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# Simulation-Based Performance Analysis of a Grid-Connected Photovoltaic Plant in Desert Climate Conditions

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***Abstract: -*** This paper looks at how well a 5 MW grid-tied PV power plant in the In Salah region of southern Algeria runs. The study addresses a 10-hectare, polycrystalline silicon panel-using plant running since 2016 using the PVsyst simulation tool. It was updated with precise meteorological data that accurately reflects the site's environmental reality, enabling adjustments to the simulation results for the challenging desert climate conditions of Ain Salah, characterized by high temperatures and intense solar radiation. According to modelling results, energy output achieved 7,603,339 kWh annually, with a performance ratio (PR) of 81.7% and a PV module efficiency of 12.67%. These figures demonstrate good performance in a climate environment that is difficult to control. Loss research also revealed that several important causes contributed to the performance drop, including component mismatches (2.1%), inverter losses (5%), and high-temperature losses (7.6%). These findings support the notion that one of the primary factors affecting PV system effectiveness in arid areas is high temperatures. Comparing these findings to the performance of comparable systems in Algeria and abroad revealed that efficiency is strongly correlated with several variables, chief among them being the climate and the solar cell technology used. The planning and assessment of PV systems benefit from advanced modeling software, such as PVsyst, as this paper demonstrates. Especially for grid-connected photovoltaic power plants in remote locations with severe conditions, simulation reflects its value in decision-making by providing precise forecasts, identifying loss factors, and enhancing overall efficiency.

***Keywords***: *PVsyst, Grid-Tied Systems, Performance Ratio, Energy Output, Solar Power.*

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## 1. Introduction

Growing environmental problems brought on by a heavy reliance on traditional energy sources, such as fossil fuels, have led to a global shift in focus toward renewable energy as a sustainable solution. Growing concerns about greenhouse gas emissions, climate change, and the depletion of non-renewable resources are the primary causes of this shift. Clean, limitless alternatives that drastically reduce their impact on the environment are provided by renewable energy sources, such as solar, wind, hydro, and geothermal. Adoption of renewable energy benefits not only the environment but also advances economic growth, energy security, and innovation in green technology. Integrating renewable energy sources into the energy mix has become a strategic and environmental necessity, simultaneously achieving sustainable development, in light of the ongoing rise in global energy consumption.[1], [2], [3]. Combined with pollution and acid rain, the continued reliance on fossil fuels has led to rising greenhouse gas emissions, causing the Earth's temperature to increase by an average of 0.3 degrees Celsius every decade. The issue of transitioning towards clean energy has become an imperative necessity in light of the accelerating environmental challenges, especially those related to climate change and deteriorating air quality at the local and global levels. In this context, solar energy is emerging as a strategic option within the renewable energy system, due to its well-established technical development and wide geographical spread [4], [5].

This accelerating dynamic embodies a strategic awareness of the central role of solar energy in the future energy mix, not only for its role in reducing greenhouse gas emissions and achieving the goals of the Paris Climate Agreement, but also for its ability to enhance energy security by diversifying generation sources, supporting decentralized models, and reducing dependence on Energy imports. In this context, solar energy is gaining a pivotal position as an effective tool for achieving the comprehensive energy transition at the national and international levels. When it comes to reaching the 2030 sustainability goals outlined in the Paris Climate Agreement, its high scalability, minimal environmental impact, and consistently cheap installation costs make it the best option. It is anticipated that solar energy will expand internationally and continue to increase in efficiency as technology develops [6], [7], [8], [9], [10].

Algeria is the largest country in Africa and the Mediterranean, spanning an area of 2.38 million square kilometers. Thanks to its expansive desert landscapes and favorable climate, it has enormous solar potential. With an average of 5 kW/m², the vast Sahara Desert, which comprises almost 85% of Algeria's land area, receives more than 3,000 hours of sunshine annually. In the southern regions, such as Adrar and Tamanrasset, surprisingly, 3,900 hours of solar radiation can be received annually, with daily solar energy exceeding 18 MJ/m² [11], [12], [13], [14]. Algeria is among the countries with tremendous capabilities to harness solar energy, thanks to its geographical location and the expansion of its territory with high radiation levels throughout

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the year. Recognizing the importance of this natural resource, the Algerian government has developed an ambitious national plan that aims to produce 40% of electricity from renewable sources by 2030. This trend involves an increasing reliance on solar photovoltaic technologies, with the installation of large-scale photovoltaic plants serving as one of the strategic pillars of this program, as shown in Figure 1 [15], [16], [17].

This study utilizes PVsyst software, one of the most prominent and reliable simulation tools, to analyze the performance of a 5 MW grid-connected solar photovoltaic power plant. This analysis aims to evaluate operating efficiency by simulating system performance based on real design parameters and local climatic conditions. Due to the harsh desert climate and high levels of solar radiation in the Algerian city of Ain Salah, it was chosen as a case study to represent dry environments. The goal of this study is to identify the variables that influence energy output, system losses, and overall efficiency, providing information that can help solar systems operate more effectively in hot, dry climates.

The long-term operational efficiency and reliability of a photovoltaic (PV) power plant depend on its performance, which is crucial given the growing role of solar energy as a sustainable energy source in the world's energy balance. Appropriate performance evaluation not only aids in better system design but also enables precise loss monitoring and maximization of energy production. In this context, sophisticated simulation tools such as PVsyst are essential, as they provide comprehensive analytical models based on site-specific geographic features, real climate data, and technical system configurations. This extensive technique enables designers and operators to make scientifically informed decisions during the planning, implementation, and operation phases of PV projects. [18], [19], [20].

The reader is guided through the various study components with ease by the logical structure of this work. In addition to assessing Algeria's vast potential in this area and outlining its ambitious plan to increase the share of renewable energy sources in the country's energy mix, the paper begins by emphasizing the strategic significance of solar energy development in Algeria. In order to assess the performance of photovoltaic systems in harsh desert environments, a case study of a photovoltaic station in the city of In-Salah is presented. This case study examines the station's location, technical features, and the local climate, which is characterized by high rates of solar radiation and severe drought. In the PVsyst simulation technique, the system configuration, input parameters, and performance modelling assumptions are then thoroughly discussed. Next, the study examines key performance indicators, including energy production, system losses, efficiency, and performance ratio. Following that, a comparative analysis is conducted with similar PV plants in different places. Following the study, a summary of the main findings is presented, highlighting insights into system reliability and performance optimization in desert environments. These are the study organization's basic outlines: Before characterizing the in Salah PV plant in detail, it first

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examines the larger framework of Algeria's adoption of renewable energy. The model assumptions and simulation methodology are then thoroughly explained, followed by an examination of the simulation's output. Reflections on system performance and suggestions for related future projects are presented after the comparative benchmarking presentation. The following list of contributions, however, includes the main contribution of this research:

- A full-scale performance assessment of a 5 MW grid-connected PV system operating under extreme desert conditions.
- Integration of precise, location-specific climate data into the PVsyst simulation to enhance model accuracy and reliability.
- Identification and quantification of principal loss factors, such as thermal degradation, inverter inefficiencies, and mismatch losses.
- Comparative benchmarking with national and international PV systems to contextualize performance and highlight efficiency gaps.
- Offering a practical and replicable methodology for evaluating and optimizing photovoltaic plants in hyper-arid climates.

