# Evaluation of On-Grid PV System Performance Compared to Two Simulation Tools Under Baghdad City Climate

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## Abstract

This research presents a performance evaluation of the solar photovoltaic system connected to the grid with a capacity of 15kWp as real data and compares it with the hypothetical data of two simulation tools (PV-syst, SAM) to find out the extent of the deviation of the Heterojunction with intrinsic thin layer (HIT) solar system from the hypothetical data. HIT PV Solar systems were installed in Baghdad city (Latitude 33.3 °N, Longitude 44.4 °E at 41m above Sea Level). The results were that the performance ratio (PR) is about 74% for the real system and is closer to the PV-Syst simulation tool at 79% compared to the simulated Performance Ratio (PR) of SAM at 83%. The difference between the energy output of the real system and PV-syst and SAM tool is 1164kWh, and 1138kWh respectively. The difference between PV-syst and SAM software tools is 26kWh. There are some evaluated results, most important expected photovoltaic losses that affect the module performance were estimated by PV-syst and SAM software tools due to irradiance level, and temperature losses were 0.51%, 7.61%, and 0.2%, 7%, respectively. The performance and productivity results of the PV system indicate the quality of performance of HIT technology in the climatic conditions of Baghdad city.

**Keywords**: Performance PV Solar System, HIT Technology, Grid-Connected, PVsyst, and SAM.

# تقييم اداء النظام الكهروضوئي متصل بالشبكة مقارنة بأداتين للمحاكاة لمناخ مدينة بغداد

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## الخلاصة

يقدم هذا البحث تقييماً لأداء النظام الشمسي الكهروضوئي المتصل بالشبكة بقدرة ١٥ كيلوواط كبيانات حقيقية ومقارنتها بالبيانات الافتراضية لاداتي محاكاة (PV-syst and SAM) لمدينة بغداد (latitude 33.3 °N, longitude 44.4 °E ) لمعرفة مدى انحراف النظام الشمسي الحقيقي HIT من القيم الافتراضية واظهرت النتائج أن نسبة الأداء (PR) للنظام حوالي ٧٤٪ وهي أقرب إلى قيمة نسبة الاداء لاداة PV-Syst عند ٧٩٪ مقارنة بقيمة نسبةالاداء لأداة SAM عند ٨٣٪. الفرق بين قيم انتاج الطاقة للنظام الفعلي وأداة PV-syst و SAM هو ١١٦٤ KWh، ١١٣٨ KWhوالفرق بين أنظمة PV-syst و SAMهو ٢٦ .KWhهناك بعض نتائج التقييم لأهم الخسائر الكهروضوئية المتوقعة التي تؤثر على أداء اللوح تم تقديرها بواسطة نظام PV-syst و SAM بسبب خسائر مستوى الإشعاع درجة الحرارة ٠,٥١ ٪ ، ٧,٦١٪ و ٠,٢٪ ، ٧٪ على التوالي. تشير نتائج الأداء والإنتاجية للنظام الكهروضوئي إلى جودة أداء تقنية HIT في الظروف المناخية لمدينة بغداد.

**الكلمات المفتاحية**: اداء النظام الكهروضوئي , تقنية (HIT) ,متصل بالشبكة ونظام (PV,SAM).

## Introduction

The Heterojunction with Intrinsic Thin-layer (HIT) technology for the manufacture of solar panels is one of the techniques that depend on the crystal structure of different crystalline materials, this technology provides good specifications for its adoption in the manufacturing of solar panels.

