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Power prediction of photovoltaic panels by
TRNSYS software compared with experiment
measurement

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ



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DEDICATION

To Allah Almighty, who bestowed His grace and assistance for the completion of this research.

To the one who has given me everything he owns to fulfill his hopes, to the one who pushes me forward towards my goals, to the person who embodies humanity with all its strength, to the one who dedicated himself to my education with immense sacrifices, venerating knowledge, to my first school in life, my dear father, may Allah prolong his life; to the one who gave her all to nurture me with love and compassion, to the one who endured everything, who cared for me with true affection and was my support in times of hardship, whose prayers for my success followed me step by step in my work, to the one whose smile in my memory is a source of tenderness, my mother, the dearest angel to my heart and eyes, may Allah have mercy on her and grant her paradise.

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NEZLA SAIDA



DEDICATION

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This only the beginning, but I wasn't alone at the start of this journey. Thus, I dedicate this accomplishment to all of you who believed in me. To everyone who had faith in my ability to take risks, you have been a vital part of this journey.

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LIST OF ABBREVIATIONS

- * V_{MPP} : the maximum peak power voltage of an individual panel in volts (V).
- * V_{OC} : the open circuit voltage of an individual panel in volts (V).
- * % Eff: It shows the calculated panel efficiency in percent.
- * I_{MPP} : the maximum peak power current of an individual panel in amperes.
- * I_{SC} : the short circuit current of an individual panel in amperes.
- * Temp: the base temperature used by manufacturer to determine rated panel power in degrees Celsius (C)
- * V_{min} : the minimum DC voltage of the inverter in percent of the rated voltage.
- * V_{max} : the maximum DC voltage of the inverter in percent of the rated voltage.
- * NOCT : the normal operating cell temperature (NOCT) in degrees Celsius (C).
- * TRNSYS: Transient System Simulation Tool
- * HVAC: Heating, Ventilation, and Air Conditioning
- * DLL: Dynamic Link Libraries
- * EES: Engineering Equation Solver
- * PV: Photovoltaic

General Introduction

General Introduction

The increasing demand for energy and the scarcity of conventional sources have driven scientists to explore renewable energy sources, particularly solar energy. The global trend towards deregulated electricity markets has significantly advanced the use of distributed energy resources, such as large photovoltaic (PV) plants and wind farms. These developments address issues like power outages, poor power quality, and voltage regulation.

Photovoltaic power plants not only enhance consumer services by providing reliable backup power but also help reduce pollution, greenhouse gas emissions, and global warming. Solar energy generation has seen substantial growth worldwide. By the end of 2021, solar energy was on track to become the second-largest renewable energy source after wind by 2050.

As non-renewable energy sources like oil and natural gas are finite and will eventually be depleted, it is crucial to find alternative electrical energy sources, such as wind, sea waves, and solar energy. Solar energy, in particular, represents a significant and sustainable resource for the future.

Numerous nations have already integrated solar energy systems into their electrical grids, including Algeria, which has significant potential for solar energy generation. Algeria's geographical location allows it to receive substantial solar radiation nearly year-round, amounting to approximately 2000 hours of sunshine annually, with potential peaks of up to 3900 hours in the highlands and desert regions. Specifically, Algeria receives 1-5 kWh of solar radiation per square meter in the north (about 1860 kWh per year per square meter) and 5-7 kWh per square meter in the southern regions (about 2738 kWh per year per square meter). This abundant solar resource positions Algeria as a prime candidate for extensive solar energy development.

Photovoltaic (PV) systems play a critical role in harnessing solar energy to generate electricity. Accurate prediction of their power output is essential for efficient design and operation, especially in regions with high solar potential like Ain El Melh, Algeria. This region benefits from abundant sunlight, making it an ideal location for PV installations. We will talk about this in the first chapter.

In the second chapter, we will discuss the news about the software used in the study and the steps that must be followed when using it in the field of renewable energies. TRNSYS (Transient System Simulation Tool) is a powerful software used to simulate and analyze the performance of energy systems, including PV panels. It enables detailed modeling and dynamic

General Introduction

simulation of PV systems under various conditions, incorporating local weather data to predict power output accurately.

In the third chapter, we discussed the results and gave reasons for the various changes that occurred. The integration of experimental measurements alongside TRNSYS simulations offers a comprehensive approach to power prediction for photovoltaic (PV) systems. While TRNSYS simulations provide a valuable tool for modeling and analyzing the behavior of PV systems under various conditions, experimental measurements provide real-world performance data that is essential for validating and refining these simulation models.

Experimental data offers insights into the actual performance of PV systems, taking into account factors such as solar irradiance, temperature variations, shading, and other environmental variables. This data serves as a benchmark for validating the accuracy of TRNSYS simulations, ensuring that the models accurately reflect the complexities of real-world conditions.

Combining TRNSYS simulations with experimental measurements creates a synergistic relationship between simulation and empirical data. This integration allows for a more thorough understanding of how different factors impact the performance of PV systems, leading to more accurate predictions and better optimization strategies.

Moreover, the integration of experimental measurements helps identify discrepancies between simulated and actual performance, facilitating improvements in the simulation models. By iteratively refining the models based on experimental data, the accuracy and reliability of predictions can be significantly enhanced.

CHAPTER 01:

Generalities about photovoltaic system

I.1 Introduction

Photovoltaic systems (PV) are installations that harness the photovoltaic effect to convert sunlight into electricity. At the core of these systems are photovoltaic cells, typically made from semiconductors such as silicon, which absorb photons from sunlight and release electrons, thereby creating an electric current.

The conversion of solar energy into electricity in photovoltaic systems can be divided into several stages. Firstly, photons incident on the photovoltaic cells are absorbed by the semiconductor material, creating electron-hole pairs. These electrons are then released and can be induced to flow through an external circuit, thereby producing an electric current. This current is then collected and directed to an inverter, where it is converted into alternating current (AC) for use in electrical applications [1].

Photovoltaic systems can be configured in various ways depending on their specific applications. Residential installations, for example, typically utilize rooftop-mounted photovoltaic panels, while large commercial installations or solar parks may employ ground-mounted structures or installations on elevated structures. Additionally, some photovoltaic systems are standalone, with energy storage devices such as batteries to provide electricity in the absence of sunlight.

In addition to their basic operation, photovoltaic systems feature technical aspects such as cell efficiency, material durability, shading management, and system design to maximize electricity production. These technical considerations are crucial to ensuring optimal performance and reliability of photovoltaic systems in a variety of environmental conditions and applications.

This chapter will delve into the principles of operation, design, and technical considerations of photovoltaic systems, as well as the latest advancements in this ever-evolving field.

I.2 Photovoltaic Cells

The photovoltaic cell (PV), also known as a solar cell, is the fundamental building block of a photovoltaic system. Developed by Bell Laboratories in 1954, the first photovoltaic module marked a significant advancement in solar technology [2]. These cells are designed to endure various weather conditions.

CHAPTER 01: Generalities about photovoltaic system

Comprised of multiple semiconductor layers, typically made of materials like silicon, each layer serves a specific function. Among these layers, the most crucial is the specially treated semiconductor layer responsible for interacting with incoming photons from the Sun. This layer, consisting of both p-type and n-type materials, facilitates the photovoltaic process, where light energy is converted into electrical energy.

Essentially functioning as a semiconductor diode, a solar cell is meticulously engineered to efficiently absorb and convert solar energy into usable electrical energy. This process, known as the photovoltaic effect, is the cornerstone of solar power generation.

A photovoltaic cell consistently generates a voltage of around 0.6 volts, regardless of its size. However, the larger the cell's surface area, the higher the current intensity it produces. As a result, individual cells serve as low-power generators, insufficient for typical electrical applications. To address this limitation, cells are combined into modules, either in series or parallel configurations. These modules are then transformed into alternating current (AC) by an inverter converter to match the requirements of the electrical grid.

Various types of photovoltaic cells exist, all employing semiconductors as their core material.

I.3 Principle of photoelectric conversion

The photovoltaic (PV) effect refers to the physical process by which a PV cell converts absorbed sunlight energy into electricity. This phenomenon was first observed by Henri Becquerel in 1839 [3].

When sunlight is absorbed by a PV cell, it energizes the electrons within the atoms of the cell. These energized electrons then move from their usual positions within the semiconductor material of the PV cell, creating an electric current. This flow of electric charge occurs through an external electric circuit connected to the terminals of the PV cell.

The PV cell contains a built-in electric field, which is a specific electric characteristic. This electric field provides a voltage potential difference that drives the current through an external load [4].

When two different p-n semiconductor layers are brought into contact, an electric potential is established between the n-type and p-type semiconductor layers. Electrons migrate across the junction from the n-type semiconductor to the p-type semiconductor, creating a static

CHAPTER 01: Generalities about photovoltaic system

positive charge in the p-type region. At the same time, holes migrate across the junction from the p-type semiconductor to the n-type semiconductor, resulting in a static negative charge in the n-type region. Eventually, these free electrons and holes recombine, neutralizing each other.

At the p-n junction, a depletion zone forms once charge carrier migration ceases, creating a barrier where charge carriers cannot cross. The separated static charges within this zone generate an electric field. This built-in electric field provides the voltage necessary to propel current through an external circuit.

When sunlight's photon energy is absorbed by the semiconductor layer, it transfers to the material's electrons. These electrons gain enough energy to transition to the conduction band, leaving behind a "hole" in the valence band. This movement of valence electrons from their normal positions in the semiconductor's atoms contributes to the flow of electric current.

Under sufficient sunlight energy, when absorbed photon energy surpasses the bandgap energy of the materials used in the PV cell, atomic collisions occur, and free electrons begin to migrate, initiating the flow of electricity [1].

Figure I.1 shows the pictorial representation of the working of Working Principle P-n junction structure and current flow in a PV cell

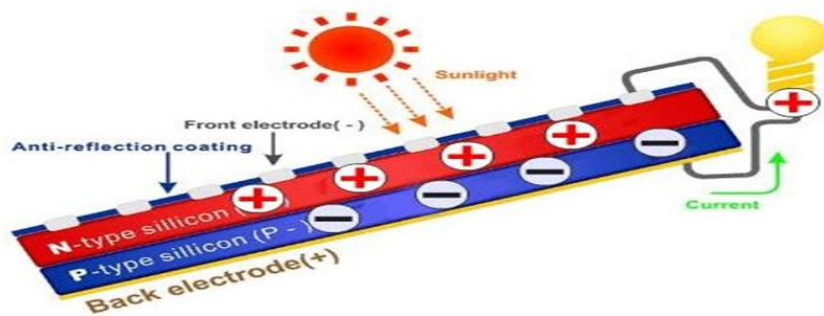


Figure I.1 Schematic representation of Photovoltaic effect in a solar cell

I.4 Electrical characteristic of photoelectric conversion

Under specific test conditions known as Standard Test Conditions (STC), which include a light intensity of 1000 W/m^2 , a temperature of 25°C , and spectral conditions equivalent to Air Mass 1.5, photovoltaic cells are characterized to allow for comparison of their efficiency. These

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characteristics are represented by a current-voltage curve (I-V curve), which illustrates all the possible electrical configurations that the cell can adopt [05].

Three key physical quantities define this curve, as depicted in Figure I.2

- Open circuit voltage (V_{CO}): This value represents the voltage generated by an illuminated cell when it is not connected to any external circuit.

- Short-circuit current (I_{SC}): This value represents the current generated by an illuminated cell when it is connected directly to itself, effectively creating a short circuit.

- Its maximum power point: MPP obtained for an optimal voltage and current: V_{OPT} , I_{OPT} (sometimes also called V_{MPP} , I_{MPP}).

Current Power

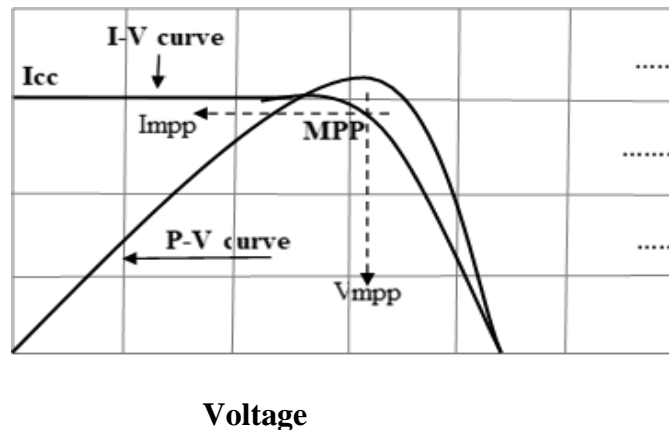


Figure I.2 I V, P V Characteristics Waveform of Solar Cell Array - Diagram

I.5 The influence of temperature on a photovoltaic cell

The performance of solar cells is significantly influenced by cell temperature; as higher temperatures lead to decreased output. Thus, choosing the right solar cell technology for a specific location, considering its typical temperatures, is crucial. On average, for every degree Celsius above 25°C [6,7], solar cell efficiency drops by around 0.4%. This decline manifests as a shift in the maximum power points on the I-V characteristics, as depicted in Figure I.3[8].

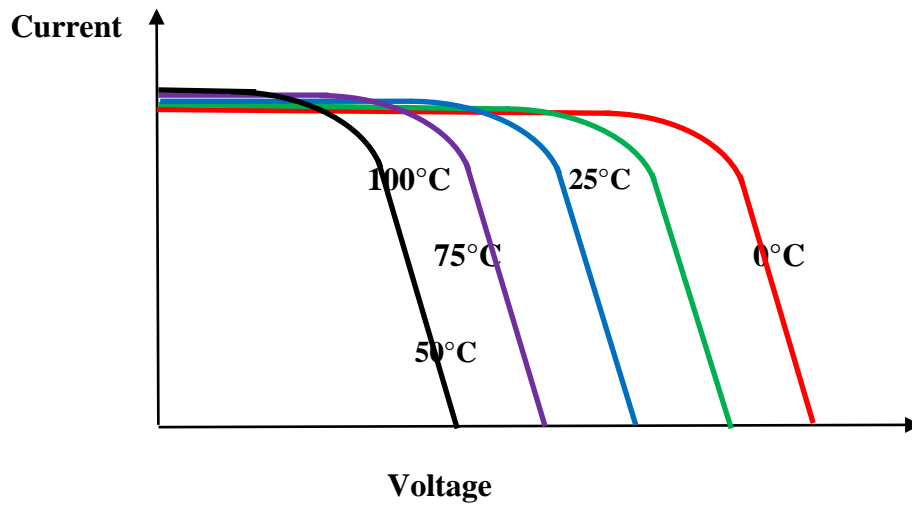


Figure I.3 The Effect of Temperature on Photovoltaic Cell Efficiency

I.6 The influence of Illumination on a photovoltaic cell

The impact of nonuniform illumination on the performance of a standard PV cell has been explored at low and medium energy flux concentration ratios. This investigation involved manipulating orientation, size, and geometrical shapes, as illustrated in Figure I.4[9].

