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# Technical and Operational Assessment of Stand-Alone Photovoltaic (SAPV) Systems

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**A B S T R A C T**

These years, the deterioration of the environment has been aggravated by desertification, fast depleting water resources, and extraordinary occurrences of drought. Accordingly, standalone photovoltaic (SAPV) systems have been a tactical way to provide effective isolated power, especially for isolated areas that lack adequate infrastructural facilities. PVSYST is a sophisticated software simulation tool for modeling, simulating, and evaluating the performance behavior of a photovoltaic (SAPV) system. The current research work aims to develop an integrated method to assess the energy productivity efficiency and technical performance effectiveness of a photovoltaic (SAPV) system by employing PVSYST software simulation. This simulation method combines high-resolution geographic data and appropriate user-designed system module layout concepts to achieve optimal system sizing, thereby maximizing production efficiency to a higher extent by incorporating various system performance optimization techniques to improve technical efficiency and economical viability. The use of simulation software for SAPV system design improves SAPV system designs and ensures a complete analysis of total energy transfer. The simulation result authenticates that PVSYST software is an accurate system for simulating daily, monthly, and annual energy production and is a potent tool for designing sustainable, economical, and efficient solar power setups for isolated areas of Iraq.

Keywords: PVSYST, Standalone Photovoltaic (SAPV) Systems, Battery Storage, Photovoltaic (PV) Cells, Solar Energy.

## 1. Introduction :

Iraq's vital infrastructure has been greatly degraded through the years of conflict, contributing to a perceptible disruption in electricity production, public service delivery, and transport infrastructure[1,2]. However, the current reconstruction phase poses a strategic opportunity for the transformation of the energy sector in the country by incorporating sustainable alternatives, especially renewable sources of energy, as an indispensable element of the country's strategic development vision[3]. Iraq has a vast potential for the development of renewable energy sources, mainly solar and wind energy sources, contributed by the country's high solar intensity and the presence of areas with suitable wind patterns. Despite the vast potential for the development of renewable sources of energy in the country, the share of these sources in the country's energy sector is remarkably small, characterizing a strategic imbalance between resource potential and the feasibility of application for development[4]. In this strategic context, the application of utility-scale PV systems can be identified as a suitable approach for Iraq in the production of clean and decentralized electricity without the use of moving components and maintaining simplicity at the utilization or application stage[5,6].Moreover, PV system performance is highly sensitive to design parameters-especially tilt angle and azimuth orientation-which directly influence incident solar irradiance and, consequently, energy yield. [7]. Therefore, optimizing the tilt configuration-in line with local climatic and geographical conditions is essential to maximizing conversion efficiency and overall system performance [8,9]. This study aims to evaluate and optimize the tilt angle of stand-alone PV systems in key regions of Iraq, using site-specific meteorological data and PVSYST simulations, to support evidence-based integration of solar energy into national infrastructure planning [10].

## 2. Stand-Alone Photovoltaic (SAPV) Systems

Standalone photovoltaic systems, also known as off-grid photovoltaic systems, and grid-connected, or on-grid, photovoltaic systems are the three basic types of solar power installations. Standalone photovoltaic power (SAPV) systems are designed to work independently, that is, they form a micro-grid. They have proven to be a simple and self-reliant way to provide power to people living in urban areas, including small residential and commercial setups, and villages far-off in areas where the extension of the electric grid has proven to be, for all practical purposes, impossible. The advantages of using a standalone photovoltaic power system to supply the load are many, some of which include the generation of electricity directly from the sun, achieving energy independence, enhancement of security, elimination of periodic bills, eased integration, and backup power support for the lifetime of the storage system in case of a storage system failure.

The SAPV systems are designed and rated to satisfy a specified DC and/or AC electrical load. SAPV systems can be divided depending on how they connect to their electrical loads into two types: a direct-coupled system, where a DC output of a photovoltaic cell is directly coupled to a DC electrical load, and an indirect-coupled system, where DC or AC electrical loads are supplied either through a battery system or an inverter, depending on whether it is a DC or AC electrical load. In a direct-coupled system, the electrical load is directly connected to PV modules, as shown in Figure 1 [11].