The topic of ever-increasing energy consumption is one of the most important issues being studied by researchers worldwide. Fossil fuels are becoming scarce and expensive. Oil and uranium are scarce resources that will be depleted in a few decades. Coal, a major energy source, will run out in a few hundred years. It is crucial to keep the environment safe during the energy production process (Gulkowski, *et al*., 2019). PV systems can be viewed as the most significant because they are static, silent, immovable, vibrationless, and free of moving parts; furthermore, they have low operating and maintenance expenses, despite their high production prices, which are still decreasing (Konneh, *et al*., 2021). A single PV cell has an approximate capacity to provide 1 to 2 W of power. PV cells can be linked to create higher power modules for increased power output. A set of modules can be joined together to form an array depending on the power plant capacity or electricity generation (Sumathi, *et al*., 2015). When the energy of the photovoltaic system is insufficient to operate the devices, it will draw energy from the electrical grid, However, when it contains excess energy production, it will export it to the electrical grid. This connection does not need batteries to transfer energy between the PV system and the electrical grid. When PV solar systems are insufficient to run all loads, government sectors turn to grid-connected systems, which directly supply the utility grid, while also drawing power for their buildings from the utility grid. This is the case (The Government Sector Case) with the solar photovoltaic system studied here (Simon, 2020). There are many PV module technologies available, such as monocrystalline, polycrystalline, amorphous silicon cells, CIS, CdTe, and multi-junction cells based on GaAs and InP compounds. New technologies depend on the utilization of organic or dye compounds and have evolved alongside these traditional solar cell technologies. However, these stay in their early stages. Currently, the Si, CdTe, and CIS technologies are the only ones that are widely employed. Despite this range of solar technologies, crystalline silicon cells dominate the photovoltaic industry, accounting for over 90% of all sales. More research has been conducted worldwide about the performance analysis and parameters of on-grid PV solar systems. (Kasim, *et al*., 2010) (Kasim, *et al*., 2017) (Kasim, *et al*., 2019), conducted a study on the evaluation of performance through dust depositing and treatment by tracking the panel and discovered that when the tracker panel bends down to gather solar radiation at sunset, dust deposits down due to gravity. (Abed ,2020), have improved Some electrical parameters (Solar Radiation, Array Efficiency, Current, Performance Ratio, Electrical Power) of PV solar systems on-grid using planer concentrators (Optical Reflectors). The second-generation technology (CIGS), an abbreviation for Copper Indium Gallium Selenide, was used. The performance ratio (PR)ranged from 86.6% to 95%, and efficiency ranged from 13.1% to 14%. Sandhya Thotakura (Thotakura, *et al*., 2020) along with colleagues evaluated the performance of a megawatt-scale rooftop PV solar system at an Indian educational institution in both dry and humid climates. This was done by comparing their simulations to the actual results. For this system, there were 23 inverters and solar panels installed. The average mean bias error (MBE) was 5.33% (PVGIS), 12.33% (PV Watts), and 30.64% (PV Syst), with the average normalized mean bias error (NMBE) being 2.954% (PVGIS), 7.88% (PV Watts), and 22.75% (PV Syst). The performance ratio of the PV plant was around 88%. In comparison, the energy yields and PR for PV Syst were higher. Nonetheless, deviations between simulated and observed energy performance were observed. VS Chandrika (Chandrika, *et al*., 2021) with colleagues also have been evaluated the system efficiency for PV connected-grid 250 kWp under different ventilation conditions in southern India. The three systems were BIPV (Building-Integrated Photovoltaic Without Ventilation), BIPV_V (Building-Integrated Photovoltaic Ventilated), and FSPV (Free-Standing PV). PVsyst software was used to simulate these systems. Electrical efficiencies for BIPV/BIPV_V and FSPV systems were 14.75%, 15.25%, and 15.45% respectively. The highest PR was 0.82% while the lowest was 0.70%. This research helps architects and the general public to design roofs that are both aesthetically pleasing and provide good noise reduction and thermal insulation, a major requirement in equatorial temperature regions. Sonali Goel and Renu Sharma (Goel and Sharma, 2021) wrote a study on the analysis and simulated performance of an 11.2kWp grid-connected PV system in Bhubaneswar India using PVSyst and HelioScope software. The array of PV modules is slanted at an angle of 21° angled towards the south. An average annual ambient temperature of 26.16°C and solar irradiation of 1783.9 kWh/m2 has been measured. The PR, PVSyst and HelioScope were measured 81%, 78.07%, and 75.20% respectively. (Guittet and Freeman, 2018) conducted a PV performance using three software packages including SAM, PV-syst, and Helioscope. The simulation deviations range from several −7.0% to 5.5% due to the difference in the weather file within each software.

The major purpose of this study is to assess the performance of a 15kWp HIT technology grid-tied PV system and compare it with the results of two simulation tools (PVsyst and SAM) in Baghdad, Iraq.

## Materials and Methods

performance depending on their design methods and locations (Kasim and Hussain, 2020). and can assess PV system performance by a set of equations.