Based on the findings at a consistent temperature of 15°C [10] and varying illuminations (ranging from 0.5 kW/m² to 1 kW/m²), the following conclusions were drawn:

The short-circuit current (I_{CC}) exhibits a proportional variation with the level of illumination.

The no-load voltage (V_{OC}) experiences minimal fluctuations with changes in illumination, remaining relatively constant across different levels. Hence, it can be treated as a constant for a given setup

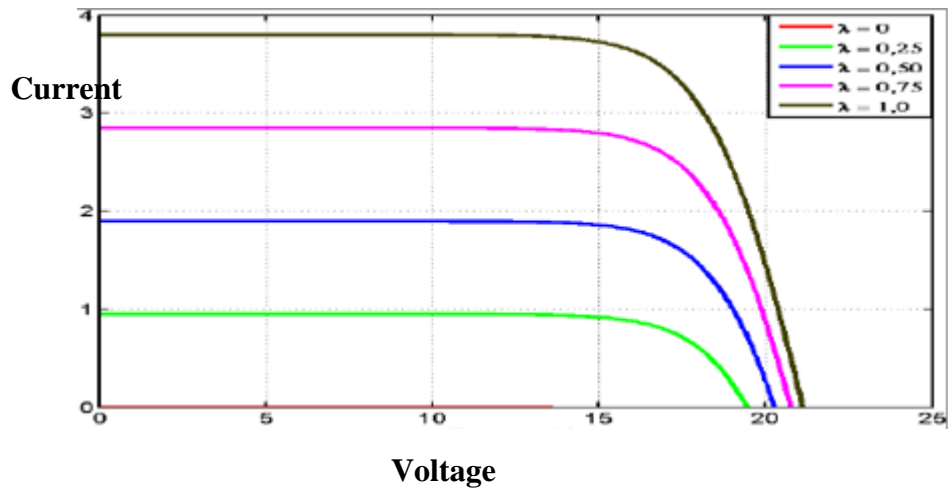


Figure I.4. The Effect of Illumination on a photovoltaic cell Efficiency

I.7 PV cells types

There are different types of solar cells (or photovoltaic cells), each with its own efficiency and cost. However, regardless of their type, their efficiency remains relatively low, ranging from 8 to 23% of the energy they receive. The main types of cells currently used are:

- Monocrystalline cells: These have the highest efficiency (12-16%; up to 23% in laboratories), but they also have the highest cost due to complicated manufacturing processes.
- Polycrystalline cells: Their design is simpler, resulting in lower manufacturing costs. However, their efficiency is lower: 11%-13% (18% in laboratories).

Amorphous cells: These cells have low efficiency (8% - 10%; 13% in laboratories), but they require very thin layers of silicon and have a low cost. They are commonly used in small consumer products such as solar calculators or watches[11,12,13].

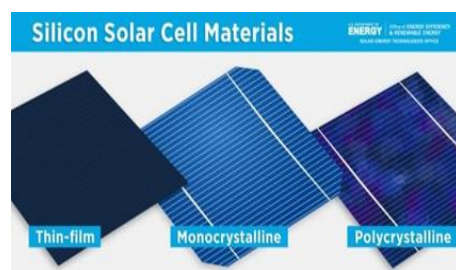


Figure I.5. Types of photovoltaic cells

Table I.1. Comparison Of Efficiency Of Solar cell

Material	Efficiency (%)
Monocrystalline Silicon	12-16
Polycrystalline Silicon Cell	11-13
Thin Film	6-11

I.8 Connecting cells PV to each other

The power provided by a single solar cell being very low, several cells with similar characteristics must be electrically connected and encapsulated in plastic to form a practical PV module.

I.8.1 Serial association:

Through series connection (referred to as "String"), the cells share the same current, and the resultant voltage is the accumulation of the voltages generated by each individual cell, as illustrated in Figure I.6 ($V_{out} = V_1 + V_2 + V_3 + \dots$). [5].

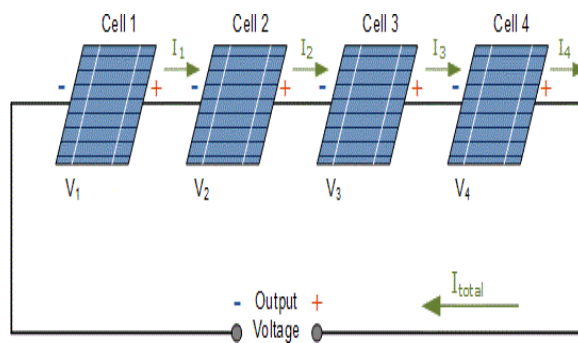


Figure I.6 Connecting PV cells in series

I.8.2 Pairing in parallel:

The parallel connection of photovoltaic cells is a versatile and effective technique for optimizing the performance and reliability of solar energy systems. By combining the current output of individual cells while maintaining consistent voltage levels, parallel connection offers resilience to shading, simplifies system design, and enhances overall system efficiency [14,15,16].

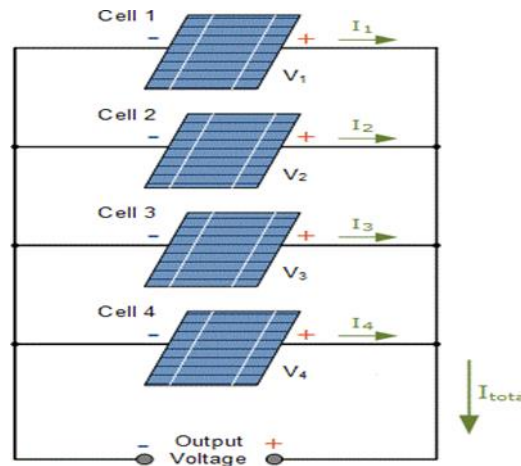


Figure I.7 Connecting PV cells in parallel

I.9 Operation Mode of a Photovoltaic System

Alternatively, there are three operational modes for a PV panel: standalone, grid-tied, and hybrid.

I.9.1 Standalone Mode

In standalone mode, the photovoltaic generator serves as the only source of electrical energy to power devices such as homes, cottages, or remote camps, as well as applications like

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surveillance and water pumping. In standalone mode, the system typically consists of the following components:

- The PV array charges the battery during periods of sunlight.
- The battery powers the load and provides storage for electrical energy.
- The charge controller safeguards the battery from overcharging by the energy produced by the PV array and usually includes protection against deep battery discharge.
- A charge converter enables the use of both direct current (DC) and alternating current (AC) appliances.

I.9.2 Grid-tied Mode

In this mode, the PV panel is connected to the electrical grid. The photovoltaic system is equipped with power converters to adapt the energy produced by the PV panels. These converters consist of a chopper, a filter, an inverter, and appropriate electronics to ensure adaptation in amplitude and frequency with the grid (grid coupling).

The significant advantage of this solution is the absence of a battery. Energy is no longer stored; it is directly injected into the local grid that powers homes at night or during sunless days. Therefore, all the energy is utilized. There is a meter that rotates in one direction for consumption and another in the opposite direction for production. These systems are not backup power supplies in case of grid failure, as they do not have any energy reserves[17,18].

I.9.3 Hybride Mode

An hybrid energy system comprises more than one electricity source such as photovoltaic panels, fuel cells, wind generators, storage batteries, diesel generators, etc. This type of installation is used for electrifying regions far from the grid. There are several configurations of these systems: PV/thermal, PV/battery, PV/fuel cells, PV/wind/battery, PV/wind, PV/diesel

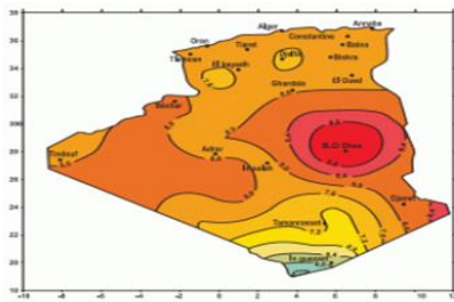
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generator. The choice is primarily based on the meteorological characteristics of the deployment site[17,18].

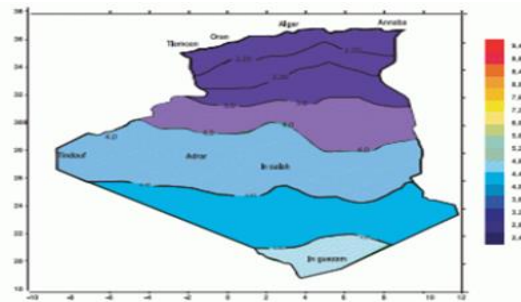
I.10 Solar Potential in Algeria

Due to its geographical location, Algeria has one of the highest solar potentials in the world. The duration of sunlight over almost the entire national territory exceeds 2000 hours annually and can reach 3900 hours (high plateaus and Sahara).

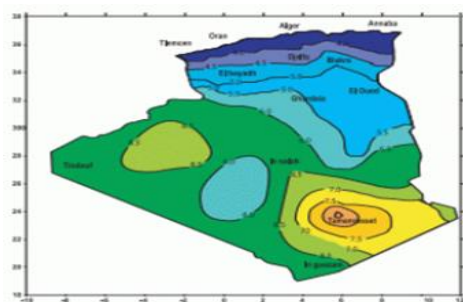
The energy received daily on a horizontal surface of 1m² is around 5 kWh over most of the national territory, which is nearly 1700 kWh/m²/year in the north and 2263kwh/m²/year in the south of the country. In the Sahara, this potential can be a significant factor in sustainable development if it is exploited economically[19].



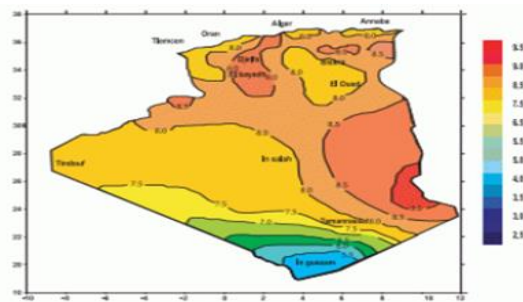
Daily global irradiation received on horizontal plane in the month of July



Daily global irradiation received on a horizontal plane in the month of Decembre



Daily global irradiation received on a normal plane in December.



Daily global irradiation received on a normal plane in July

CHAPTER 01: Generalities about photovoltaic system

Table I.2 Sunshine rate for each region of Algeria

Regions	Coastal regions	High plateaus	Sahara
Surface area	4%	10%	86%
Average sunshine duration (hours/year)	2650	3000	3500
Average energy received (kWh/m ² /year)	1700	1900	2650

This solar potential exceeds 5 billion GWh/year. The most utilized aspect of solar energy in our country is photovoltaic solar, while other solar aspects, such as thermal and thermodynamic, remain in the experimental stage.

I.11 Solar radiation

Solar radiation, also known as the solar resource or sunlight, encompasses the electromagnetic radiation emitted by the sun. This radiation can be harnessed and converted into practical forms of energy, including heat and electricity, through various technologies. Solar irradiation, a radiometric measure, quantifies the solar energy received per unit area. It is typically expressed in kilowatt-hours per square meter (kWh/m²) or in joules per square meter (J/m²) within the International System of Units.

I.11.1 Direct radiation:

Direct radiation refers to sunlight that reaches the Earth's surface without obstruction, such as clouds. It follows the shortest path to an object and can be partially transmitted as diffuse radiation. Photovoltaic (PV) plants absorb some of this solar energy and convert it into electrical energy. However, a significant portion is also reflected and scattered as diffuse radiation. Together with diffuse radiation, direct radiation constitutes global radiation[20].

I.11.2 Diffuse radiation:

When sunlight reaches the Earth's surface, it does so either directly or indirectly. Indirect solar radiation is known as diffuse or scattered radiation. The term "diffuse" indicates that the light arrives irregularly scattered and lacks a uniform direction. This occurs, for instance, when sunlight penetrates through clouds or changes its direction and intensity due to airborne

CHAPTER 01: Generalities about photovoltaic system

particles. These particles can include dust grains, sand, or even soot particles. Water, whether in the form of rain or bodies of water, can also act as a diffuser. Together with direct radiation, diffuse radiation contributes to global radiation[20].

I.11.3 Reflected Radiation:

Reflected radiation refers to sunlight that has bounced off non-atmospheric surfaces such as the ground. Asphalt, for instance, reflects approximately 4% of the light it receives, while

alawn reflects about 25%. However, solar panels are often tilted away from the direction of reflected light.

Reflected radiation, typically originating from the ground, is usually disregarded, particularly on surfaces with inclinations less than 60° . It's important to ensure that radiation measurement devices are positioned to avoid capturing reflected radiation from nearby walls or the ground. However, distinguishing this component from diffuse radiation can be challenging[21].

I.11.4 Global radiation:

Global radiation refers to the total solar radiation received on a horizontal surface. It comprises both direct radiation and diffuse radiation. Pyranometers are commonly used to measure global radiation. Typically, radiation is more intense at midday than in the morning .

and evening, and it's stronger during summer compared to winter. Moreover, proximity to the equator correlates with higher levels of global radiation[20].

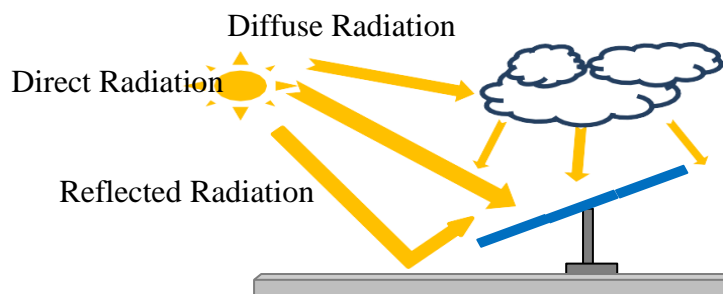


Figure I.8. The three main components of solar radiation

I.12 Tilt Angle

To enhance your statement about optimizing tilt angles for solar collectors, you might consider incorporating the following adjustments[22]:

- **Local Climate Conditions:** Besides latitude, local climate conditions such as cloud cover, humidity, and atmospheric pollution can affect solar irradiation. Adjustments should be made to account for these factors.

CHAPTER 01: Generalities about photovoltaic system

▪ **Seasonal Variations:** The optimal tilt angle may vary throughout the year due to changes in the sun's position relative to the Earth. Consider adjusting tilt angles seasonally to maximize efficiency.

▪ **Shading:** Obstructions like buildings, trees, or nearby structures can cast shadows on solar panels, reducing their efficiency. Adjustments to tilt angles should consider minimizing shading effects.

▪ **Technological Advances:** With advancements in solar technology, especially in tracking systems that adjust panel orientation throughout the day, the optimal tilt angle may deviate from traditional fixed angles. Incorporate flexibility in tilt angle adjustments to accommodate evolving technology.

▪ **Economic Factors:** The cost of installation and maintenance should also be factored into tilt angle decisions. Sometimes, a compromise between optimal tilt angle and economic feasibility is necessary.

• **Regulatory Requirements:** Some regions may have regulations or guidelines regarding solar panel installations, including tilt angles. Ensure compliance with local regulations when determining tilt angles.