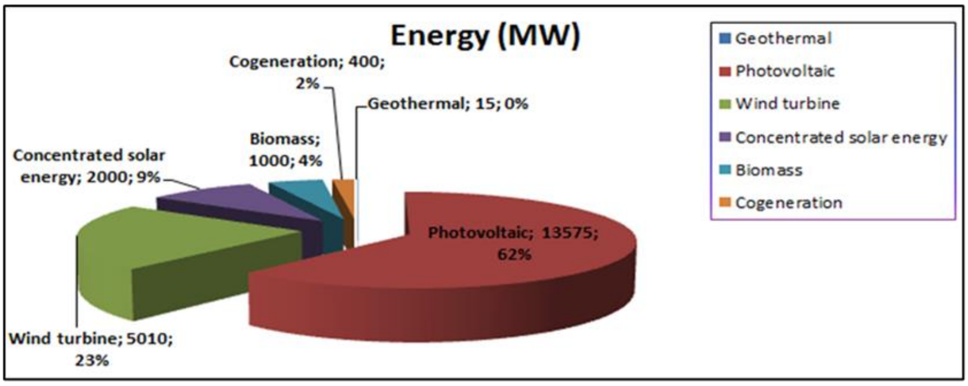


**Figure 1 The National Renewable Energy Program in Algeria for 2030. [21].**

## 2. Solar Plant and Climate Overview of In-Salah

### *2.1 Technical Description of the PV Plant*

The SKTM solar power station is situated in the southern Algerian province of In Salah (coordinates: 27°10'54" N, 2°30'17" E), in the center of the Sahara Desert. This area is renowned for its year-round sunshine and high levels of solar radiation. The plant, which was officially put into service on February 11, 2016, has a 5-megawatt (MW) installed capacity and occupies approximately 10 hectares of land. By encouraging the diversification of energy sources, bolstering the country's electrical system stability, and minimizing environmental impact, this facility strategically advances Algeria's National Program for Renewable Energies. To ensure effective energy conversion and grid integration, the facility is divided into five

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subfields, comprising a total of 20,460 solar panels and several electrical transformers. Utilizing the region's vast solar potential, SKTM helps Algeria move towards a more environmentally conscious and sustainable energy future, while also reducing greenhouse gas emissions and meeting local energy needs (Figure 2a).

The photovoltaic station includes an advanced weather monitoring system with precise sensors for temperature, humidity, wind speed, and solar irradiance. It operates wirelessly in real time, powered by independent PV or battery units, ensuring reliability in desert conditions. Data are sent to a central unit for performance analysis and maintenance optimization (Figure 2b).


**Figure 2. (a) The photovoltaic station under study, (b) the climate data monitoring unit.**

The YL245P-29b polycrystalline photovoltaic modules installed in the solar power plant in Salah exhibit exceptional performance efficiency in the face of extreme desert conditions, such as high temperatures and dust accumulation. It was chosen due to its reliable and consistent performance, making it the ideal choice for striking a balance between technical excellence and long-term operating costs. These panels are designed to achieve an efficiency of up to 15.4% and a power tolerance of ±3%, ensuring consistent performance despite small production tolerances. With its corrosion-resistant structure and its ability to operate at 1000 V, it is well-suited to desert conditions, especially with its 25-year factory warranty.

***2.2 Climatic Characteristics and Solar Resource Analysis***

In Salah has a hyper-arid desert climate with minimal rainfall, frequent sandstorms, and summer temperatures up to 50 °C, while the average monthly temperature ranges between 15.5 °C and 39 °C.

Solar radiation varies seasonally, reaching its maximum in March for both horizontal and in-plane irradiation (Figure 3a). For PV panels tilted at 28°, the global horizontal irradiation peaks

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in May (243.28 kWh/m²) and is lowest in January (142.16 kWh/m²). The in-plane irradiation also reaches its maximum in March (243.83 kWh/m²) and its minimum in January (203.85 kWh/m²) (Figure 3b).

The diffuse-to-global irradiation ratio ranges from 0.25 in January to 0.3 in October (Figure 3c), while in-plane irradiation, which directly impacts panel performance, peaks at 230.9 kWh/m² in March and drops to 197.9 kWh/m² in November (Figure 3d).

These climatic and radiative conditions make In Salah an optimal location for large-scale solar power generation, supporting Algeria's renewable energy strategy.

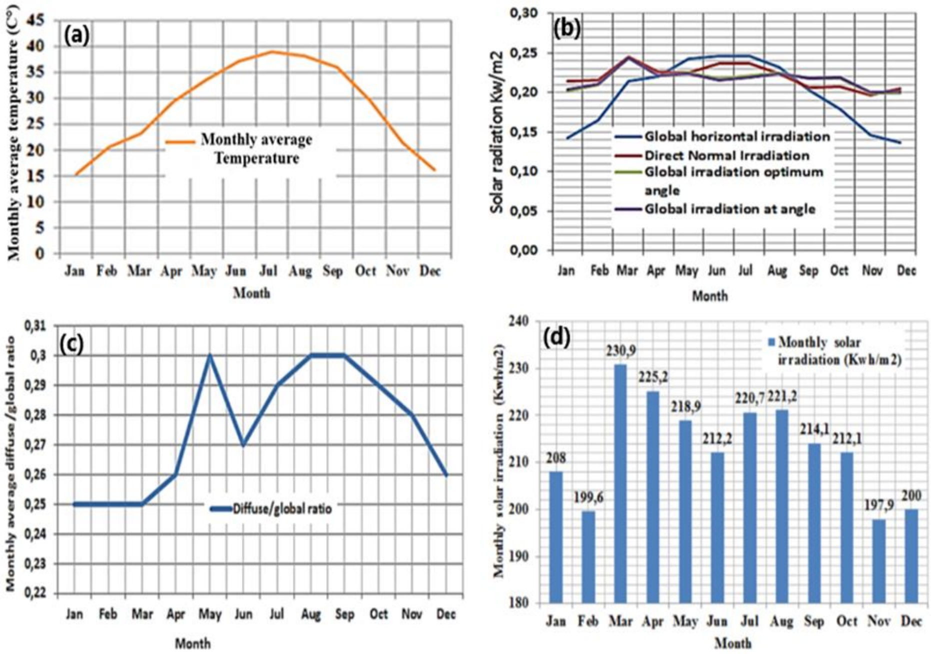


**Figure 3: (a) Monthly average temperature, (b) Different irradiations around the station, (c) The monthly average diffuses to global irradiation ratio, (d) Monthly in-plane irradiation for fixed-angle panels**