### 1. Energy Produced

Energy Produced indicates the amount of alternating current energy that exits from the photovoltaic system during operation, and the energy production can be calculated on an hourly, daily, and monthly basis, as in equations 1 to 3 (Bansal, 2016):

$$\mathrm{EAC,h.} = \sum_{t=1}^{60} \mathrm{EAC,t} \quad \ldots\ldots\ldots (1)$$

$$\mathrm{EAC,d.} = \sum_{h=1}^{24} \mathrm{EAC,h} \quad \ldots\ldots\ldots\ldots (2)$$

$$\mathrm{EAC,m} = \sum_{d=1}^{N} \mathrm{EAC,d} \quad \ldots\ldots\ldots (3)$$

### 2. Performance Ratio

Performance Ratio (PR) shows the total losses of the solar photovoltaic system. The performance ratio indicates how close the photovoltaic system is to the ideal performance (100%) during the actual working time. This parameter also allows comparison between the performance of different photovoltaic systems (Ozden, *et al*., 2017). The PR is defined as the ratio of the Final Yield (YF) to the Reference Yield (YR) of the PV solar system (Padmavathi and Daniel, 2013), and Equation 4 gives it.

$$PR = \frac{YF}{YR}\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Final yield (YF) represents AC energy (after converted from DC energy by inverter) and be either (daily (YF,d)) or (monthly (YF,m)) by rated (Nominal) power for installed PV array (Ramanan and Karthick, 2019). It can be expressed as:

$$Y_F = \frac{EAC}{PPV;rated} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Reference Yield (YR) refers to the ratio Ht (In collimated) solar irradiation in the unit (W/m$^2$) to Hr (Reference -Solar Irradiation) in a unit (W/m2) during standard test conditions (STC) (1 kW/m$^2$) (Karthick, *et al*., 2020) as follows:

$$Y_R = \frac{Ht}{Hr} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

### 3. The Capacity Factor

Capacity Factor (CF) is the number of times the unit is working at confirmed nominal electrical power. The CF is precisely the AC energy produced by a PV system to the nominal PV system installed (Padmavathi and Daniel, 2013). The capacity factor is given by the following equation:

$$CF = \frac{EAC}{Ppv,rated} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

EAC represents the AC energy (the energy after converted from DC energy by inverter).

### 4. Degradation Rate

Degradation Rate (DR) which is brought by operating circumstances, is the progressive degradation of a component's or a system's characteristics that may impact its capacity to function within the parameters of acceptable criteria, its can be calculated as follows (Theristis, *et al*., 2020) (DR):

$$DR = \frac{\text{initial PR} - \text{final PR}}{\text{initial PR}} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

### 5. Simulation of PV Solar System

The main part of the simulation software, which provides us with a complete study of the project, is the project design and simulation process. This design includes the selection of climate data files; system design; shading; Determining the values of losses and economic evaluation. The simulation takes place on an annual basis and has hourly steps and at the end provides a complete report file on the project. The primary characteristics of simulation two software designed for solar system design are reviewed in this part, as well as a comparison study.

The project designed in its main form in simulation programs can be developed in simple and sequential steps (SA, 2019):

- Create a project with geographic area selection and climate data file selection
- Determining the angle of inclination, the direction of the panels, the required energy, the area of the existing area, the determination of the panel technology, and the determination of the inverter, and then default values will be set close to all the required

parameters, and the simulation can be performed again and the file is saved.

- Gradually adding losses such as shadows, specific loss criteria, economic evaluation .... etc.

- Each variable must be simulated and saved so that we can compare and understand the details that have been added to the simulation.

**5.1 Photovoltaic System**

PhotoVoltaic system (PVsyst) contains a set of tools for studying, sizing and analyzing PV arrays. Numerous meteorological and PV system component databases, in addition to generic solar energy tools, are supported, including grid-connected, stand-alone, pumping, and DC-grid PV systems. The program is helpful for architects, engineers, and academics. It also has the potential as a teaching tool. Swiss physicist Andre Mermoud and electrical engineer Michel Villoz developed PVsyst (Belmahdi and El Bouardi, 2020). When it comes to designing and simulating PVsyst , this program is universally considered to be the gold standard. The latest release, V7.2, has a trial period of 30 days in DEMO mode.