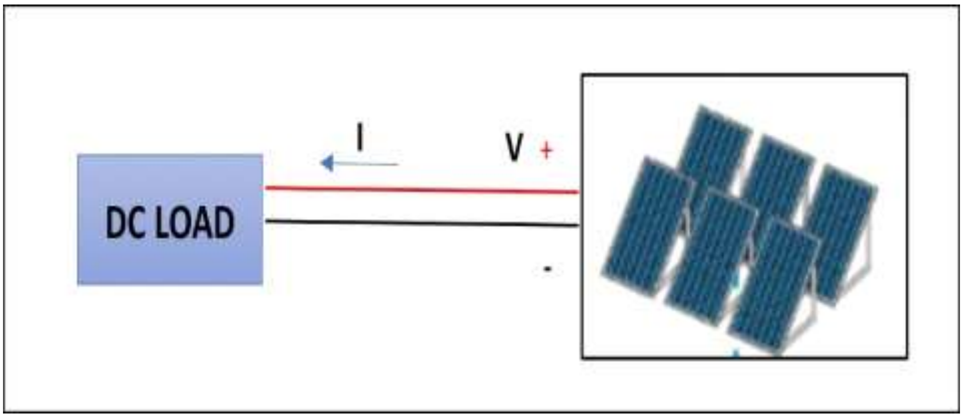


Figure 1 :Diagram of direct-coupled SPAV systems

## 3. System Description and Methodology

The components of Stand-Alone Photovoltaic (SAPV) system generally are photovoltaic (PV) modules, battery storage units, an inverter, and a charge controller. The system's overall performance depends on sizing and the proper integration of these components to match environmental conditions and load demand [12,13]. Appropriate design ensures appropriate that the system operates efficiently, provides stable power in off-grid settings ,and minimises losses [14].

## 4. Indicators of a PV system's effectiveness

Key performance indicators (KPIs) that encompass operational, technical, and economic aspects are essential for a thorough assessment of photovoltaic (PV) system performance. These readings are essential in comprehending the way in which the power is created, and the way in which the maximum utilization of the composite capability is achieved. The key indicators and the corresponding citations are mentioned below.

4.1. Performance Ratio (PR)

The PR is a dimensionless indicator that represents the quality and efficiency of a PV system. It is precisely defined as the ratio of the actual energy output to the theoretical energy output that would be expected under the measured in-plane solar irradiance if the system operated at its Standard Test Conditions (STC) efficiency, accounting for various system losses such as inverter inefficiencies, temperature-related derating, and wiring resistance.

1 PR= ×100

The performance ratio (PR) is independent of the intensity of local solar radiation, and is therefore a reliable criterion for evaluating and comparing photovoltaic systems in different geographical locations. The high PR value indicates a well-performing system with minimal energy loss's locations [15,16].

### 4.2. Capacity Factor (CF)

Is a ratio of the actual electrical energy produced by a PV system over a given time period to the amount of energy that would have been produced if the system had operated at its rated (nominal) capacity throughout that period.

2 CF=

Measures the CF how effectively the installed capacity of the system is utilised over time. It is an essential indicator of economic performance and long-term energy yield. Higher CF values indicate better utilisation of installed capacity and fewer operational losses [17].

### 4.3. Availability

It refers to the percentage of time that a PV system is operational and capable of generating power compared to the total observation period. It reflects the reliability and maintenance quality of the system.

3 Availability= ×100%

The high availability value signifies minimal system downtime and effective maintenance . It is often used alongside PR to assess the combined effects of reliability and efficiency [18].

### 4.4. Energy Ratio (ER)

Is the ratio of the total actual energy produced by a PV system to the total theoretical energy that could be produced based on available solar irradiation. It combines both factors into one comprehensive measure reliability (Availability) and performance (PR).

4 ER= ×100%

The Performance Ratio (PR) is a good and comprehensive measure of solar system health because it combines the effects of energy conversion losses and operational unavailability into a single, dimensionless statistic [19].

