

Evaluating Performance Decline and Investigating Root Causes for a Solar Power Plant in Southern Algeria

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Article Info	ABSTRACT
Article history: Received , 24/04/2025 Revised , 24/05/2025 Accepted , 11/06/2025	This study evaluated the performance of a grid-connected photovoltaic (PV) system in the Zaouit Kounta desert region (Adrar), analyzing energy production variations and the influence of local meteorological conditions. Meteorological and electrical data were collected throughout 2021, following International Electrotechnical Commission (IEC) standards. Performance metrics, including final yield, reference yield, performance ratio, capacity factor, and total system losses, were calculated to assess system efficiency. The PV system delivered a total of 10,305.4245 MWh to the grid over the year. Monthly average reference yields ranged from 4.1 to 7.1 hours per day, while final yields varied between 6.0 and 45.39 hours per day. The system demonstrated an annual average daily performance ratio of 70.35%, a capacity factor of 19.63%, and total losses of 1.95 hours per day. This comprehensive analysis provides valuable insights into the performance of a large-scale PV system in desert conditions, contributing to the optimization of solar energy utilization in similar environments
Keywords: PV system Grid-connected Final yield PV system efficiency Performance ratio Total losses	

I. Introduction

The global energy sector is undergoing a significant transformation, driven by the depletion of conventional energy sources and growing environmental concerns[1][2]. This shift has led to increased focus on renewable energy, with many countries, including Algeria, actively pursuing sustainable alternatives.[3]. Algeria, blessed with abundant solar resources, has embarked on an ambitious renewable energy program[3], [4]. The country has implemented numerous grid-connected photovoltaic systems across various climate zones[5], [6], aiming to diversify its energy mix and reduce reliance on fossil fuels. This study examines the performance of these systems, particularly in the challenging environment of the Sahara Desert, to better understand the factors influencing their efficiency and reliability. By analyzing these renewable energy installations, we aim to contribute valuable insights to the successful integration of sustainable energy solutions in harsh climatic conditions.

II. Letrature Review

The Sahara Desert, the world's largest hot desert, poses significant challenges for the deployment and operation of grid-connected renewable energy systems. The extreme environmental conditions, including high solar irradiation, ambient temperatures, and frequent dust storms, can significantly impact the performance and reliability of these systems[7]. Understanding the factors that influence the performance of grid-connected systems in this harsh environment is crucial for ensuring the successful integration of renewable energy into the local power grid.

II.1. High Temperature

Younce Mohammed et al.[8] found that desert environments pose the most challenging conditions for PV panel performance, with the extreme heat and dryness significantly stressing standard solar cells and affecting their long-term reliability and expected lifetime. The research notes that the major degradation mechanisms in these environments involve physical and chemical changes to the material properties of the PV components, leading to premature failure or undesirable defects. The most commonly observed failure modes include discoloration of the ethylene-vinyl acetate (EVA) encapsulant, ranging from browning to dark browning, as well as delamination above the solar cells.

II.2. Dust and dustrom

According to recent scientific studies, the efficiency and power output of photovoltaic modules can be dramatically reduced due to the accumulation of dust.

Kazem et al.[9] investigated the impact of dust on the efficiency of photovoltaic (PV) panels in desert areas. Their findings showed that the efficiency of the panels decreased by a range of 8% to 16% over a 45-day period. In a separate study conducted in Saudi Arabia, the researchers placed PV panels at a tilt of 26 degrees. Over the same 45-day period, they measured a dust concentration of 5 g/m², which resulted in a reduction of around 20% in the panels' conductivity.

Because of the observed impacts of dust on PV panel efficiency, numerous studies have aimed to develop models for predicting dust settlement and its effects on PV power output. The goal of these efforts is to enhance the performance and optimization of PV systems, especially in desert or dusty environments where dust deposition can significantly reduce the power generation capabilities of the panels.