There is an approximate 631$ price tag for the unlimited version. Windows software PVsyst V7.2 can access PVGIS and NASA databases for irradiance data import. The four main elements of PVsyst are preliminary design, project design, databases, and tools. Plane orientation, system components, PV array (Number of PV Modules in Series and Parallel), inverter model, battery pack, and so on are all inputs into the simulator, which then runs the simulation (González. *et al.*,2020).

A comprehensive report can be generated for each simulation run, detailing not only the run's main outcomes but also all of the simulation's settings (Kumar, *et al.*, 2021). Pvsyst software has 3 limitations as follows:

- The screen cannot be enlarged in the program and this causes boredom in seeing the parameters if the user is on a small screen.
- unavailability to control shadow research with accuracy.
- No single-line diagram.

**5.2 System Advisor Model**

The System Advisor Model (SAM) is a performance and financial model designed to help people in the renewable energy industry make decisions. It is freely available software developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories in the United States. The first public version was released in August 2007; since then, two new versions have been released each year, with new technologies and financial models being added. Over 35,000 people have downloaded the software since its initial public release (Gurupira and Rix, 2017). SAM is a visual C++ programming language that runs on both Windows and Mac OS X. SAM simulates system configuration and makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model. SAM uses weather from NREL's National Solar Radiation Database (NSRDB), SAM uses inputs like module type, inverter specifications, system design, losses, lifetime, and so on. The SAM simulation's graph and table can be exported to Excel or text formats. The main limitations of SAM are as follows:

• 3D shade modeling for PV systems is not supported.

• No available weather data for all the locations of the world.

Experimental work

PVsyst and Helioscope, simulation programs include the same actual options in terms of location, nominal power, azimuth angle, tilt angle, latitude, longitude, and panel technology. The PV solar system lies in the central Baghdad/Alwaziriyah region in the Training and Energy Research office, Iraq-Baghdad (latitude 33.3° N, longitude 44.4 ° E). The size of the system is 15kWp the system was related to the feeder that provided contentious electricity to the principal building and the Modules area is 83.57m2. The current system has a tilt angle of 30° and an azimuth angle of 0°.

The mentoring system is connected to the Sunny Portal program and gives us daily, monthly, and yearly data on power production. The current investigation used 12 modules in string linked together in series to increase the voltage. The number of strings in the system is six that are connected in parallel, leading to a higher output current. The total of modules for the PV solar array is 72 modules. A single solar module (HIT Techniques) has a power output of 205 W as shown in Figure (1).

**Figure (1) HIT Technology 15kwp Solar System Grid-Tied.**

**1- Modules Technology of PV**

The link between first-generation technique (Silicon Wafer Technology), second-generation technique (Thin Film Technology), and third-generation technology (Promising Technology) produces novel technologies such as HIT technology (Heterojunction with Intrinsic Thin-layer) is the first module in the world and without competitor where the record of studies in different places showed the ability of panels to produce stable energy for more than 10 years and when compared to traditional homo-junction c-Si solar cells, HIT solar cells have low module degradation comparing with second-generation technologies, low-temperature losses coefficient(-0.29 %/°C) and high efficiency reached 25.6% (Jiang, *et al*., 2020). Electrical Specifications for HIT Photovoltaic Module; see Table (1). HIT technology is Sandwiched between two layers of amorphous silicon is the efficient monocrystalline silicon part. The thin layer of monocrystalline silicon that serves as the sandwich's "meat" is referred to as the "intrinsic thin layer." Solar panels are usually classified as either crystalline or amorphous technology. The HIT panels are created by combining these into a single module. HIT solar cell structure is shown in Figure (2).