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Table 1 Performance parameters of PV Array Characteristics

| | | | |
|---|---|---|---|
| PV module | | Inverter | |
| Manufacturer | HBL Power Systems Ltd | Manufacturer | Huawei Technologies |
| Model | HB_250 | Model | SUN2000-40KTL-M3-380V |
| (Original PVsyst database) | | (Original PVsyst database) | |
| Unit Nom. Power | 250 Wp | Unit Nom. Power | 40.0 kWac |
| Number of PV modules | 160 units | Inverters number | 4 * MPPT 25%<br>1 unit |
| Nominal (STC) | 40.0 kWp | Total power | 40.0 kWac |
| Modules | 8 Strings x 20<br>In series | Operating voltage | 200-1000 V |
| At operating cond. (50 °C) | | Max. power (=>15 °C) | 44.0 kWac |
| P mpp | 36.3 kWp | Pnom ratio (DC:AC) | 1.00 |
| U mpp | 626 V | Total inverter power | |
| I mpp | 58 A | Total power | 40 kWac |
| Total PV power | | Number of inverters | 1 unit |
| Nominal (STC) | 40 kWp | | |
| Total | 160 modules | | |
| Module area | 271 m² | Pnom ratio | 1.00 |
| Cell area | m²241 | | |

### 5. Results and discussion

PVsyst uses sophisticated algorithms and meteorological data to create a precise simulation model of photovoltaic (PV) system performance. Meteonorm, a globally recognized and very reliable climate database, is directly integrated with the application. The primary parameters influencing solar energy generation are the sun's radiation incident on the PV array, wind direction and speed, the specific technological characteristics of the PV modules, and ambient temperature. The latter three traits were recorded by the Shatra site in 2025.

During the summer months, the solar fraction (SF) was 42.69%, and the qualitative production was 1,495 kWh/kWp/year. This period coincides with a higher frequency of clear-sky days and solar radiation, as the Sun's apparent path approaches closer to the Earth's surface. **Table 2** summarises the prevailing weather conditions for **Shatra City**, based on recent climatic data obtained from the **Meteonorm 8.1** database. This database has been integrated into **PVsyst** starting from version **7.3.1**, ensuring that simulations for this location accurately represent the most up-to-date climatic conditions.

Table 2: The mean of the monthly climatic data of Shatra

| **Month** | **GlobHor** KWh/m$^2$ | **DiffHor** KWh/m$^2$ | **T-Amb** Co |
|---|---|---|---|
| January | 98.3 | 44.9 | 12.04 |
| February | 109.6 | 55.8 | 14.80 |
| March | 148.6 | 78.5 | 20.39 |
| April | 176.6 | 92.0 | 25.87 |
| May | 199.4 | 102.8 | 33.47 |
| June | 219.3 | 101.0 | 37.14 |
| July | 221.2 | 97.2 | 39.30 |
| August | 194.2 | 95.5 | 38.65 |
| September | 172.3 | 69.9 | 33.67 |
| October | 131.7 | 68.5 | 27.80 |
| November | 100.1 | 46.8 | 18.77 |
| December | 88.3 | 43.5 | 13.36 |
| Year | 1859.4 | 896.4 | 26.34 |

Table 3 presents an analysis that demonstrates a strong interdependence between the projected PV system's grid-injected energy, **E_User**, and prevailing weather conditions. The highest energy yield is recorded in July at 4,074 kWh, while the lowest occurs in November, with 2,786 kWh. On an annual basis, the system injects 42,737 kWh of energy into the grid and supplies 39,998 kWh to the user.

Table 3: Energy pumped into the grid, as well as the **E_User**

| **Month** | **E-Grid KWh** | **E_User KWh** |
|---|---|---|
| January | 3335 | 3397 |
| February | 3249 | 3068 |
| March | 3802 | 3397 |
| April | 3675 | 3288 |
| May | 3501 | 3397 |
| June | 3992 | 3288 |
| July | 4074 | 3397 |
| August | 3862 | 3397 |
| September | 4062 | 3288 |
| October | 3420 | 3397 |
| November | 2786 | 3288 |
| December | 2979 | 3397 |

The arrow losses graph in Fig. 2 was made with the PVsyst application. The solar PV system uses the sun's rays to make power that can be used by homes and businesses in a way that doesn't harm the environment. There are a lot of energy-saving losses hidden behind the pretty outside. The arrow loss diagram shows that the PV system's profits and losses are precisely managed. This provides a look at the overall system's performance, including losses in optics, arrays, and the system

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as a whole. But a high-efficiency inverter, decreased total wiring losses, and the right choice of parts can all help to lessen their effects.