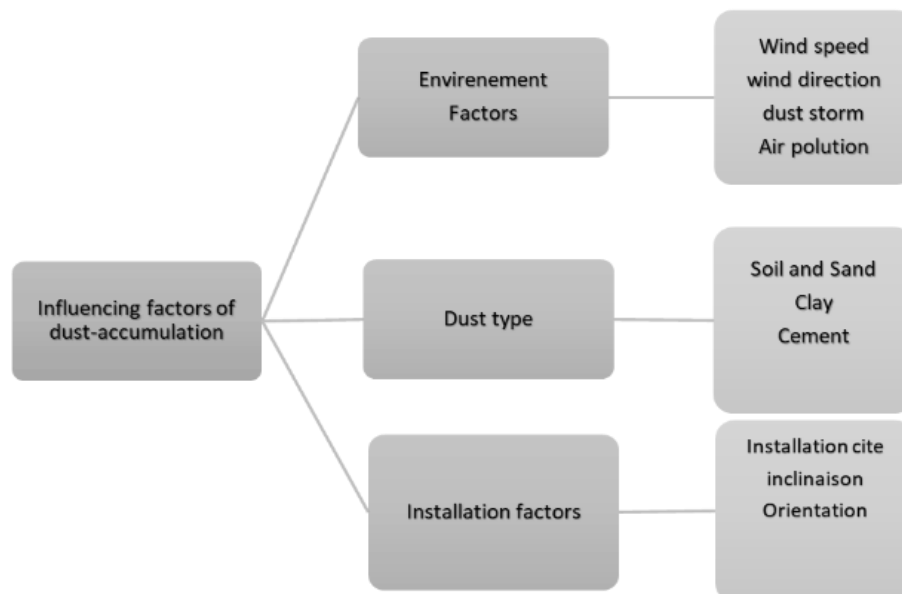


Figure 1. Factors affecting dust aggregation[10]–[12]

III. Pv Plant Description

This photovoltaic power plant covers an area of 12 hectares, with polycrystalline solar panels installed across the site. The plant is divided into six sub-fields, each with a capacity of 1 megawatt. Each sub-field is connected to two inverters, which then feed the generated power into a transformer. The transformer is then connected to the electrical grid, allowing the plant to inject the generated energy into the wider power network. Photovoltaic module specifications at standard test conditions STC are shown in the table below

Table 1. Photovoltaic module specifications at standard test conditions

Trandmark	YINGLI SOLAR
Model	YL245-29b
Cells type	polycrystalline
Power at STC (W)	245
Power at PTC (W)	215.1
Vmp: (V)	29.6
Imp: (A)	8.28
Voc (V)	37.5
Isc: (A)	8.83
Efficiency: (%)	15

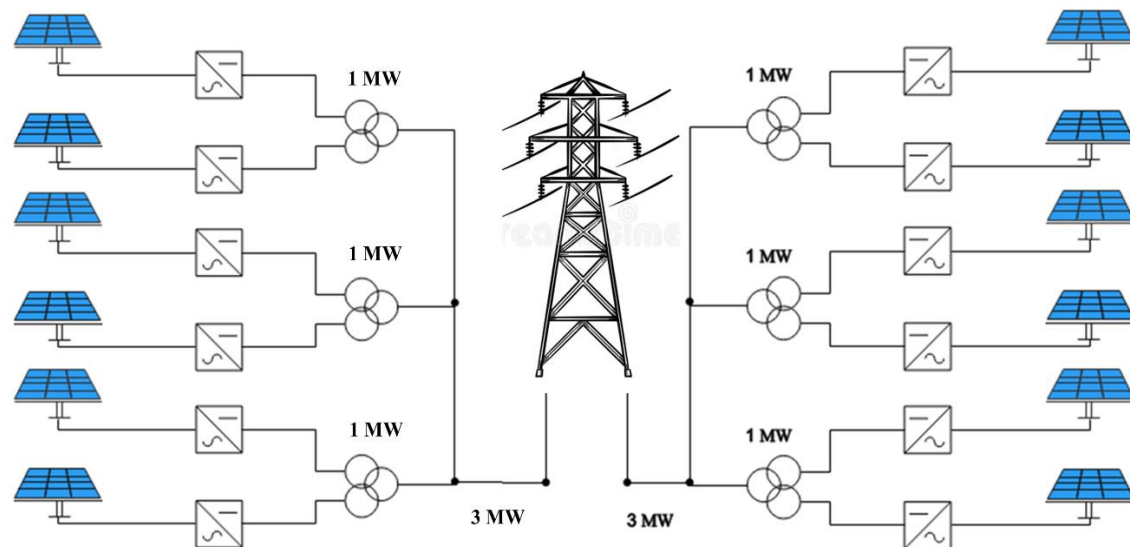


Figure 2. 6 MW Solar Power System Diagram

IV. Performance Analysis

The evaluation of the 6 MWp grid-connected photovoltaic system employs performance metrics established by the International Energy Agency (IEA) and outlined in IEC Standard 61724 (1988). These key performance indicators include array yield (YA), final yield (YF), reference yield (YR), energy loss (L), and performance ratio (PR). By utilizing these standardized parameters, the study ensures a comprehensive and internationally comparable assessment of the system's efficiency and operational characteristics under local environmental conditions. [13]-[14]