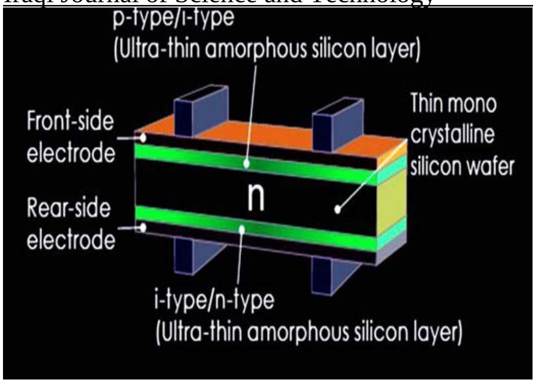



**Figure (2) HIT Solar Cell Structure (Ahmed, 2023).**

2- Inverter

The inverter transforms the direct current (DC) produced by PV modules into alternating current (AC). An inverter is a device that supplies synchronized frequency power into the utility grid (50Hz). Maximum Power Point Tracking (MPPT) is a device installed into the inverter that can raise the voltage when it dips during hot days until it reaches the maximum power point. The inverter used in the experimental work was selected from SMA and has a Maximum efficiency is 97%, model SUNNY TRI POWER 15000 TL.

**Table (1) Electrical Specifications for HIT Photo-Voltaic Module.**

| **Model** | **HIT Power 205 or HIP-205** |
|---|---|
| Rated Power (Pmax)1 | 205 W |
| Maximum Power Voltage (Vpm) | 40.7 V |
| Maximum Power Current (Imp) | 5.05 A |
| Open Circuit Voltage (Voc) | 50.3 V |
| Short Circuit Current (Isc) | 5.5 4 A |
| Temperature Coefficient (Pmax) | -0.29% / °C |
| Temperature Coefficient (Voc) | -0.172 V / °C |
| Temperature Coefficient (Isc) | 0.88 mA / °C |
| Cell Efficiency | 20.2% |
| Module Efficiency | 17.7% |
| Maximum System Voltage | 600 V |
| Series Fuse Rating | 15 A |
| Warranted Tolerance (-/+) | -0% / +10% |
| Module Area | 1.16 $m^2$ |
| Dimensions L*W*H | 1580*812*35 mm |
| Weight | 15Kg |
| Cable Length – Male/+Female | (780/630 mm) |

## Result and Discussion

Figure (3) shows the Monthly energy produced and solar Irradiation in a real system. The lowest value of electrical energy production was recording in December with 1607.2 kWh, due to the influence of weather factors (low solar intensity with a short period between the sunrise and sunset (PSH), Rain, Clouds). While, the highest value of electrical energy production was in the summer season months of August with 2198.28 kWh. which is related to the clear sky and high solar irradiance with a long period between sunrise and sunset (High Value of Peak Sun Hours PSH). There was a difference in energy production between summer and winter related to solar radiation and ambient temperature variation during the month of the year; as in Table (2).

**Table (2) Electrical Energy Production for Real System.**

| **Energy production in kWh** | | |
|---|---|---|
| **Season** | **Month** | **Real System** |
| Winter | January | 1716.9 |
| | February | 1833.7 |
| | December | 1607.2 |
| Summer | May | 1287.2 |
| | June | 2087.4 |
| | July | 2096.9 |
| | August | 2198.28 |