I.13 Description of Ain El Melh photovoltaic plant with a capacity of 20 megawatts:

The Ain El Melh power plant utilizes photovoltaic solar panels to generate electricity, boasting a total capacity of 20MW and operating at an injection voltage of 60 kV.

Spanning across an area of approximately 41.16 hectares, its construction necessitated an investment totaling nearly 3.9 billion dinars [23].

This station is located 120 km southwest of the Wilayat of M'Sila. Established on January 25, 2017, Figure I.9 illustrates the remarkable topographical advantage of the area surrounding the Ain El Melh power plant, showcasing its abundant potential for solar energy harnessing. This facility stands as one of the projects spearheaded by Sonelgaz's renewable energy arm, SKTM, further solidifying its commitment to sustainable energy initiatives.

The site encompasses 20 photovoltaic subfields, each with a capacity of 1MWp. Each subfield is equipped with two inverters and one step-up transformer. The key equipment and major components of the power plant are outlined in Table I.3 below

CHAPTER 01: Generalities about photovoltaic system

Table I.3 Configuration of the Ain El Melh 20 MWp power plant

Equipment	Number
255 Wp modules	80080
Number of underfield panels	4004
Number of strings/subfields	91
Number of panel/chain	44
junction boxes	40
1 MW subfields	20
500kw Inverters	40
315v/31.5kv/1MW transformers	20
elevator	
MT evacuation station (31.5kv/60kv/20MW transformer)	01
control room	01



Figure I.9 Aerial view of the Ain El Melh 20 MVp solar (photovoltaic) power plant

I.14 Geographical location of the site:

The AIN EL MELH 20 MW solar power plant is situated at a latitude of 34.86109° or $34^\circ 51' 40''$ North and a longitude of 4.20407° or $4^\circ 12' 15''$ East, with an altitude of 915 m [24, 25]. Positioned in a geographically favorable location, it benefits from optimal solar radiation absorption throughout the year. The power generated by the solar plant is directly influenced by the sun's insolation, making its location crucial for maximizing energy output.

I.15 Description of the 1 MW subfields

Each sub-field of the PV power plant is outfitted with 4004 solar panels strategically spaced to prevent shading. These panels are connected to two inverters, which convert DC to

CHAPTER 01: Generalities about photovoltaic system

AC with an output voltage of 315 VAC. The generated AC power is then transmitted through AC cables to a 1,250 kVA step-up transformer, increasing the voltage to 31.5 kV. Direct current from the solar panels is gathered via collector boxes to minimize the length of DC cables and reduce ohmic losses, thus enhancing energy efficiency. The 20 sub-fields are linked to a 60 kV step-up transformer, facilitating the transfer of electricity to the national grid. The equipment specifications for the 1 MW sub-field are detailed in Table I.4, and the schematic diagram is depicted in Figure I.10.

Table I.4 The characteristics of the 1 MW subfield equipment of the PV power plant

DESIGN PARAMETER	CHARACTERISTICS
Module type	Poly-crystalline silicon
Photovoltaic module efficiency	15%
Orientation and tilt	26.5°, south
Installation type	Fixed
Distance between photovoltaic rows	8 m
Inverters	500 kW
Transformers	1.250 kVA, 47–52 Hz, 315 V/31.5 kV

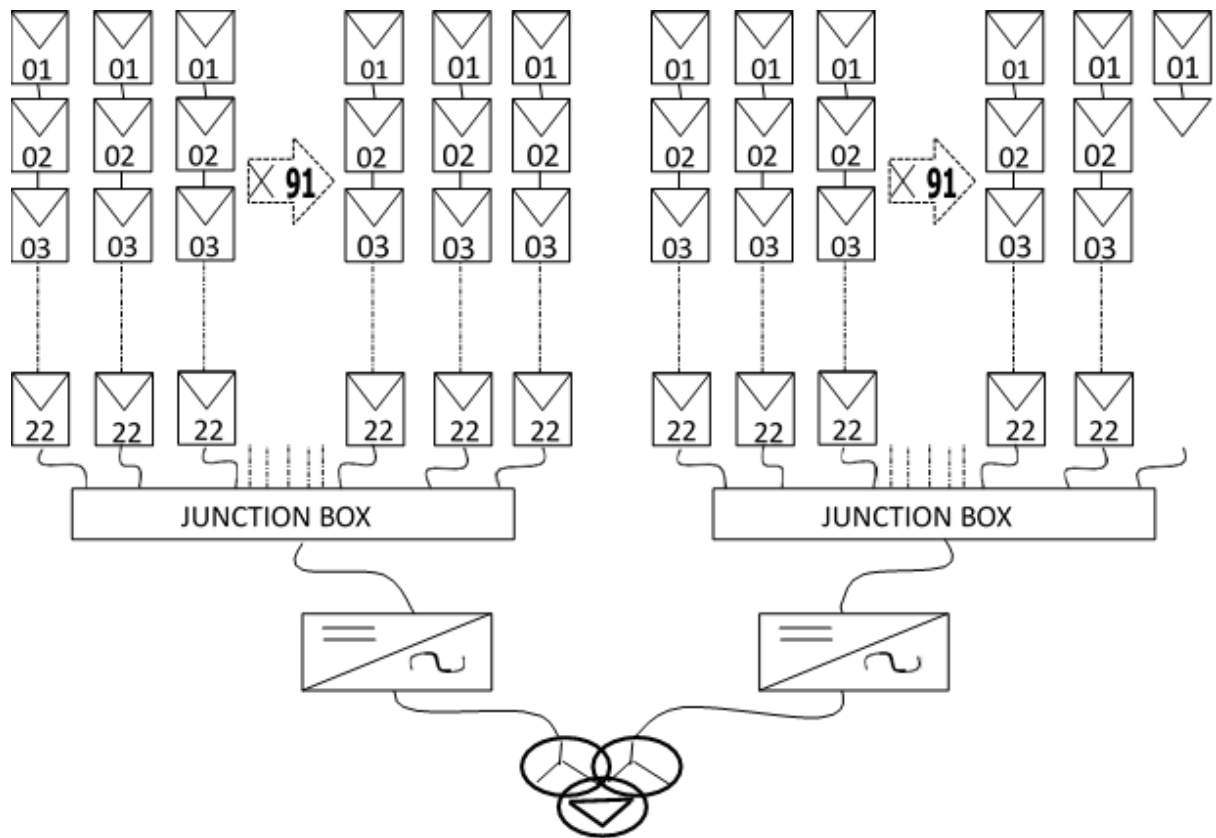


Figure I.10 Schematic outline of a 1 MW subfield in the Ain El Melh photovoltaic power plant

I.15.A/ Description of the Photovoltaic modules:

The panels designated by SKTM feature solar cells from the Yingli series, manufactured in China using polycrystalline silicon blocks. While these cells are more cost-effective to

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produce compared to monocrystalline ones, they exhibit higher energy loss in hot conditions. The specifications of these solar modules are outlined in Table I.5.

Table I.5 Power plant panel characteristics (SKTM, 2017)

Module type	Characteristics
The Brand	YINGLI SOLAR
Module Type	YL250-29b
Measured Power	250 W (0/+5 W)
Measured Voltage	29.8 V
Measured Current	8.39 A
Open-Circuit Voltage	37.6 V
Short Circuit Current	8.92 A
An Irradiance	1000 W/M ²
Fire Resistance Class	C
Application Class	A
The Cell Temperature	25 °C
Tension Système Max	1000 V

I.15.B/ Inverters:

The inverter serves as an electronic intermediary, converting the direct current generated by photovoltaic modules into alternating current through control and protection mechanisms. It's capable of handling the maximum current and voltage output of the photovoltaic array.

Efficiency, denoted as the ratio of output power to input power, is expressed as a percentage. Elevated temperatures can diminish the efficiency of the inverter.

The power station employs 40 inverters from the Chinese brand SUNGROW, each with a capacity of 500 kW DC/AC, with 2 inverters allocated per subfield. With an input range of approximately 520–820 VDC, these inverters ensure stable AC output voltage, supporting a maximal current of 1008 A while maintaining a high efficiency of 98%. On the DC side, each inverter is equipped with four two-polarity inputs, each featuring direct current fuse protection,

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a general disconnect switch, and a DC lightning arrester. Detailed technical specifications of the inverters are presented in Table I.6.

Table I.6 Technical Specifications of the inverters

Inverter	Specification
The Brand	SUNGROW
Type Of	SG500MX
Operating Temperature	-30C/50C
IP Protection	IP21
DC Input	
Max Voltage	1000V
I _{sc}	1344A
Voltage V _{mppmin}	500V
Voltage V _{mppmax}	850V
Max Input Current	1120A
Overtoltage Category	II
AC Output	
Rated Output Power	500KW
Rated Output Voltage	3-315V
Rated Output Frequency	50Hz
Max Output Current	1008A
Power Factor	-0.9/0.9
Overtoltage Category	///

I.16 The measuring devices used in the Ain El Melh station

The Ain El Melh station is outfitted with meteorological measuring instruments, as depicted in Figure I.11. These include sensors for solar radiation, temperature, humidity, wind speed (anemometers), rainfall (rain gauges), and lightning protection systems.

Data collected from these instruments is logged into one of the facility's data acquisition computers, which are located in the control room. This data is crucial for predicting weather conditions and optimizing the performance of the solar power plant



Figure I.11. The measuring devices used in the Ain El Melh station

Humidity Sensor Rain Sensor Pyranometer

5 Element Sensor (T, P, H, DW, SW)

I.17 Estimation PV Electricity and Solar Radiation in the Ain El Melh station:

❖ The first method:

To comprehensively assess the long-term performance of the Ain El Melh solar energy conversion plant, it's essential to have detailed meteorological and radiative data. This includes parameters such as wind speed, insolation (solar radiation), temperature, relative humidity, atmospheric pressure, and the components of solar radiation.

Numerical simulation programs are utilized to analyze this data. Following an analysis of meteorological data and a comparative study between the measured solar radiation values at the Ain El Melh station and those estimated by Leo Jordan's theoretical model [26], the study concluded that Ain El Melh is an excellent location for a photovoltaic project. This determination is based on its favorable climate conditions and the significant influx of solar radiation.

The results of the solar radiation estimation for various clear and cloudy days are illustrated in Figure I.12, providing insights into the solar potential of the region and supporting the viability of the photovoltaic project in this area.

At Ain El Melh, the solar irradiance values typically range from 750 kWh/m² per day to 850 kWh/m² per day. Additionally, the average tilt angle throughout the year was determined to be $\beta=30^\circ$. These parameters are crucial for assessing the solar energy potential and optimizing the performance of photovoltaic systems in the region.

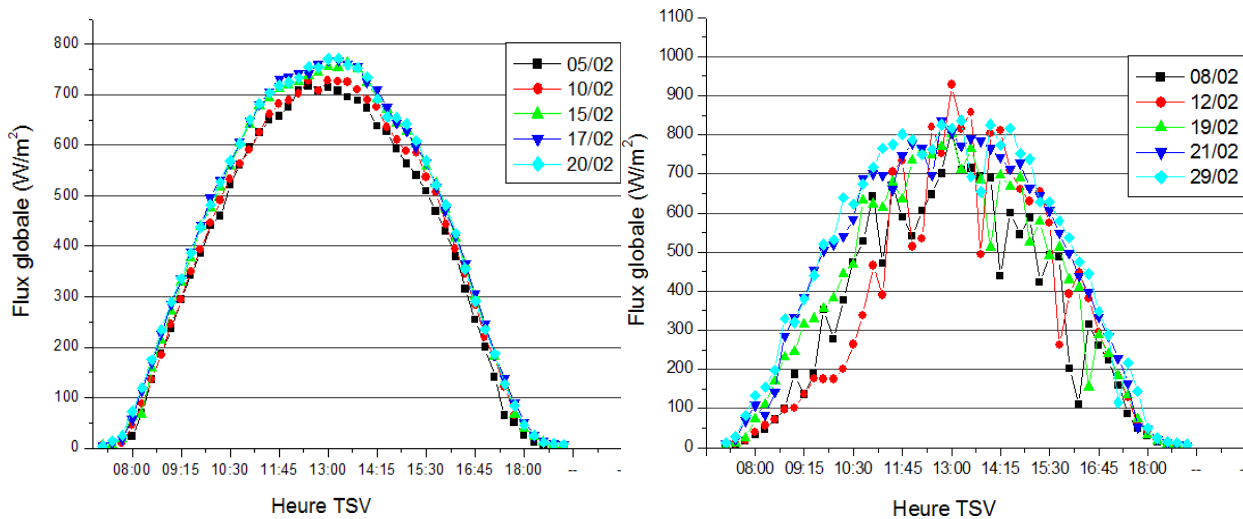


Figure I.12. Estimate of the global solar radiation of the Ain El Melh station on February 2020

❖ The second method:

The automatically generated report utilizes sun brightness data collected at the site in Ain El Melh, M'Sila, sourced from the Global Solar Atlas online application. This application, prepared by Solargis for The World Bank, provides estimates of solar resource, air temperature data, and potential solar power output for selected locations, based on Solargis's solar resource database. These estimates are suitable for preliminary studies, though more detailed analysis may require tools allowing for greater configuration of photovoltaic power projects and utilization of more comprehensive solar and weather data. The report includes monthly global solar insolation and daily average bright sunshine hours specifically for Ain El Melh city, aiding in the assessment of solar energy potential for photovoltaic projects.

1.18 Conclusion

In conclusion, photovoltaic (PV) systems represent a critical technology in the transition to renewable energy. They convert sunlight directly into electricity through semiconductor materials, offering a clean, sustainable, and increasingly cost-effective alternative to fossil fuels. PV systems are versatile, with applications ranging from small-scale residential installations to large-scale solar farms. Advancements in technology have improved their efficiency and reduced costs, making solar energy more accessible. As the global focus on reducing carbon emissions intensifies, the role of photovoltaic systems in achieving energy sustainability and combating climate change becomes ever more significant.

CHAPTER 02:
MODELING of TRNSYS

II.1 Introduction

TRNSYS (Transient Systems Simulation Program) is a robust software package renowned for its advanced modeling capabilities in simulating the dynamic behavior of energy systems. Developed by the Solar Energy Laboratory at the University of Wisconsin-Madison, TRNSYS offers a versatile platform for designing, analyzing, and optimizing a wide range of renewable energy, HVAC, and building energy systems [27].

II.2 Key Modeling Features

1_Modular Architecture: TRNSYS employs a modular approach, allowing users to construct complex energy systems by assembling predefined components. These components represent various physical processes, equipment, and control strategies, enabling the creation of custom models tailored to specific applications.

2_Component Library: The software provides an extensive library of validated components, encompassing renewable energy technologies, thermal storage systems, HVAC equipment, and building envelope elements. Users can select and configure these components to accurately represent the components of real-world systems [28].

3_Transient Simulation: TRNSYS specializes in transient simulation, enabling the modeling of dynamic behavior over time. This capability is essential for assessing the performance of systems under changing operating conditions, weather variations, and user behavior patterns.

