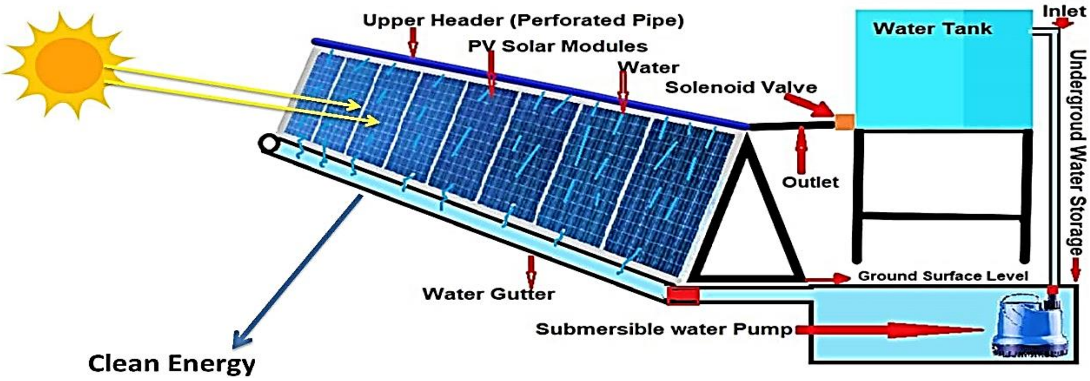
Improve The Conversion Efficiency and Electrical Output of The Solar PV System by Developing and Implementing a Cooling System

Alaa N. Abed[1,*] Naseer K. Kasim[2] and Basim I. Wahab[1]
[1,3] Department of Atmospheric Science, College of Science, Mustansiriyah University, Baghdad-Iraq
[2] Ministry of Electricity/Training and Energy Research Office, Baghdad-Iraq



ABSTRACT: The performance of the grid-connected solar photovoltaic (PV) system in the present study is improved using cooling technology. This technology reduces the temperature of solar PV modules and thus increases their efficiency and lifespan. The current solar PV system has been installed in northern Baghdad in the city of Taji. This study included improving electrical power, conversion efficiency, and performance ratio. All of these improvements are achieved by cooling using water. The performance ratio (PR) and efficiency maximum values of the reference (unimproved) and improved solar PV modules are at 10:10 am at 88.30% & 96.30% and 13.4% & 14.6%, respectively. Improved and reference PV modules maximum solar radiation values occur at 12:00 pm at 1.91 W and 1.566 W, respectively. The maximum solar radiation values of the reference and improved PV modules are at 12:00 pm at 922.9 W/m² and 1012.22 W/m², respectively. The maximum daily gain of the power and solar irradiance are 22% and 10%, respectively. The significant innovation in the study is the successful performance optimization of the grid-connected solar PV system. Using different equations to study performance by following different behaviors. Along with improving and studying CIGS PV module performance.

الملخص: تم تحسين أداء نظام الطاقة الشمسية الكهروضوئية المتصل بالشبكة في الدراسة الحالية باستخدام تقنية التبريد. تعمل هذه التقنية على خفض درجة حرارة وحدات الطاقة الشمسية الكهروضوئية وبالتالي زيادة كفاءتها وعمرها. تم تركيب النظام الشمسي الكهروضوئي الحالي في شمال بغداد في مدينة التاجي. تضمنت هذه الدراسة تحسين الطاقة الكهربائية وكفاءة التحويل ونسبة الأداء. يتم تحقيق كل هذه التحسينات عن طريق التبريد باستخدام الماء. يبلغ الحد الأقصى لنسبة الأداء (PR) وقيم الكفاءة للألواح الشمسية الكهروضوئية المرجعية (غير محسنة) والمحسنة عند الساعة 10:10 صباحاً بنسبة 88.30% و96.30% و 13.4% و14.6% على التوالي. القيم العظمى للإشعاع الشمسي للألواح المحسنة والوحدات المرجعية يكون عند الساعة 12:00 ظهرًا بمقدار 1.91 واط و1.566 واط، على التوالي. الحد الأقصى لقيم الإشعاع الشمسي للوحدات المرجعية والمحسنة هو عند الساعة 12:00 ظهرًا عند 922.9 واط/م2 و1012.22 واط/م2، على التوالي. الحد الأقصى للربح اليومي للطاقة والإشعاع الشمسي هو 22% و10% على التوالي. الابتداع المهم في الدراسة هو تحسين الأداء الناجح للنظام الشمسي الكهروضوئي المتصل بالشبكة . استخدام معادلات مختلفة لدراسة الأداء من خلال اتباع سلوكيات مختلفة. بالإضافة الى تحسين ودراسة أداء الوحدة الكهروضوئية ذات الاغشية الرقيقة CIGS.

Keywords: Solar Radiation, Cooling, Performance, Efficiency, Thin film.

الكلمات المفتاحية: الإشعاع الشمسي، التبريد، الأداء، الكفاءة، الأغشية الرقيقة.

Corresponding author's e-mail: alaajaw716@gmail.com

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NOMENCLATURES

AC: Alternating-Current.
Am: Array area.
CIGS: Copper Indium GalliumSelenide.
DC: Direct Current.
EAC: Alternating energy production.
PINCP: Power Increment Percentage.
INCP: Increment Percentage.
HR: Reference Solar Irradiance.
HT: In-plane solar insolation.
MPPT: Maximum Power Point Tracking.
PR: Performance Ratio.
PV: Photovoltaic.
S.IR: Solar Irradiance.
Tm: PV module temperature.
Tref: PV module reference temperature.
β: Temperature-coefficient.
Href: Rated efficiency.
T/PV: Thermal/Photovoltaic system.
Timp: The improved PV modules' temperature.
Tref: The reference PV modules' temperature.

