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Using Solar-Pro Software Tool to Simulate a 10 kWp Photovoltaic Solar System

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Abstract: The simulated solar photovoltaic (PV) system is located in Baghdad at coordinates 33.33º N and 44.44º E. The current system is a 10 kWp on-grid polycrystalline photovoltaic solar system. The current system is simulated for a full year under the Iraq-Baghdad climate. Throughout the year, the solar modules have a tilt angle of 30º, and the orientation angle (azimuth angle) is zero. In addition to atmospheric variables such as temperature and solar radiation, all electrical parameters of the solar system are investigated. The effect of atmospheric factors on solar PV system production is considered. The accuracy of the present simulation model (Solar-Pro) is also verified by comparing it with a real photovoltaic solar system. The annual values of alternating current energy (AC) and direct current energy (DC) are 16 MWh and 17 MWh, respectively. The average accuracy of the Solar-Pro is 97%. The annual values for specific PV energy and specific AC energy are 1666.17kWh/kWp and 1574.53kWh/kWp, respectively. The annual average values for the system output coefficient (performance ratio), capacity factor, conversion efficiency, PV temperature, and air temperature are 70.07%, 17.98%, 9.62% (nominal efficiency is 13%), 35.08 ºC, and 22.49 ºC, respectively.

Keywords: **Simulation tool, PV system, performance, atmospheric factors, sustainable development, solar insolation.**

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1. Introduction

Simulation software can be used to estimate energy production and evaluate the performance of solar PV systems under different conditions before installation. Popular software includes SolarGIS, PV F-Chart, RET-Screen, Solar-Pro, HOMER, Helioscope, PVsyst, SAM, and PV*SOL (González-Peña et al., 2021). These specialist packages are used to assess and build solar systems, with the goal of achieving the best level possible of realism for actual installations. These tools use location, meteorological data, and real system components, such as module type and characteristics, inverter type, size and characteristics, tilt angle, orientation angle, and system installation site (ground or roof), to achieve precise forecasts about PV system performance. This enables less expensive system designs (Mishra et al., 2024). These packages simulate DC and AC energy, electrical current, voltage, efficiency, performance ratio, PV module temperature, shading, and solar radiation. They also visualize the photovoltaic solar system shape, surrounding buildings, and any trees that might shade it, using 3D technology. Additionally, these packages provide animated shadow simulations throughout the year. These simulation tools can be used to simulate a wide range of photovoltaic system types, including off-grid PV solar systems, on-grid PV solar systems, and hybrid systems that combine different energy sources (Zulramadhanie et al., 2024).

The utilization of clean energy resources is essential to solve economic and environmental problems. Increasing reliance on clean energy sources, such as solar energy and wind energy, has the potential to reduce carbon emissions and the environmental impact of conventional fuels. Renewable energy is now an affordable choice due to lower technical costs and improved system efficiency (Kourkoumpas et al., 2018; Najem et al., 2024). By producing clean and sustainable energy, photovoltaic systems reduce the need for conventional fossil fuels, helping to reduce environmental pollution. According to studies, solar energy contributes to a decrease in carbon dioxide emissions, which complements global efforts to address climate change. Among the alternatives that try to meet environmental sustainability goals are photovoltaic systems (Connolly et al., 2010; Abed & Kasim, 2023).

Further studies have been conducted to simulate solar PV systems using various kinds of simulation packages. Using PVsyst, PVGIS, and HOMER, S.A. Mohammadi and C. Gezegin modeled a 5 MW grid-connected solar power system in the Ghor region of Afghanistan. When compared with other technologies, they concluded that PVsyst is the best tool for performance analysis (Mohammadi & Gezegin, 2022). Pradhan et al. (2017) used HOMER-Pro software to conduct a techno-economic investigation of a standalone hybrid power system for providing electricity to a rural community. They concluded that hybrid systems combining solar, wind, and diesel with battery storage are the best option for remote regions since they reduce carbon emissions and have low energy costs. Benghanem et al. (2018) used MATLAB/Simulink to construct a simulation model for solar cells and modules. This model allows researchers to explore how photovoltaic cells perform when exposed to environmental conditions such as dust and temperature. The researchers assessed the impact of dust on the solar cell properties using the Shockley equation. Biberci (2023) studied the grid-tied PV solar system performance for irrigation of agricultural lands in Konya, Turkey, using the PV*SOL software. The simulation results showed that the system achieved 46.6% self-sufficiency and 83% performance efficiency, with a return on investment of 9.14% and a payback period of 8.7 years. The system also saved 9,201 kg of CO_2 emissions per year, confirming its technical and economic feasibility for sustainable irrigation. Thula et al. (2017) used Solar-Pro software to design and simulate a 100-kW solar system installed on the Guru Nanak Institute of Technology's roof. The power generated over a year was examined and compared with actual measured data to enhance the system's efficiency.

The aim of the current work is to assess the Solar-Pro tool's ability to simulate a PV system under Iraq-Baghdad meteorological circumstances. It also aims to explore the feasibility of installing a grid-tied PV system in the future.

The novelty of this research is the comparison of four simulation software programs (Solar-Pro, PVsyst, Helioscope, and PVGIS) with a real solar system in Iraq. This study provides a clear result regarding the accuracy of the simulation programs compared to a real system operating under local Iraqi conditions, showing that Solar-Pro achieved the highest accuracy of 97%. The results confirm the reliability of these packages in predicting the performance of PV systems.

2. PV Solar System Details

The simulated solar PV system is located at 33.33° N and 44.44° E in Baghdad city. The simulated solar PV system is a 10 kWp on-grid polycrystalline system. The PV solar modules are Sharp model ND170E1F. A year-long

simulation of the current system is conducted under the Iraq-Baghdad climate. Throughout the year, the tilt angle of the solar modules remains 30°, and their orientation angle is zero (azimuth angle is zero). Details of the simulated PV solar modules are displayed in Figure 1. The simulated PV solar system consists of 60 PV solar modules. The current PV system is composed of six strings, each of which has 10 PV modules connected in series. These strings are connected in parallel. This PV system employs one 10 kW inverter with a 95% efficiency. Figure 2 displays the single-line diagram of the current PV solar system.