4_Graphical Interface: TRNSYS features an intuitive graphical interface for system configuration, simulation setup, and results visualization. The user-friendly interface streamlines the modeling process, allowing users to interactively design, simulate, and

5_Parametric Studies: The software supports parametric studies, facilitating sensitivity analysis, optimization, and design exploration. Users can vary system parameters, input conditions, and control strategies to evaluate their impact on performance metrics such as energy consumption, thermal comfort, and economic viability. Analyze energy systems without extensive programming knowledge.

II.3 Applications

TRNSYS finds application in various domains, including:

- Renewable Energy System Design and Optimization
- Building Energy Performance Assessment
- HVAC System Design and Control
- Solar Energy Integration and Analysis
- District Energy System Planning
 - Energy Policy Evaluation and Decision Support

II.4 Components in TRNSYS

Numerous components are at the fingertips, categorized into physical entities like buildings and auxiliary tools such as data readers or printers. Furthermore, users can opt to incorporate their own components or establish connections between TRNSYS and other simulation programs.

II.4.1/Physical Components:

TRNSYS's standard library boasts a diverse range of components, enabling the simulation of conventional, regenerative, and hybrid energy systems alongside buildings. These components are categorized as follows:

- Thermal solar collectors (e.g., flat plate collectors, tube collectors, etc.).
- Thermal storage systems (e.g., various water storage tanks, etc.).
- Hydraulic elements (e.g., pipes, mixers, pumps, heat exchangers, etc.).
- Heat and cold generators (e.g., heaters, chillers, heat pumps, etc.).
- Buildings (e.g., multi-zone building models, simple capacity models, etc.).
- Controllers (e.g., on/off hysteresis, PID controllers, etc.).
- Electrical components (e.g., PV modules, batteries, etc.).
- Hydrogen systems (e.g., fuel cells, electrolyzers, gas storage, etc.).

Moreover, the standard library is enriched with additional libraries and individual components. For instance, the "Geothermal Heat Pump" library facilitates the simulation of geothermal systems utilizing geothermal probes, while the "Ground Coupling" library computes adjacent ground temperatures in building simulations. Cogeneration plants are

covered by the "Cogeneration" library, and high-temperature solar applications such as parabolic trough power plants are supported by the "High Temperature Solar" library [29].

II.4.2/Auxiliary components:

Auxiliary components within TRNSYS serve functions essential solely within the simulation environment, not in the actual system. These encompass input and output components, operation and occupancy schedules, averaging and interpolation tools, as well as components for computing physical processes like material properties and radiation conversion. Additionally, users have the flexibility to define blocks of equations according to their requirements.

Data readers in TRNSYS are designed to extract information from text files and make it accessible to other components within a project. These readers offer capabilities for manipulating data through addition and multiplication factors and can perform linear interpolation when necessary.

For meteorological data, specialized weather data readers are provided. These readers support common standard formats like TRY, TMY3, Metronome, among others, as well as free formats, and conduct various computations. Key variables for thermal simulation, such as ambient air temperature, humidity, pressure, wind speed/direction, solar radiation, and cloud cover, are included.

While instantaneous values like ambient air temperature are linearly interpolated, solar radiation interpolation considers that the data represents an average value over the dataset's time interval. The weather data reader can convert solar radiation to any oriented area, distinguishing between direct and diffuse components. Various diffuse sky models are available for this conversion. Additionally, the reader calculates and outputs the current position of the sun, effective sky temperature, and other ambient air state variables.

Equation blocks empower users to calculate almost any quantity within a project. Structurally similar to components, an equation block allows users to define input variables, which can be assigned outputs from other components. These inputs are then utilized freely within user-defined equations to compute new quantities. The calculated variables are subsequently transferred to other components or equation blocks as inputs.

Equations within these blocks can employ standard mathematical operators, trigonometric and logarithmic functions, as well as logical operators, granting flexibility in formulation.

Simulation results can be visualized in real-time using an Online Plotter or saved to a text file via a printer. The Online Plotter proves invaluable, enabling users to monitor results without waiting for the simulation to conclude. Notably, there are no restrictions on the types of output variables; all output variables from all components can be displayed. Therefore, alongside conventional variables like temperature, humidity, power, or energy, users can also observe switch states for assessing control, operational, and occupancy statuses, among others.

II.4.3/User defined components:

While equation definition within TRNSYS has considerable flexibility, certain limitations exist. For instance, users cannot define loops or if-then queries. However, for tackling more complex systems of equations, users can develop their own components and seamlessly integrate them into the simulation.

Adhering to the modular philosophy, each component's mathematical model is described by its own subroutine. Users have the liberty to create custom components using popular programming languages like C, C++, or FORTRAN, and then incorporate them into TRNSYS as Dynamic Link Libraries (DLLs). Notably, since the source code of most components is available, users even have the option to modify standard components to suit their specific needs.

II.4.4/Components for coupled simulations:

TRNSYS offers the capability to integrate with various simulation environments like Excel, Matlab, EES, or Fluent through its included coupling modules. This functionality facilitates the seamless exchange of results between programs within a single simulation step, enhancing interoperability and enabling users to leverage the strengths of different simulation tools in their analyses [30].

II.5 Simulation Studio Steps

TRNSYS (Transient Systems Simulation Program) is a software suite used for simulating the behavior of transient systems. Here's a basic guide to getting started with TRNSYS Studio.

- **Installation:** Start by installing TRNSYS Studio on your computer. Follow the installation instructions provided with the software.

- **Familiarize Yourself with the Interface:** Open TRNSYS Studio once it's installed. Familiarize yourself with the different sections of the interface, including the project workspace, component library, and properties window.

- **Create a New Project:** Start a new project by clicking on "File" > "New" > "Project". Give your project a name and save it in an appropriate location on your computer as shown in figure II.1.

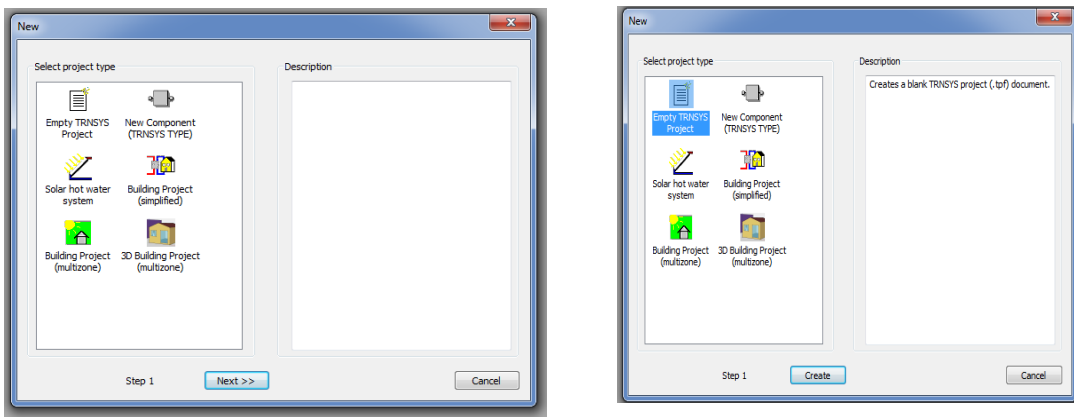


Figure II.1 The first step to create a new project

- **Add Components:** Drag and drop components from the component library onto the project workspace. These components represent different parts of your system, such as solar collectors, buildings, HVAC systems, etc. (figure II.2).

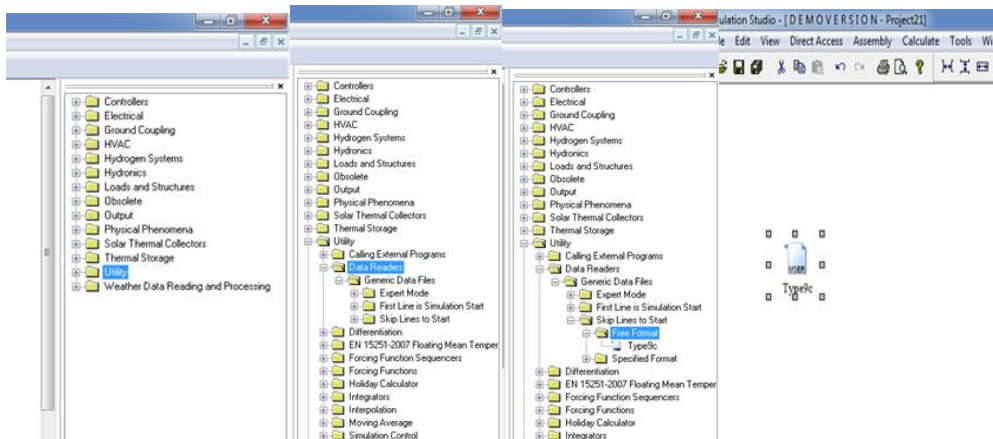


Figure II.2 Drop components from library

CHAPTER 02: MODELING of TRNSYS

▪ **Build the System:** Use the graphical interface of TRNSYS Studio to build your system model. This typically involves selecting and connecting various components from the TRNSYS component library to represent the different parts of your system (e.g., solar collectors, heat exchangers, HVAC units, etc.).

In the figures II.3 and II.4 we will explain the method of building Photovoltaic system model.

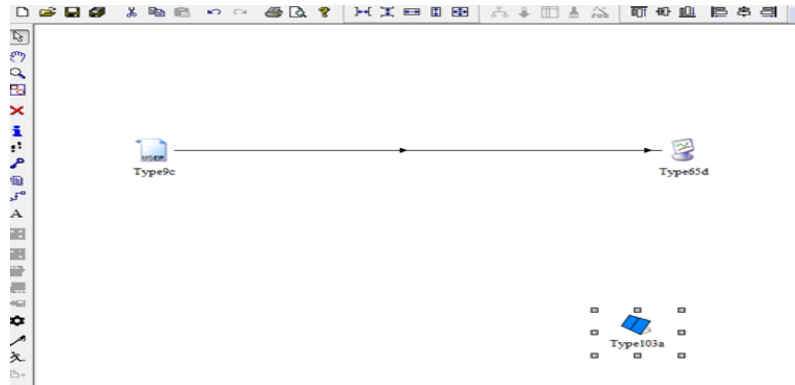


Figure II.3 PV system model before connected

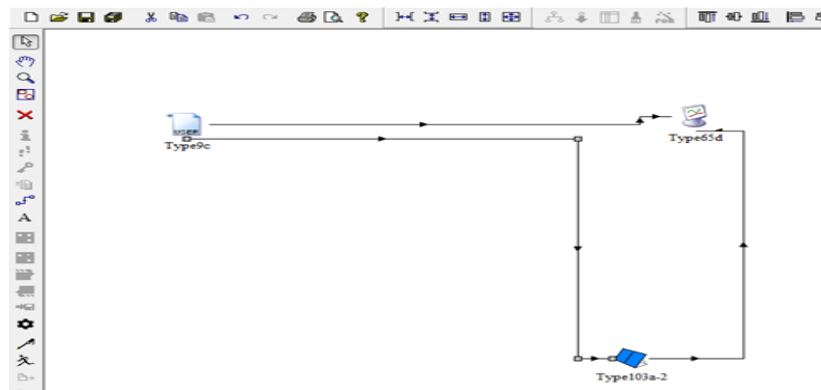


Figure II.4 Final PV system model

- **Connect Components:** Use the connection tool to connect the components together. This defines how energy flows between the different parts of your system. (figure II.5).

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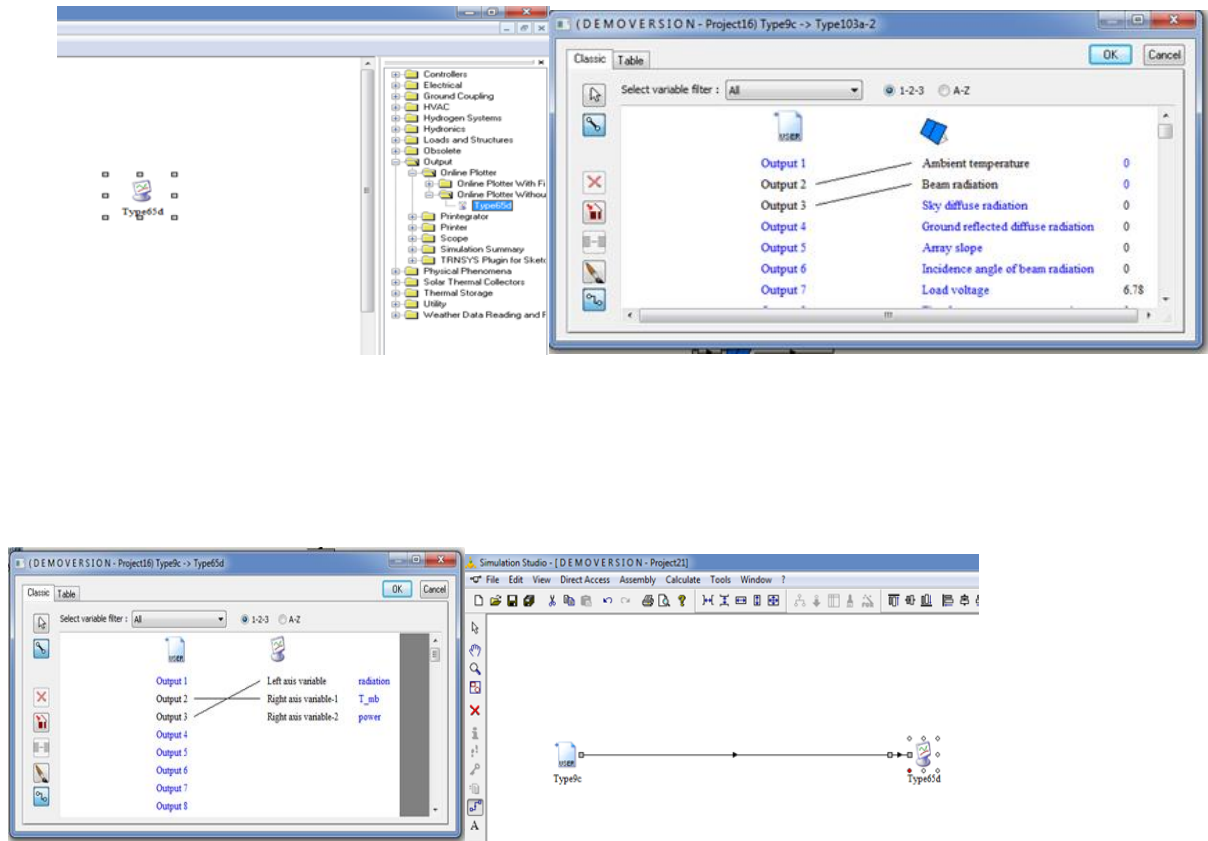


Figure II.5 Connect components

- **Configure Component Parameters:** Double-click on each component to open its properties window. Here you can configure various parameters such as size, efficiency, operating schedule, etc. (figure II.6 and figure II.7).