• Final yield (YF)	$Y_{F,d} = \frac{E_{AC,d}}{P_{rated}}$	(1)
	$Y_{F,m} = \frac{1}{N} \sum_{d=1}^N Y_{F,d}$	(2)
• Reference yield (YR)	$Y_{R,d} = \frac{\tau * \sum G_t}{G_{STC}}$	(3)
	$Y_{R,m} = \frac{1}{N} \sum_{d=1}^N Y_{R,d}$	(4)
• Performance ratio (PR)	$PR = \frac{Y_F}{Y_R}$	(5)
• Total energy losses (LT)	$L_T = Y_R - Y_F$	(6)
• Capacity factor (CF)	$CF_y = \frac{E_{AC,y}}{P_{PV,rated} * 8760}$	(7)
	$CF_m = \frac{E_{AC,m}}{P_{PV,rated} * 24 * N}$	(8)

V. Performance Analysis

Throughout the study period, we tracked the daily mean ambient temperature and solar irradiance on the plane of the array. Figure 3 illustrates the fluctuations in these parameters. Temperatures oscillated between a low of 17°C in January and a peak of 43°C in July, with the summer period (May to September) consistently recording higher readings than the rest of the year. The solar irradiance data revealed a comparable seasonal trend, peaking at 7.1 kWh/m² in June and dipping to 6 kWh/m² in February 2021. This synchronization of elevated temperatures and increased solar exposure during summer highlights the extreme conditions faced by the grid-tied photovoltaic (PV) system in this arid desert environment.

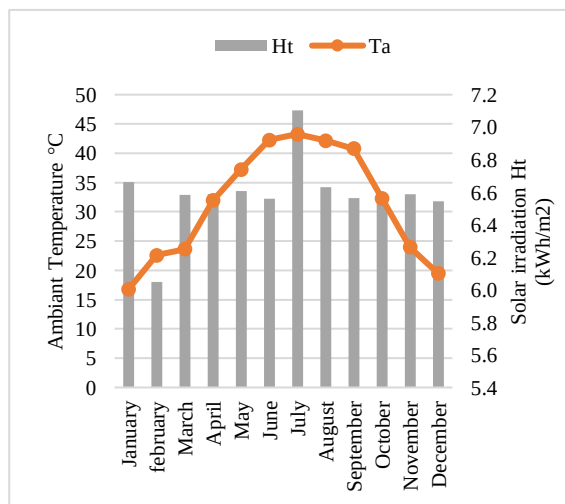


Figure 3. Monthly average ambient temperature and solar radiation

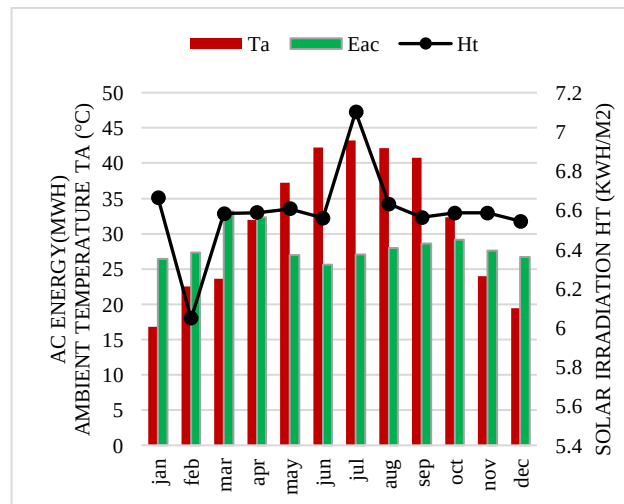


Figure 4. Monthly trends in AC energy production, ambient temperature, and solar irradiation throughout the study period.

Figure 4 presents the monthly data for three key parameters: total AC energy fed into the grid, ambient temperature, and solar irradiance on the array plane throughout the study period. The in-plane solar irradiance exhibited its peak average value of 7.1 kWh/m² in June, while the lowest reading of 6 kWh/m² was recorded in

February 2021. Interestingly, the AC energy production patterns did not directly correspond to these irradiance levels. The system generated its minimum output of 25.6 MWh in June, despite this month having the highest solar irradiance. Conversely, the maximum energy production of 33.1 MWh occurred in April, suggesting that factors beyond solar irradiance significantly influence the system's performance.

The system's performance ratio (PR) fluctuated throughout the year, peaking at 82% in April and dropping to its lowest point of 63% in June, with an annual average of 70%. Notably, the PR values were at their minimum during the warmest period from May to September, coinciding with ambient temperatures between 41°C (September) and 43°C (July). During this same timeframe, solar irradiance levels ranged from 6.5 kWh/m² in June to 7.1 kWh/m² in July. This data suggests a potential inverse relationship between high temperatures and system performance, despite the increased solar resource availability during these months.

