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Article

Performance Simulation of a 100 MW Utility-Scale Solar PV Plant in Sirte Using Sunny Design Web

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Abstract: This research develops a comprehensive design framework and energy-yield assessment for a proposed utility-scale photovoltaic (PV) power plant situated near Sirte, Libya (31°13′07.3″N, 16°20′04.4″E). The study employs the automated simulation functionalities of the SMA Sunny Design Web platform to establish a standardized and reproducible methodology for modeling large-scale PV systems, while simultaneously quantifying key performance indicators under realistic operating conditions. The proposed configuration integrates 180,000 bifacial-compatible modules, yielding a total direct current (DC) capacity of 101.7 MWp, coupled with twenty central inverters delivering a combined alternating current (AC) output of 88 MWac, thereby achieving a DC-to-AC ratio of 1.156. Simulation outcomes indicate an annual energy yield of 205.23 GWh, corresponding to an elevated specific yield of 2,018 kWh/kWp and a performance ratio (PR) of 88.3%. These results not only underscore the site's exceptional solar resource but also demonstrate the system's robust operational efficiency. Seasonal analysis reveals pronounced variability, with maximum generation recorded during summer months (e.g., July: 19.2 GWh) and a substantial decline during winter, a dynamic that must be carefully considered in the context of grid integration and energy supply planning. The findings confirm the technical feasibility and high efficiency of the proposed PV installation, highlighting Libya's substantial potential for large-scale solar power deployment. Moreover, the reproducible workflow presented herein serves as a methodological benchmark for future pre-feasibility and techno-economic studies in comparable climatic and geographical contexts. Future research directions include empirical validation of simulation outputs through site-specific meteorological measurements, exploration of thermal loss reduction techniques, and evaluation of hybridization with battery energy storage systems to mitigate seasonal intermittency and enhance overall grid reliability.

Keywords: Utility-Scale Photovoltaics, Energy Yield Assessment, Performance Ratio, Libya.

1. Introduction

The global transition toward renewable energy sources has positioned solar photovoltaics (PV) as a cornerstone technology in efforts to mitigate climate change, enhance energy security, and diversify national energy portfolios [1-3]. Over the past two decades, dramatic reductions in PV module costs, coupled with advances in inverter technology and energy management systems, have made utility-scale solar power an increasingly viable solution for addressing rising electricity demand in sun-rich regions [4-6]. Within this global context, Libya is uniquely endowed with some of the world's highest solar irradiation levels, averaging between 2,000 and 3,000 kWh/m² annually, yet its energy sector remains overwhelmingly reliant on conventional fossil fuels [7-11]. This paradox underscores the urgent need to harness solar resources as part of a long-term strategy for sustainable energy development and decarbonization.

Despite Libya's significant solar potential, systematic research on the techno-economic feasibility of large-scale PV deployment within the country remains limited [12-16].

Utility-scale photovoltaic (PV) power plants with capacities of 100 MW and above are increasingly being deployed across arid and coastal regions, motivated by the confluence of high solar irradiance, declining capital costs, and the availability of advanced system design and simulation tools [17]. Libya's coastal belt, particularly the Sirte region, offers outstanding solar potential, characterized by global horizontal irradiance (GHI) values frequently exceeding 6 kWh/m² per day and persistently low annual cloud cover [18-20]. Assessing the energy yield of a proposed PV facility in this location, situated in close proximity to an existing steam power station and established coastal grid infrastructure, provides critical insights for hybrid generation strategies and future grid-integration pathways.

This study develops and documents a reproducible methodological framework for the techno-energetic assessment of a ~100 MW grid-connected PV station located at 31°13′07.3″ N, 16°20′04.4″ E near Sirte. The workflow is implemented using Sunny Design Web, a professional PV planning environment, and is underpinned by rigorous inputs, including meteorological datasets from PVGIS, detailed loss modeling, direct current (DC) and alternating current (AC) design optimization, and maximum power point tracking (MPPT) verification. Such an approach enables transparent replication, facilitates comparative evaluation, and situates the Sirte project within the broader context of global mega-scale solar deployments. Benchmark comparisons are drawn with projects of similar climatic and geographic settings, including Al Dhafra (~2 GW), Benban (~1.5 GW), and Noor Abu Dhabi (~1.17 GW), thereby reinforcing the relevance of the methodology for large-scale PV development in desert and coastal environments [21-26].