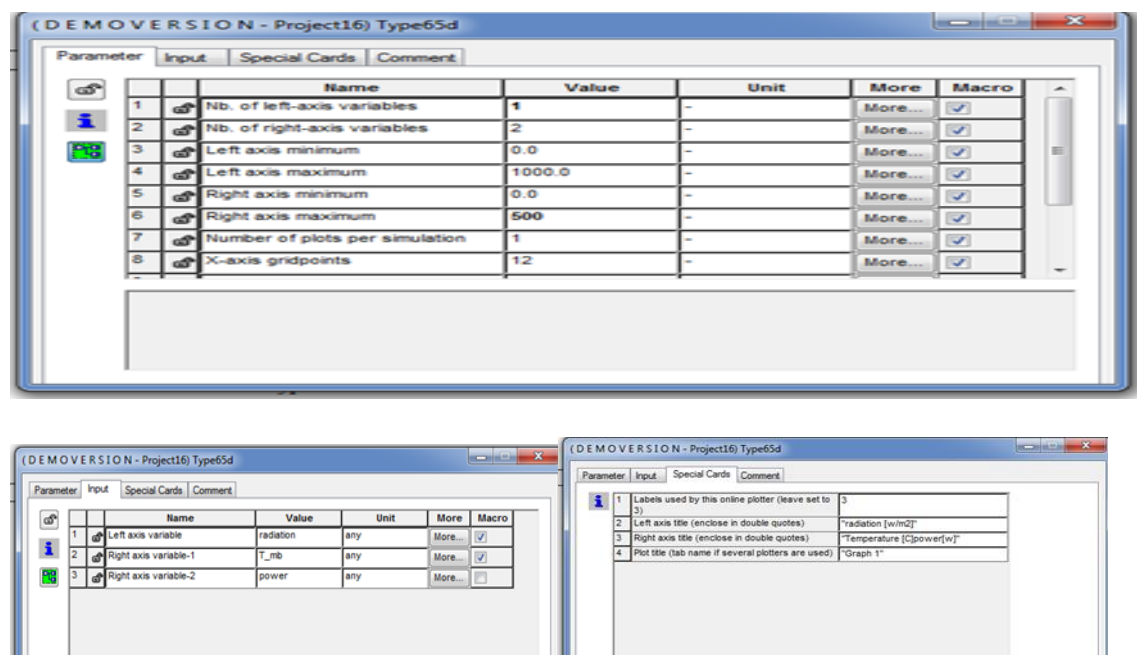


Figure II.6 Parameters inside components

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When we do double-click on each component, the setting appear that allow us to change them according to the data we need in our study.

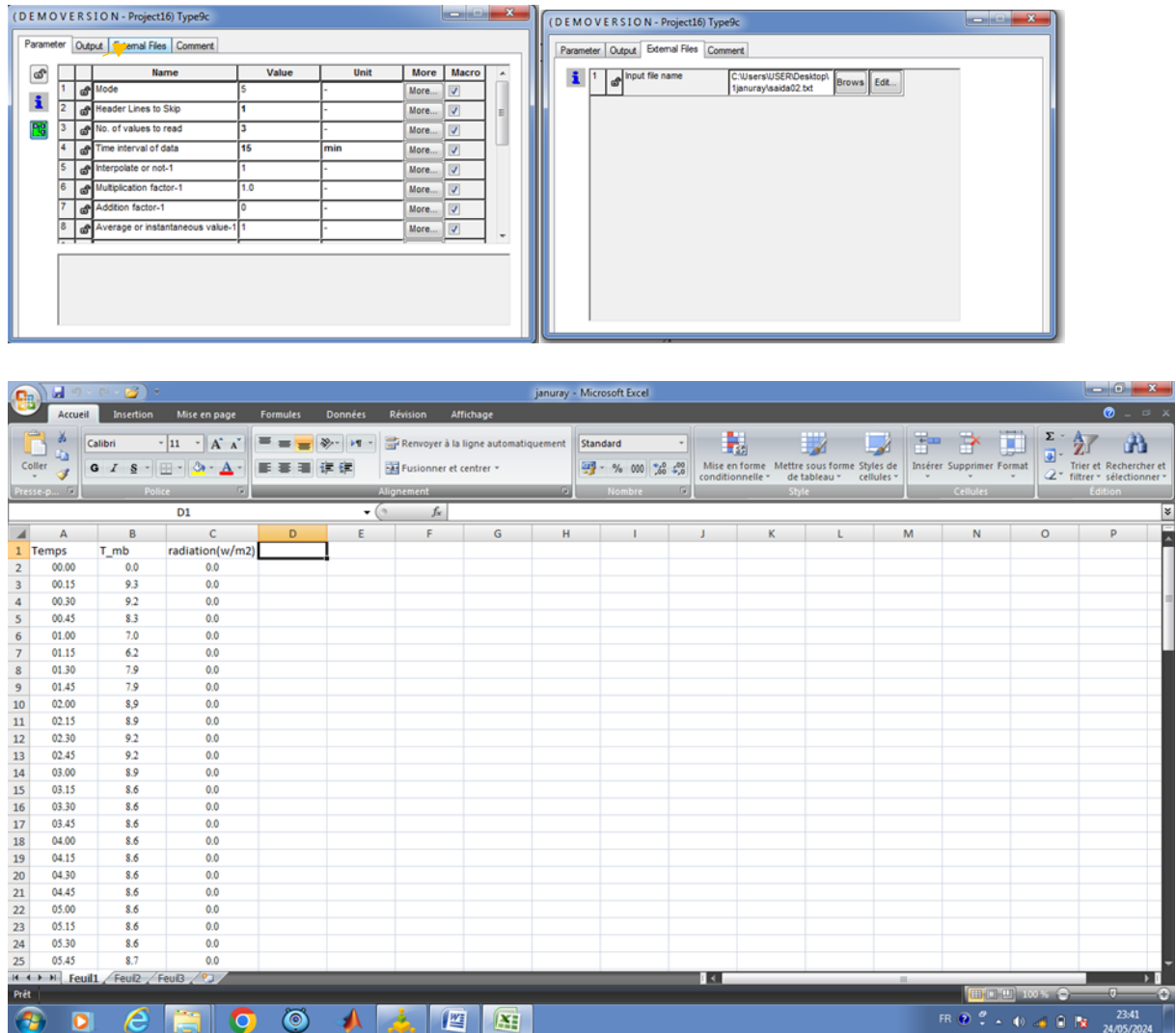


Figure II.7 Weather conditions of 1STJanuary 2019 in Excel field

We integrate Excel field in meteo settings in the Ain El Melh area on different days of the year.

Figure II.8 below shows us the measured values in the day of first January 2022 as an example, in which we note ambient temperature and radiation every quarter of an hour.

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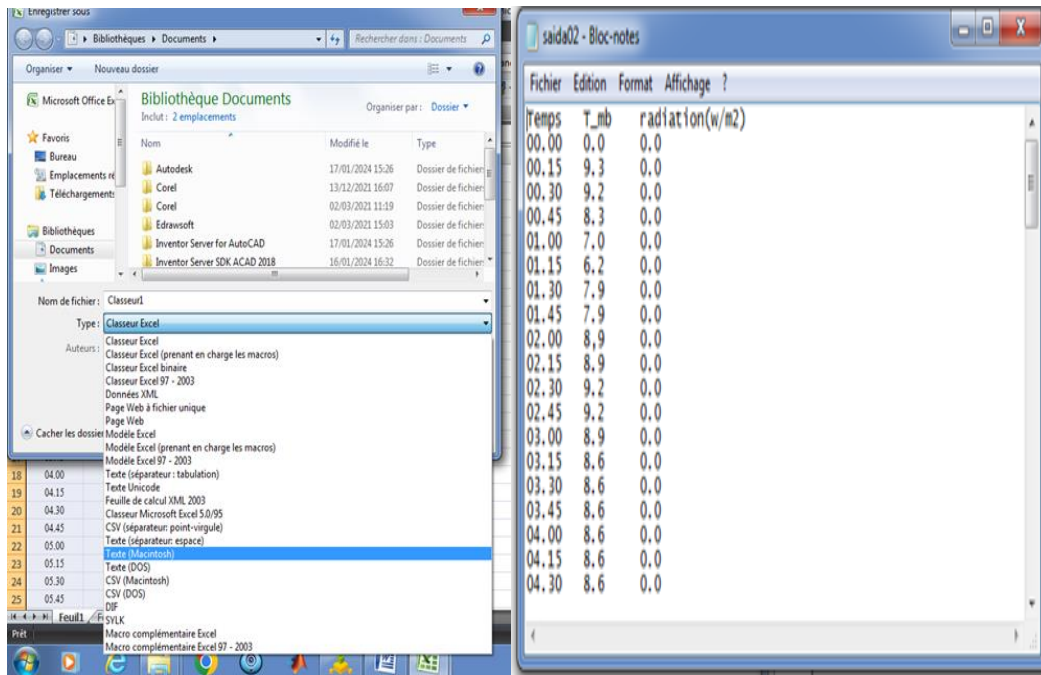


Figure II.8 Excel field integrated in setting

At this step we try to enter the values in a way that TRNSYS understands. We convert the Excel field into text form so that TRNSYS can consider it a part of it not an external element that causes difficulty in reading it.

- **System Control:** Define the control logic for your system. This involves specifying how the components interact with each other over time. For example, you might set temperature setpoints for HVAC systems, control strategies for solar collectors, etc. This step is crucial for accurately simulating the dynamic behavior of the system.
- **Simulation Settings:** Configure the simulation settings such as simulation duration, time step, convergence criteria, etc. These settings determine how the simulation progresses over time and the accuracy of the results. Adjust these parameters based on the complexity of your system and the desired level of detail in the simulation.

The figure II.9 shows how we can change during, time step, start time and end time.

CHAPTER 02: MODELING of TRNSYS

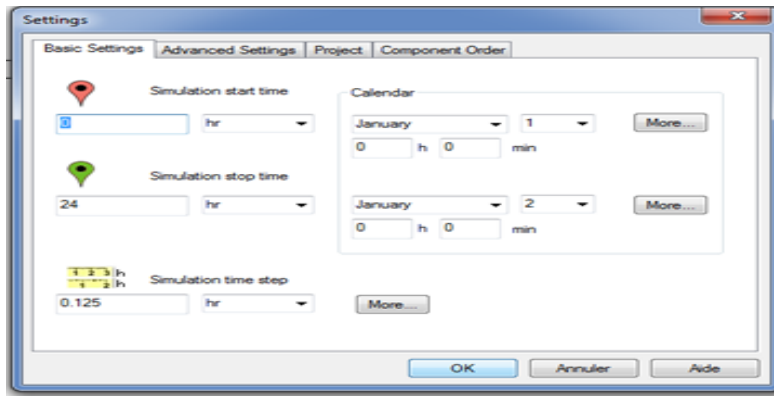


Figure II.9 Define simulation duration and time settings

- **Initialization:** Initialize the simulation by specifying the initial conditions of the system. This could include initial temperatures, pressures, state of charge for storage components, etc. Proper initialization ensures that the simulation starts from a realistic state and produces meaningful results.
- **Run Simulation:** Once everything is set up, run the simulation. TRNSYS will simulate the behavior of the system over the specified time period, calculating energy flows, temperatures, and other relevant parameters at each time step (figure II.10).

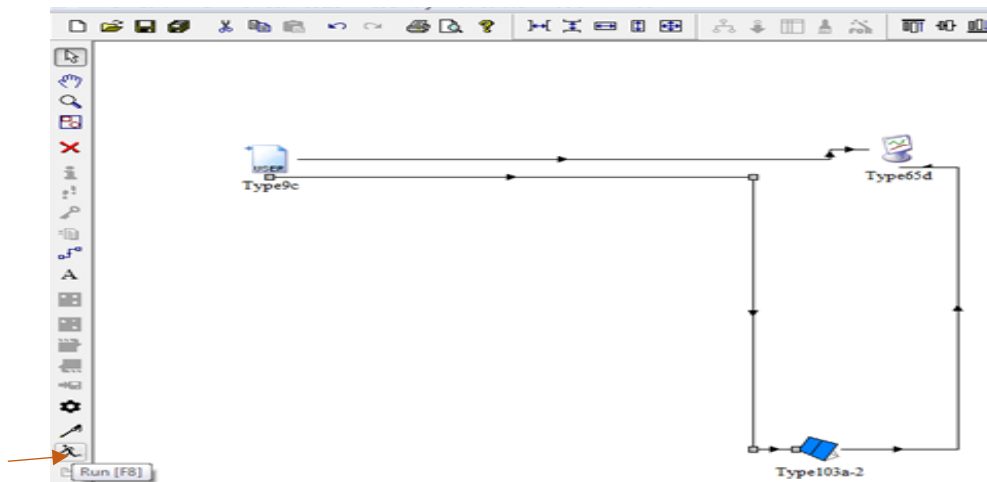


Figure II.10 Click on Run button to observe simulation

- **Analysis:** After the simulation is complete, analyze the results. TRNSYS provides various tools for visualizing and analyzing simulation results, including time series plots, energy balance tables, and performance indicators. Evaluate the performance of your system based on the simulation results and identify any areas for improvement.
- **Optimization:** If desired, you can use the simulation results to optimize the design or operation of your system. This might involve adjusting component parameters, control

strategies, or system configurations to improve performance, energy efficiency, or cost-effectiveness.

- **Documentation:** Finally, document your simulation methodology, assumptions, and results. This documentation is essential for reproducibility and sharing your findings with others.

By following these steps, you can effectively use TRNSYS Studio to simulate energy systems and analyze their performance. Remember to validate your simulation results against real-world data whenever possible to ensure accuracy and reliability.

II.6 Why TRNSYS Simulation Studio is important in renewable energies study

TRNSYS Simulation Studio holds significant importance in the studies of renewable energies for several reasons:

- **System-Level Understanding:** TRNSYS allows for the simulation of complex renewable energy systems at a system level, considering interactions between various components such as solar panels, wind turbines, energy storage systems, and conventional energy sources. This holistic approach enables researchers and engineers to assess the overall performance, efficiency, and economic viability of renewable energy systems in real-world conditions [33].

- **Technology Evaluation:** Researchers use TRNSYS to evaluate the performance of different renewable energy technologies under varying operating conditions, geographical locations, and system configurations. By simulating the behavior of solar, wind, biomass, geothermal, and other renewable energy sources, TRNSYS helps identify the most suitable technologies for specific applications and optimize their integration into energy systems.

- **Design Optimization:** TRNSYS facilitates the optimization of renewable energy system designs by allowing users to explore different design parameters, component configurations, and control strategies. Through parametric studies, sensitivity analyses, and optimization algorithms, researchers can identify optimal design solutions that maximize energy production, minimize costs, and meet performance requirements [31].

- **Policy Support:** TRNSYS aids policymakers and decision-makers in evaluating the impact of renewable energy policies, incentives, and regulations on energy systems and the environment. By simulating scenarios with varying policy interventions, TRNSYS helps assess the potential benefits, challenges, and trade-offs associated with transitioning to renewable energy sources and achieving sustainability goals.