The performance of photovoltaic (PV) systems is significantly impacted by the climate of In-Salah, which is situated in the Algerian Sahara. One of the most notable desert regions in Algeria is the In-Salah region, characterized by a dry environment with high solar radiation, minimal precipitation, and significant temperature fluctuations between day and night. Desert environments are a technical challenge that limits the long-term sustainability and efficiency of PV systems. The region is one of the richest in solar radiation in the country, with an annual average of approximately 2,200 kWh/m² and 9.4 hours of sunshine per day, according to 2024 data, making it an ideal location for solar energy applications.

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While the desert environment is ideal for solar energy, it still presents technical challenges, including high temperatures, dust, and operational fluctuations, which necessitate effective design and operational solutions to ensure stability and efficiency.

Thermal stresses are one of the most prominent problems, as high temperatures in summer –, which may exceed 45 °C –, lead to the expansion of panel components and the system in general, while a sharp drop in temperatures at night leads to their contraction, causing recurring stresses that affect the operational life of the panels or for the entire station. Significant solar radiation also causes PV modules to overheat, resulting in a decrease in their efficiency, particularly in the absence of adequate ventilation or cooling systems. [21], [22]

Sandstorms and dust accumulation complicate the operation of the photovoltaic system, reducing incident solar radiation on the panels and resulting in production losses. Therefore, these conditions necessitate regular maintenance and cleaning, particularly in large plants such as the 5 MW plant under study. To obtain accurate results in the simulation using the PVsyst software, its settings were adjusted based on accurate microclimatic data, including temperatures, solar radiation, and sunshine period, to ensure that the results corresponded to the reality of performance in extreme desert conditions [23], [24]. The average daily global solar radiation in the research area ranges between 16.5 and 26.4 megajoules per square meter per day, as shown in Figure 4.

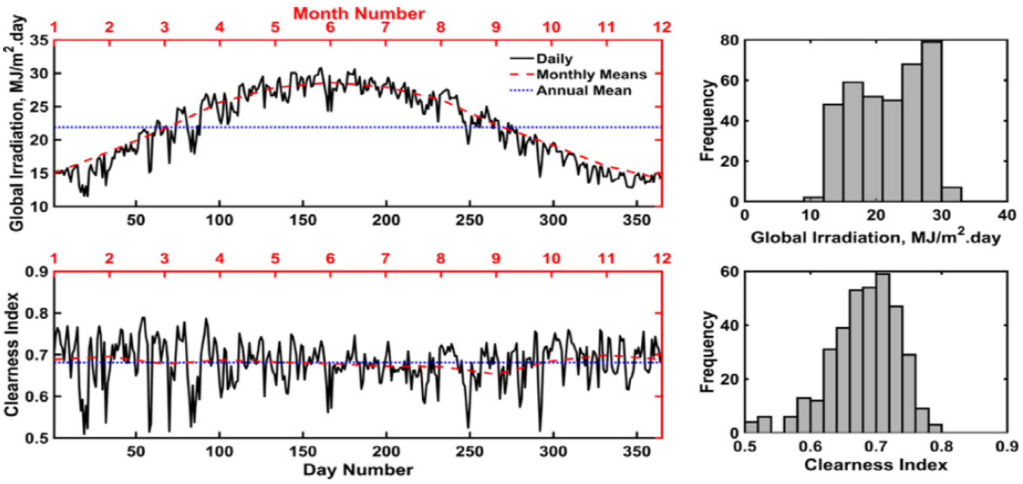


**Figure 4. Monthly distribution of solar radiation and clarity index in the In Salah area.**

The sky clarity index (Kt) ranges between 0.48 and 0.66, and the standard deviation of solar radiation is estimated to be between 0.07 and 0.11, reflecting an apparent annual variation and confirming the suitability of the climatic conditions in the region for solar energy use [25-26].

The polynomial distribution of solar radiation exhibits a clear seasonal pattern, with values increasing in spring and summer and then gradually decreasing in winter. As for the beta

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distribution of the sky clarity index (Kt), it reflects its influence on dust and cloud changes, exhibiting greater dispersion during transitional periods and noticeable stability during the dry season. These characteristics aid in selecting the most suitable model to accurately estimate radiation and enhance the efficiency of photovoltaic modeling [25], [27].

## 3. Modeling of PVSYST Simulation

PVsyst is an advanced simulation software that accurately evaluates solar system performance using design, climate, and shading data. It provides detailed reports on power output, PR, and system losses, with a user-friendly interface that simplifies analysis and enhances result reliability—making it essential for engineers and researchers optimizing solar projects [19-20].

The grid-connected PV system uses polycrystalline silicon (Si-poly) cells for their high efficiency and cost-effectiveness in large projects. A PVsyst simulation model was developed, incorporating the site's technical and environmental conditions. Three major interrelated units make up this system:

The system consists of three main units: PV modules that convert solar radiation into electricity, inverters that transform DC to grid-compatible AC, and a network interface that ensures safe and efficient power delivery to the grid.

Figure (5) presents the methodological framework of the simulation as a flowchart showing the sequence from data input to results analysis. It summarizes the PVsyst approach in system design, performance modeling, loss evaluation, and power estimation, including site characterization, capacity calculation, component selection, and validation with real climatic and operational data [28], [29], [30], [31].