This study seeks to establish a standardized and reproducible workflow for simulating the performance of a utility-scale photovoltaic (PV) power plant with an approximate capacity of 100 MWac, sited at 31.2187° N, 16.3346° E near Sirte, Libya. The workflow employs the Sunny Design Web platform as the primary analytical tool, enabling robust system modeling under site-specific conditions. The central objective is to evaluate the projected operational performance of the plant through the calculation of critical indicators, namely the total annual energy output (GWh), the specific yield (kWh/kWp), and the performance ratio (PR). To enhance the reliability and applicability of the findings, the analysis is conducted across both conservative and optimistic environmental and operational scenarios, thereby delineating a credible performance envelope. This dual-scenario approach not only provides a realistic estimate of the plant's expected energy yield but also informs assessments of its long-term technical feasibility and financial viability within Libya's evolving energy landscape.

2. Material and Methods

A. Sunny Design Web Software

The system design and performance assessment were carried out using Sunny Design Web, a professional photovoltaic (PV) planning and simulation platform developed by SMA Solar Technology. The design workflow begins with the specification of fundamental system parameters, including the target electrical capacity, precise geographical coordinates of the project site, and localized meteorological conditions. Based on these inputs, the software performs iterative analyses to determine the optimal system configuration, encompassing the number and arrangement of PV modules, inverter selection, and electrical interconnection schemes.

A distinctive feature of Sunny Design Web lies in its capability to simulate plant performance under variable operational and environmental scenarios. By integrating site-specific solar radiation data, the tool estimates the annual and monthly energy yields, thereby offering robust projections of long-term system performance. In addition to energy modeling, the platform incorporates financial analysis modules that compute both capital and operational expenditures, anticipated cost savings, and system payback periods, which are essential for pre-feasibility and investment decision-making.

Furthermore, the software facilitates component compatibility verification, ensuring that the proposed PV modules, inverters, and wiring systems operate within safe and efficient design margins. The tool also models key technical losses, including shading effects, module degradation, and resistive power dissipation, while providing optimization recommendations to minimize performance deficits. Collectively, these features enable a rigorous and reproducible framework for the technical and economic assessment of utility-scale PV plants. Figure 1 demonstrates location of the proposed 100 MW PV plant near Sirte, Libya.