INTRODUCTION

Technology that relies on solar energy is environmentally friendly. While the fossil fuel sources (traditional fuels) used in conventional electrical power generation systems are limited and expected to become less abundant and more expensive in the future, the demand for electricity is steadily rising (Abdeen and Rosen, 2011). Conventional fuels are hazardous to the environment because they contribute to acid rain, global warming, air pollution, ozone layer depletion, and ground and surface water pollution. Due to carbon dioxide emissions into the atmosphere, global warming is the main cause of environmental damage and human risks. Approximately 32,381 million tons of carbon dioxide are emitted globally in 2014 (Jacobson and Delucchi, 2009). While solar PV systems reduce CO2 emissions by more than 100 gigatonnes (Qasim et al., 2023). The PV module cost is reduced by 50% to 60% when using concentrated solar power (CSP) (Al-Shamani et al., 2016). Solar PV and solar thermal energy are the two categories under which solar energy applications are classified. The photovoltaic sector includes applications that use solar photovoltaic to convert solar radiation into electricity, such as traffic lights, satellite applications, etc., while the solar thermal sector includes the conversion of solar energy into useful heating, such as solar cookers, solar heaters using solar collectors, etc. That (Anderson et al., 2009).

There are many studies on using cooling to boost energy production, increase efficiency, and lower the temperature of solar PV modules, but they all have different approaches. The cooling system created by Firouzzadeh et al., (2022) consists of fins built with different zigzag and straight geometries. According to the results, the straight and zigzag geometry with 10 fins can achieve a temperature reduction of 9°C and 15°C, as well as an increase in output power of 8% and 14%, respectively. A cooling system is established by Ozgoren et al., (2013) to reduce the temperature of PV module in ambient conditions of Konya Province (Turkey). They found that the conversion efficiency of the PV module increased by 10% when using water cooling. Hadipour et al., proposed two different types of cooling systems: pulsed spray water cooling system and constant spray water cooling system. According to the results, the use of steady spray water cooling and pulsed spray cooling, respectively, enhances the electrical power output of solar modules by about 33.4% and 27.7% Hadipour et. al, (2021).

In order to increase efficiency and reduce the impact of thermal degradation in hot and arid environments, Dida et al., (2021) developed passive cooling systems for PV modules. They discovered that when the temperature of the PV module decreased by 20°C, the efficiency increased to 14.75% where the reference efficiency is 13.27%. The developed cooling system is based on water evaporation and capillary action of burlap fabric which is directly fixed on the back surface of the PV module. Yildirim, Cipolla and Sović developed the thermal photovoltaic (T/PV) collector system. Under normal operating cell temperature (NOCT) conditions, different mass flow rates and temperatures are simulated. The results show that at a mass flow rate of 0.0140 kg/s and an input flow temperature of 15°C, the solar PV module produces a thermal efficiency of 76.13% and an electrical efficiency of 17.790% (Yildirim et al., 2022). Zubair and Ali proposed a concentrator PV module (CPV) and a CPV system with cooling method to improve the electrical performance of PV modules. When compared with the reference PV module, they found that the maximum electrical output of the CPV system and the CPV system with cooling improved by 8% and 18.5%, respectively (Zubair et al., 2021). Bahaidarah, Rehman, Gandhidasan, and Tanweer built a solar PV system in Dhahran, Saudi Arabia that uses water flow to cool the back of a PV module. The results indicated that the conversion efficiency of the solar PV module increased to 9%, and its operating temperature decreased to about 20% (Bahaidarah et al., 2013). Muneshwaran et al., (2020) developed a cooling system that uses an air conditioner installed on the roof of a building to cool a rooftop PV module. The cooled PV module has a temperature

6-12°C lower than the uncooled module, according to experimental data.

Figure 1. Present PV solar modules.

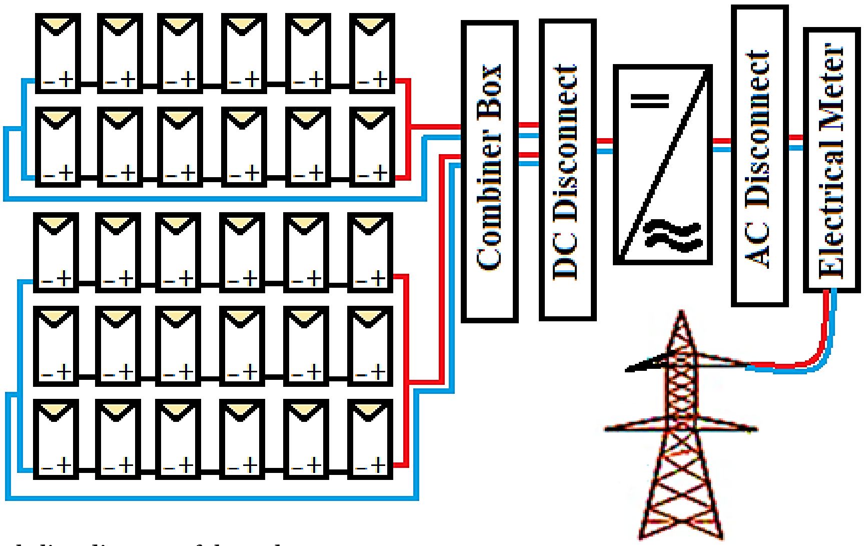

Figure 2. Single line diagram of the solar PV system.

Table 1. Properties of PV systems and PV modules.

PV System Specifics	Information	PV Module Specifics	Information
Array area	32 m2	Max power (Pmax)	165W
System size	5 kW_p	Open-circuit.voltage(V_{oc})	88.7V
Inverter efficiency	97%	Short. Circuit.current(I_{sc})	2.66A
Inverter size	5.30 kWp	Max power voltage(V_{mpp})	68.5V
Modules number	30	Max power current (I_{mpp})	2.41A
PV modules Tilt angle	30^{O}	Max. reverse. current (I_R)	6.5A
Temperature coefficient Pmax	-0.3%/^{O}C	Operating temperature	-40°C to 85°C
Inverter model	SMA- SB-5000T-21	Module model	TS-165C2- CIGS

Alberto Benato et al., also tried the 1.5 bar spraying technique and concluded that the efficiency and power generation increased to 13.27% and 212.31 W from 11.18% to 178.88 W, respectively (Benato et al., 2021).