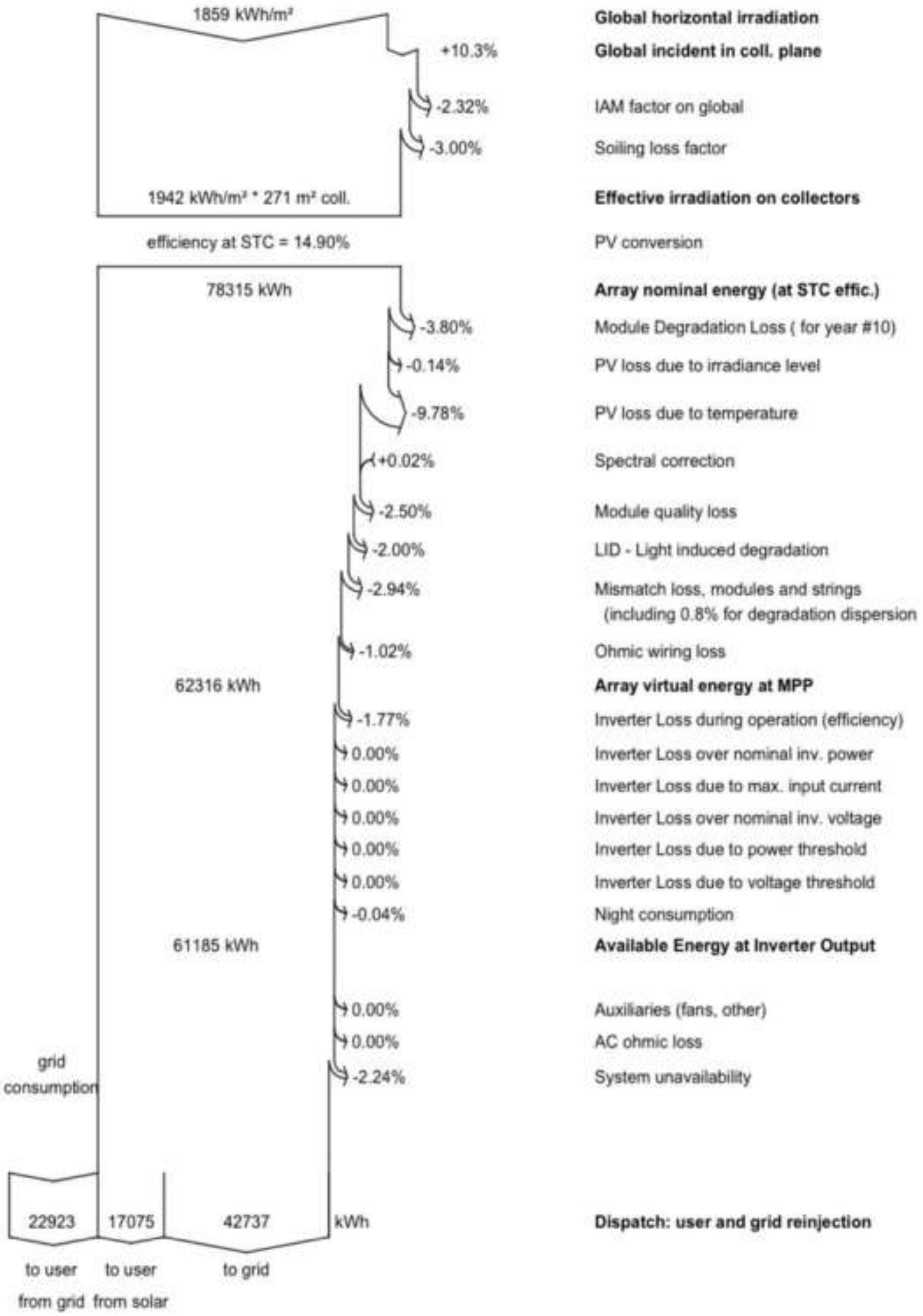

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Figure 2: Proposed PV Systems Arrow Loss Diagram.