3. Simulation Software (Solar-Pro) Details

The present simulation package provides details about shade, PV module size, and inverter size, but it does not include electrical details. The solar PV system's electrical parameters include PV power, AC power, PV voltage, PV current, PV temperature, air temperature, output coefficient, PV efficiency, PV specific power, and AC specific power. These details are included in this package. The program does not explain the equations used to calculate these electrical parameters. This work includes all the equations used to calculate these electrical parameters.

Mechanical data

Cell	Polycrystalline (156.5 mm)² Sharp silicon solar cells
Quantity and wiring of cells	48 in series
Dimensions	1,318 x 994 x 46 mm (1.31 m²)
Weight	16 kg
Connection type	Cable with plug connector (MC-3)

Limit values

Operating temperature (cell)	– 40 to + 90	°C
Storage temperature	– 40 to + 90	°C
Maximum system voltage	1,000	V DC
Maximum mechanical load	2,400	N / m²
Over-current Protection	15	A

Electrical data

Made in EU / Made in Japan		ND-175 (E1F)	ND-170 (E1F)	ND-162 (E1F) ND-Q2 (E3EF)	ND-158 (E1F) ND-P8 (E3EF)	ND-N8 (E3EF)	
Maximum power	P_{max}	175 W_p	170 W_p	162 W_p	158 W_p	148 W_p	
Open-circuit voltage	V_{oc}	29.4	29.3	28.8	28.6	28.4	V
Short-circuit current	I_{sc}	8.10	8.04	7.95	7.92	7.61	A
Voltage at point of maximum power	V_{mpp}	23.3	23.2	22.7	22.5	22.3	V
Current at point of maximum power	I_{mpp}	7.52	7.33	7.14	7.03	6.64	A
Module efficiency	η_m	13.3	13.0	12.4	12.1	11.3	%
NOCT		47.5	47.5	47.5	47.5	47.5	°C
Temperature coefficient – open-circuit voltage	αV_{oc}	– 104	– 104	– 104	– 104	– 104	mV / °C
Temperature coefficient – short-circuit voltage	αI_{sc}	+ 0.053	+ 0.053	+ 0.053	+ 0.053	+ 0.053	% / °C
Temperature coefficient – power	αP_{max}	– 0.485	– 0.485	– 0.485	– 0.485	– 0.485	% / °C

The electrical data applies under standard test conditions (STCs): irradiation 1,000 W/m² with light spectrum AM 1.5 and a cell temperature of 25 °C. The rated electrical characteristics are subject to a manufacturing tolerance of – 5 % / + 10 %. NOCT conditions: irradiation of 800 W/m², ambient temperature of 20 °C and wind speed of 1 m/sec. The modules manufactured in Europe and Japan are identical in construction.

Figure 1. Simulated PV solar module details.

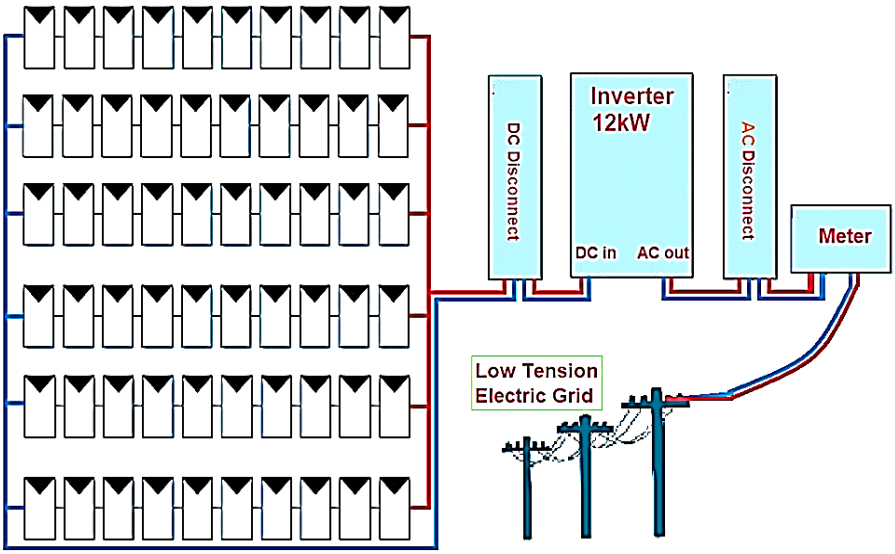


Figure 2. PV solar system single-line diagram.

Since this software provides a single-line diagram of the solar PV system with little information (Figure 3), the author designed a more detailed single-line diagram, as shown in Figure. 2. The simulated PV solar design and its virtual location are displayed in Figure 4. The simulation result (report) generated by Solar-Pro software is shown in Appendix A.

This software uses the 1600-point meteorological database to collect meteorological data such as ambient temperature and solar radiation. The number 1600 in "Meteorological Data 1600 Points" refers to specific time points.

These "100 points" reflect the number of climate measurements or data collected across specified periods of time throughout the year, such as solar radiation, temperature, or wind speed. In simulation models, such as those used for PV system analysis, a year is represented by a specific number of hours or time steps. For example, if there are 1600 time points, this indicates that climate data are collected or calculated over 1600 intervals (hourly or daily) throughout the year. This is less than the typical coverage of 8760 hours (the number of hours in a year), but it provides sufficient time to simulate changing weather conditions and evaluate the performance of solar systems (Garniwa et al., 2021; Grylls et al., 2019). Solar Pro accurately calculates losses and uses complex algorithms to simulate solar system performance. The accuracy of the results depends on how carefully the researcher inputs data.