The goal of this work is to improve the performance and efficiency of PV solar modules, which will increase electricity production and provide good economic feasibility. Moreover, prevent the PV module from deteriorating due to cooling, as the life of the PV module decreases as the temperature increases. In addition, an evaluation of thin-film PV module technology and grid-connected PV system performance was performed. There are instruments in this PV system that can be used to reduce excess heat in PV modules. Cooling enhances the efficiency of the PV module by reducing excess heat.

2. SOLAR PV SYSTEM DESCRIPTION

The existing photovoltaic system is situated in the Baghdad/Al-Mansour company at the coordinates 33.33ºN (latitude) and 44.4ºE (longitude), as shown in Fig 1. This photovoltaic system consists of 30 modules arranged in 5 series of 6 modules each shown in Fig 2. Table 1 lists the details of the PV system and PV module.

3. COOLING SYSTEM AND PV MODULE DIVISION

In this study, the existing PV system is divided into two groups; The first set, consisting of 12 modules, is classified as an improved group, and the second group, consisting of 18 modules, is a reference group. The percentage increase (gain) in the electrical parameters of the solar PV system (power output, performance ratio, conversion efficiency) is calculated by comparing the improved group with the reference group. There are two inputs to the inverter used in existing solar PV systems: the improved group input, which includes 12 PV solar modules and produces 1980Wp, and the reference group input, which includes 18 PV solar modules and produces 2970 Wp. The inverter is connected to the computer via a speed wire, which is used to collect data. The data is shown by the inverter in two groups (A and B), as shown in Fig 3.

While Group (A) displays data for the improved group, Group (B) displays data for the reference group. The inverter device in the current PV system consists of two inverters using maximum point tracking (MPPT) technology (Babaa et al., 2014).

In terms of cooling technology, Figs.4 and 5 show this technology. The improved group includes a cooling system while the reference group remains without a cooling system. Water will flow towards the solar PV modules inside the perforated tube that runs along the improved group (modules) when the water tank tap is opened. The water will then drip over these PV modules and collect in the gutter, after which it will collect in the groundwater storage before being pumped back into the tank. During the cooling process, this circulation is constantly repeated.

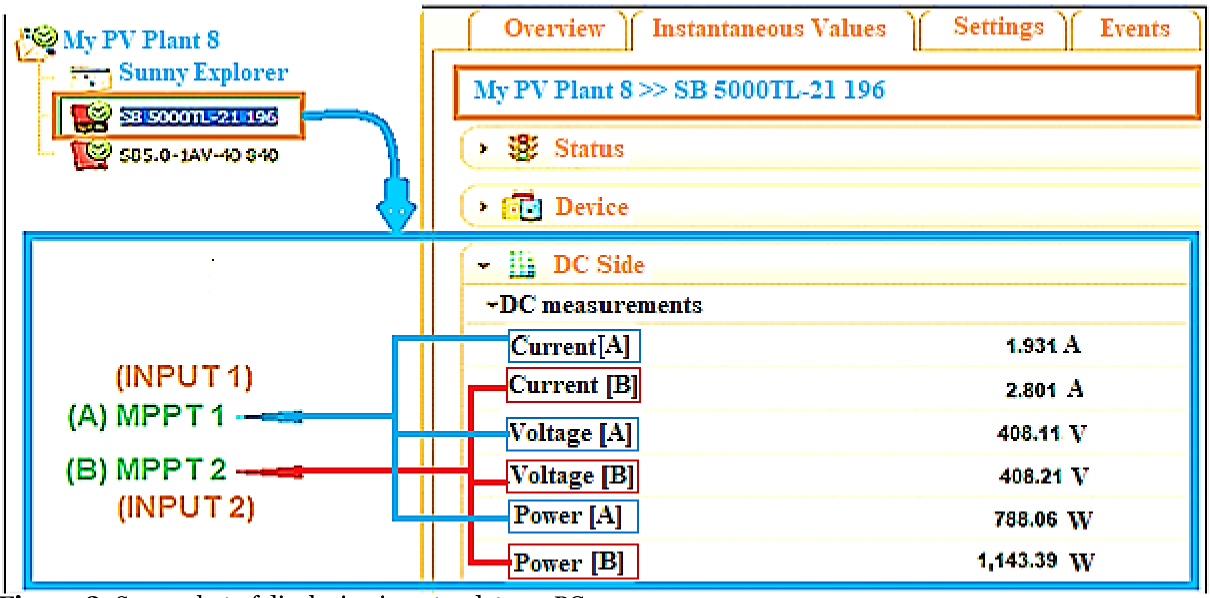

Figure 3. Screenshot of displaying inverter data on PC.

4. STUDY PLANNING

This experimental work is conducted to study the effect of water cooling on the performance of solar PV systems. The maximum solar radiation and ambient temperature are 950 W/m2 and 45°C, respectively. The current solar PV system has a capacity of 5 kW and is located in Baghdad / Al-Mansour Company (latitude: 33.3°N, longitude: 44.4°E). In addition to solar radiation, module temperatures and ambient temperatures, electrical parameters that are improved include power, performance ratio and efficiency. The temperatures of the improved and reference groups are recorded. For the reference and improved groups, the aforementioned electrical parameters are recorded. Inverter Displays solar PV system data separately in (A and B) format, and provides data for each input (group). On July 15, 2020, current work takes place from 9:00 am to 6:00 pm. The weather is clear and the PV modules are clean.

The cooling period runs from 9:50 am to 12:10 pm on the day of the study. At 9:50 am, the water temperature inside the tank reaches 33oC, and at 12:10

pm the temperature reaches 37 degrees Celsius. This increase in the tank water temperature is due to the heat of the PV modules, as the water absorbs heat from these PV modules and then returns to the tank again. Cooling stops for one hour to study the temperature gradient of the PV modules to determine how long the cooling will last. After one hour, cooling begins again for one hour. Although the water tank is wrapped in cardboard, it is heated by solar radiation and ambient air. Most of the heat is removed by water flowing along the gutter, then into the underground storage and then into the tank, i.e. by water circulation as shown in the Figs. 4 and 5 below. The actual and virtual cooling systems are shown in Figs. 4 and 5, respectively.

