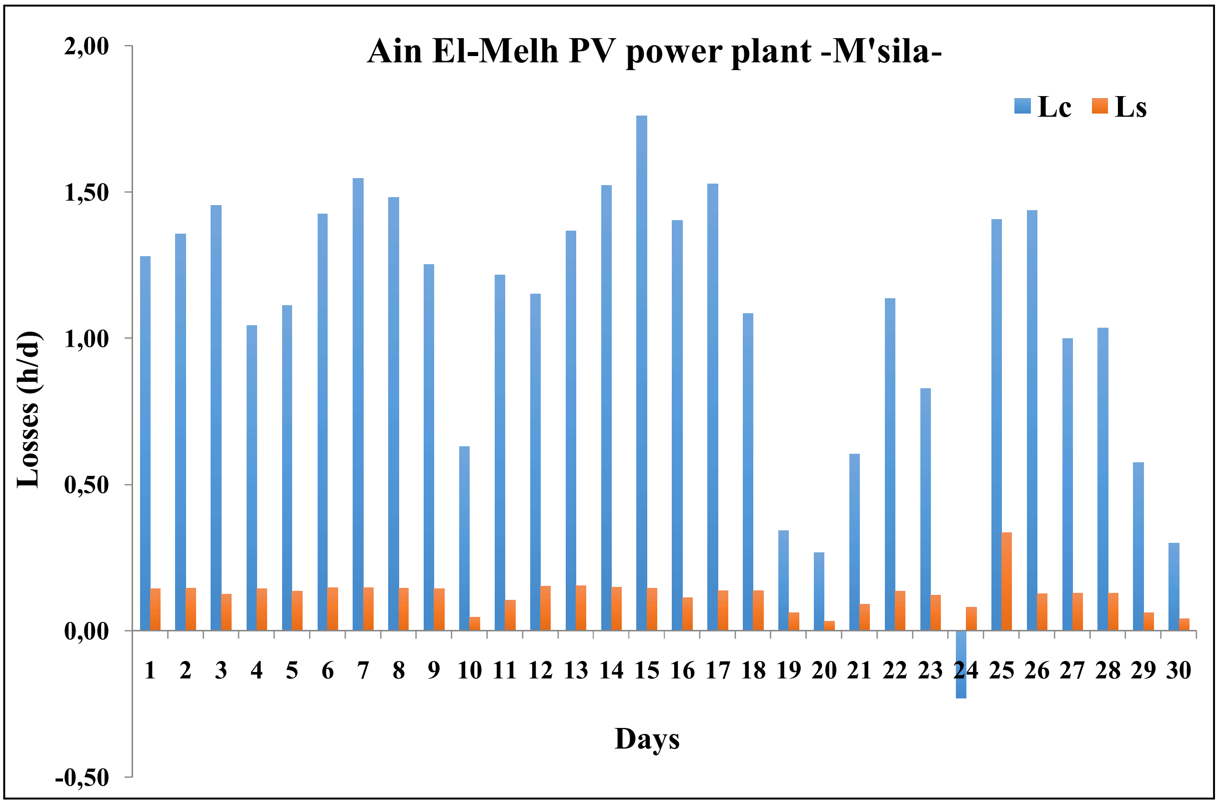

Figure III.8. Daily evolution of losses from the Ain El-Mleh PV plant.

III.3.2.5. Field, system and inverter efficiencies

The daily progressions of field and system efficiencies for the shetler 1 subfield are depicted in Figure III.9 both efficiencies exhibit similar trends, with the system efficiency being less pronounced compared to the field efficiency.

The daily field efficiency ranges from 16.71%, observed on January 24th, to a minimum of 11.67% on the 10th day of the same month, with an average monthly value of 12.86%. Conversely, the daily system efficiency fluctuates between a maximum of 16.31% and a minimum of 11.39% on the corresponding dates as the field efficiency. The daily average system efficiency stands at 12.54%.