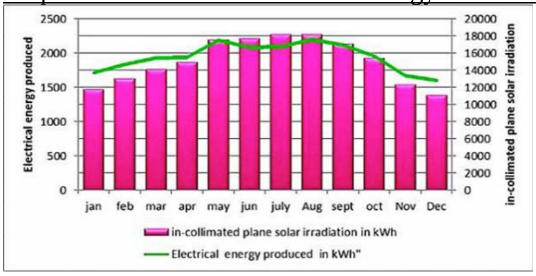


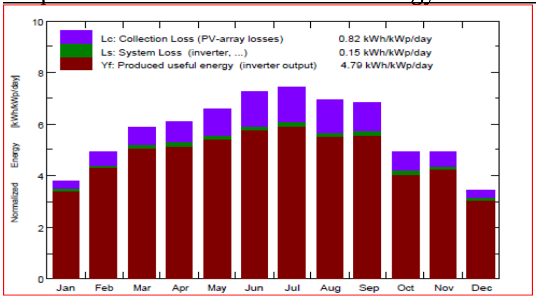

**Figure (3) Monthly Energy Produced and Solar Irradiation in a Real System.**

The overall energy production for 12 months of the year 2020 was calculated, where the monthly average is 1945.5 kWh. The total energy produced during 12 months by nominal power 14.76 kWp for HIT solar system is called Annual Energy Yield and by dividing it by 365 days, it gets a term Daily Final Yield; see Table (3). The total annual solar radiation of POA (Plane of Array) was 2172.3KWh/m$^2$ and varies from 133 kWh/m$^2$ in December 2020 to 218 kWh/m$^2$ in July 2020, the lowest values of solar irradiance during the period of rainy, dusty, and cloudy weather, while the highest values were in clear summer days. The average monthly ambient temperature ranges from 16.8°C in January to 44°C in July, while the annual average is 30.3°C. As it is noted, the high temperature in August leads to a reduction in the energy production of the system. However, in this month, it gets the highest value of energy production due to the high PSH that about (15 Hours). Further, the lowest value of energy production was in December due to a decrease in PSH (About 10 Hours).

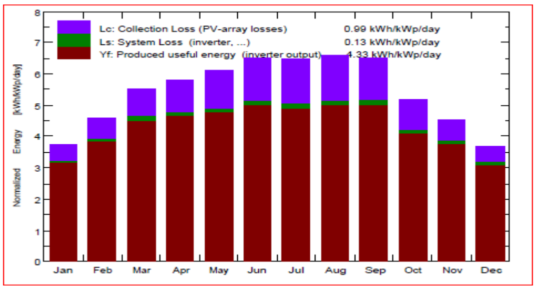
Figures (4 and 5); show the monthly energy production by PV-syst and SAM software. For simulation, the long-term weather data derived from Meteonorm was used in PVSyst and NREL (National Renewable Energy Laboratory) in SAM. The average annual ambient temperature and GlobInc (Global Incident in Coll. Plane) for PV-syst and SAM software is 24.07°C, 2101.2 kWh/m² and 23.8°C, 2101.2 kWh/m² respectively. By PVsyst and SAM software (for 1st year) and (10$^{th}$ Year) the lowest values of electrical energy production were in December 1399 kWh, 1421 kWh, 1200 kWh, and 1350 kWh respectively due to the influence of weather factors (Decrease in PSH, Rain, Clouds), while the highest values of electrical energy production by PVsyst and SAM software (for 1st Year) and (10th Year) was in July, August 2708 kWh, 2298 kWh and 2700 kWh, 2400 kWh respectively due to the clear sky and (High Peak Sun Hours).

**Table (3) Measurement and Simulation Performance Parameters of 15kWp Solar PV System.**

| Software | Real System | PVsyst | | SAM | |
|---|---|---|---|---|---|
| | | 1$^{st}$ year | 10$^{th}$ year | 1$^{st}$ year | 10$^{th}$ year |
| Energy Produce (kWh) | 23346.49 | 25810 | 24510 | 25784 | 24687 |
| Performance ratio (%) | 74 | 83.22 | 79 | 83 | 79 |
| Annual Energy Yield (kWh/kWp) | 1581.7 | 1748.6 | 1660.5 | 1746.88 | 1672.5 |
| Daily Final Yeild (kWh/kWp) | 4.33 | 4.7 | 4.54 | 4.78 | 4.58 |
| Accuracy (%) | - | 98.87 | 98.93 | 98.87 | 98.93 |
| Error (%) | - | 1.12 | 1.06 | 1.12 | 1.06 |




**(a)**




**(b)**

**Figure (4) Monthly Energy Produced by PV-syst Software for, a) 1st Year, and b) 10th Year.**

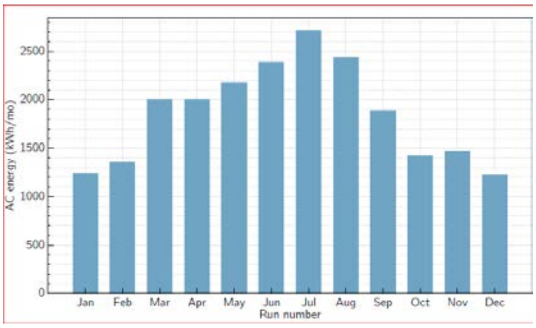



**Figure (5) Monthly Energy Produced in SAM Software.**

Table (3); shows the annual average energy production and the annual energy yield for PVsyst and SAM software (1st year) and (10th year). By dividing it into 365 days, it gets a term daily YF for PVsyst and SAM software (1st Year) and (10th year). The difference in electrical power output between the real system (HIT) and PV-syst, SAM software for (10th year) was small 1164kWh, 1341kWh respectively as a result of weather variations, the efficiency of the modules and inverter, and other factors. This means the practical measurement results were very good because they are very close to PV-syst, and SAM simulation results. While, the difference in electrical power output between real system (HIT) and PV-syst, SAM software for (the 1$^{st}$ Year) was big due to the Degradation Factor.