The solenoid valve shown in Fig 5 controls the water flow in the event of a power outage. When the power goes out, this valve closes the water tap. This valve is critical because when the power goes out, the submersible water pump shuts down and is no longer able to lift water into the tank. Electricity is still on at the work site.

5. ELECTRICAL PARAMETERS ASSESSMENT

The reference and improved groups are studied in terms of the above mentioned electrical parameters (PR, array efficiency, and power output). The power output that exists the inverter is obtained via the speedwire. While the performance ratio (PR), solar radiation, and array efficiency are calculated using the set of equations below. The ambient temperature and PV module temperatures are measured using a digital thermometer. A dual-channel digital thermometer is used to measure ambient temperatures and solar PV modules. The sensor type is thermocouple K (NiCr-NiAI). The temperature range of the digital thermometer is about -40 to 1200°C (OC mode), -40 to 2000°C (OFF mode).

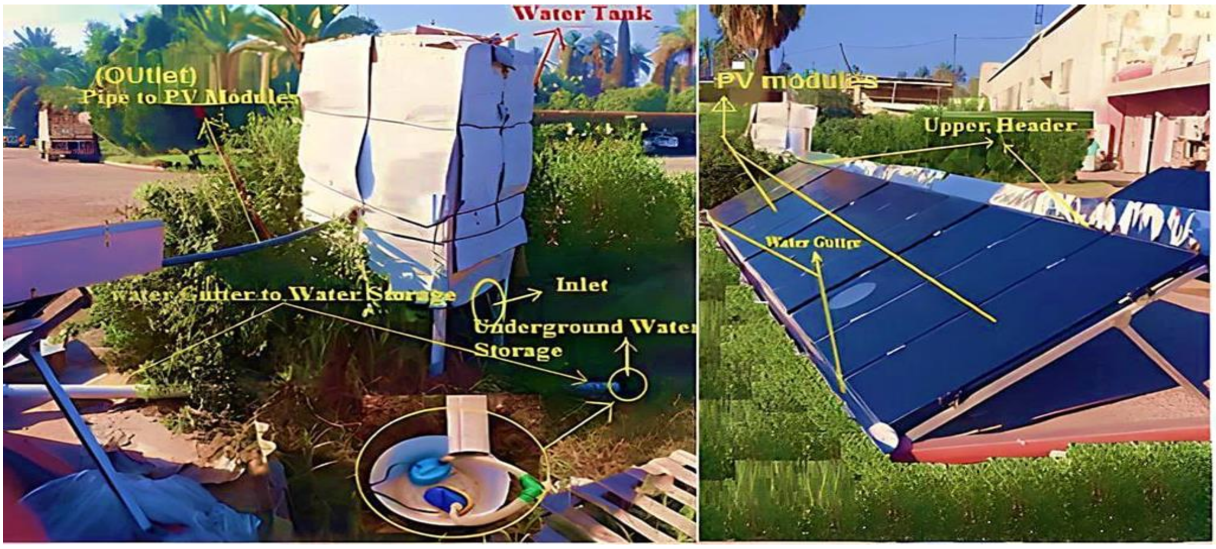

Figure 4. Actual diagram of the cooling system.

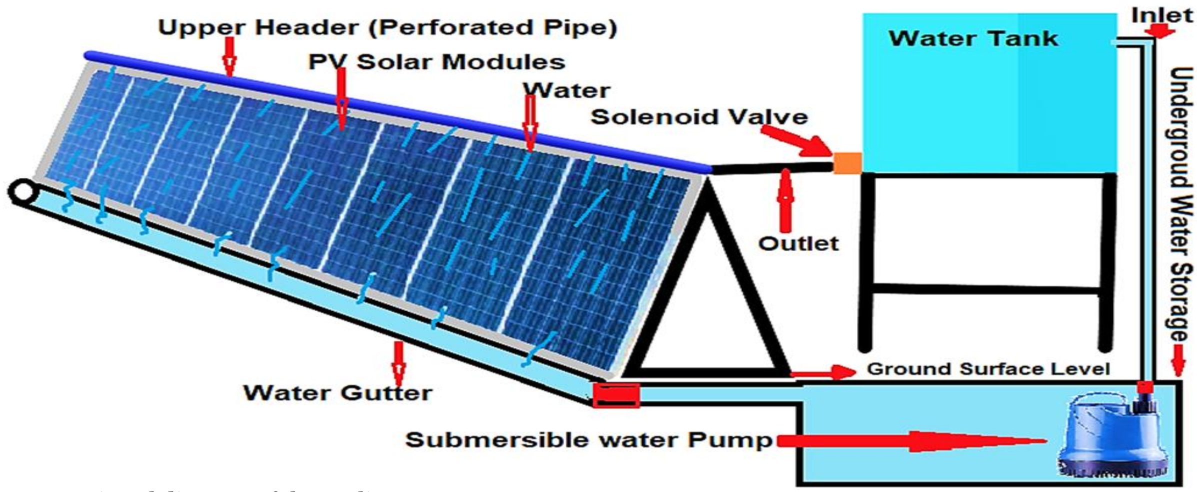

Figure 5. Virtual diagram of the cooling system.

5.1. Efficiency

There are three types of PV system efficiency: inverter efficiency, system efficiency, and array efficiency. System efficiency (ηsys) is calculated using the AC power (or AC energy) output. The array efficiency (ηPV) is calculated using the DC power (or DC energy) output (Satsangi et al., 2018). ηPV is estimated as the average DC power production divided by the area of the PV array (PV modules) multiplied by the average in-plane solar insolation .ηPV is estimated as follows (de Lima et al., 2017):

$$\eta_{PV} = \frac{E_{DC}}{H_T\ A_m} 100\% \quad (1)$$

The system efficiency is estimated as (Najem, A., 2022):

$$\eta_{Sys} = \frac{E_{AC}}{H_T\ A_m} 100\% \quad (2)$$

Where; E_{DC}: DC energy, E_{AC}: AC energy , H_T: solar insolation (in-plane), and A_m: PV array area.
The inverter efficiency is estimated as follows:

$$\eta_{INV} = \frac{E_{AC}}{E_{DC}} 100\% \quad (3)$$

An inverter efficiency ranges from 97% to 96% (Kasim et al.,2020).