Figure 3 illustrates the annual variation of the Performance Ratio (PR) for the grid-connected photovoltaic (PV) system installed at the Al-Orouba Health Centre. PR is a key indicator of the operating efficiency and reliability of a solar power system, and it represents the ratio between the theoretical maximum energy output and the actual energy output under standard test conditions. The annual average PR of the system was 72.94%, indicating sufficient and stable performance throughout the year.. According to the investigation, the lower ambient temperatures during the winter increase the efficiency rate of the PV modules, resulting in higher PR values. The location of the sun also influences the temperature, resulting in intermediate amounts. However, the PR decreases in the summer due to high temperatures in individual solar cells and fluctuations in solar incidence angles, both of which have a detrimental effect on energy conversion. This seasonal shift in the PR process's behavior is consistent with the IEC 61724-1:2021 standard for solar systems' performance evaluation system.

**System Production**

| | | | |
|---|---|---|---|
| Produced Energy | 59812 kWh/year | Specific production | 1495 kWh/kWp/year |
| Used Energy | 39998 kWh/year | Performance Ratio PR | 72.94 % |
| | | Solar Fraction SF | 42.69 % |

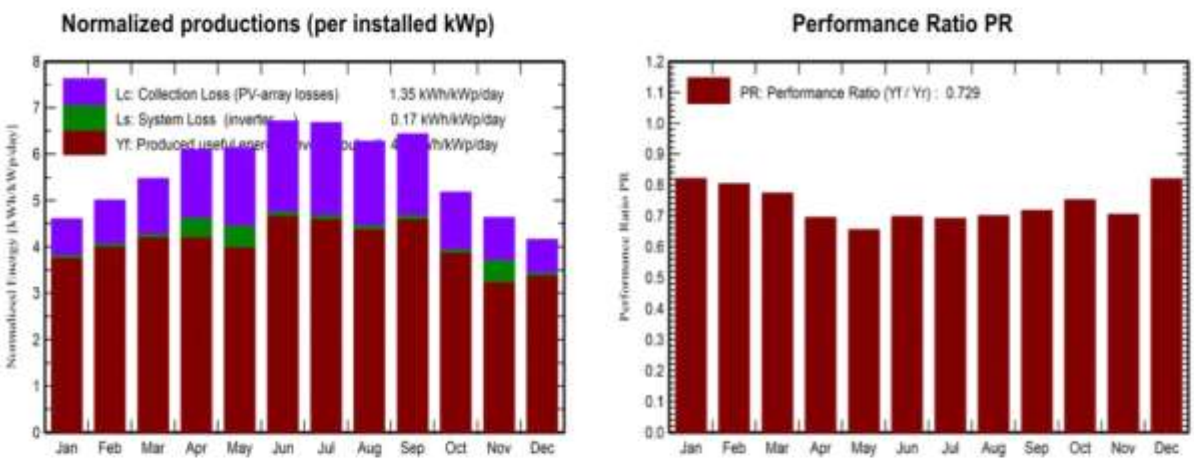


Figure3 Shows the system's Performance Ratio (PR), and Normalized Monthly Production (NMP).

Figure 4 explains the daily output and input process for the grid-connected solar energy system, including energy production, energy supply to the grid, and surrounding solar radiation. It also has consistent and reliable performance pattern, because of the high correlation between the incident solar radiation and the relevant energy output. This indicates the efficiency of the photovoltaic (PV) modules used in the conversion of solar converts the solar radiation/irradiance into useful electricity. However, regular cleaning/maintenance of the PV panels play vital roles in counteracting the buildup of dust and debris that may otherwise contribute to losses in the optical system and a system efficiency. Continuous observation and 7ptimization of operating parameters would also increase the long-term behavior of the system and its stable interconnection to the local grid.