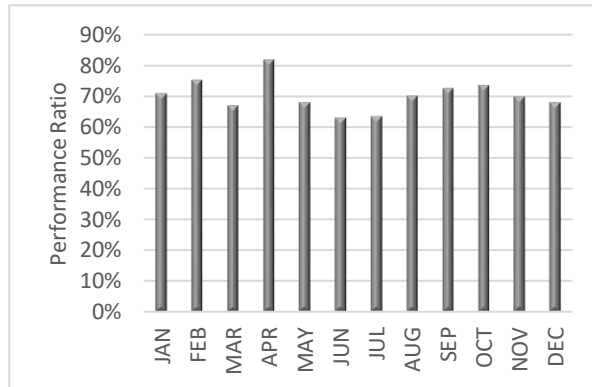


Figure 5. Performance ratio over the monitored period.

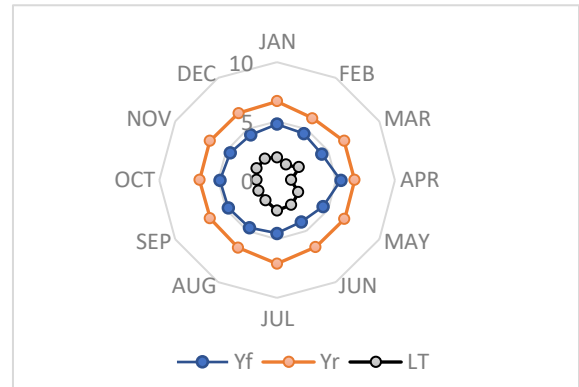


Figure 6. Monthly fluctuations in average energy yield and energy losses during the observation period.

The reference yield showed a marked increase from May to August, attributable to heightened solar irradiance and extended daylight hours. Energy losses fluctuated throughout the year, with the lowest at 1.18 hours in April and peaking at 2.59 hours in July. The warm season, particularly May through August, experienced the most significant energy losses. These reductions in efficiency can be primarily attributed to two factors: accumulation of dust on the panels and elevated ambient temperatures. The latter cause is especially impactful, as the heating of photovoltaic cells diminishes the power output capability of the modules. This pattern underscores the challenges faced by solar installations in hot, dusty environments.

The PV system's monthly and annual capacity factors are illustrated in Figure 7. Over the course of the year, the monthly capacity factor fluctuated, reaching its lowest point of 17.23% in June and peaking at 23.01% in March. When averaged across the entire year, the system achieved a capacity factor of 19.63%. These figures provide insight into the efficiency and utilization of the PV installation throughout different seasonal conditions.

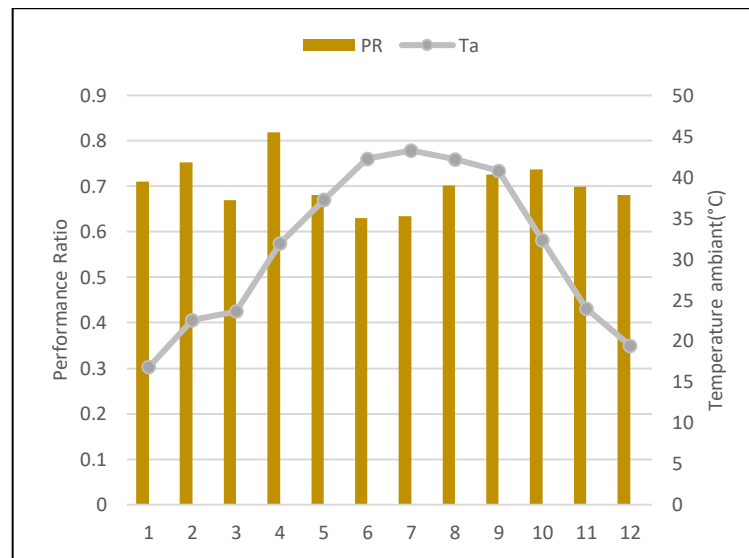


Figure 7. Monthly average capacity factor.

VI. Conclusion

This study analyzes a 6 MW photovoltaic installation in southern Algeria, focusing on key performance indicators over a year. It identifies dust accumulation, temperature fluctuations, and solar radiation variations as primary efficiency reducers. The research emphasizes the importance of understanding these factors for successful integration of renewable energy systems into local power grids, especially in harsh environments. By examining site-specific variables like solar irradiance, temperature, wind, and particulates, the study aims to improve modeling, design, and operation of renewable energy plants. This knowledge is crucial for optimizing clean energy integration, ensuring consistent electricity supply, and maintaining grid stability in challenging climates.

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