- **Education and Training:** TRNSYS serves as a valuable educational tool for teaching students and professionals about renewable energy technologies, energy systems analysis, and simulation modeling. Its user-friendly interface, extensive documentation, and educational resources make it accessible for learning purposes, empowering future generations of engineers and researchers to address global energy challenges [32].
- **Research and Innovation:** TRNSYS supports cutting-edge research and innovation in the field of renewable energies by providing a flexible platform for developing, testing, and validating new technologies, control algorithms, and system integration strategies. Researchers use TRNSYS to investigate emerging concepts, evaluate experimental data, and contribute to the advancement of renewable energy science and technology.
- **Decision Support:** TRNSYS aids stakeholders in making informed decisions regarding investments in renewable energy projects, infrastructure development, and energy policy formulation. By providing accurate predictions of system performance, energy production, and financial returns, TRNSYS helps assess the feasibility, risks, and benefits associated with renewable energy investments and adoption.

Overall, TRNSYS Simulation Studio plays a crucial role in advancing the studies of renewable energies by enabling comprehensive system analysis, technology evaluation, design optimization, policy support, education, research, and decision-making in the pursuit of a sustainable energy future.

II.7 Conclusion

In the landscape of renewable energy research and development, TRNSYS Simulation Studio emerges as a cornerstone tool, facilitating a comprehensive understanding and optimization of renewable energy systems. Its multifaceted capabilities encompass modeling, simulation, and analysis of intricate energy systems, spanning various renewable sources such as solar, wind, geothermal, biomass, and more. By providing a versatile platform that accommodates diverse system configurations and operational scenarios, TRNSYS empowers researchers and engineers to delve into the complexities of renewable energy integration, offering insights into system performance, efficiency, and reliability under different environmental conditions [34].

One of the paramount strengths of TRNSYS lies in its capacity for design optimization. Researchers can employ the software to explore a myriad of design configurations, component sizes, and control strategies, seeking to maximize energy output, minimize costs, or achieve

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specific performance objectives. Through iterative simulations and sensitivity analyses, TRNSYS facilitates the iterative refinement of renewable energy systems, ensuring that they are tailored to meet the unique requirements of their intended applications [35].

Furthermore, TRNSYS plays a pivotal role in policy development and decision-making processes. Researchers can utilize the software to evaluate the potential impacts of renewable energy incentives, regulations, and market mechanisms, facilitating evidence-based policymaking and strategic planning. By simulating various policy scenarios, stakeholders can gain valuable insights into the implications of different policy interventions on energy markets, environmental sustainability, and societal welfare, thereby facilitating the formulation of robust and effective policy frameworks [33].

Additionally, TRNSYS serves as an invaluable educational resource, nurturing the next generation of renewable energy professionals and practitioners. By providing hands-on experience in modeling and simulation of renewable energy systems, the software equips students and professionals with the skills and knowledge necessary to address the complex challenges facing the renewable energy sector. Through practical experimentation and exploration within a virtual environment, learners gain a deeper understanding of renewable energy technologies, their applications, and their implications for sustainable development.

In essence, TRNSYS Simulation Studio emerges as a pivotal enabler in the pursuit of a sustainable energy future. Its robust capabilities empower researchers, engineers, policymakers, and students to explore, analyze, and optimize renewable energy systems with precision and rigor. By facilitating informed decision-making, fostering innovation, and driving progress towards renewable energy adoption, TRNSYS contributes significantly to the global efforts aimed at mitigating climate change, enhancing energy security, and fostering sustainable development.

CHAPTER 03:

Results and Discussions

III.1 Introduction

Within the dynamic landscape of renewable energy, the accurate prediction of photovoltaic (PV) panel performance stands as a pivotal endeavor, influencing system design, operational efficiency, and overall energy yield. In this section, we embark on a rigorous examination of the predictive prowess of TRNSYS software in forecasting the power output of PV panels, juxtaposed against empirical measurements obtained through experimentation.

The integration of TRNSYS software into the realm of PV panel analysis represents a convergence of cutting-edge simulation technology and real-world application. With its capacity to simulate intricate environmental variables and system parameters, TRNSYS offers a platform for predicting PV panel performance under diverse conditions, holding profound implications for both research and practical implementation.

Our investigation delves into the comparative analysis of TRNSYS predictions and experimental measurements, unraveling the intricacies of simulated versus observed outcomes. Through meticulous scrutiny of data concordance, deviation patterns, and underlying factors, we endeavor to elucidate the reliability, accuracy, and limitations of TRNSYS in power prediction—a critical pursuit in advancing the efficacy and adoption of solar energy technologies.

As we navigate through the results and discussions herein, we traverse the interface between simulation and reality, striving to illuminate the pathways toward enhanced predictive modeling and informed decision-making in the realm of renewable energy.

III.02 Simulation and Interpretation

III.02.1 Understanding TRNSYS and Photovoltaic Systems:

- TRNSYS (Transient System Simulation Tool) is a software suite used for simulating the performance of renewable energy systems, including photovoltaic panels.
- Photovoltaic panels convert sunlight into electricity. Their performance depends on factors like irradiance, temperature, and panel characteristics.

Table III.1 PV cell parameters

Name	Value
MPPT mode	0
Module short-circuit current at reference conditions	7.21 A
Module open-circuit voltage at reference conditions	44.06 V
Reference cell temperature	25 °C
Reference isolation	1000 W/m ²
Module voltage at Max power point at reference conditions	37.63 V
Module current at Max power point at reference conditions	6.78 A
Temperature coefficient of I _{SC} (ref .Cond)	0.02 A/K
Temperature coefficient of V _{OC} (ref .Cond)	-0.079 V/K
Number of cells wired on series	72
Module temperature at NOCT	46°C
Module area	0.89 m ²
Number of module in series	22
Number of module in parallel	81

The table presents the parameters of PV system that we use to make this study in the area of Ain El Melh “M’sila”, we integrate these settings in TRNSYS Software inside the component of PV module to realize the correct simulation.

III.02.2 Modeling PV Panels in TRNSYS:

Use TRNSYS to create a simulation model of the PV panels. This involves inputting parameters such as panel specifications, orientation, tilt angle, weather data, and system configuration. We talk about the details in the past chapter, the figure III.1 shows the simulation model that we create by TRNSYS Software.

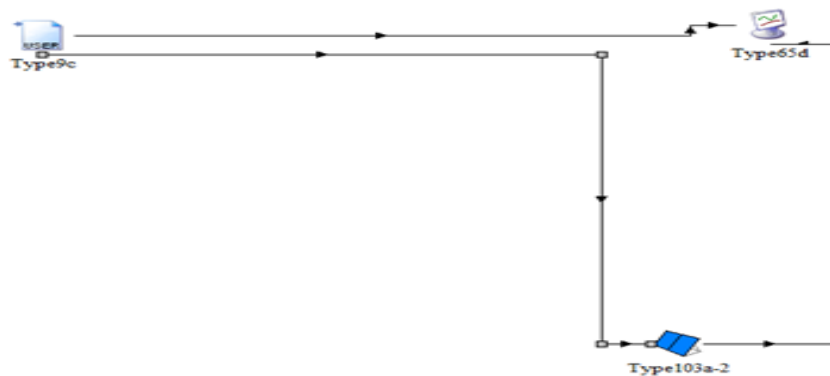


Figure III.1 Simulation model by TRNSYS

This figure shows the MODELING of PV system, the component (Type 103a-2) represents an integrated system whose internal settings we can control according to what the field study needs in the area of Ain El Melh.

III.02.3 Validation of TRNSYS Model:

- Design an experiment to measure the actual power output of the PV panels under various real-world conditions. This could involve setting up a test rig with monitoring equipment to capture data on solar irradiance, temperature, and PV output.
- Ensure the experiment encompasses a range of scenarios representative of typical operating conditions, including variations in solar insolation, temperature, and shading.

We enter an Excel file containing Data base for the days we are studying. The file contains the real values and experimental values that will be converted into written text that can be read by TRNSYS Software and display the curves that express the validity of the data.

III.02.4 Data Collection:

- Conduct the experiment while simultaneously collecting data from TRNSYS simulations under the same conditions. Ensure that the simulation inputs align with the parameters used in the experimental setup.
- Record all relevant data, including solar irradiance, ambient temperature, panel temperature, and the corresponding power output from both the experiment and TRNSYS simulations. Like we note in figure II.8.

III.02.5 Results Analysis:

Present the results obtained from TRNSYS simulations, including predicted power outputs under different conditions and scenarios. Discuss any trends, patterns, or insights observed in the simulation results.

We teste the results in two stages.

- The first stage was to take one day in the winter, 1STJanuay 2019, and we relied on the real values of weather conditions, such as temperature and solar radiation.

CHAPTER 03: Results and Discussions

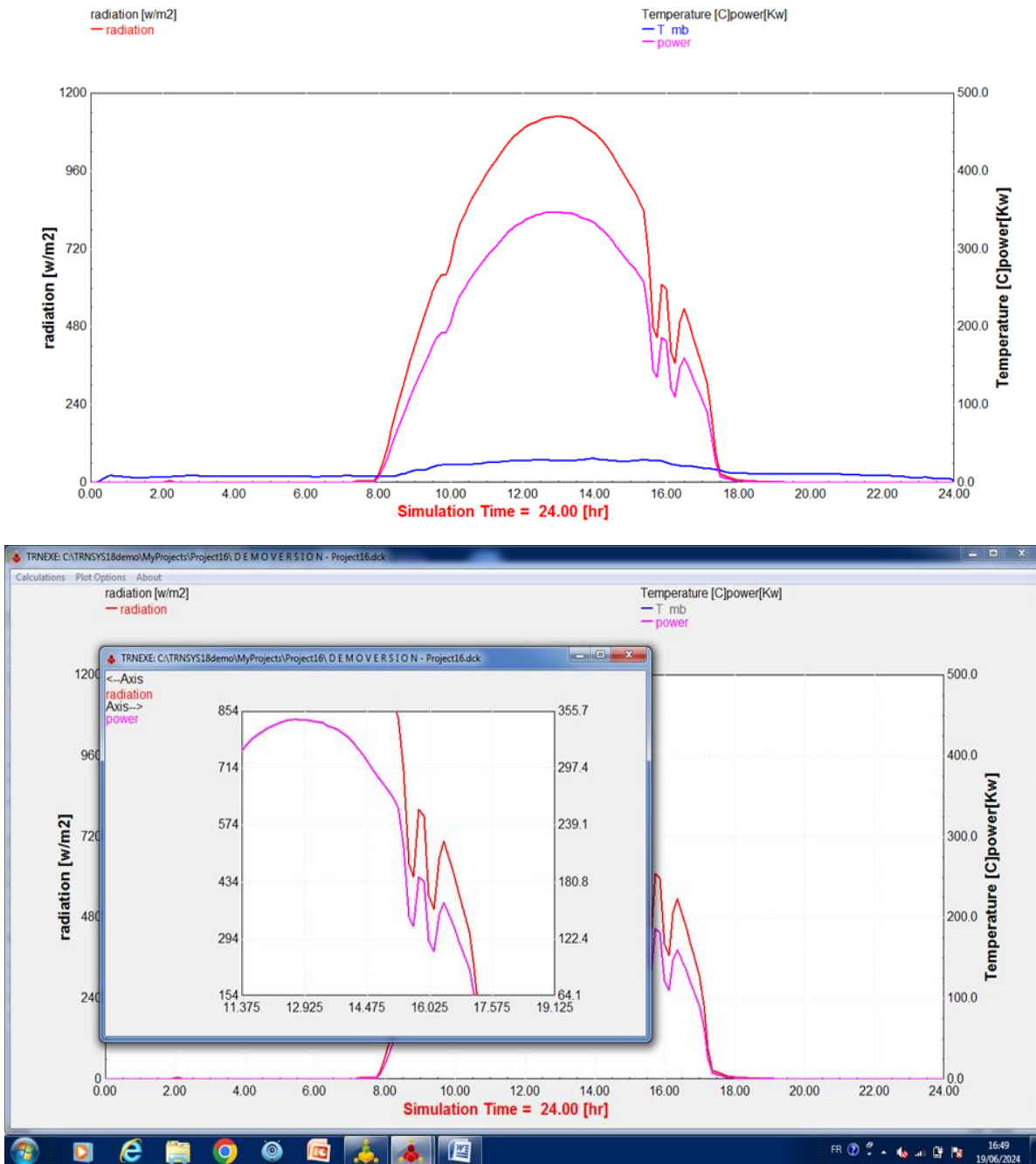


Figure III.2 The 1STJanuary 2019 curve

The figure represents the curve with inputs (T_{amb} and radiation) with the output that we need (power) in the first day of January 2019. The curve draws by TRNSYS software.

The fluctuations that we observe on the graphic curve are only an interpretation of real changes that occurred in the weather conditions on this day.

The following graphic curve (figure III.3) expresses the temperature changes we measured every quarter of an hour.

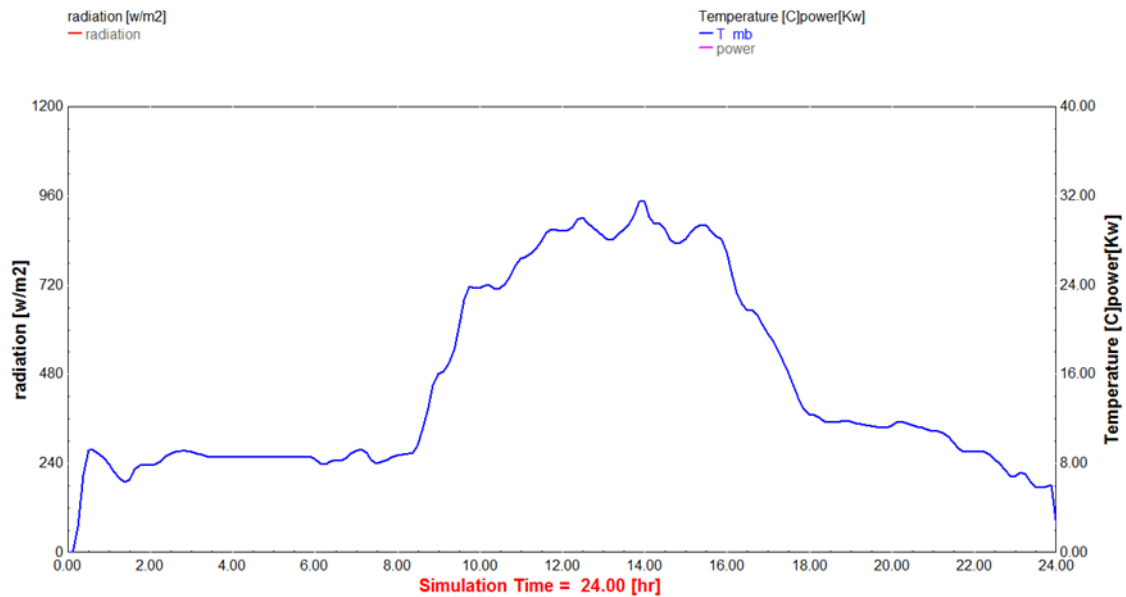


Figure III.3 Temperature graphic curve on 24 hours.