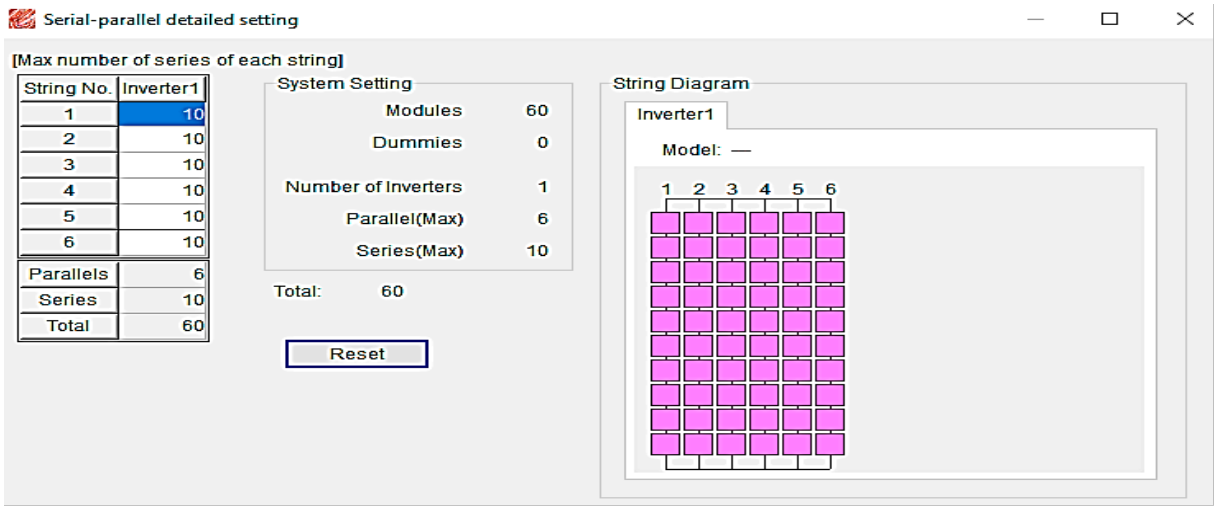


Figure 3. Simulation software's single-line diagram.

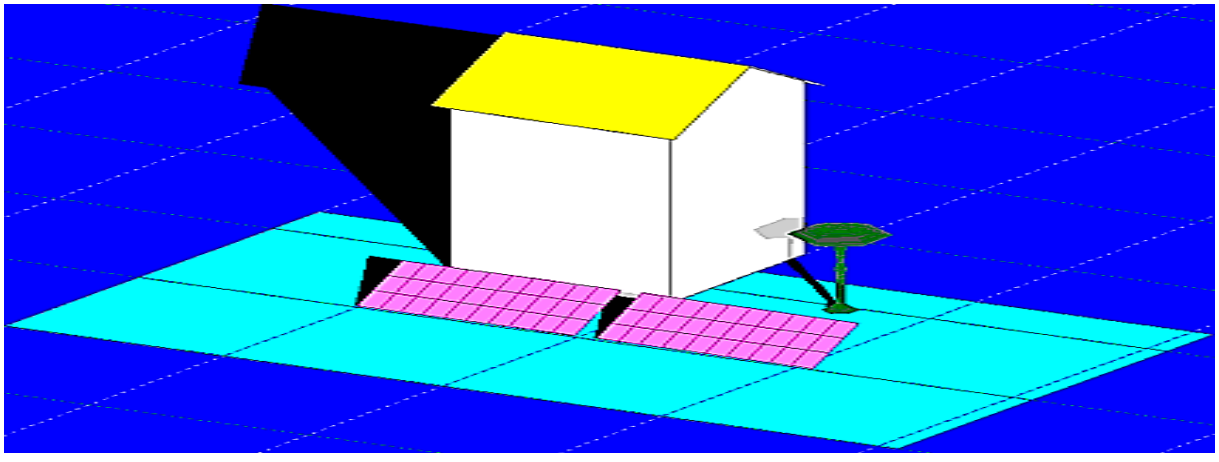


Figure 4. 10 kWp PV solar system design simulation.

4. Performance Assessment Equations

To evaluate the performance of any on-grid PV solar system, various equations must be utilized. The equations utilized to assess the performance of these PV solar systems include energy production, conversion efficiency, array yield (specific PV energy), final yield (specific AC energy), capacity factor, performance ratio (energy output coefficient), voltage-current, and module temperature equations (Najem et al., 2022; Abed & Kasim, 2023).

4.1. Energy Production Equations

The following equations can be used to calculate the amount of AC energy a solar PV system produces and delivers to the utility grid on a yearly, monthly, daily, and even hourly basis (Abed et al., 2025). Simulation software computes energy production by integrating solar radiation, temperature effects, and system losses using the following equations (Kasim et al., 2023; Kasim et al., 2022):

$$E_{AC} = G * A * \eta \quad (1)$$

$$E_{AC,h} = \sum_{t=1}^{60} E_{AC,t} \quad (2)$$

$$E_{AC,d} = \sum_{h=1}^{24} E_{AC,h} \quad (3)$$

$$E_{AC,m} = \sum_{d=1}^{n} E_{AC,d} \quad (4)$$

where E_{AC}: AC energy, $E_{AC,h}$: hourly AC energy, $E_{AC,d}$: daily AC energy, $E_{AC,m}$: monthly AC energy, G: solar irradiance (W/m^2), A: module area, and η: module efficiency.

4.2. Efficiency Equations

The array efficiency (η_{PV}) depends on the DC output power (or energy). In solar-pro software, array efficiency is referred to as PV efficiency (Kasim et al., 2022). η_{PV} is expressed as follows:

$$\eta_{PV} = (E_{DC} / H_t * A_m) *100\% \quad (5)$$

where E_{DC}, $H_{t,}$ and A_m are DC energy, in-plane solar irradiation (kWh/m^2), and array area (m^2), respectively.