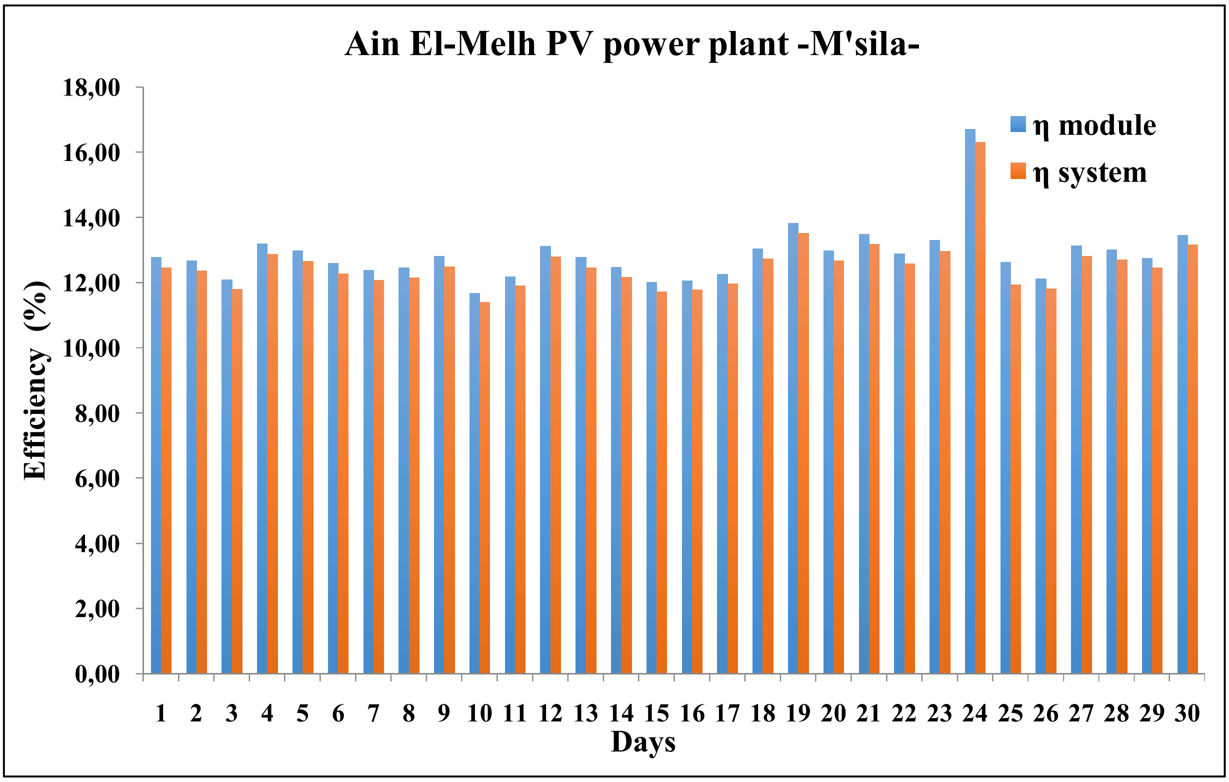

Figure III.9. Daily evolution of efficiencies (fields and system) of the Ain El-Melh PV plant.

Figure III.10 illustrates the daily efficiency trends of the inverters within the shelter sub-field. It ranges from a peak of 97.85% recorded on January 30th to a low of 94.49% on the 25th day of the same month, with an average monthly value of 97.49%. This pattern aligns with the findings regarding daily system losses due to conversion.