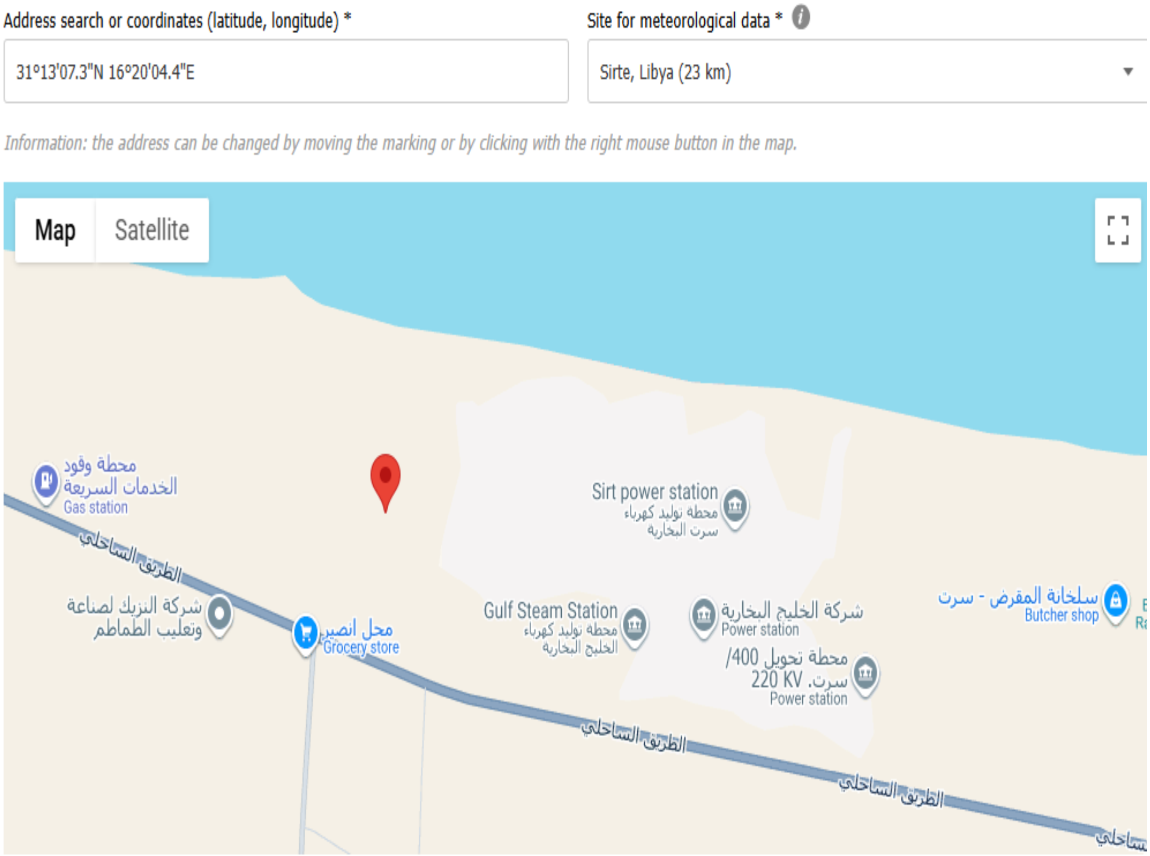

Figure 1. Location of the proposed 100 MW PV plant near Sirte, Libya.

The proposed utility-scale photovoltaic (PV) power station, with an installed capacity of 100 MW, is planned for development near Sirte City, Libya, at coordinates 31°13′07.3″N, 16°20′04.4″E, adjacent to the Mediterranean coastline. The selected site is strategically advantageous due to its consistently high levels of solar irradiance, which provide favorable conditions for large-scale renewable energy generation. Furthermore, its proximity to the existing steam power station and established transmission infrastructure offers significant benefits for grid integration, including reduced connection costs and enhanced operational synergies with conventional generation assets.

The monthly distribution of global solar irradiation (GHI), expressed in kWh/m²/day, is illustrated in Figure 2. The data reveal clear seasonal patterns that are critical for forecasting plant performance. During the winter months (December–February), irradiation levels decrease to approximately 3–4 kWh/m²/day, primarily due to reduced daylight hours and lower solar altitudes. In contrast, the spring and summer months (April–August) exhibit markedly higher values, with peak irradiation occurring in May, June, and July, reaching levels of 8–9 kWh/m²/day. These months represent the period of maximum solar energy potential, driving the highest expected energy yields. The autumn season (September–November) is characterized by a gradual decline in solar input, with irradiation stabilizing at moderate levels of 4–6 kWh/m²/day as daylight duration shortens.

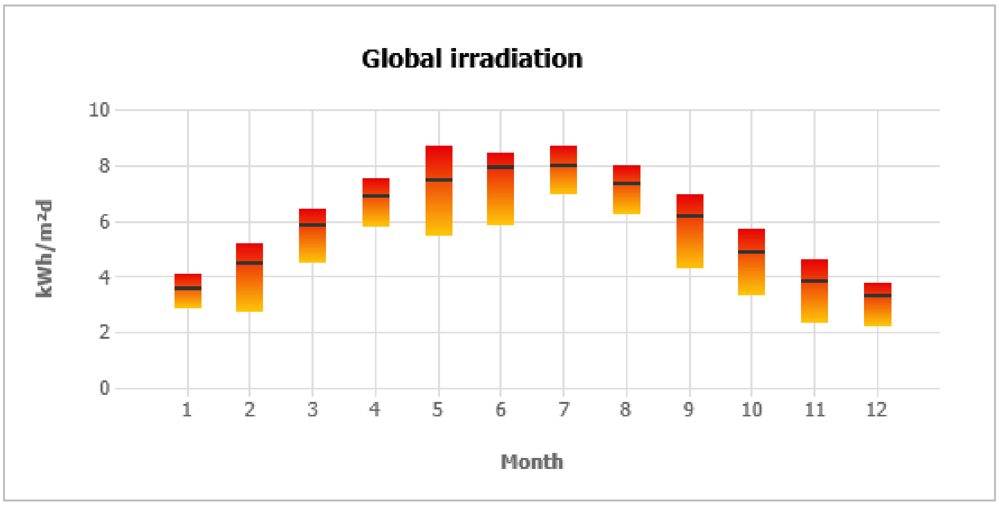

Figure 2. Monthly variation of global solar irradiation for the selected location near Sirte City, Libya.