We note that the graph consists of three stages.

- The first one extends from midnight until approximately 08:00 am, during which temperature changes are stable, due to the cold winter season first, and then the absence of sunlight which is considered a source of heat at night.
- The second stage, we observe a noticeable increase from approximately 08:30 am until 16:00 pm, with fluctuations at different times during the afternoon. Although the highest temperature recorded during this day did not exceed 32°C, the difference is clear and natural during this period of the year.
- In the last stage of the graph, in the evening period from 14:00 pm to midnight, we see a drop in temperature and stability at low levels of about 09°C.

In the next figure III.4, we will try to address the second element of weather conditions, which is solar radiation, and discuss its changes.

CHAPTER 03: Results and Discussions

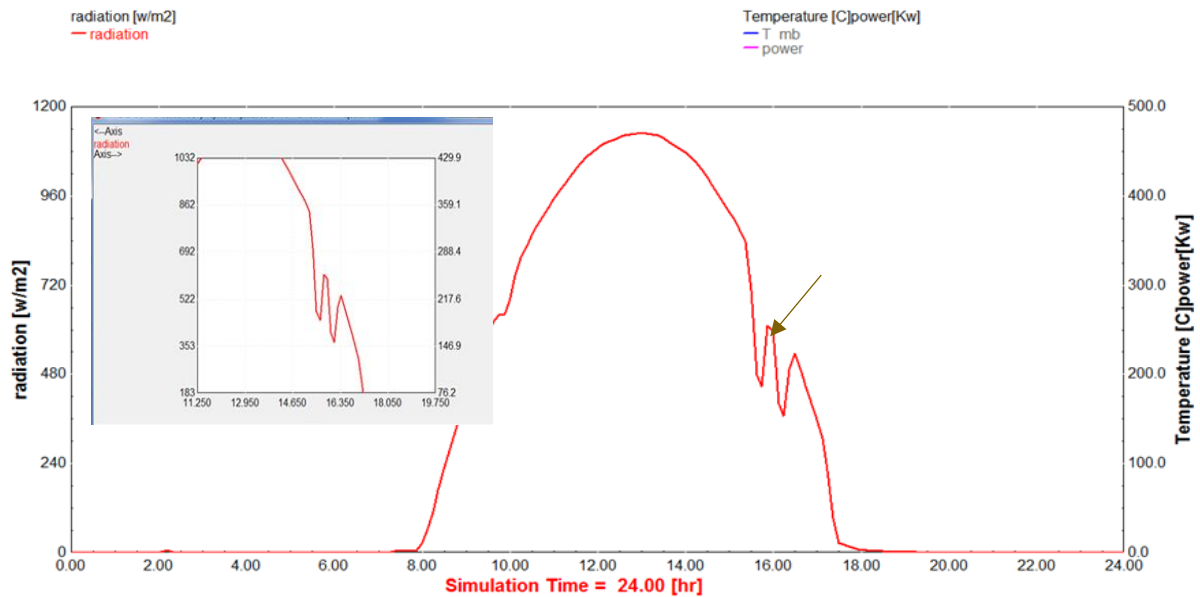


Figure III.4 Solar radiations in the day of 1ST January

- In the first section of the graph, we see that there is no change and the regularity of the graphic at zero, due to darkness in the period extending from midnight to 08:00 am.
- As for the second section, it is expected to notice a sharp increase, especially in the morning and afternoon period. The explanation is simple, which is the presence of clear solar radiation that reached its peak at 1048 W/m².
- In the third part of the curve, which is indicated by the arrow above, we notice a rapid and sudden fluctuation, a decline in a very short period of time around 15:00 pm, then a rise in the next minute that reached approximately 600 W/m². The large number of rapid fluctuations in a short period of time indicates the occurrence of an unexpected accident. It is expected, such as shading the photovoltaic panels with a large cloud, which is normal matter in the law of nature, as the curve rises with the increase in radiation and decreases with its decrease.
- At the last section of the graph, in the period between 17:20 pm and 00:00 am, we notice the return of the graph to point zero, coinciding with the return of darkness in that evening period.

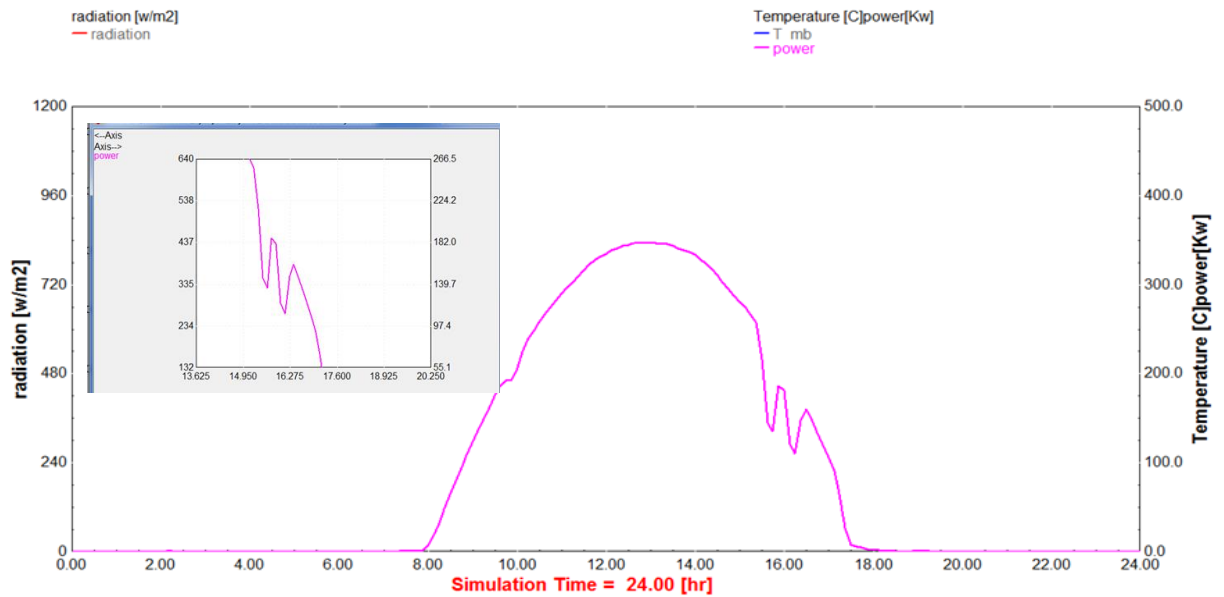


Figure III.5 The graphic curve of power

We can conclude from the graphic curve represented in the figure III.5 above that the power curve follows the path of the solar radiation curve. As we know that temperatures directly affect voltage, while solar radiation affects the intensity of the current, which together constitute the system's power according to this equation:

$$I(A) \times V(V) = P(W)$$

In this case, there is a proportionality between the values translated I to the statement, meaning that whatever the effect, whether from heat or radiation, the form of the power statement will not change radically, but rather is affected by the climatic conditions in that period.

- The second stage was to take one day in the summer, 21ST June 2019, and we relied on the real values of weather conditions, such as temperature and solar radiation.

CHAPTER 03: Results and Discussions

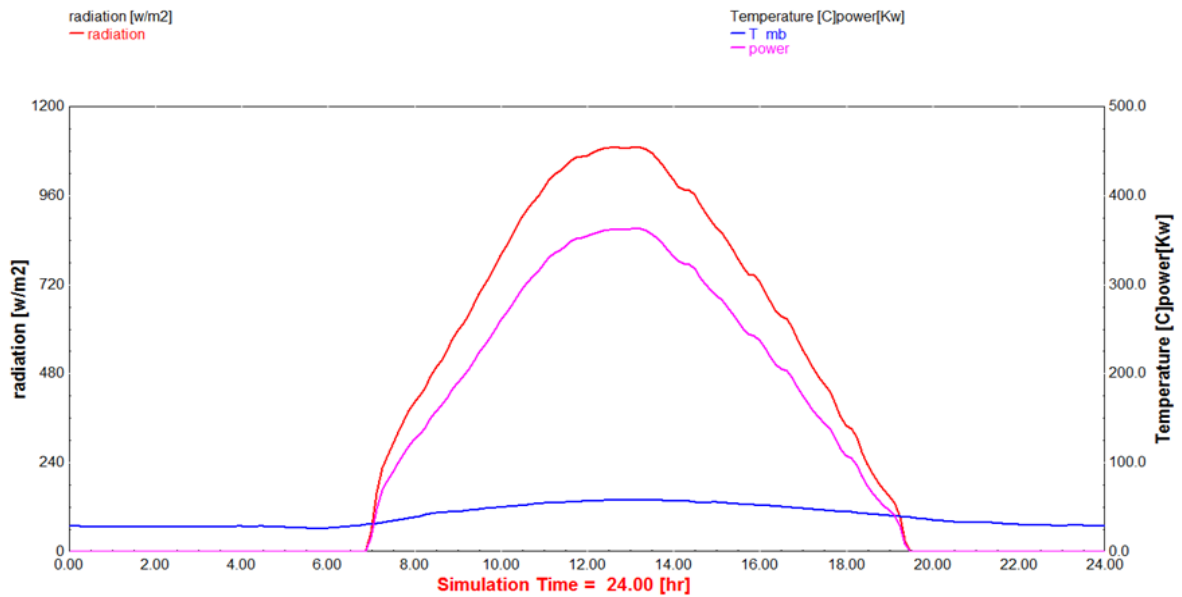


Figure III.6 The 21ST June 2019

The figure represents the curve with inputs (T_amb and radiation) with the output that we need (power) on 21ST June 2019. The curve draws by TRNSYS software.

The graphic curve clearly shows us changes in inputs, like temperatures and solar radiation, and the output curve, which represents power.

As we see the power curve follows path of radiation graph.

In the next figure III.7 we will talk about each graphic curve alone with mentioning the causes of all changes and fluctuations.

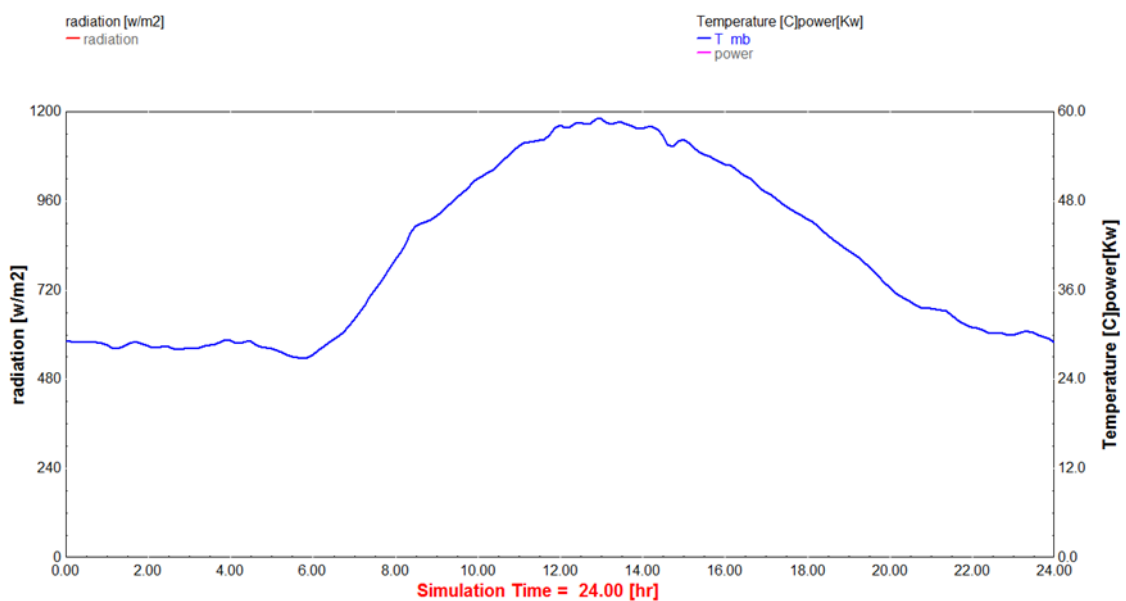


Figure III.7 Temperature curve in 21ST June 2019

CHAPTER 03: Results and Discussions

As we can see in the graph, temperatures were not low even in the late hours of the night, reaching approximately 26°C.

The start of the rise was at 06:00 am, until it reached its peak at 13:00 pm, when the temperature was 62°C.

At the end of the evening, the temperature dropped slightly, reaching 30°C at midnight, which are very high temperatures that can affect the system's performance in general.

In the following figure III.8 we will also talk about changes in solar radiation and its effects.

The curve below is a graphical representation of solar radiation during 24 hours on 21ST June 2019. Although the general shape on the curve does not contain many fluctuations, the solar panels did not capture a large amount of radiation.

As usual, from midnight to 07:00 am the graphic curve is at the point zero, and the reason is clear: there is no sunlight at night.

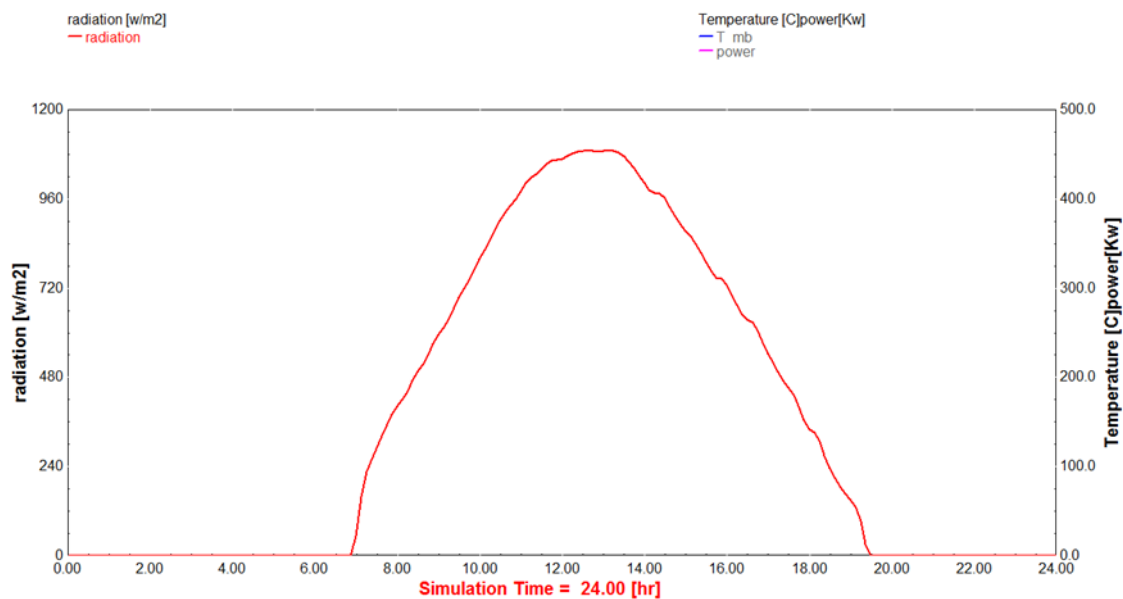


Figure III.8 Solar radiation graphic curve

The highest peak reached by the graph was at 12:30 pm, reaching approximately 468 W/m², until it returned at 20:00 pm to zero again.