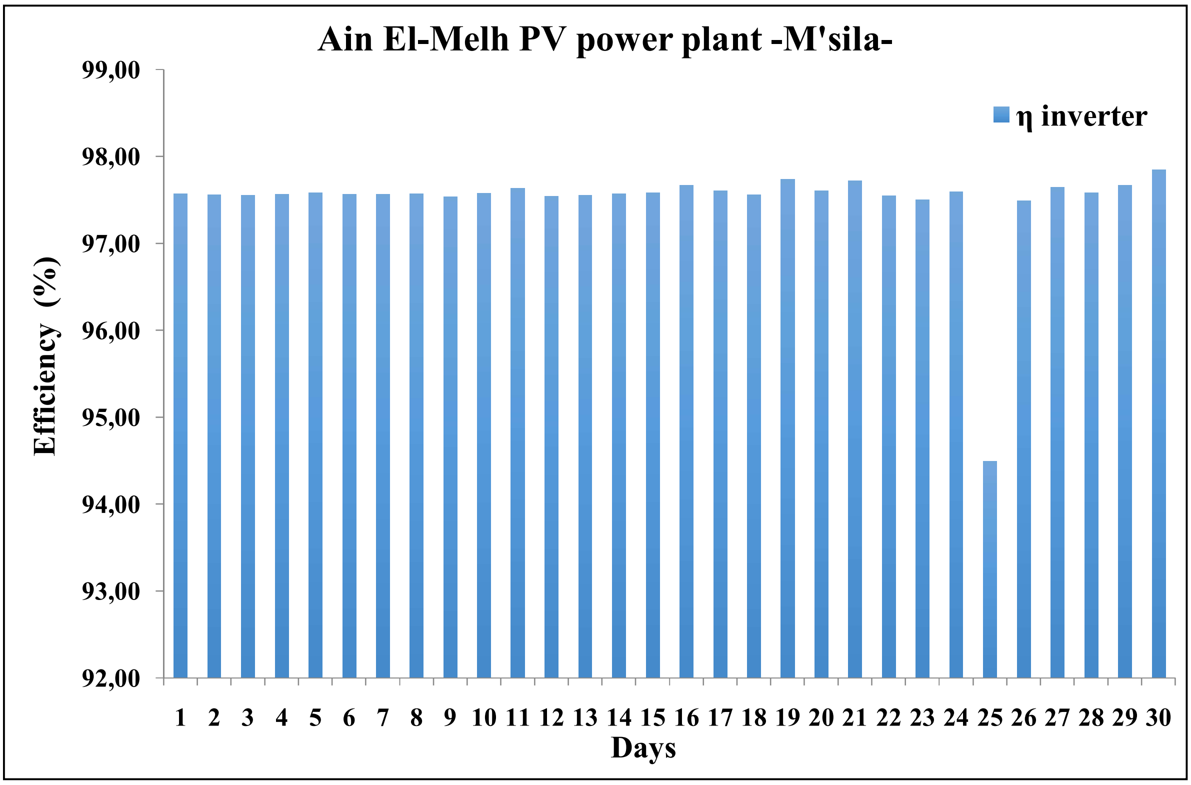

Figure III.10. Daily evolution of the efficiency of the inverters of the PV plant Ain El-Mleh.

II.4. Conclusion

In this chapter, the performance investigation of the large-scale grid-tied PV plant in Ain El-Melh highlights the significance of monitoring and analyzing the operational efficiency and energy output of such solar installations.

The study provides valuable insights into the performance metrics, including energy generation, losses, system efficiencies, and inverter efficiencies. By adhering to international standards and guidelines, such as those set by the International Energy Agency (IEA) and IEC 61724, the study ensures a comprehensive evaluation of the PV plant's performance.

The analysis of energy generation and delivery, conversion losses, and system efficiencies reveals important trends and patterns in the plant's operation. The findings suggest areas for improvement and optimization to enhance the overall performance and output of the PV plant. By monitoring daily energy generation, losses, and efficiencies, operators can make informed decisions to maximize the plant's potential and contribute effectively to the transition towards sustainable energy systems.

Overall, the chapter underscores the importance of continuous performance monitoring and analysis in large-scale PV plants to ensure optimal operation, efficiency, and contribution to the renewable energy landscape.

"General Conclusion"

General Conclusion

The study of the performance of a large-scale grid-tied photovoltaic (PV) plant located in Ain El-Melh, M'sila, under high plateau climate conditions provides valuable insights into the efficiency, reliability, and overall feasibility of solar power in such environments. High plateau climates are characterized by specific challenges, including high irradiance, significant temperature fluctuations, and varying atmospheric conditions, which can impact the performance of solar PV systems.

The analysis of a 20 MWp grid-tied PV plant in Ain El-Melh, Algeria revealed promising results.

The plant achieved significant monthly yield values, demonstrating efficient energy production. The high-efficiency rates of the inverter and the overall system contribute to the plant's optimal performance.

The calculated performance ratio utilization factor indicate the effective utilization of the PV plant.

The study's findings hold significant importance for Algeria and similar regions with comparable high plateau climates.

The research demonstrates the feasibility and effectiveness of large-scale grid-tied PV plants in harnessing solar resources and achieving renewable energy goals.

❖ **Key Findings**

- Energy Yield and Performance Ratio (PR)

The PV plant in Ain El-Melh demonstrated a robust energy yield, the performance ratio, a key indicator of PV system efficiency, was found to be within acceptable ranges, suggesting effective conversion of solar irradiance into electrical energy.

- Impact of Temperature

Moderate temperatures, particularly in January, had a noticeable effect on the performance of the PV modules. Elevated temperatures can reduce the efficiency of PV cells, leading to decreased energy output.

However, the cooling effect of the high plateau's nighttime temperatures somewhat mitigated this issue.

- Irradiance Levels

The high plateau region benefits from high levels of solar irradiance, which positively impacts the overall energy production of the PV plant. The abundance of sunlight is a significant advantage for solar power generation in Ain El-Melh.

- Dust and Soiling (our visit)

Dust accumulation and soiling on PV panels were identified as factors that can reduce the energy output. Regular cleaning and maintenance are essential to maintain optimal performance and prevent significant efficiency losses.

- System Reliability and Maintenance

The PV plant exhibited high reliability with minimal downtime. Routine maintenance and prompt addressing of any technical issues were critical to sustaining the plant's performance.

- Economic and Environmental Impact (our visit)

The large-scale PV plant contributes to the reduction of greenhouse gas emissions and dependence on fossil fuels, aligning with environmental sustainability goals. Economically, the plant provides a cost-effective alternative to conventional energy sources, particularly in remote areas.

❖ **Further Research**

Continued research into the long-term impacts of high plateau climatic conditions on PV systems will provide deeper insights and facilitate the development of more resilient solar technologies.

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