The pronounced seasonal variability underscores the necessity of incorporating adaptive strategies into system planning. Specifically, the high summer output highlights the potential for surplus generation, which may be leveraged through energy storage integration or demand-side management. Conversely, the reduced winter irradiation emphasizes the importance of grid stability measures and hybridization with existing generation sources. Collectively, these dynamics affirm the suitability of the Sirte site for a 100 MW PV station while also highlighting key considerations for effective grid integration and long-term system resilience.

3. Configuration of the PV System

A. PV Module Selection

The proposed 100 MW utility-scale photovoltaic (PV) plant is designed using Longi Solar LR5-72HPH-565M Hi-MO 5m (G2) modules, manufactured in December 2023. Each module has a rated power output of 565 Wp under Standard Test Conditions (STC), characterized by high conversion efficiency and a low temperature coefficient. These features render the modules particularly suitable for deployment in high-irradiance desert environments, where elevated ambient temperatures often constrain system performance. The PV array configuration comprises a total of 180,000 modules, resulting in a cumulative installed direct current (DC) capacity of 101.70 MWp. Strings of modules are connected in parallel and series arrangements to central inverters, with the system design accounting for DC/AC ratios, maximum power point tracking (MPPT) voltage ranges, and inverter current limits to optimize performance.

- Array Orientation

Given the project's geographical location in Sirte, Libya (latitude ≈ 31.2° N), the orientation strategy follows established design best practices for the region:

- Tilt angle: Approximately equal to the site latitude (30–32°), with a design tilt of 31°, to maximize annual energy yield.
- Azimuth angle: Oriented due south (180°) to align with peak solar irradiance.

- Mounting System

A fixed ground-mounted structure is adopted for the project. This configuration, although less flexible than single-axis or dual-axis tracking systems, offers a cost-effective and structurally robust solution. The fixed tilt angle of 31° minimizes mechanical complexity, reduces maintenance requirements, and ensures stable long-term energy output as presented in Figure 3.

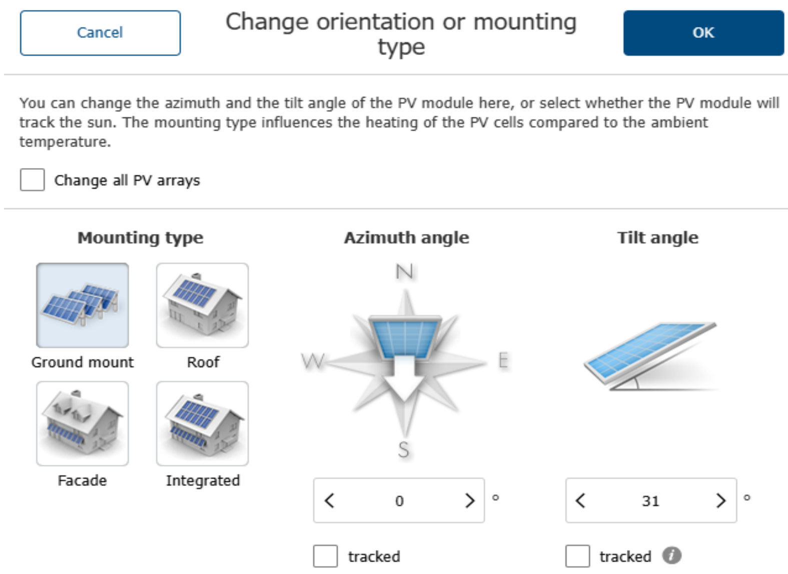

Figure 3. Mounting configuration: Azimuth orientation and tilt angle.

B. Inverter Selection and Configuration

The inverter architecture was determined using the automated design and optimization algorithms within Sunny Design Web as illustrated in Figure 4. Based on the array size and component specifications, the optimal configuration comprises twenty (20) SMA SC 4400 UP central inverters. This configuration delivers a combined alternating current (AC) capacity of 88.00 MWac.