5.2. Performance Ratio (PR).

PR is an important indicator because it displays the overall losses in a solar PV system. The PR value indicates how close the PV system's actual PR is to the ideal PR under actual operating circumstance . PV systems can be compared via PR regardless of installation location, azimuth angle, tilt angle, solar radiation and rated power. The PR is given as follows (Abed et al., 2023; Ozden et al., 2017).

$$PR = \frac{Y_F}{Y_R} 100\% \quad (4)$$

Where: Y_F and Y_R are the final yield and the reference yield calculated via equations 5 and 6, respectively.

Y_F is the AC energy output for a limited time dividing by the PV solar system's rated power. The final yield indicates how many hours per day the PV system produces its nominal power. Y_F is given as follows: (Sundaram et al.,2015; Abed et al., 2020).

$$Y_F = \frac{E_{AC}}{P_{PV.rated}} 100\% \left(kWh / kW_P\right) \quad (5)$$

The reference yield (Y_R) is the in-plane global insolation (irradiance) over the reference irradiance (1000 W/m^2). Y_R is estimated by equation 6 (Rezk et al., 2019; Humada et al., 2016):

$$Y_R = \frac{H_T}{H_R} \left(kWh / kW_P\right) \quad (6)$$

Where: H_T and H_R are the in-plane global insolation and reference irradiance , respectively. Equations (5) and (6) are substituted into equation (4) to obtain equation (7) as follows (Kasim et al.,2019 ; Vikraman et al.,2020).

$$PR = \frac{E_{AC} H_R}{P_{PV,rated} H_T} 100\% \quad (7)$$

PR can also be given in another equation as follows: (Kasim et al.,2020):

$$PR = \frac{\eta_{Actual}}{\eta_{ref}} \tag{8}$$

In this work, the PR is estimated using equation 8.
Rated power (P_{Rated}) and actual power (P_{AC}) are calculated as follows:

$$P_{Rated} = H_R \, \eta_{ref} \, A_m \tag{9}$$

$$P_{AC} = H_R \, \eta_{Actual} \, A_m \tag{10}$$

The actual efficiency (η_{Actua}) is calculated as follows:

$$\eta_{Actual} = \eta_{ref} \, [1-\beta(T_m-T_{ref})] \tag{11}$$

Or.

$$\eta_{Actual} = \frac{\text{Electrical Power}}{\text{Solar Irradiance}*Area} \tag{12}$$

Where: η_{ref} : nominal efficiency (15.20%), A_m : area of improved and reference PV modules (13.04 m^2 each), β:thermal coefficient (-0.3%/^{O}C), T_{ref} : reference temperature of PV module (25^{O}C), and T_m : Actual temperature of the PV module.
From equation10 , equation 13 is attained as follows:-

$$H_R = \frac{P_{AC}}{A_m \eta_{Actual}} \tag{13}$$

Where: P_{AC} and η_{Actual} represent, respectively, the actual power output and the actual efficiency.
The actual efficiency (η_{Actual}) and solar irradiance (H_R) are estimated using equations 8 and 13, respectively.
The power increment percentage (PINCP) is calculated by equation 14.

$$PINCP = \left(P_{im} - P_{ref}\right) / \; P_{ref} 100\% \tag{14}$$

6. RESULTS AND DISCUSSION

Figure 6 displays the power output of the reference PV modules (reference group) and the improved PV modules (enhanced group). The highest power output of the improved and reference PV modules at 12:00 pm are 1.91 kW and 1.566 kW, respectively, and the highest PINCP (power gain) is 22%. The daily average of PINCP (during cooling time) is 18%. This gain has a significant effect on the economic feasibility of constructing a solar PV system. There are a tops and bottoms in the PINCP curve and in the power bars of the improved PV modules in this Fig. Bottoms are formed due to cooling stopping, but the tops are formed by cooling continuing. The cooling technique improves the voltage as it increases the band gap of the semiconductor and thus reduces the potential barrier resistance. Ultimately, cooling technology increases the electrical power, efficiency, performance ratio and lifespan of the PV module.

The water used in the cooling process aids in removing soiling from the PV modules. Removing soiling from PV modules makes them clean, increases power output and reduces heat because soiling causes hot spots on solar PV modules.

The performance increment percentage (PR INCP), PR of the reference PV modules, and PR of the improved PV modules are displayed in Fig 7. The highest PR values of the improved group and the reference group PR are at 10:10 am, at 96.3% and 88.3%, respectively. Whereas the highest value of PR INCP (gain) is at 12:00 pm, at 10%. The maximum temperatures of the improved PV modules (Timp) and the reference PV modules (Tref) during the cooling time at 12:00 pm are 41°C and 73.0°C, respectively, with the ambient air at 42.8°C. When cooling stops it can be noticed that the performance ratio of the improved PV modules decreases slowly and after 20 to 30 seconds reaches equality with the PR of the reference modules (when Timp is equal to Tref). Performance ratio is a crucial indicator since it shows overall on-grid PV system losses. It is noticed in Fig. 7, the PR rises and drops with decreasing and increasing the temperature of the modules, respectively. The performance ratio is a crucial indicator because it shows the overall on-grid PV system losses . It is observed in Fig 7 that PR rises and falls as the temperature of the modules decreases and increases, respectively. PR is a metric used to evaluate how well a PV system is performing, taking into account environmental factors such as temperature, radiation, weather condition change, etc. The temperature outside and the amount of pollution are among the most important atmospheric variables that affect PR (Syahindra et al.,2021).