An inverter efficiency is given as follows (Jed et al., 2020; Hussein et al., 2024):

$$\eta_{INV} = (E_{AC} / E_{DC}) *100\% \quad (6)$$

4.3. Array Yield and Final Yield Equations

In Solar-Pro, the array yield and final yield are denoted as specific PV energy and specific AC energy, respectively. The array yield (Y_A) is referred to as the product of the PV array's power output (DC energy) divided by its rated power (P_{Rated}). The final yield (Y_f) is defined as the product of the power produced by the PV solar system (AC energy) divided by its rated power (P_{Rated}). Y_A and Y_f are given in Equations 7 and 8 below(Kasim et al., 2023).

$$Y_A = E_{DC} / P_{Rated} \ (kWh/kWp) \quad (7)$$

$$Y_f = E_{AC} / P_{Rated} \ (kWh/kWp) \quad (8)$$

4.4 Capacity Factor (CF) Equation

The Solar-Pro tool does not calculate the capacity factor, but it can be estimated using the data provided by this tool (its report). The capacity factor is essential for comparing the current simulated solar PV system with the actual solar PV systems to determine the Solar-Pro's ability to reflect reality. The CF is provided as follows (Abed et al., 2020):

$$CF = E_{AC} / (P_{Rated} *8760)(\%)$$
$$\boldsymbol{CF = E_{AC} / (P_{Rated}} \quad (9)$$

4.5 Performance Ratio (PR) Equation

In solar-pro software, the PR is referred to as the system output coefficient. The performance ratio reflects all PV solar system losses. PR reveals how near a real PV system is to an ideal PV system (PR = 100%, indicating no losses). PR is stated as follows (Kasim et al., 2019):

$$PR = Y_F / Y_r \quad (10)$$

4.6 Voltage-Current Equations

4.6.1 Current (I) Equation

The electrical current in the PV solar module is calculated using the Shockley diode model, which diagnoses the electrical behavior of PV solar cells (Saadaoui et al., 2025).

$$I = I_{ph} - I_0 * (\exp^{(q*(V+I*Rs)/(n*k*T))}-1)-(V + I*R_s) / R_{sh} \quad (11)$$

$$I_{ph} = (G/G_{ref})*I_{ph,ref} \quad (12)$$

$$I_0 = I_{0,ref}*(T/T_{ref})^3*\exp((q*E_g/k)*(1/T_{ref}-1/T)) \quad (13)$$

4.6.2 Voltage (V) Equation

The voltage is rated based on the operating current and open-circuit voltage (Prakash et al., 2021):

$$V = V_{oc} - I*R_s \quad (14)$$

Alternatively, it can also be stated as follows:

$$V = (n*k*T/q)*1n(I_{ph}/I_0 + 1) \quad (15)$$

I: Output current (ampere), I_{ph}: Photogenerated current (ampere), I_0: Saturation current (ampere), V: Output voltage (volt), Rs: Series resistance, R_{sh}: Shunt resistance (Ω), q: constant =1.602*10^{-19}, n: Ideality factor of the diode (usually 1-2), k: Boltzmann constant (1.38*10^{-23} J/K) and T: Cell temperature (kelvin), G: Solar irradiance (W/m^2), G_{ref}: Reference irradiance (1000 W/m^2), $I_{ph,ref}$: Photogenerated current under reference conditions (Ampere), $I_{0,ref}$: Saturation current under reference conditions (ampere), T_{ref}: Reference temperature (kelvin), E_g: Band gap energy of the semiconductor (electron volts) and V_{oc}: Open-circuit voltage.

4.7 PV Solar Module Temperature Equation

$$T_C = b_1 * T_{air} + b_2 * G_2 * + b_3 \quad (16)$$

where T_C is the module (or cell) temperature. T_{air} is the ambient air temperature, and b_1 measures the extent to which ambient air temperature influences the cell temperature. When b_1=1.00, it indicates that the influence of ambient air temperature on the cell (or module) is directly proportional to the ambient air temperature. G_2 represents solar radiation. The parameter b_2 determines how much solar radiation heats the cell. When b_2 = 34.00, it indicates that solar radiation has a significant impact on cell temperature. b_3 considers other factors that may influence cell temperature, which are not directly associated with radiation or ambient temperature. When b_3 = 00, it indicates that no additional fixed effects are applied.

5. Results and Discussion

In this section, in addition to explaining the simulation findings, a comparison with an actual solar PV system is performed to ensure the accuracy of this simulation tool. This comparison is summarized in Table 1.

Figure 5 shows the solar radiation, DC power, and AC power produced by the simulated solar PV system. The maximum energy output in August and April is about 1540 kWh for DC energy and 1455.5 kWh for AC energy. The minimum energy output occurs in January and December. The tilt and orientation angles of the PV module play a key role in capturing the greatest amount of solar radiation and thus obtaining the greatest electrical energy. The tilt and orientation angles of the current PV modules are responsible for significant gains in DC and AC power, as well as in-plane solar radiation, in August and April, although the highest horizontal solar radiation occurs in June. This means that the PV module's tilt angle (30°) is ideal for a fixed frame in Baghdad year-round.

The reasons AC energy is less efficient than DC energy include primary losses from inverter efficiency, along with wiring losses and losses in DC circuit breakers.

Figure 6 illustrates the relationship between voltage and current over the course of a year, along with ambient temperature and the temperature of solar modules. The voltage is rather stable throughout the year, although the current fluctuates slightly, with a slight rise in the summer. The temperature of PV modules and the ambient temperature both increase during the summer. This rise in temperature results in a decrease in voltage due to the high internal resistance of the PV modules. There is an inverse relationship between temperature and voltage: as temperature rises, voltage decreases, although the

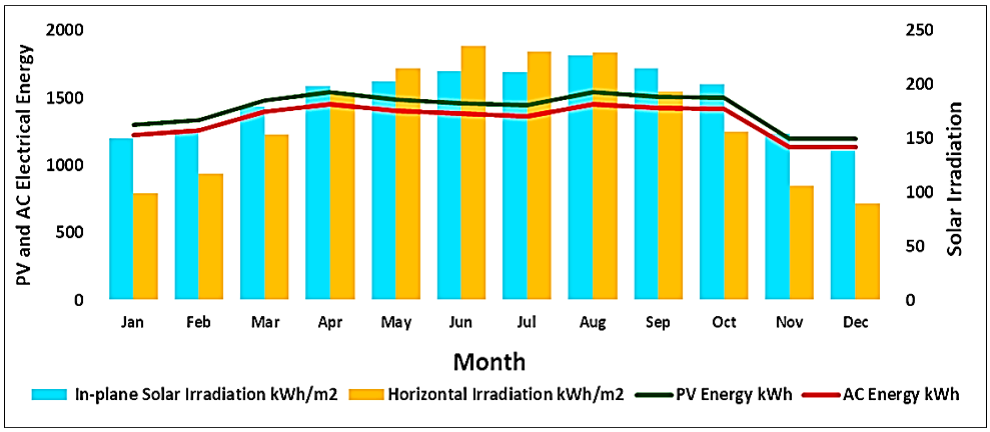


Figure 5. Solar irradiation, DC and AC energy production.