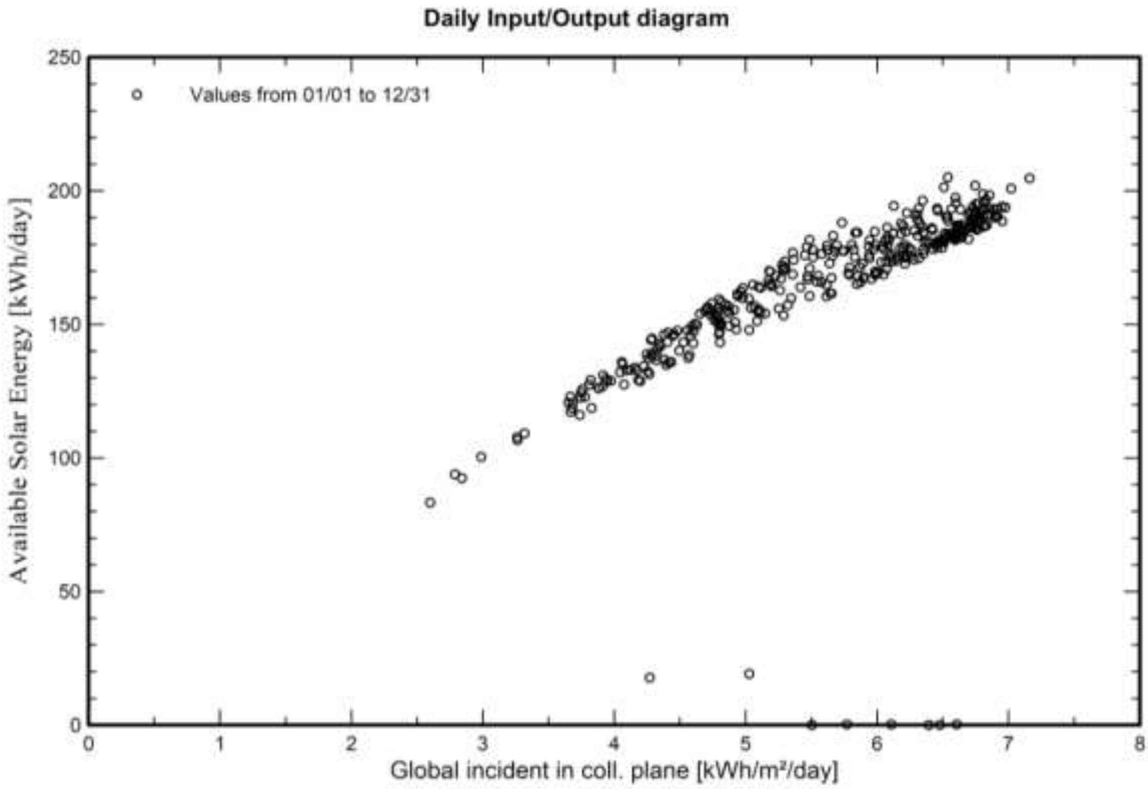


Figure 4: displays a daily diagram of the projected PV system’s incoming and output energy

.

The Al-Orouba Health Center has a megawatt-hour (MWh) photovoltaic (PV) system installed. In energy performance simulations, the probability distribution approach is frequently used to estimate the variability, dependability, and anticipated energy yield of photovoltaic systems. The suggested approach makes it possible to better understand the operational behavior of the system in the local climate by examining the frequency and probability of different power output levels. As a result, it provides highly helpful information about the Al-Orouba PV system's reliability, efficiency, aprospective gift to the local electricity grid.