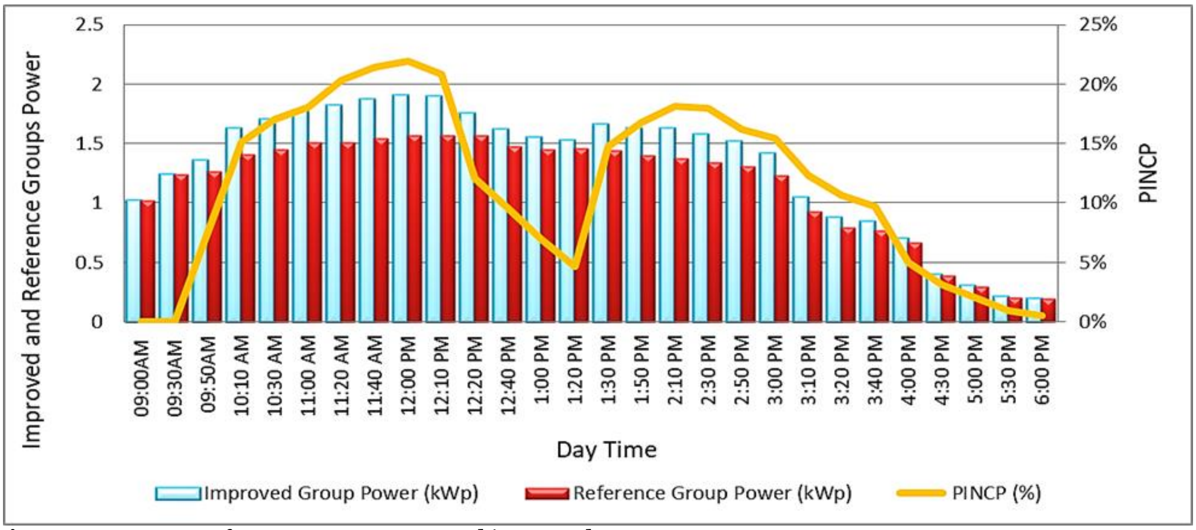

Figure 6. PINCP, Reference group power and improved group power

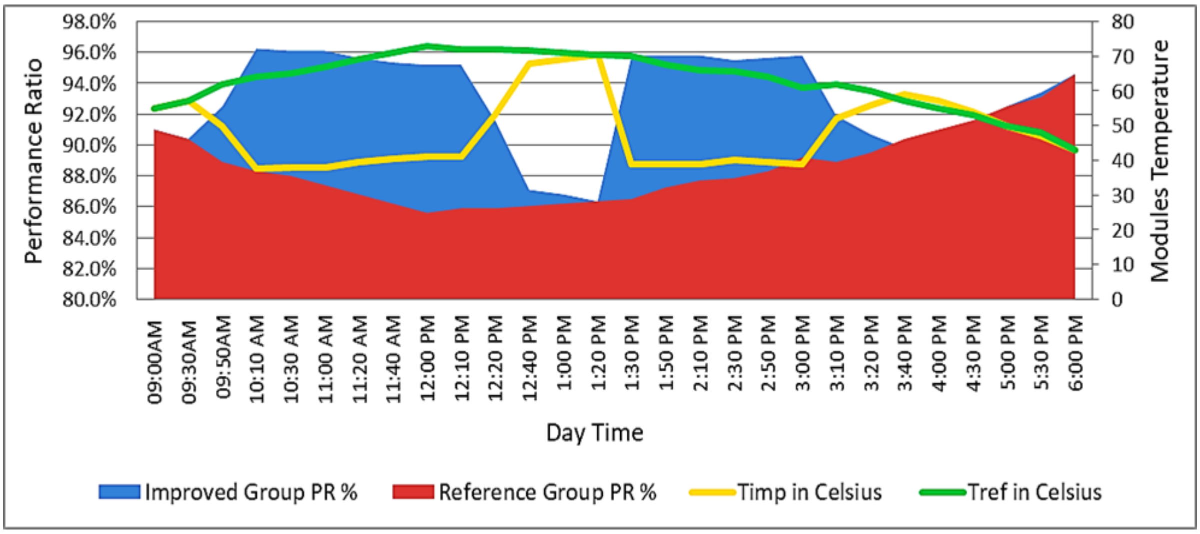

Figure 7. PR INCP and PR for the reference group and improved group

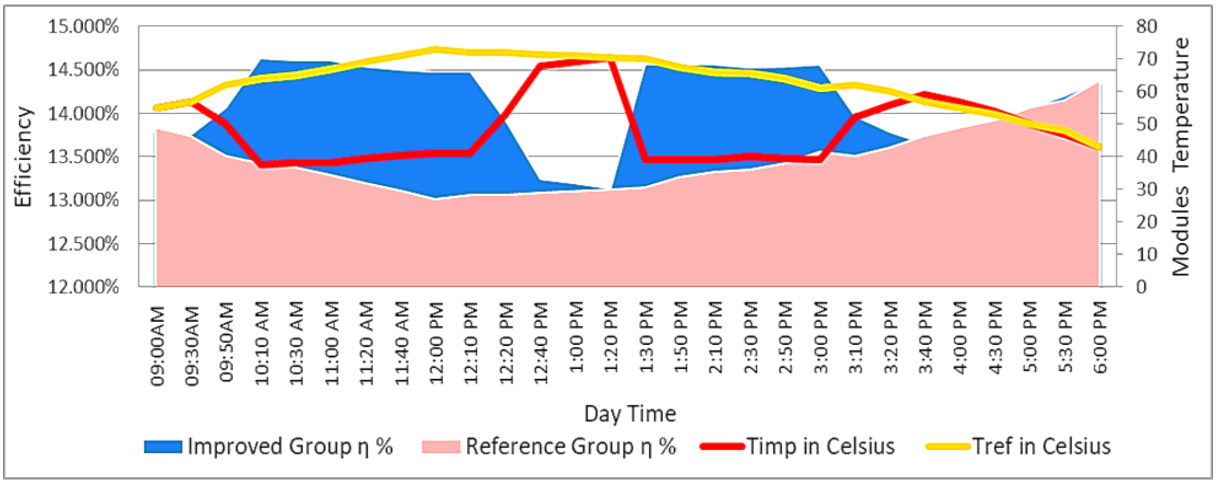

Figure 8. Efficiency (η) INCP, improved group efficiency and reference group efficiency