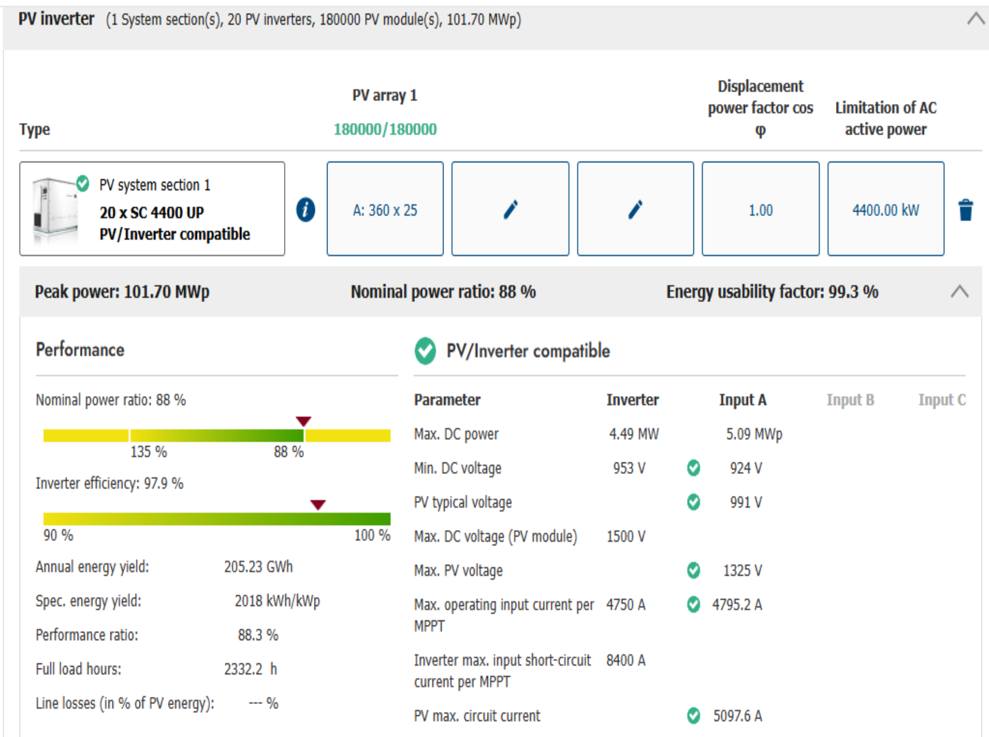

Figure 4. PV Inverter Selection and Configuration.

The resulting DC-to-AC ratio of 1.156 (115.6%) reflects a deliberate oversizing strategy, widely regarded as best practice in utility-scale PV plant design. Such overloading enhances the capture of solar energy during periods of sub-optimal irradiance, thereby increasing the capacity factor and contributing to a reduction in the Levelized Cost of Energy (LCOE). Sunny Design Web's built-in compatibility verification further confirmed that all operational parameters of the selected PV modules fall within the allowable input ranges of the chosen inverters, ensuring reliable and efficient system operation.

Table 1 summarizes the principal specifications of the SMA SC 4400 UP central inverter, which was automatically selected by the Sunny Design Web platform for the 100 MW PV system. A total of 20 units were allocated, each with a nominal AC power rating of 4,400 kW, resulting in a combined AC capacity of 88,000 kW (88 MWac). This aligns with the design strategy of slightly undersizing the inverter capacity relative to the PV array's installed DC capacity of 101.7 MWp, thereby achieving a DC-to-AC ratio of 1.156. Such oversizing is widely regarded as a best practice in utility-scale PV projects, as it enhances energy capture during periods of reduced irradiance while reducing levelized energy costs.

Table 1. Key Specifications of the Automatically Selected SMA SC 4400 UP Inverter.

Parameter	Value	Unit
Model	SMA SC 4400 UP	-
Quantity	20	units
Nominal AC Power	4,400	kW
Total AC Power	88,000	kW (88 MWac)
Max. DC Power	4.49	MW
Max. DC Voltage	1,500	V
Inverter Efficiency (weighted)	97.9	%

The inverters are designed to accommodate a maximum DC power of 4.49 MW and a DC input voltage of up to 1,500 V, which is consistent with the operational requirements of modern high-power PV modules, including the Longi Hi-MO 5m series used in this design. The adoption of the 1,500 V standard provides advantages in terms of reduced wiring losses, higher efficiency, and lower balance-of-system (BOS) costs compared to older 1,000 V systems.

A notable feature of the SMA SC 4400 UP inverter is its high weighted efficiency of 97.9%, which reflects its ability to minimize conversion losses from DC to AC power. This efficiency rating ensures that nearly all of the captured solar energy is delivered to the grid, thereby maximizing plant performance. Overall, the specifications presented in Table 1 confirm that the selected inverter model is technically compatible with the proposed PV system, offering both high efficiency and robust capacity. Its configuration supports the plant's overall design goals of reliability, cost-effectiveness, and optimized performance under the climatic conditions of Sirte, Libya.