**Meteo data**

| | | |
|---|---|---|
| Source | Meteonorm 8.1 (1998-2000), Sat=100% | |
| Kind | Monthly averages | |
| Synthetic - Multi-year average | | |
| Year-to-year variability(Variance) | | 5.0 % |

**Specified Deviation**

| | |
|---|---|
| Climate change | 0.0 % |

**Global variability (meteo + system)**

| | |
|---|---|
| Variability (Quadratic sum) | 5.3 % |

**Simulation and parameters uncertainties**

| | |
|---|---|
| PV module modelling/parameters | 1.0 % |
| Inverter efficiency uncertainty | 0.5 % |
| Soiling and mismatch uncertainties | 1.0 % |
| Degradation uncertainty | 1.0 % |

**Annual production probability**

| | |
|---|---|
| Variability | 3.18 MWh |
| P50 | 59.84 MWh |
| P90 | 55.76 MWh |
| P95 | 54.61 MWh |

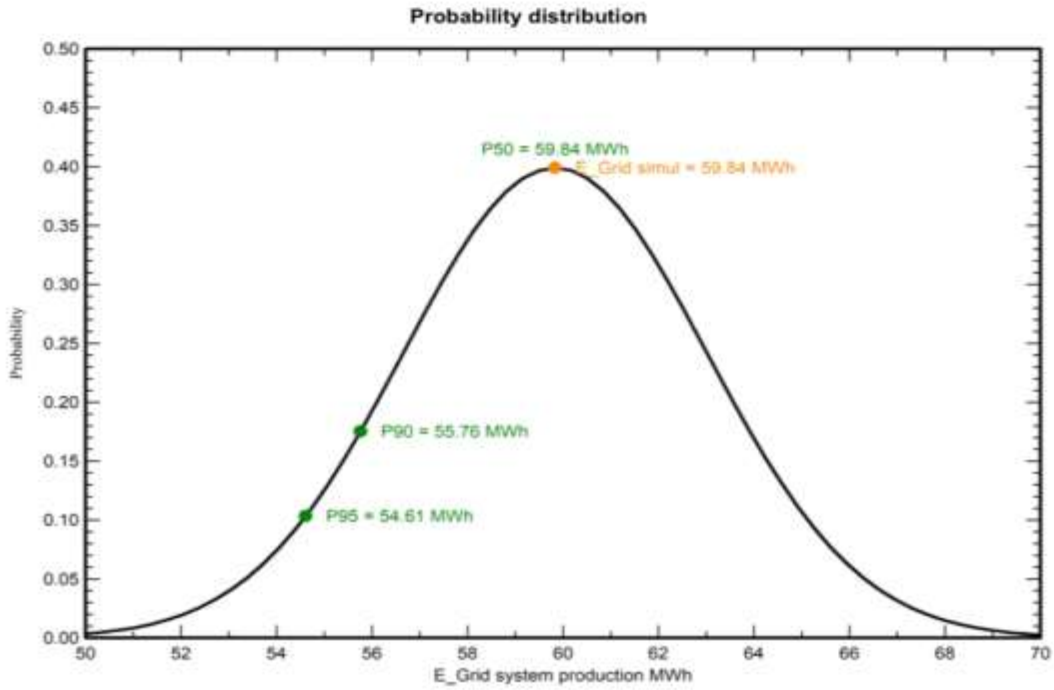


Figure 5: Probability distribution

## 6. Conclusions

According to the study's findings, photovoltaic solar power systems and wireless networks offer a workable and efficient option for solar power systems at medical facilities with plenty of solar resources, like those in southern Iraq. 40 kW nominal capacity system was installed at the Al-Aruba Health Center (located at 46.16°E longitude, 31.41°N latitude, and 9 meters above sea level) using the PVSYST software. The system was found to generate an annual energy output of 59,812 kWh, with a performance ratio of 72.94%, demonstrating good efficiency under local climatic conditions.

The study also showed the impact of heat waves on system performance, especially in summer. Voltage fluctuations are caused by voltage fluctuations due to the increase in cell temperature. Therefore, it is important to incorporate four thermal management strategies in the early planning stages of solar power systems operating at high temperatures, whether in design or passive technology.

On the basis of the above results, it is recommended that the additional medical facilities within the region should implement the solar power system. This will lead to increased stability in the functioning of the medical facility while reducing dependence on conventional sources of power. Additionally, the sustainability associated with the medical service or procedure offered via the solar power system, which is the delivery.

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