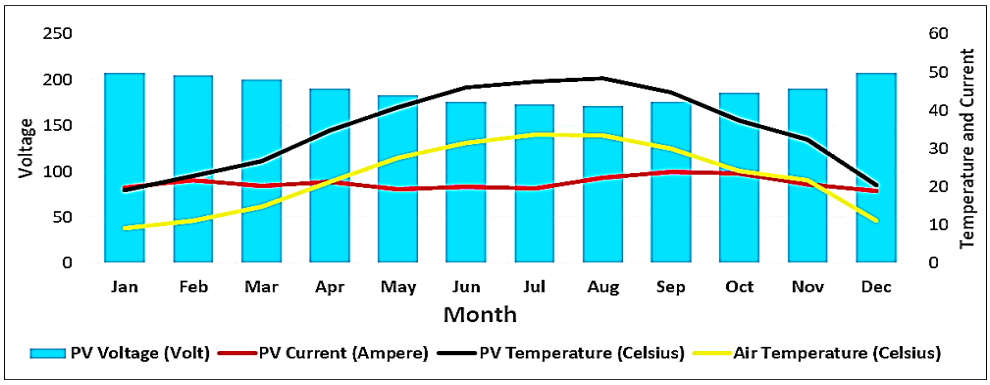


Figure 6. Temperature, voltage, and current.

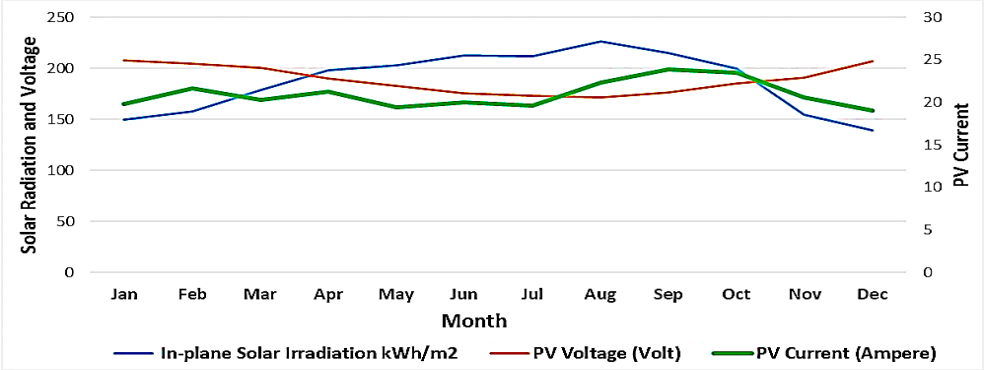


Figure 7. In-plane solar irradiation, voltage, and current.

current experiences only a slight increase. The physical explanation for this inverse relationship is that increasing temperature reduces the energy gap (band gap) of the semiconductor materials used to make solar cells, resulting in a lower voltage. Conversely, increasing temperature improves the mobility of electrons, resulting in an increase in electrical current, but this does not compensate for the lower voltage, overall efficiency, or power.

Figure 7 shows the relationship between in-plane solar irradiation, voltage, and current throughout a year. Solar radiation increases in the summer, in August, due to a longer duration of sunshine and the suitable tilt angle of the PV modules. This results in a direct increase in current due to the production of more electrons. In contrast, as solar radiation increases, the voltage gradually drops due to the heat effect on the semiconductor material's energy gap. The figure clearly shows that solar radiation has a significant impact on the electrical characteristics of the photovoltaic system, with each having a different effect on voltage and current. Solar radiation affects the current, while ambient temperature affects the voltage.

Figure 8 depicts the relationship between PV module temperature, air temperature, and PV module efficiency (conversion efficiency) throughout the year. The average daily temperature of the PV modules varies from about 20°C in winter (January and December) to 49°C in summer (July and August); these values are very close to reality. This rise is caused by direct solar radiation (more perpendicular to the PV modules) in the summer, which heats the modules. Efficiency begins at about 11% in the winter and then drops to about 8.64% in the summer. This decrease (2.36%) is extremely close to reality because it is comparable to the decrease value (2.6%) observed in the published study's actual on-grid solar PV system, which has the same characteristics as the Solar-Pro (see Table 1) (Abed & Kasim, 2023). The harmful impacts of heat on the PV modules are the reason for the efficiency drop with rising ambient temperatures. As the temperature rises, the energy gap of the semiconductor material narrows, allowing electrons to move more freely within the conduction band, resulting in energy loss as heat. The electron-hole recombination rate also increases, and the internal resistance of the cell increases, all of which lead to a decrease in efficiency.

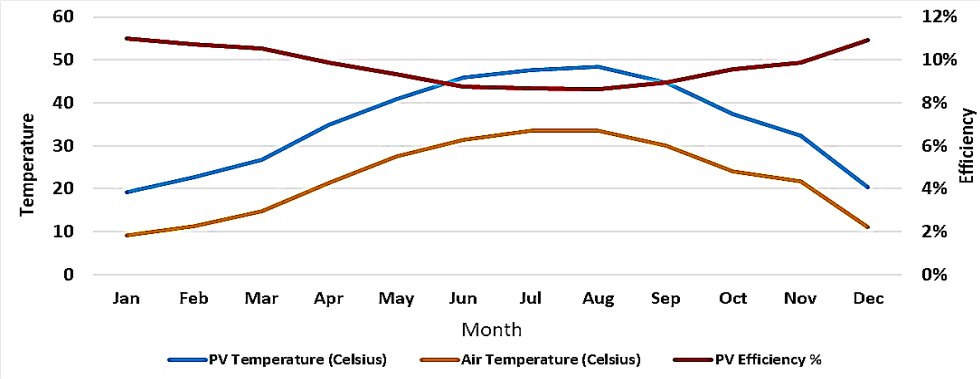


Figure 8. Temperatures and PV module efficiency.