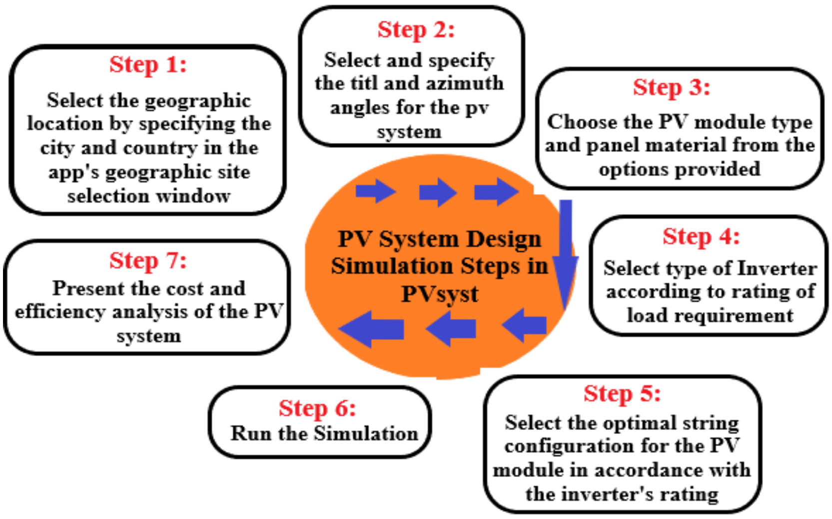


**Figure 5. Steps to simulate a photovoltaic system with PVsyst software**

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The International Energy Agency (IEA) established benchmark indicators to assess the efficiency and reliability of grid-connected PV systems, enabling consistent comparisons across various designs and locations. These indicators help identify performance gaps and enhance system efficiency. Accordingly, this study applies these standard indicators to evaluate energy output, losses, and overall efficiency using real climatic data to improve reliability and operational performance [32-33].

The solar system yield (AY) represents the DC power produced relative to the nominal power under standard test conditions, as shown in Equation (1). The amount of EDC is calculated using the relationship (2). Where, VDC is constant voltage, IDC is DC current and t is the operating time.[34], [35].

$$Y_a = \frac{E_{DC}}{P_{PV(STC)}} \tag{1}$$

$$E_{DC} = V_{DC} * I_{DC} * t \tag{2}$$

The reference yield (Reference Yield – RY) represents the amount of energy expected from the system if it operates at its nominal efficiency under standard test conditions (STC). It is calculated in kWh/m²/day by dividing the total solar radiation incident on the photovoltaic surface (Ht) by the reference value G0 = 1000 W/m² [17].

$$Y_r = \frac{H_t}{G_0} \tag{3}$$

While the final system return (Final Yield – Yf) expresses the amount of energy delivered to the grid, whether daily, monthly or annually. It is calculated by comparing the generated power (AC) with the nominal power of the matrix, according to equation (4) [36-37].

$$Y_f = \frac{E_{AC}}{P_{PV(STC)}} \tag{4}$$

Finally, the Performance Ratio – PR is one of the most important metrics for evaluating the overall efficiency of a PV system. It shows the overall losses due to thermal, electrical, and environmental factors, by comparing the actual yield with the reference yield. The relationship is given as follows [38], [39], [40], [41]:

$$PR = \frac{Y_f}{Y_r} = \frac{Egrid}{GlInc} \tag{5}$$

## 4. Results and discussions

This study evaluates the operational performance of a 5 MW grid-connected PV plant using the PVsyst software, focusing on energy production efficiency under the desert climate of Ain Salah. The analysis considers key indicators such as the performance ratio (PR), specific yield, and annual energy output. It also examines major system losses—thermal, inverter, wiring, and

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environmental. Together, these parameters assess the plant's feasibility, efficiency, and reliability.

Figure (6) illustrates the plant's configuration and the energy transfer path from panels to the electrical grid.

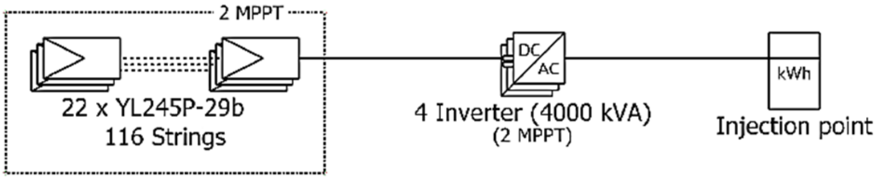


**Figure 6 Schematic diagram of the grid-connected photovoltaic station under study**

The orientation phase defines the tilt and azimuth angles of the PV panels. In this study, the optimal configuration was a 27° tilt and 0° azimuth (true south), maximizing annual solar energy capture, Figure 7. Although PVsyst allows sun-tracking modeling, a fixed-tilt system was adopted due to maintenance and cost constraints typical of desert sites. Subsequent steps involved defining the field layout and electrical parameters—including module arrangement, inverter sizing, and connection topology—illustrated in Figure 8.

The solar path diagram for Salah, southern Algeria, is shown in Figure 9, which offers information on the geometry of the sun and how it varies with the seasons. With the shortest day of the year, December 21st, providing almost 10.5 hours of daylight, and the longest day, June 21st, offering over 13.5 hours, the diagram illustrates how daylight hours vary throughout the year. Important details regarding dawn and sunset periods as well as the sun's azimuthal advancement during the day—which usually ranges from 90° (east) to 270° (west)—are also included in the solar path chart. The axial tilt of the Earth causes these patterns to change every month, which is crucial for determining seasonal energy production and optimizing panel orientation.

The 5 MWp PV system demonstrated excellent performance under desert conditions, producing 7,603,339 kWh annually with a performance ratio (PR) of 81.7%. As shown in Table 1, the global horizontal irradiance (GHI) reached 1,996 kWh/m², and the irradiance on the tilted plane was 1,785.1 kWh/m². The system achieved 7.6 GWh DC output and delivered 7.51 GWh AC to the grid, with overall system efficiency of 12.52% and PV array efficiency of 12.67%.

A breakdown of energy performance parameters, normalized by installed capacity per day (kWh/kWp/day), is shown in Figure 10a, facilitating comparisons between systems of various sizes. System losses (Ls), which take into consideration inverter losses, wire losses, and other balance-of-system inefficiencies, were computed at 0.11 kWh/kWp/day. In contrast, collection losses (Lc), which comprise optical, thermal, and mismatch losses, were measured at 0.43

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kWh/kWp/day. The system's high daily yield was confirmed by the estimated sound energy delivered (Yf), which was 4.62 kWh/kWp/day.

The simulation assessed grid-injected energy, as well as performance stability, to further quantify energy delivery. Following DC/AC conversion, the system successfully supplied 7,511,836 kWh to the grid annually, indicating excellent energy retention with minimal losses.