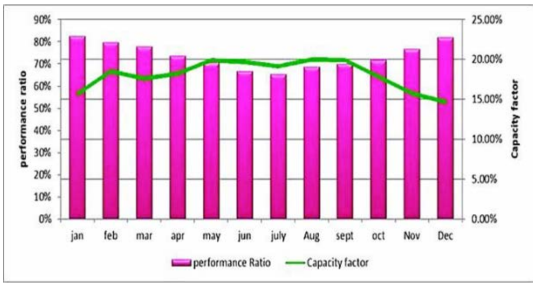
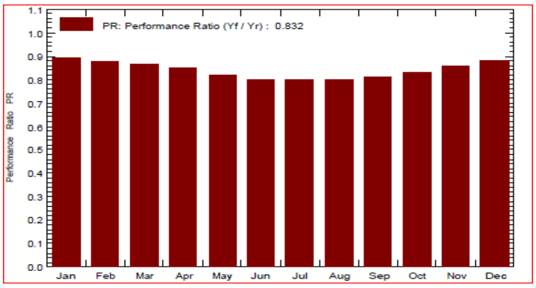



**Figure (6) Performance Ratio and Capacity Factor of a Real System.**

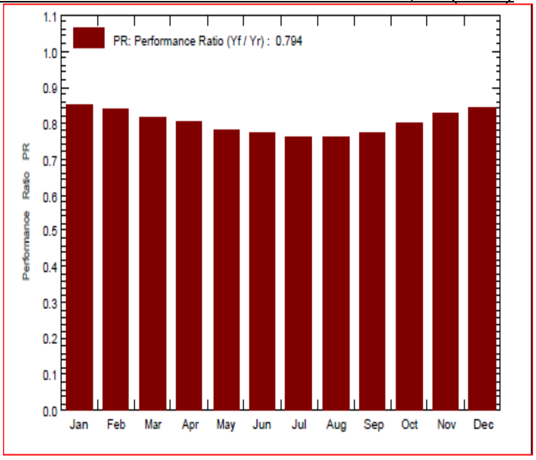
Figure (6); shows the monthly PR and CF in a real system. The CF increased with higher energy yield in summer and lower in winter. The annual average CF was 18.06%, with a maximum of 20.02% in August and a minimum of 14.64% in December. CF indicates how long the PV system operates at its maximum capacity, which is about 67 days or 1612 hours per year. CF affects the cost of power generation from the PV system. PR and CF are important parameters to evaluate grid-tied PV systems. Some techniques can improve the PV modules' performance, such as cooling with optical reflectors (Zubeer and Ali, 2021). During the summer months, the PR experienced a decline compared to the winter season. The average annual PR for the examined PV solar system stands at 74%. January, the coldest month, has the highest PR at 83%, while July, the warmest month, reveals the lowest PR at 65%. The current system's performance saw a drop in June, July, August, and September due to the rising temperature module. With a reduction in overall losses, the PR improves. PR serves as an indicator that demonstrates the proximity of the actual performance to an ideal performance throughout its operation.

Figure (7); shows the results of a study on the PR of PV-syst software in its 1st and 10th years of operation. The annual average PR for the 1st year was 83.22%, while for the 10th year it was 79%. The study found that the PR decreased below average during May, June, July, and August due to an increase in ambient temperature causing thermal loss in PV panels.

When comparing these results to a real system with an annual average PR of 74% at an average temperature of 30.3°C, it was found that there was a drop in performance between the first year by PVsyst software and the real system. This drop is attributed to the operating age of the system and a calculated Degradation Factor of 5% over ten years (0.4%/year). Despite differences in temperature rates, the difference between PR for both systems was close, indicating that high ambient temperatures did not significantly affect performance. The study shows that PV-syst software had an annual average CF of 19.96% and 18.95% for its first and tenth years respectively. These values were only slightly different from those of a real system (HIT), which had CFs of only 1.9% and 0.89% higher despite working at higher ambient temperatures.