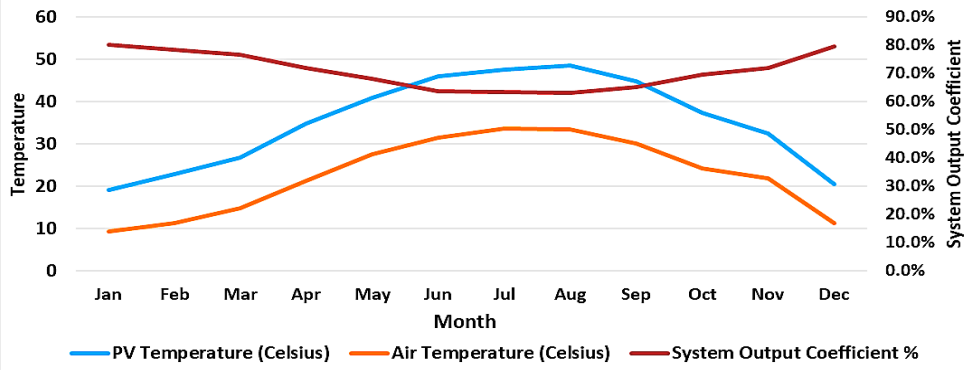


Figure 9. Temperatures, system output coefficient.

Figure 9 depicts the relationship between PV module temperature, air temperature, and system output coefficient (performance ratio 'PR') throughout the year. The maximum PR values are in January and December (winter) at about 80.14% and 79.67%, respectively. The minimum PR values in June, July, August, and September (summer) range from 63.73% to 62.95%. The lowest PR corresponds to the maximum PV module temperature (in August). PR reveals all PV solar system losses. The annual average of the PR is 70.1%. When PR is 70.1%, the losses are around 30%. PR compares different solar PV systems independent of tilt angle, orientation angle, nominal capacitance, location, or solar resource (Kasim et al., 2019). Table 1 shows a comparison between the virtual system (sola-pro) and the real PV system. It is essential to consider the impact of temperature when designing PV systems. In addition, cooling techniques may be used to increase the performance of a PV system. The most important weather factors affecting the PR are ambient temperature and soiling. The Arabian Gulf region, especially Iraq, is characterized by high temperatures, which reduce the PR and shorten the lifespan of PV modules.

Figure 10 shows the capacity factor (CF), specific PV energy (array yield), and specific AC energy (final yield) across the year. The maximum values of specific PV energy and specific AC energy in August and April are 151 kWh/kWp and 142 kWh/kWp, respectively. The minimum values are in December and January due to low solar radiation intensity. DC and AC specific energy represent the number of hours a solar PV system can operate at its rated capacity. Specific PV energy, specific AC energy, and CF are essential performance evaluation parameters because they allow comparison between different solar PV systems. This comparison will be made in Table 1.

In terms of CF, the highest values are around 19.4% in April, August, and September since these months receive more solar energy than other months due to the optimal tilt angle. The annual average CF is 17.98%, which corresponds to 65.6 days a year. CF represents the percentage of time that the solar PV system runs at its nominal capacity.

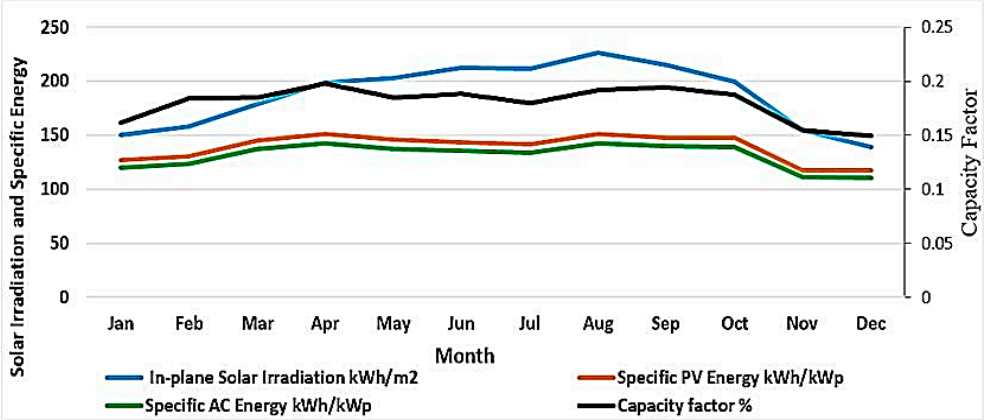


Figure 10: CF, specific PV energy and specific AC energy.

6. Verification of Solar-Pro Tool's Accuracy

There are several performance evaluation parameters that can be used to compare different PV solar systems. These parameters include PR, CF, energy yield, and energy output (if the PV systems have the same nominal capacity). To verify the accuracy of the solar-pro tool, it will be compared to an actual PV system with the same electrical features. The real PV system is a 5 kW on-grid monocrystalline silicon system installed in Baghdad (Abed & Kasim, 2023). Table 1 shows the comparison between several virtual PV systems and a real PV solar system (Abed & Kasim, 2023). Table 2 represents the specifications of different PV system simulation packages.

7. Conclusions

Solar-Pro software has an average accuracy of 97%. There is large convergence in the results between Solar-Pro, PVsyst, PVGIS, and Helioscope, as shown in Table 1. The average daily temperature of PV modules calculated by Solar-Pro ranges from 20°C in winter to 49°C in summer, causing a decrease in efficiency from 11% to 8.64%. PR drops from 80% in winter to about 63% in summer due to the high temperature of the PV modules; this indicates how closely the performance of Solar-Pro approaches the ideal. The voltage remains relatively stable throughout the year, but it decreases in the summer due to the high temperature of the PV modules.