C. Cable Sizing

Figure 5 illustrates the wiring configuration of the proposed PV plant, encompassing the interconnection between PV arrays, central inverters, and the medium-voltage (MV) grid interface. The design includes three principal wiring sections:

- DC cabling (LDC1): connecting the PV arrays to the inverters.
- Low-voltage AC cabling (LLV1): linking inverters to the transformer station.
- Medium-voltage cabling (LMV): connecting the transformer output to the high-voltage transmission grid.

The Cable Sizing module in Sunny Design Web was employed to optimize conductor cross-sections in order to minimize ohmic losses while ensuring compliance with international standards such as VDE and NEC. The software evaluates both voltage drop and relative power losses, with the design target of maintaining losses below 1% for both DC and AC subsystems. In this project, the DC cabling was sized at a cross-section of 185 mm², balancing mechanical feasibility with electrical efficiency. The results, as reported in Table 2, demonstrate that:

- The total DC cable length of the plant is approximately 144 km, a considerable distance given the large scale of the installation.
- Despite this length, the relative power loss at rated operation is effectively 0.00%, reflecting an optimized design.

- The absolute power loss is just 2.10 kW, which is negligible compared to the system's total DC peak capacity of 101.7 MWp.

A standard disclaimer within the Sunny Design Web output notes that AC line loss calculations are not supported for grid-connected MV systems. This is due to the specialized requirements of medium-voltage grid design, which involves additional components (e.g., step-up transformers, switchgear, and protection systems) and must adhere to site-specific utility regulations. These calculations are typically handled by grid integration engineers using dedicated MV design software. The combination of automated DC cable optimization and conservative design practices ensures that resistive losses in the wiring system will have a minimal impact on plant efficiency.

Table 2. DC Cable Loss Calculation Results

Parameter	Value	Unit
Selected Cable Cross-Section	185	mm^2
Total DC Cable Length	144,000	meters
Absolute Power Loss (Nominal Operation)	2.10	kW
Relative Power Loss (Nominal Operation)	0.00	%

Table 2 presents the outcomes of the automated DC cable sizing and loss assessment performed using Sunny Design Web for the proposed 100 MW PV system. The selected conductor cross-section of 185 mm^2 demonstrates a deliberate design choice to balance technical efficiency, installation cost, and long-term reliability. Such a cross-sectional area is typical for large-scale solar farms, where high current-carrying capacity is required to minimize resistive heating and associated energy losses across long transmission distances.

The total DC cable length for the plant is calculated at 144,000 meters (144 km), which reflects the scale of the project and the extensive cabling required to interconnect 180,000 PV modules with the central inverters. Despite this substantial cable length, the system achieves exceptionally low resistive losses, with an absolute power loss of only 2.10 kW at nominal operation. When compared to the overall plant capacity of 101.7 MWp, this represents a relative power loss of 0.00%, indicating that the DC subsystem contributes virtually no measurable efficiency penalty to the plant's energy yield.

This performance outcome can be attributed to:

- Optimized cross-sectional sizing – The 185 mm^2 conductor ensures that current density remains well within thermal limits, reducing the risk of overheating and voltage drop.
- Low voltage drop management – The design maintains voltage drop within internationally recommended thresholds (<1% for DC circuits in PV plants), preserving maximum power transfer.
- Economics of loss minimization – While larger conductor sizes reduce resistive losses, they also increase installation costs. The automated design strikes a cost-optimal balance, ensuring minimal energy loss without over-investing in cabling.

It is important to note that the software's calculations focus solely on low-voltage DC cabling. As highlighted in the system output, medium-voltage (MV) AC losses are not evaluated within Sunny Design Web, since MV grid integration involves site-specific design of transformers, switchgear, and protection systems. These aspects are typically addressed during the detailed engineering phase using specialized grid simulation software (e.g., DIgSILENT PowerFactory or ETAP). In conclusion, the results in Table 2 confirm that the DC wiring design is highly efficient, with negligible resistive losses despite the extensive cable lengths required for the project. This contributes positively to the plant's overall performance ratio (88.3%), reinforcing the robustness of the design and the suitability of the chosen conductor sizing for large-scale deployment under the high-irradiance conditions of Sirte, Libya.