**Tabl.1 System balance and primary outcomes derived from PVSyst**

| | Glib.Hor KW/m$^2$ | Diff.Hor KW/m$^2$ | T. Amb C° | Glob.Inc KW/m$^2$ | Glob.Eff KW/m$^2$ | E. Array KWh | E. Grid KWh | Eff. ArrayR (%) | Eff SysR (%) |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 158,3 | 85,07 | 26,37 | 173,8 | 171 | 717028 | 708277 | 14,34056 | 14,16554 |
| Feb | 152,4 | 83,8 | 26,97 | 156,7 | 153,9 | 642555 | 634740 | 12,8511 | 12,6948 |
| Mar | 180,6 | 89,27 | 27,3 | 169,8 | 165,8 | 698377 | 690037 | 13,96754 | 13,80074 |
| Apr | 181,4 | 76,84 | 26,74 | 152,1 | 147,2 | 627838 | 620318 | 12,55676 | 12,40636 |
| May | 162,1 | 81,56 | 26,39 | 124 | 118,1 | 514674 | 508337 | 10,29348 | 10,16674 |
| Jun | 149,7 | 71,26 | 24,56 | 109,4 | 103,5 | 457276 | 451557 | 9,14552 | 9,03114 |
| Jul | 163,7 | 74,32 | 24,2 | 120,9 | 114,8 | 507278 | 501061 | 10,14556 | 10,02122 |
| Aug | 173,2 | 80,22 | 23,65 | 139,5 | 134,1 | 588835 | 581819 | 11,7767 | 11,63638 |
| Sept | 169,9 | 71,6 | 24 | 153,1 | 148,7 | 639701 | 631943 | 12,79402 | 12,63886 |
| Octo | 176,3 | 73,67 | 25,41 | 176,2 | 172,3 | 725167 | 716531 | 14,50334 | 14,33062 |
| Nov | 173,5 | 66,36 | 26,05 | 191,5 | 188,2 | 780682 | 771683 | 15,61364 | 15,43366 |
| Dec | 152,5 | 83,78 | 26,6 | 170,4 | 167,5 | 703928 | 695533 | 14,07856 | 13,91066 |
| Year | 1993,6 | 937,75 | 25,68 | 1837,4 | 1785,1 | 7603339 | 7511836 | 12,672231 | 12,5197267 |

On average, the specific energy injection was 4.17 kWh per kWp per day and 125.19 kWh per kWp per month. Table 2 shows that seasonal irradiance changes resulted in the maximum monthly energy input in March (690,037 kWh) and the lowest in July (451,557 kWh). Figure (10b), which shows monthly energy delivery trends and aids in load balancing and grid integration planning, provides a visual representation of this distribution.

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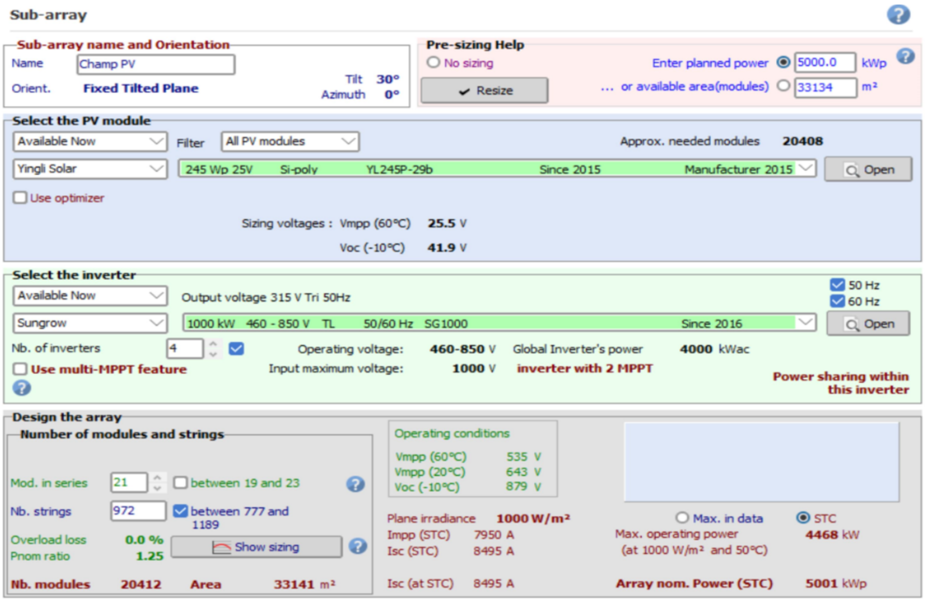


**Figure 7 Layout and key configurations of the project page**

**Table.2 Energy fed into the grid & PR: PV (5000KWp)**

| | EGrid KWh | EmGrid (KWh/KWp) | EdGrid (KWh/KWp) | PR Ration (%) |
|---|---|---|---|---|
| Jan | 708277 | 141,65 | 4,72 | 81,5 |
| Feb | 634740 | 127 | 4,23 | 81 |
| Mar | 690037 | 138 | 4,6 | 81,3 |
| Apr | 620318 | 124 | 4,13 | 81,5 |
| May | 508337 | 101,67 | 3,4 | 82 |
| Jun | 451557 | 90,3 | 3,01 | 82,5 |
| Jul | 501061 | 100,2 | 3,34 | 82,8 |
| Aug | 581819 | 116,36 | 3,87 | 83,4 |
| Sep | 631943 | 126,4 | 4,2 | 82,5 |
| Octo | 716531 | 143,3 | 4,8 | 81,3 |
| Nov | 771683 | 154,3 | 5,14 | 80,6 |
| Dec | 695533 | 139,1 | 4,6 | 81,6 |
| Year | 7511836 | 125,19 | 4,17 | 81,7 |

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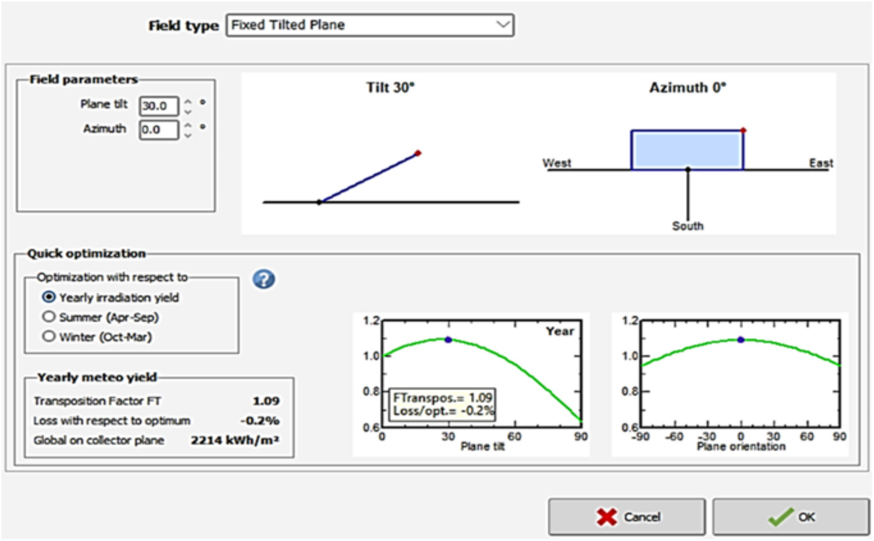


**Figure 8 Page simulating Solar panel orientation**

Lastly, the plant's total efficiency profile is depicted in Figure 11, which shows an average yearly performance ratio of 81.7%. Additionally, the chart shows minor monthly performance differences that are ascribed to environmental factors, including temperature swings, dust buildup, and variations in the sun's angle throughout the year. These observations validate the plant's suitability for deployment in arid settings such as Salah by confirming that it produces electricity consistently and dependably throughout the year.