Solar-Pro exclusively simulates on-grid PV installations. This software does not simulate standalone, hybrid, or off-grid systems. Solar-Pro simulates all performance evaluation parameters, except capacity factor. Solar-Pro's single-line diagram requires improvement. Solar-Pro is excellent at simulating animation shadows. The author plotted all figures, as the software does not provide them for performance evaluation parameters.

Solar-Pro does not provide data on PV solar system losses. Solar-Pro does not provide data on dust (or soiling).

This software takes soiling and all losses into account because it has excellent accuracy. The annual averages of PR and CF for mono-Si, Solar-Pro, PVsyst, PVGIS, and

Table 1. Comparison between real and virtual PV solar systems.

Performance parameter	PVGIS	Helioscope system	PVsyst system	Real PV system (Abed & Kasim, 2023)	Solar-Pro system	Solar-Pro accuracy
PR	75%	70.9%	71.5	74%	70.1%	95%
CF	18.2%	17.85%	18.7%	17.75%	17.97%	98.7%
Daily AC Energy yield	4.39 kWh/kWp	4.31 kWh/kWp	4.49 kWh/kWp	4.45 kWh/kWp	4.313 kWh/kWp	96.1%
Daily in-plane solar irradiation	5.92 kWh/m^2	6.04 kWh/m^2	6.28 kWh/m^2	6.06 kWh/m^2	6.15 kWh/m^2	98.6%
					Accuracy verage	97.0%

Table 2. Specifications of different PV system simulation software.

Package	Analysis types	Pros	Cons
SAM (Blair et al., 2013)	Economic analysis and performance analysis.	Supports various systems; analyzes economic and technical aspects; ability to manually add custom PV modules and inverters.	Complex for beginners; does not support 3D shadow modeling; does not provide climate data for all locations.
PVsyst (Hosseini et al., 2025)	Performance analysis and financial estimation; for all types of systems (on-grid, off-grid, stand-alone, hybrid and solar water pumping systems).	High-accuracy energy forecasting; detailed loss analysis; comprehensive climate and solar system components database;	Traditional interface, difficulty importing complex 3D models, high cost.
HOMER (Hoarcă et al., 2023)	Improvement and Sensitivity Analysis; Technical and Economic Analysis.	Easy-to-use interface, good accuracy, support for many system configurations; determines the best combinations of multiple techniques; detailed results.	Slow computation, does not support multi-objective optimization; simplified mathematical modeling; need for detailed data.
PV*SOL (Umar et al., 2018)	3D representation, Shade Analysis, and Financial Performance Analysis.	Extensive climate database including more than 8,000 locations worldwide; solar panel database including more than 13,000 panels and 3,100 inverters;	Does not support sensitivity analysis; difficult to model; errors in single-line diagram; does not support advanced calculations.
RET-Screen (Kassem & Furaiji, 2022)	Economic feasibility analysis; analysis of both performance and portfolio	Integrated climate databases; reliable and easy to use compared to other study tools; supports economic feasibility analysis and relies on data from over 6,700 ground stations and NASA satellite data.	It does not cover comprehensive environmental efficiency assessment, such as emission reduction or sensitivity analyses required in complex energy projects; does not support advanced estimations.
Helioscope (Govindarajan et al., 2024)	Technical and shadows analysis	Performance Ratio estimation accuracy close to reality (deviation ~4.74%); easy to use; online; detailed single-line diagram; 3D design.	Relatively higher deviation in production cost compared to PVsyst (less accurate in terms of economic feasibility).
Solar-Pro (Milosavljević et al., 2022)	Technical and shadow analysis; economic feasibility examination; performance modeling.	3D-CAD design for designing solar systems on roofs; tracking systems; integrated climate databases; advanced 3D shadow analysis; accurate algorithms for calculating the I–V curve based on panel properties, radiation, thermal, and shadow effects.	Complex software compared to others; does not support advanced feasibility study.
SolarGIS (Milosavljević et al., 2022)	Energy analysis; Design and enhancement; Technical analysis.	High accuracy in solar radiation and meteorological data estimation, supported by a well-studied and documented methodology.	Does not support financial analysis, advanced emissions assessment, or complex shading; does not support feasibility analysis; requires an internet connection.
PVChart (Umar et al., 2018)	Financial and Technical analysis	Easy to use; graphical and numerical results; manual climate data entry.	Does not support shadow analysis; does not support advanced calculations; Cannot export graphics.

Helioscope are 74% and 17.75%, 70.1 & 17.97%, 71.5% and 18.7%, 75% and 18.2%, and 71.9% and 17.85%, respectively. When the PR of Solar-pro is 70.1%, the losses are around 30%, and so on for other PV solar systems. The daily energy yields for mono-Si, Solar-pro, PVsyst, PVGIS, and Helioscope are 4.45kWh/kWp, 4.313 kWh/kWp, 4.49 kWh/kWp, 4.39 kWh/kWp, and 4.31 kWh/kWp, respectively. Solar radiation and ambient temperature are the most significant atmospheric elements affecting PV systems. The authors suggest adding a cooling system to clean PV modules and reduce their temperature.

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Conflict of Interest

The authors declare that they have no conflicts of interest to disclose.