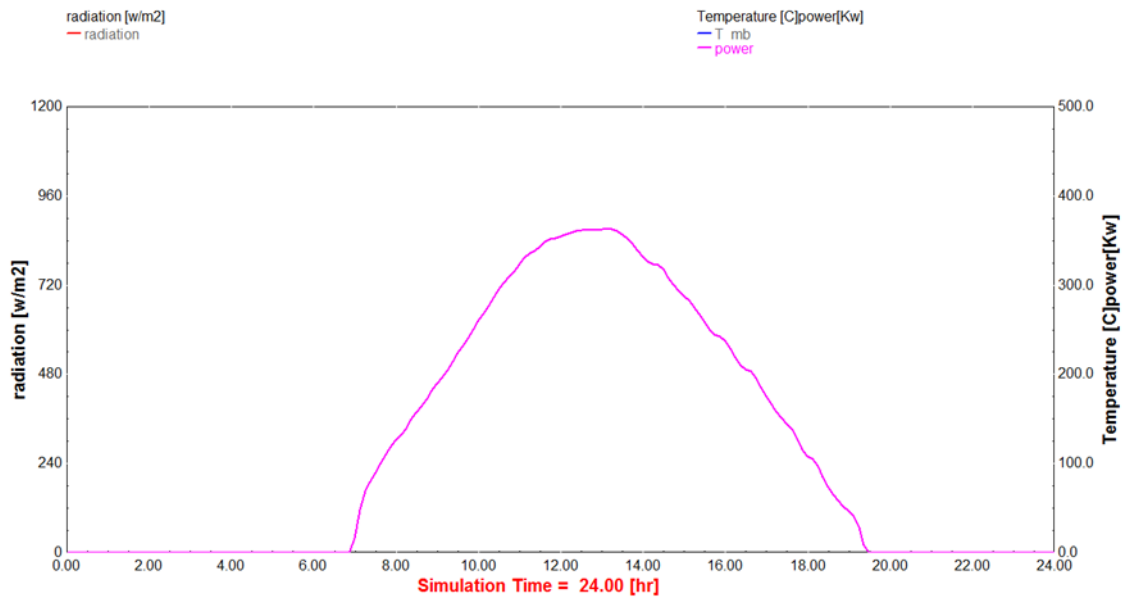


Figure III.9 Power graphic curve

Figure III.9 represents the power graphic curve of the 21ST June 2019, we can observe the absence of the power at night and it begins to appear with the onset of solar radiation, but the maximum it reached was 368 KW, and here lies to effect of high temperatures on panels performance, as power levels decreased coinciding with a terrible rise in temperatures in summer.

III.03 Comparison between real values and TRNSYS

III.03.1 Statistical Analysis

- Present the statistical comparison between TRNSYS predictions and experimental data using the defined metrics.
- Highlight areas of strong correlation and significant discrepancies.

III.03.2 Sources of Discrepancies

Investigate potential sources of discrepancies, such as:

- Simplifications and assumptions in the TRNSYS model.
- Calibration errors or inaccuracies in the experimental setup.
- Environmental factors not fully captured in the simulation (e.g., micro-shading, soiling of panels).

In the figure III.10 below, we will make the first comparison between the real values and those that we extracted from the graphic curve draw by TRNSYS.

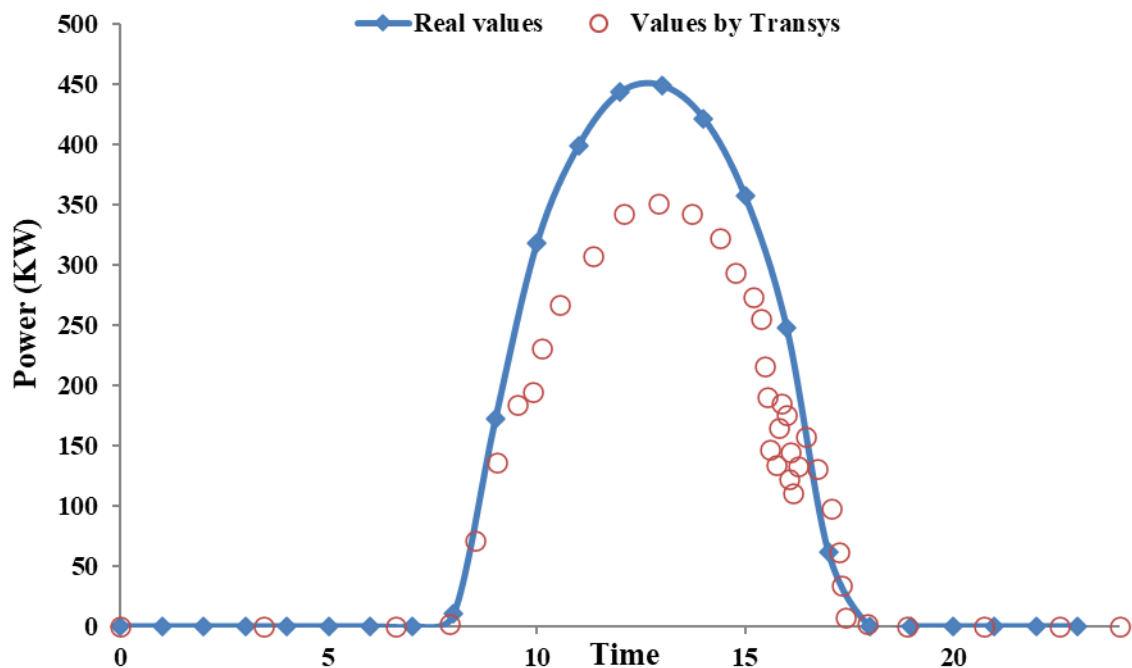


Figure III.10 Comparison for the 1ST January 2019

CHAPTER 03: Results and Discussions

In general, we compared the average values between the real and the measured values using TRNSYS software on the first day of January 2019. The two curves follow the same shape with a clear difference at the peak, as we find the true value is slightly larger, and this is likely to happen as the software is new in the field of renewable energies. It is subject to development and is affected by general changes inter to it, whether in the form of files or data base.

The figure represents two graphical curves on the same parameters taken at the same time periods, and it is clearly noticeable that the difference between the highest and the lowest value in power is about 100 KW. It is considered a somewhat significant difference, but it can be improved if we study carefully.

We will study another comparison below in figure III.11.

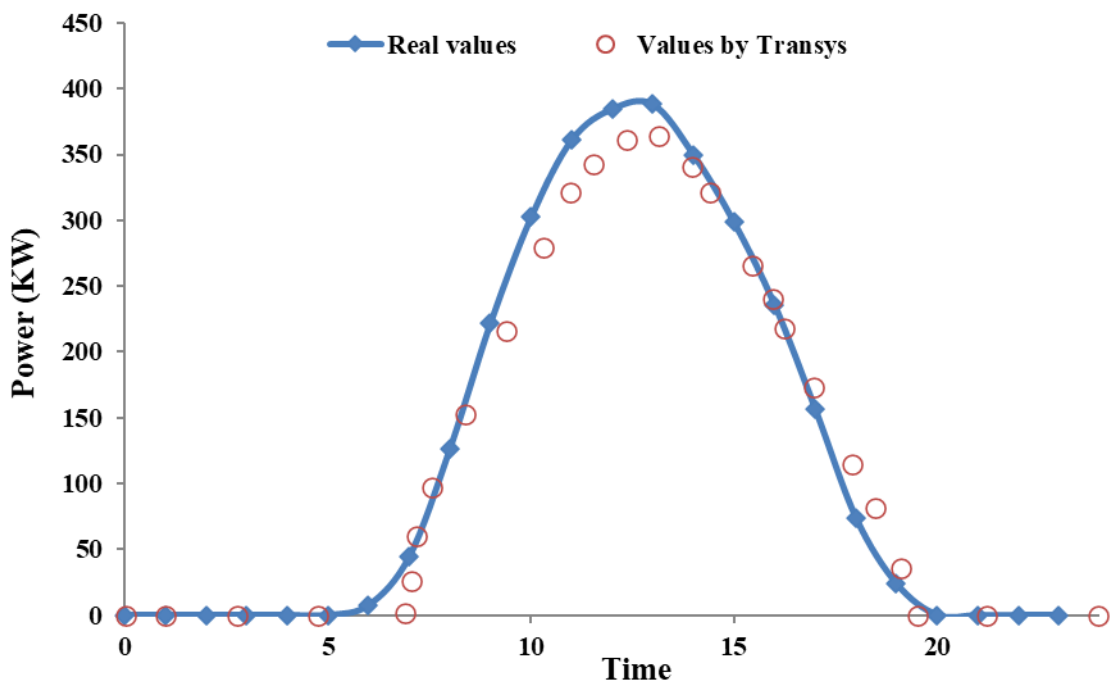


Figure III.11 Comparison on 21ST June 2019

As can be seen in the figure III.11, there are two graphic curves on the same parameters, the first representing the real values and the second those extracted from TRNSYS software, but unlike the previous figure III.10, here we notice a match in some periods and an approach in other periods that we can neglect, meaning that the two curves are close to matching in

general, which is what proves the effectiveness of this software at this sensitive time of the year.

- ✓ We can rely on TRNSYS software in our predictions of future energy values, and to ensure its effectiveness, the user must follow the correct steps and deal with the data base he enters accurately.

III.04 Conclusion

The comparison of power prediction for photovoltaic panels using TRNSYS software with experimental measurements reveals that TRNSYS is a reliable tool for simulating PV panel performance. The software shows high accuracy in predicting power output when calibrated with precise input data, closely matching experimental results. Discrepancies can arise due to environmental factors and data quality, but overall, TRNSYS proves to be cost-effective and efficient for scenario analysis and system optimization.

Experimental data is crucial for validating and refining TRNSYS models, enhancing their accuracy. This integration supports informed decision-making for PV system deployment, aiding in system sizing, location selection, and financial planning. Reliable simulation tools like TRNSYS also assist policymakers in designing effective incentives for solar energy projects. Future improvements in modeling techniques and real-time data integration will further increase prediction accuracy, fostering the broader adoption and effective management of photovoltaic systems.

General Conclusion

General Conclusion

In conclusion, the global push towards renewable energy solutions, notably solar power, reflects a strategic response to the growing demand for clean energy and the imperative to mitigate climate change. Algeria, with its geographical advantage of abundant solar radiation, presents a prime opportunity for significant solar energy development.

The integration of TRNSYS simulations and empirical measurements offers a robust framework for predicting the power output of photovoltaic systems, particularly in regions like Ain El Melh, where solar potential is substantial. This integrated approach not only leverages the advanced modeling capabilities of TRNSYS but also validates these simulations with real-world performance data.

By combining the flexibility and precision of simulation models with the authenticity of empirical observations, this methodology ensures a comprehensive understanding of PV system behavior under varying conditions. Through iterative refinement and calibration, these models become increasingly accurate and reliable, facilitating informed decision-making in system design, operation, and optimization.

Ultimately, the successful integration of TRNSYS simulations and experimental measurements contributes to the advancement of sustainable energy solutions, fostering resilience and efficiency in electricity generation. As nations worldwide seek to transition towards cleaner and more renewable sources of energy, this approach stands as a testament to the power of innovation and collaboration in addressing the challenges of a rapidly evolving energy landscape.

At the end of project, we conclude, through the first chapter, the importance of location in determining the capacity needed for the study, which enables us to know the appropriate weather conditions, while through the second chapter we learned about TRNSYS software and the most important steps that enable us to study a photovoltaic system in a clear and proven way on the Ain El Melh system. As for the last chapter, we devoted it to discussing the results, analyzing the graphic curves, and interpreting the most important phenomena that occur on a daily basis in the photovoltaic systems. Then we compared the real values and those that we extracted from TRNSYS software in order to obtain a final result that we can confirm, thanks to which software is effective, and in this way it can Specialists in the field of renewable energies use it to prediction studies and avoid energy losses and thus the financial profit that any commercial organization is looking for.

Abstract

Nowadays, the integration of photovoltaic (PV) systems into distribution networks is becoming increasingly popular due to the advantages of incorporating renewable energy into traditional power grids. In this project, we present the design of a 20MW micro grid system that connects to a distribution network under various operating conditions.

PV system is modeled using TRNSYS software. The load flow of the entire system, starting from the PV module to the consumers, is studied, using the parameters of the Ain El Melh PV station to validate all results. The simulation results hold practical significance for real engineering applications.

Keyword: photovoltaic power plants, TRNSYS, Load Flow, power flow, short circuit analysis, power grids.

Résumé

De nos jours, l'intégration des systèmes photovoltaïques (PV) dans les réseaux de distribution devient de plus en plus populaire en raison des avantages qu'ils offrent en intégrant les énergies renouvelables aux réseaux électriques traditionnels. Dans ce projet, nous présentons la conception d'un système de micro-réseau de 20 MW connecté à un réseau de distribution dans diverses conditions de fonctionnement.

Le système PV est modélisé à l'aide du logiciel TRNSYS. Le flux de charge de l'ensemble du système, allant du module PV jusqu'aux consommateurs, est étudié en utilisant les paramètres de la station PV d'Ain El Melh pour valider tous les résultats. Les résultats de la simulation ont une signification pratique pour les applications d'ingénierie réelle.

Mots-clés : centrales solaires photovoltaïques, TRNSYS, Flux de charge, Flux de puissance, Analyse de court-circuit, Réseaux électriques

ملخص

في الوقت الحاضر، أصبح دمج أنظمة الطاقة الشمسية الكهروضوئية في شبكات توزيع الكهرباء شائعاً بشكل متزايد بسبب مزايا دمج الطاقة المتجددة في الشبكات الكهربائية التقليدية. في هذا المشروع، نقدم تصميم نظام شبكة مصغرة بقدرة 20 ميغاوات يتصل بشبكة توزيع تحت ظروف تشغيل متنوعة .

تم تصميم نظام الطاقة الشمسية باستخدام برنامج TRNSYS.

يتم تدفق الحمولة للنظام الشمسي بأكمله، بدءاً من وحدة الإنتاج إلى المستهلكين باستخدام معلومات محطة عين الملح للتحقق من جميع النتائج. تحمل نتائج المحاكاة أهمية عملية لتطبيقات الهندسة .

الكلمات الرئيسية: محطات الطاقة الشمسية الكهروضوئية ، TRNSYS ، تدفق الحمولة ، تدفق الطاقة، شبكات الطاقة.

الكلمات الرئيسية: محطات الطاقة الشمسية الكهروضوئية، TRNSYS، تدفق الحمولة، تدفق الطاقة، شبكات الطاقة.

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