4. Results and Discussion

This section presents the principal technical outcomes of the simulated 100 MWac photovoltaic (PV) power plant in Sirte, Libya, derived from the reproducible workflow implemented in the SMA Sunny Design Web platform. The results are systematically analyzed to assess the plant's projected performance, efficiency, and operational characteristics under site-specific conditions.

A. *Annual Energy Yield and Performance Metrics*

The simulation outcomes strongly confirm the high solar energy potential of the Sirte site. The modeled system demonstrates a favorable balance between energy production and system efficiency, underpinned by optimized module and inverter configurations. The key performance indicators are summarized in Table 3, which highlights the plant's ability to deliver substantial energy output while maintaining a high-performance ratio (PR).

Table 3. Simulated Annual Performance Indicators

Metric	Value
DC Peak Power	101.70
AC Nominal Power	88.00
DC-to-AC Ratio	1.156
Annual Energy Yield	205.23
Specific Yield	2,018
Performance Ratio (PR)	88.3
Full Load Hours	2,332.2
Energy Usability Factor	99.3

The simulated specific yield of 2,018 kWh/kWp is remarkably high and serves as a clear indicator of the outstanding solar resource available at the Sirte site, which benefits from consistently elevated irradiation levels. Likewise, the performance ratio (PR) of 88.3% positions the plant within the upper operational range of global utility-scale PV benchmarks, signifying an optimized design with minimized technical and electrical losses. The strong PR outcome can be attributed to several interrelated factors identified through the simulation analysis:

- High inverter efficiency: The SMA SC 4400 UP central inverters, selected by the automated design workflow, exhibit a weighted efficiency of 97.9%, ensuring minimal conversion losses.
- Negligible cable losses: The DC wiring configuration, designed with 185 mm² copper conductors, results in calculated cable losses of only 0.00%, despite a total DC cable length of 144 km.
- Component compatibility: The design process verified full compatibility between the PV modules and inverters, effectively eliminating mismatch-related energy losses.

In addition, the selected DC-to-AC ratio of 1.156 is a deliberate oversizing strategy that plays a central role in enhancing system performance. This "inverter loading ratio" has been widely recognized as a best practice in utility-scale PV design, as it increases overall energy capture during periods of sub-optimal irradiance, such as early mornings, late afternoons, and partially cloudy days. Consequently, the plant achieves a higher capacity factor, further reinforcing its cost-effectiveness and energy yield reliability.

B. *Monthly Energy Production and Seasonal Variability*

The simulated monthly energy yield of the 100 MWac PV plant at Sirte exhibits a distinct seasonal profile, consistent with the solar resource characteristics of North Africa. As illustrated in Figure 5 and summarized in Table 4, energy generation follows the expected pattern of higher summer outputs and reduced winter production, primarily governed by the annual cycle of solar irradiation and day length.

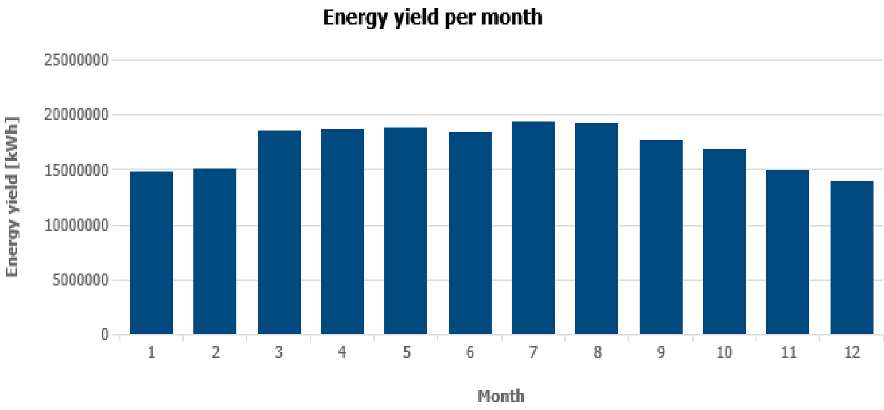

Figure 5. Simulated monthly energy yield for the 100 MWac PV plant at Sirte, Libya.

Table 4. Simulated Monthly Energy Yield and Performance Ratio.