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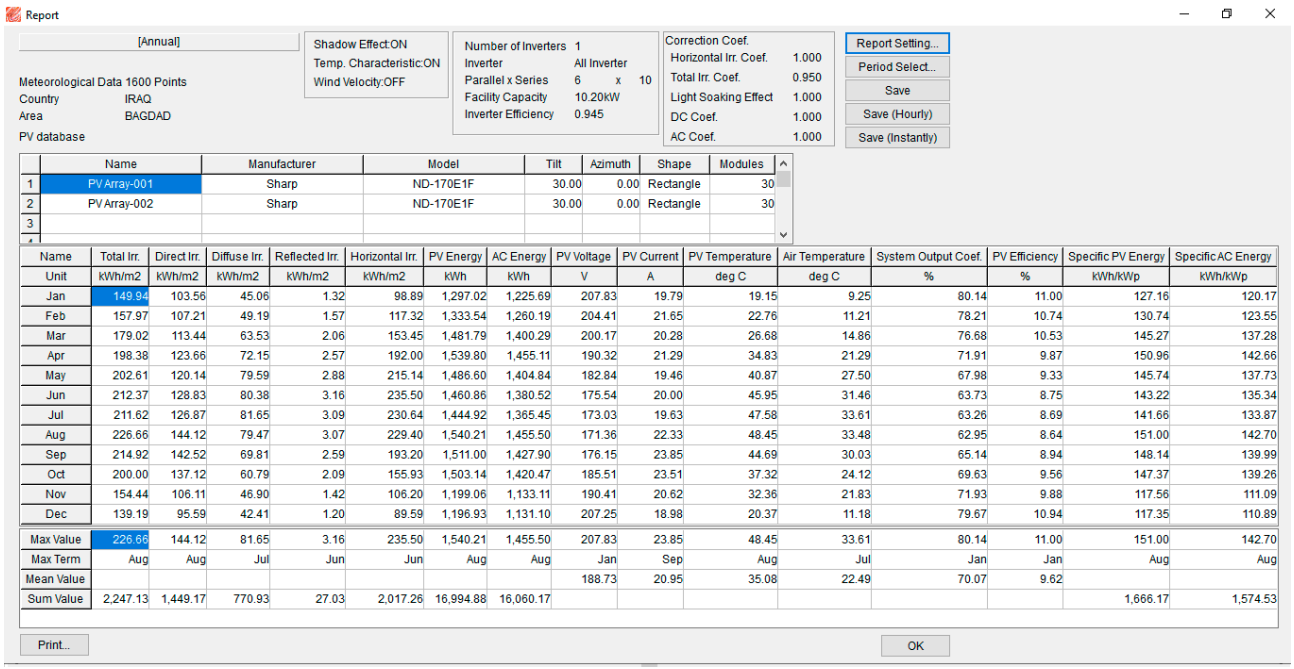
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Appendix A. Solar-Pro software tool report.



Report

[Annual]

Meteorological Data 1600 Points
Country IRAQ
Area BAGDAD
PV database

Shadow Effect:ON
Temp. Characteristic:ON
Wind Velocity:OFF

Number of Inverters 1
Inverter All Inverter
Parallel x Series 6 x 10
Facility Capacity 10.20kW
Inverter Efficiency 0.945

Correction Coef.
Horizontal Irr. Coef. 1.000
Total Irr. Coef. 0.950
Light Soaking Effect 1.000
DC Coef. 1.000
AC Coef. 1.000

Report Setting...
Period Select...
Save
Save (Hourly)
Save (Instantly)

	Name	Manufacturer	Model	Tilt	Azimuth	Shape	Modules
1	PV Array-001	Sharp	ND-170E1F	30.00	0.00	Rectangle	30
2	PV Array-002	Sharp	ND-170E1F	30.00	0.00	Rectangle	30
3							

Name	Total Irr.	Direct Irr.	Diffuse Irr.	Reflected Irr.	Horizontal Irr.	PV Energy	AC Energy	PV Voltage	PV Current	PV Temperature	Air Temperature	System Output Coef.	PV Efficiency	Specific PV Energy	Specific AC Energy
Unit	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh	kWh	V	A	deg C	deg C	%	%	kWh/kWp	kWh/kWp
Jan	149.94	103.56	45.06	1.32	98.89	1,297.02	1,225.69	207.83	19.79	19.15	9.25	80.14	11.00	127.16	120.17
Feb	157.97	107.21	49.19	1.57	117.32	1,333.54	1,260.19	204.41	21.65	22.76	11.21	78.21	10.74	130.74	123.55
Mar	179.02	113.44	63.53	2.06	153.45	1,481.79	1,400.29	200.17	20.28	26.68	14.86	76.68	10.53	145.27	137.28
Apr	198.38	123.66	72.15	2.57	192.00	1,539.80	1,455.11	190.32	21.29	34.83	21.29	71.91	9.87	150.96	142.66
May	202.61	120.14	79.59	2.88	215.14	1,486.60	1,404.84	182.84	19.46	40.87	27.50	67.98	9.33	145.74	137.73
Jun	212.37	128.83	80.38	3.16	235.50	1,460.86	1,380.52	175.54	20.00	45.95	31.46	63.73	8.75	143.22	135.34
Jul	211.62	126.87	81.65	3.09	230.64	1,444.92	1,365.45	173.03	19.63	47.58	33.61	63.26	8.69	141.66	133.87
Aug	226.66	144.12	79.47	3.07	229.40	1,540.21	1,455.50	171.36	22.33	48.45	33.48	62.95	8.64	151.00	142.70
Sep	214.92	142.52	69.81	2.59	193.20	1,511.00	1,427.90	176.15	23.85	44.69	30.03	65.14	8.94	148.14	139.99
Oct	200.00	137.12	60.79	2.09	155.93	1,503.14	1,420.47	185.51	23.51	37.32	24.12	69.63	9.56	147.37	139.26
Nov	154.44	106.11	46.90	1.42	106.20	1,199.06	1,133.11	190.41	20.62	32.36	21.83	71.93	9.88	117.56	111.09
Dec	139.19	95.59	42.41	1.20	89.59	1,196.93	1,131.10	207.25	18.98	20.37	11.18	79.67	10.94	117.35	110.89
Max Value	226.66	144.12	81.65	3.16	235.50	1,540.21	1,455.50	207.83	23.85	48.45	33.61	80.14	11.00	151.00	142.70
Max Term	Aug	Aug	Jul	Jun	Jun	Aug	Aug	Jan	Sep	Aug	Jul	Jan	Jan	Aug	Aug
Mean Value								188.73	20.95	35.08	22.49	70.07	9.62		
Sum Value	2,247.13	1,449.17	770.93	27.03	2,017.26	16,994.88	16,060.17							1,666.17	1,574.53

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