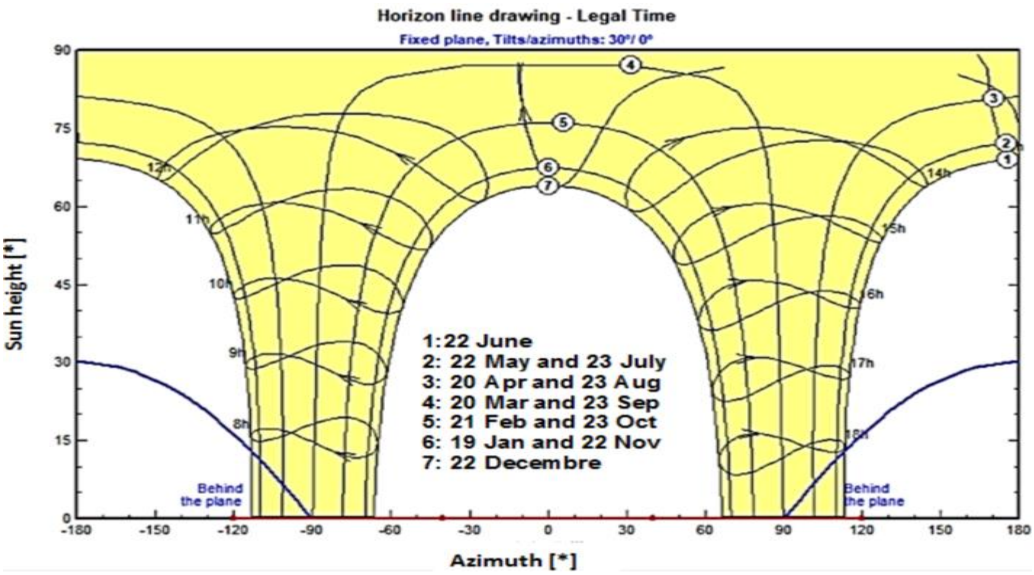


**Figure 9 The sun path at the In Salah solar power plant**

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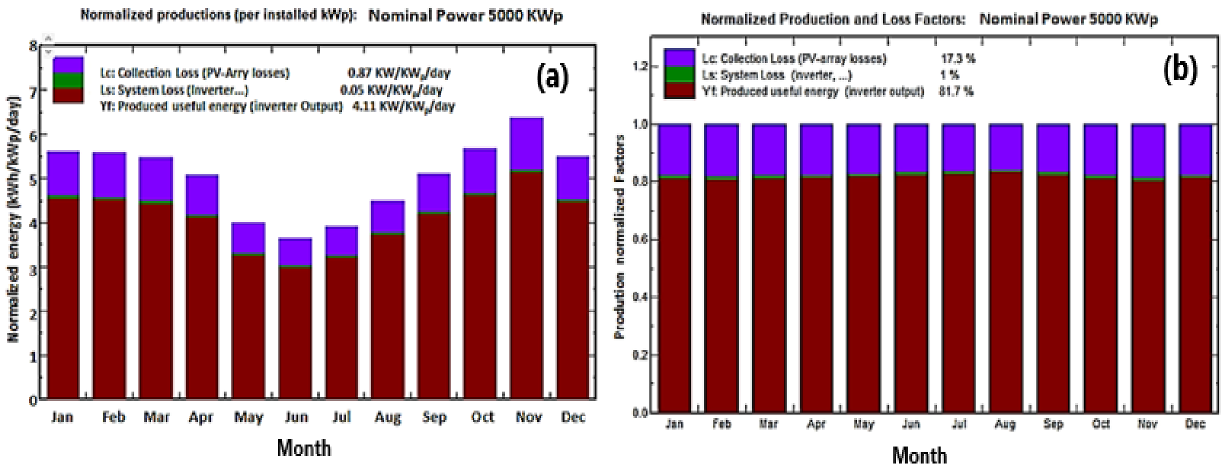


**Figure 10: (a) Normalized energy productions per installed KWp, (b) Normalized productions and Loss Factors**

Figure (12) illustrates the correlation between available solar energy (kWh/day) and global incident irradiation on the collector plane (kWh/m²/day), commonly represented through daily input/output diagrams. In PVsyst, this diagram helps visualize the relationship between daily irradiation and the energy generated by the solar plant, offering insights into system performance. Ideally, the plot follows a near-linear trend, with slight deviations at high irradiance due to temperature effects. Larger deviations may indicate system overload.

Figure (13a) presents the system output power distribution, showing how solar energy (kWh) relates to available power (kW) in 50 kW intervals (bins). It reflects how energy is distributed across power levels during simulation, aiding in understanding the behavior of power output over time.

Figure (13b) shows the monthly energy injected into the grid, providing a clear overview of how energy production varies throughout the year and helping assess the plant’s long-term performance.