**(a)**




**(b)**

**Figure (7) Performance Ratio for, a) 1st Year, and b) 10th Year by PVsyst Software.**

The rate of PV module degradation is influenced by manufacturing methods, ambient factors, and technology. Transferring the findings of degradation analysis from one nation to another is difficult. As a result, it is difficult to estimate how quickly PV modules would degrade in the hostile environment of hot, dry Iraq. Additionally, certain breakdown patterns are only visible after years of fieldwork. The Japanese 15kW high-efficiency system has a low rate of degradation that doesn't go over 5%. which has a service life of more than 10 years and this means 0.4 %/year.

The reason for the difference in losses between the real system and the simulation software is the cleaning method, where the soiling loss has been evaluated in the simulation software PVsyst and SAM 2%. So, the performance Ratio becomes higher, while in the real system, the cleaning was between spaced periods because of the high temperature in summer which means a higher loss, and this makes the PR for the real system less than the PR in the simulation software; as shown in Table (4).

**Table (4) Expected losses for the Actual System by Simulation Tools.**

| Losses | PV-syst | SAM |
|---|---|---|
| Near Shading | No Shading | No Shading |
| IAM factor on global | -2.4% | -1.48% |
| Soiling loss factor | -2% | -2% |
| PV loss due to irradiance level | -0.5% | -0.43% |
| PV loss due to temperature | -7.6% | -6% |
| Mismatch loss, modules, and strings | -3% | -2% |
| Ohmic wiring loss | -1% | -1.5% |
| Inverter Loss due to power threshold | -0.01% | -0.49% |
| Inverter Loss during operation (efficiency | -2.8% | -2.52% |
| Energy to grid | -0.1% | -0.2% |
| Degradation factor | -0.4% | -0.5% |

## Conclusions

In the current study, many facts were confirmed:

• PV Energy Generation of HIT system near simulation programs (PVsyst and SAM) works with an annual rate of the ambient temperature of 24.07°C and 23.8°C unlike the real HIT system, which has an annual rate of the ambient temperature of 30.3°C and is affected by rain, clouds, and dust. This means that the real system (HIT System) is not significantly affected under hot weather for the city of Baghdad concerning the temperature coefficient of the module that equal to -0.29%/°C.

• Annual average performance ratio and capacity factor are found to be 74% and 18.06 % respectively, which is within the range of studies conducted in other countries. The annual degradation rate is determined based on the PR of the system and is found to be 0.4 %/year.

• The difference between the energy output values of the actual system and PV-syst, SAM software for (10th year) is 1164kWh, 1138kWh while the difference values between PV-syst and SAM software systems was 26kWh.

• There are some evaluated results, the most important expected PV losses that affect the module performance were estimated by PV-syst and SAM software due to irradiance level, and temperature losses were 0.5%, 7.6%, and 0.2%, 7%, respectively.

• The simulation results of solar PV generally deviate from the actual performance, due to the impact of factors like soiling, shading, array mismatch, and wirring losses.

**List of Abbreviations.**

| Abbreviation | Meaning |
|---|---|
| PV | Photovoltaic |
| YF | Final Yield |
| YR | Reference Yield |
| CdTe | Cadmium Telluride |
| CIGS | Copper Indium Gallium Selenide |
| CIS | Copper Indium Selenide |
| MPPT | Maximum Power Point Tracking |
| AC | Alternating Current |
| DC | Direct Current |
| PR | Performance Ratio |
| CF | Capacity Factor |
| DR | Degradation Rate |
| SAM | System Advisor Model |
| HIT | Heterojunction with Intrinsic Thin Layer |
| PSH | Peak Sun Hours |
| MPPT | Maximum Power Point Tracking |
| POA | Plane of Array |

**List of Symbols.**

| Symbol | Meaning |
|---|---|
| EAC,t | AC energy output in min. |
| EAC,h | AC energy output in hour |
| EAC,d | daily AC energy output |
| EAC,m | monthly AC energy output |

| | |
|---|---|
| EAC | Alternating current energy product |
| N | Number of days in a month |
| HT | in-collimated plane solar irradiation |
| HR | Reference Solar Irradiance |

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