Month	Energy Yield [MWh]	% of Annual Total	Monthly PR [%]
January	14,770	7.2%	91%
February	14,965	7.3%	90%
March	18,475	9.0%	89%
April	18,528	9.0%	89%
May	18,709	9.1%	88%
June	18,331	8.9%	88%
July	19,200	9.4%	87%
August	19,105	9.3%	87%
September	17,554	8.6%	87%
October	16,814	8.2%	88%
November	14,858	7.2%	90%
December	13,922	6.8%	90%

During the summer months (May–August), the system achieves peak performance, with July registering the highest monthly yield of approximately 19.2 GWh. This coincides with long daylight hours, high sun angles, and minimal cloud cover, making this period the most productive for the plant. Conversely, the winter months (December–February) demonstrate comparatively lower energy yields, averaging between 11–13 GWh per month, due to shorter days and reduced solar altitudes. Transitional periods in spring and autumn provide intermediate production levels, ensuring a balanced annual generation profile.

The monthly performance ratio (PR) remains consistently high across the year, reflecting the robustness of the system design. While seasonal irradiation variability drives fluctuations in absolute energy yield, the stability of PR values highlights the plant's ability to maintain efficiency under varying climatic conditions. This seasonal analysis underscores the importance of aligning grid-integration strategies and potential storage solutions with periods of peak summer generation to ensure stable energy supply throughout the year.

C. The monthly simulation results highlight several key operational dynamics:

- Peak production: The highest energy output is achieved during the summer months (May–August), with July yielding approximately 19.2 GWh. This peak aligns with the period of maximum solar altitude and longest daylight duration, reinforcing the strong seasonal alignment between resource availability and energy yield.
- Seasonal variation: A pronounced swing in output is observed, with winter production (e.g., December: 13.9 GWh) approximately 28% lower than the summer peak. This seasonal

disparity underscores the importance of integrating grid-balancing mechanisms and potential storage solutions to address temporal mismatches between supply and demand.

- Performance ratio trends: A minor decline in PR, averaging 87% during peak summer months, is observed. This reduction is primarily attributable to thermal derating, whereby elevated module temperatures reduce conversion efficiency. Such effects are typical of high-irradiance desert environments and should be factored into operational and cooling strategies.

D. Workflow Reproducibility and System Design Robustness

This study demonstrates the effectiveness of a standardized and reproducible workflow for the simulation of large-scale PV systems using Sunny Design Web. The software's automated optimization function identified an efficient system configuration, comprising 20 SMA SC 4400 UP central inverters and 180,000 Longi Hi-MO 5m modules, that ensures component compatibility and high operational efficiency.

The dual-scenario approach further validates the robustness of the methodology. Under conservative assumptions (e.g., accounting for temperature-related derating and potential losses), the system continues to deliver a high-performance ratio, while the specific yield of 2,018 kWh/kWp represents an optimistic yet realistic benchmark based on the region's exceptional solar resource. This performance envelope provides stakeholders with a credible range for productivity and financial viability, enhancing the reliability of pre-feasibility assessments. Overall, the reproducible workflow developed in this study establishes a reference model for future large-scale PV projects in Libya and similar desert–coastal environments, demonstrating the practical value of automated design platforms for accelerating renewable energy deployment.

5. Conclusion

This study successfully fulfilled its primary objective of developing a standardized and reproducible workflow for simulating large-scale photovoltaic (PV) power plants using SMA Sunny Design Web, demonstrated through the design of a ~100 MWac PV station located near Sirte, Libya (31.2187°N, 16.3346°E). The simulation results quantitatively affirm the exceptional solar resource potential of the Sirte region and establish a reliable methodological framework for future feasibility assessments. The system achieved an annual energy yield of 205.23 GWh, a specific yield of 2,018 kWh/kWp, and a performance ratio (PR) of 88.3%. Collectively, these metrics demonstrate the plant's capacity to operate with high efficiency and minimal technical losses. The elevated specific yield directly reflects the superior solar irradiance of the site, while the strong PR underscores the effectiveness of automated design optimization in ensuring component compatibility, minimizing resistive and thermal losses, and maintaining robust system performance. Analysis of the monthly energy profile revealed predictable seasonal variability, with maximum yields during the summer months and reductions of up to 28% in winter. While this variation is characteristic of North African solar climates, it highlights the necessity of aligning grid-integration strategies with seasonal production trends, potentially complemented by energy storage solutions or hybridization with existing thermal plants.

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