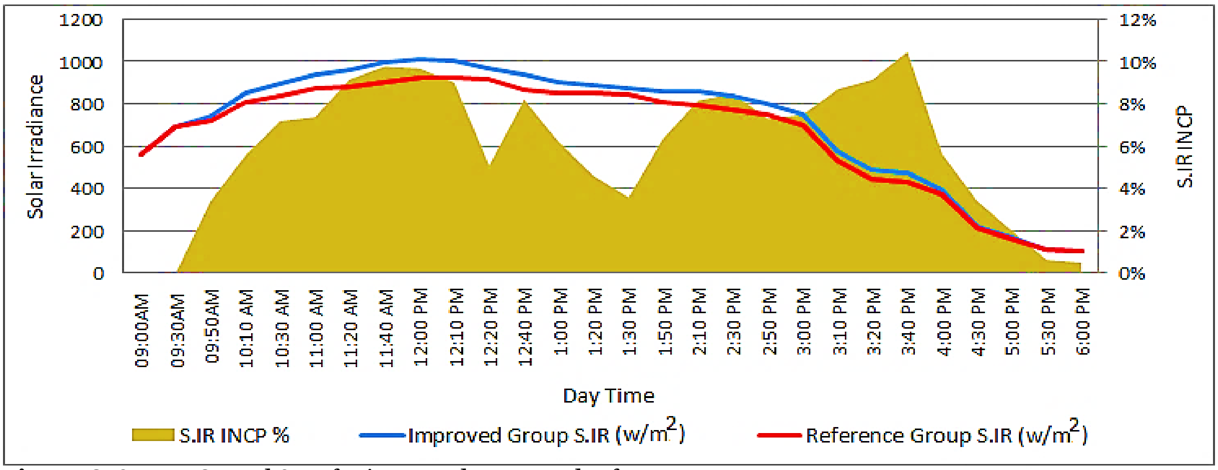

Figure 9. S.IR INCP and S.IR for improved group and reference group .

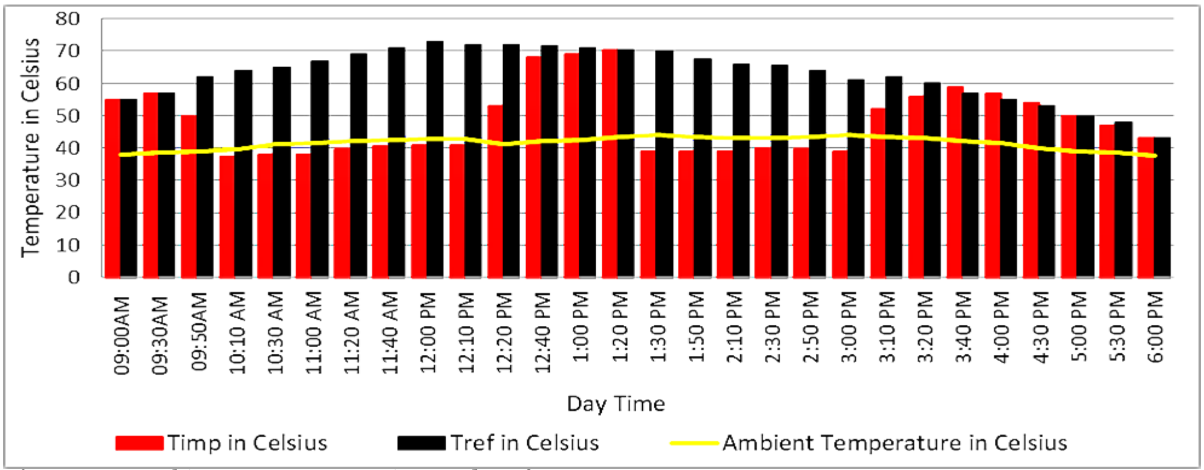

Figure 10. Ambient temperature, Timp and Tref.

The efficiency increase percentage (INCP), improved efficiency group, and reference group efficiency are shown in Fig 8 . The highest efficiency INCP (gain) value is 1.5% at 12 pm, while the maximum efficiency of improved and reference PV modules is 14.5% and 13% respectively at 10:10 am. Timp, Tref and Ambient Temperature are 41ºC, 73ºC and 42.8ºC respectively. In general, the maximum efficiency values are associated with the lowest ambient temperature, specifically at the beginning of sunrise and sunset as shown in Fig 8, where the efficiency at this time for both the improved group and the reference group is 14.4%.

Since the soiling on these PV modules is removed by the cooling water, there is a gain even after cooling stops. Therefore, the gain (INCP) remains even after the cooling influence finishes because the improved PV modules (clean modules) are cleaner than the reference PV modules (which contain some dust).

The two main atmospheric variables that affect efficiency are ambient temperature and the amount of soiling. PV module temperature and ambient temperature have an inverse relationship with efficiency.

The solar irradiance (S.IR) for the improved and reference groups, as well as the solar irradiance increment percentage (S.IR INCP), are shown in Fig 9. The maximum S.IR INCP, improved group S.IR and reference group S.IR at 12:00 pm are 10%, 1012.2 W/m² and 922.9 W/m², respectively. The minimum values are recorded at 6:00 pm are 1%, 106.13 W/m², and 105.59 W/m², respectively.

The INCP value (10%) corresponds to 92.2 W/m2. The water used in the cooling process reduces the reflection of solar radiation from these solar PV modules, which increases solar radiation. This is achieved by acting as an anti-reflective layer.

The water used in the cooling process also removes soiling from the PV modules . soiling reduces solar radiation reaching the PV modules.

Figure (10) displays the ambient temperature in addition to the Timp and Tref. The maximum values of Timp and Tref are measured at 41°C and 73°C, respectively, at 12:00 pm at an ambient temperature of 42.8°C. The minimum values are at 6:00 pm, 43°C and 43°C, respectively, at an ambient temperature of 37.5°C. The temperature of the PV modules decreases by 32°C due to cooling. The voltage rises when cooling reduces the potential barrier resistance of the solar cell. The highest temperature of the PV modules is at 12:00 pm, as solar radiation is perpendicular to these PV modules at that time, while the maximum temperature of the ambient air is at 3:00 pm.