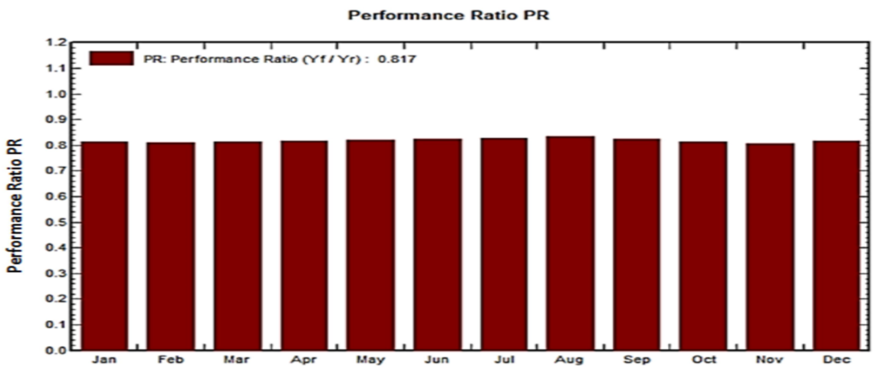


**Figure 11 Performance Ratio**

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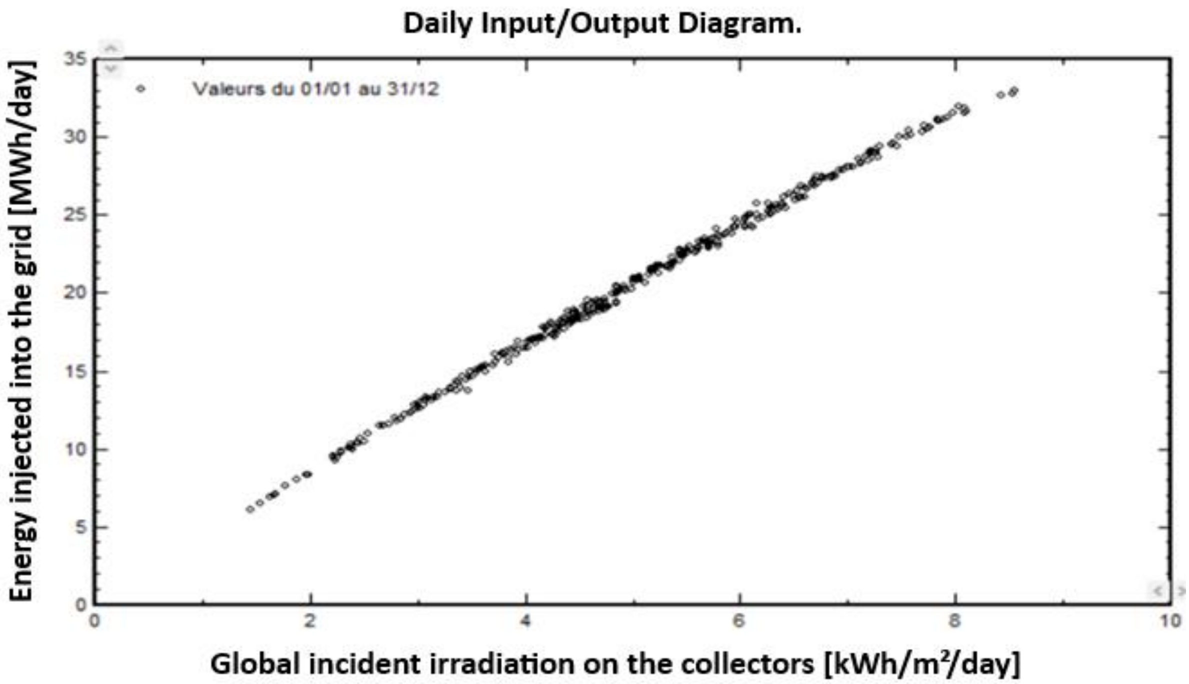


**Figure 12. Daily input/output diagram of 5 MW module**

The arrow loss diagram, Figure 14, illustrates the key energy losses throughout the PV system. Starting with a global horizontal irradiance of 1930 kWh/m², only 1857 kWh/m² reaches the collector, resulting in a loss of 3.8%. The PV array, which boasts an efficiency of 15.3% under standard test conditions (STC), generates a nominal energy output of 8448 kWh; however, the effective energy at the maximum power point (MPP) decreases to 7804 kWh. Energy losses comprise 7.6% attributed to temperature, 2% from light damage, 2.1% from mismatches, and 1% from ohmic losses. The inverter produces 7240 kWh annually, with additional losses of 3.5% occurring during operation and 1.5% due to overload before transmitting power to the grid. The In Salah PV plant has a performance ratio of 81.7%, which is considered average compared to other solar plants, as shown in Table 3. This ratio is lower than that of Algerian sites such as Sidi-bel-Abbés at 88.3% and Saida at 85.52%, but higher than Adrar at 73.68% and 74.36%, as well as M'Sila at 71.59%. Globally, performance ratios range from 85.4% in Malaysia to 70–80% in Abu Dhabi, with Turkey at 81.15% exhibiting similar results. These variations can be attributed to factors such as cell technology, tilt angle, and climate.

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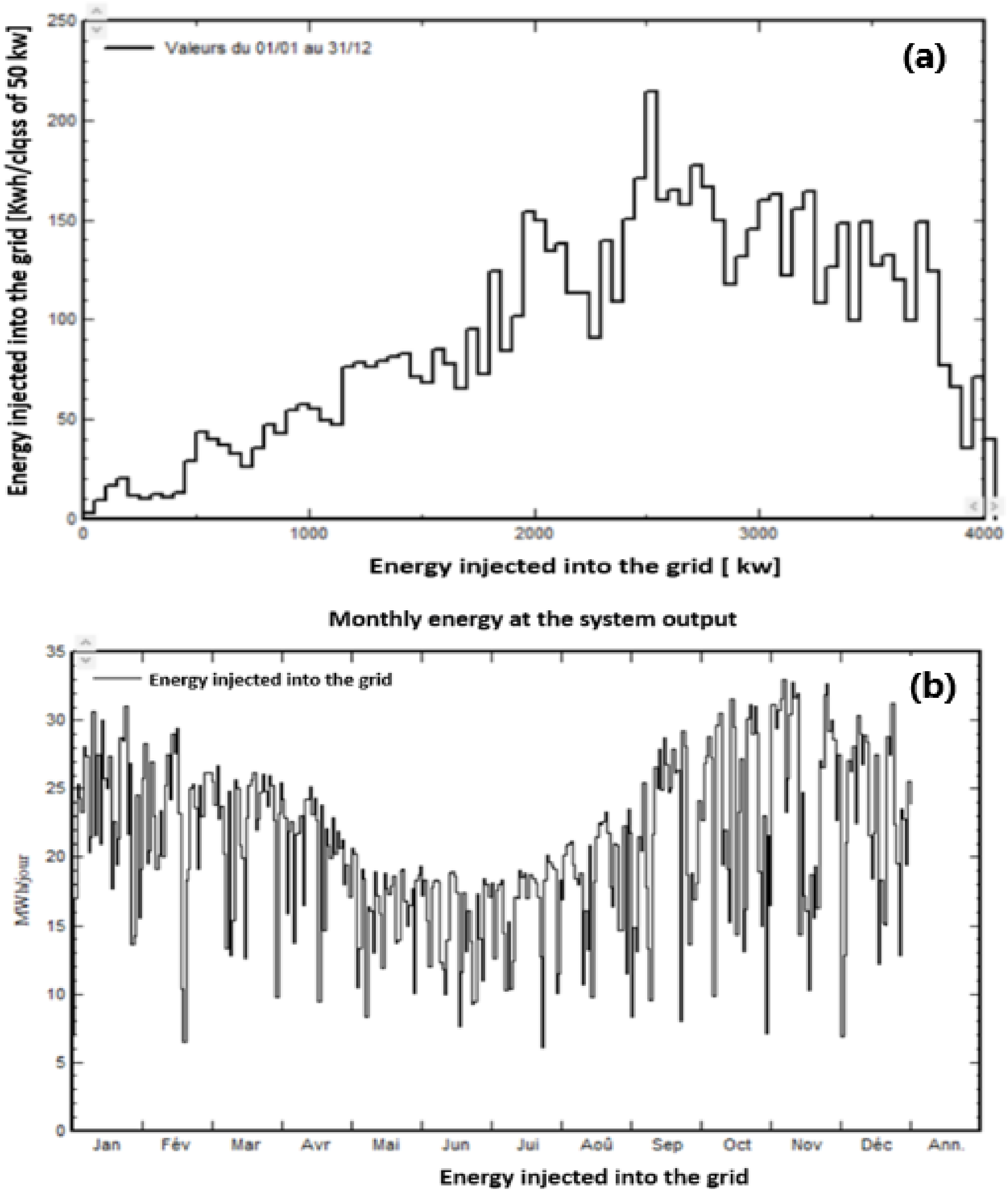


**Figure 13. (a) System output power distribution, (b) Energy injected into the grid of 5 MW module.**

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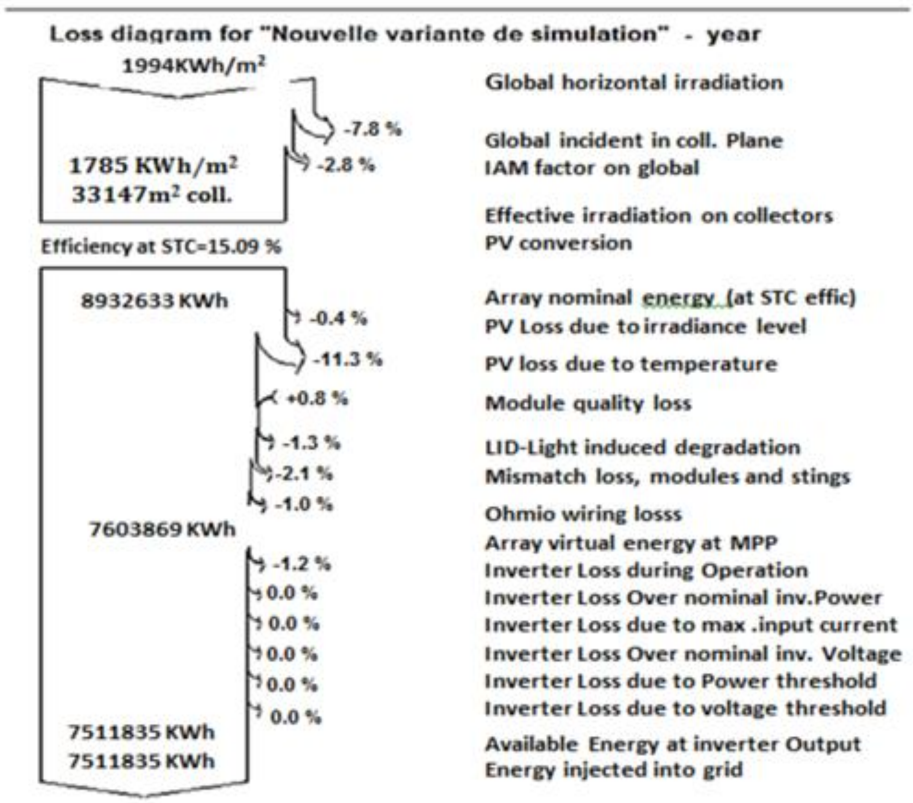


**Figure 14 Power loss diagram of the 5 MWp grid-tied photovoltaic system**

**Tble.3 Performance Ratio (PR) of solar photovoltaic plants across different locations**

| Place | PV (MWp) | PV Technology | Final Yield | PR (%) | Ref. |
|---|---|---|---|---|---|
| In Salah, Algeria | 5 | Si-Poly | 4,11 | 81,7 | Present Study |
| Sidi-Bel-Abbès, Algeria | 12 | Si-Poly | 4,15 | 83,01 | [37] |
| Adrar, Algeria | 6 | Si-Poly | 5,15 | 73,68 | [38] |
| Adrar, Algeria | 20 | Si-Poly | 4,98 | 74,36 | [39] |
| Saida, Algeria | 30 | Si-Poly | 4,9 | 85,52 | [40] |
| El Bayadh, Algeria | 23,9 | Si-Poly | 4,95 | 82,02 | [41] |
| Sidi-bel-Abbés, Algeria | 60 | Si-Poly | 4,68 | 88,3 | [37] |
| Malaysia (rooftop PV) | 0.2325 | Si- mono | --- | 85,4 | [42] |
| M’Sila, Algeria | 20 | Si-Poly | 3.99/5.897 | 71,59 | [43] |
| Turkey | 2,13 | Si-Poly | 4,53 | 81,15 | [44] |
| Abu Dhabi (rooftop PV) | 0,2157 | Si- mono | 3,63 | 70 | [45] |
| | 0,1144 | Si-Poly | 4,16 | 80 | |
| | 0,994 | Si- mono | 3,94 | --- | |

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## 5. Conclusions

This study emphasises an exceptional photovoltaic power plant located in the southernmost region of Algeria in pursuit of clean and efficient energy solutions. The study utilises PVsyst simulation software to evaluate the operational efficiency of a 5-MW grid-connected solar power facility, which produces an annual energy output of 7,603,339 kWh. The system functions efficiently in adverse weather conditions, achieving a performance ratio of 81.7%.

The analysis identifies the primary system losses resulting from thermal effects, inverter inefficiencies, and module discrepancies. It evaluates the plant's performance in comparison to analogous national and international photovoltaic projects, highlighting the influence of solar module technology, tilt angle, and regional climate on energy output. These insights are essential for optimising photovoltaic system designs, improving outputs, and ensuring long-term cost-effectiveness and sustainability in solar energy implementations.

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