The temperature curve of the improved PV modules in Fig 10 has tops and bottoms. When cooling stops, the tops appear, and when cooling begins, the bottoms appear. It is observed that the temperature of the PV modules drops rapidly at the start of cooling, and rises gradually when cooling stops, then stabilizes at the final temperature.

CONCLUSION

The current study comes to the following conclusions:

- By implementing a cooling system, significant improvements are made in terms of efficiency, power output, PR and solar radiation.
- Maximum PINCP (power gain) is 22%. Compared to power output increased to (8% and 14%), (13.27%), and (33.4% and 27.7%) by Firouzzadeh et al., Alberto Benato et al., and Hadipour, respectively.
- The maximum improvements in performance and efficiency ratio are 10% and 1.5% respectively. While Dida et al., reduced the PV module at around 20°C, this means a 1.47% increase in efficiency because efficiency increases by 0.5% when the solar module temperature drops by 1°C.
- This cooling system is considered the most efficient compared to other cooling systems in the list of cooling systems as the module temperature in this work decreased more than any other literature study in this paper.
- The maximum value of S.IR INCP during cooling is estimated to be 10%.
    - At 12:00 pm, when the temperature of the solar PV modules reaches its maximum, cooling reduces it by 32°C. While the highest temperature drop of PV module in the literature review presented is 20°C.
    - Water used for cooling has a significant effect on removing soiling from solar PV modules.
    - The authors suggest the following:
        1- Improving the performance of PV modules by using water cooling through the back side jacket.
        2- Study the extent of the effect of cooling on reducing the deterioration of PV modules.
        3- Integrating a smart water-spray cleaning mechanism into solar PV modules.
        4- To release the heat absorbed by the water from the solar PV modules, bury the water tank in the ground.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding this article.

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REFERENCES

Abed AN, Hussain HH, Kasim NK (2020), Efficiency and Performance Improvement Via Using Optical Reflectors of On-Grid CIGS PV Solar System. Karbala International Journal of Modern Science 6, 1, 1-0.

Abed A. N., Kasim, N. K. and Hussain H. H. (2023) "On-Grid Mono-Si PV Solar System Performance Evaluation in Baghdad," In IOP Conference Series: Earth and Environmental Science, 1223, 1, 12025, IOP Publishing.

Abedin A. and A Rosen M (2011), A critical review of thermochemical energy storage systems. The open renewable energy journal 4, 1, 42-46.

Al-Shamani AN, Sopian K, Mat S, Hasan HA, Abed AM, Ruslan MH (2016), Experimental studies of rectangular tube absorber photovoltaic thermal collector with various types of nanofluids under the tropical climate conditions. Energy Conversion and Management 15, 124 , 528-42.

Anderson TN, Duke M, Morrison GL, Carson JK. (2009), Performance of a building integrated photovoltaic/thermal (BIPVT) solar collector. Solar energy 83, 4, 445-55.

Babaa SE, Armstrong M, Pickert V (2014), Overview of maximum power point tracking control methods for PV systems. Journal of Power and Energy Engineering. 2, 59-72.

Bahaidarah H. M., Rehman S., Gandhidasan P. and Tanweer B. (2013) "Experimental evaluation of the performance of a photovoltaic panel with water cooling. In 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC) 2987-2991, IEEE.

Benato A, Stoppato A, De Vanna F and Schiro F (2021), Spraying Cooling System for PV Modules: Experimental Measurements for Temperature Trends Assessment and System Design Feasibility. Designs 5, 2, 25.

de Lima LC, de Araújo Ferreira L, de Lima Morais FH (2017), Performance analysis of a grid connected photovoltaic system in northeastern Brazil. Energy for Sustainable Development 37, 79-85.

Dida M, Boughali S, Bechki D, Bouguettaia H (2021), Experimental investigation of a passive cooling system for photovoltaic modules efficiency improvement in hot and arid regions. Energy Conversion and Management 243, 114328.

Firoozzadeh M, Shiravi AH, Chandel SS (2022), An experimental analysis of enhancing efficiency of photovoltaic modules using straight and zigzag fins. Journal of thermal analysis and calorimetry, 147, 16, 8827-8839.

Hadipour A, Zargarabadi MR, Rashidi S (2021), An efficient pulsed-spray water cooling system for photovoltaic panels: Experimental study and cost analysis. Renewable Energy 1, 164, 867-75.

Humada AM, Hojabri M, Hamada HM, Samsuri FB, Ahmed MN (2016), Performance evaluation of two PV technologies (c-Si and CIS) for building integrated photovoltaic based on tropical climate condition: A case study in Malaysia. Energy and Buildings, 1, 119, 233-241.

Jacobson M Z and Delucchi MA (2009), A path to sustainable energy by 2030 Scientific American. November. 58-65.

Kasim NK., Hussain HH and Abed AN (2019) Performance analysis of grid-connected CIGS PV solar system and comparison with PVsyst simulation program. International Journal of Smart GrÄ±d 3, 4, 172-179.

Kasim NK, Hussain HH, Abed AN (2020), Studying the performance of second-generation PV solar technology under Baghdad climate. *Research Journal in Advanced Sciences* 1, 2, 37-48.

Kasim NK., Hussain HH and Abed AN (2023), Annual Optimization of Grid-Tied Solar PV System Performance Parameters Using Two Techniques. JEEE 15, 2, 118-128.

Muneeshwaran M, Sajjad U, Ahmed T, Amer M, Ali HM, Wang CC 2020,Performance improvement of photovoltaic modules via temperature homogeneity improvement. Energy 15, 203, 117816.

Najem A (2022), Yearly Improvement of Grid-Connected Solar PV System Parameters by Planar Concentrators. *The Journal of Engineering Research [TJER]* 19, 2, 140-51.

Ozden T, Akinoglu B G and Turan R (2017), Long term outdoor performances of three different on-grid PV arrays in central Anatolia–An extended analysis. Renewable energy 1, 101, 182-195.

Ozgoren M, Aksoy MH. Bakir C and Dogan S (2013), Experimental performance investigation of photovoltaic/thermal (PV–T) system. In EPJ Web of Conferences, 45, 01106. EDP Sciences.

Rezk H, Gomaa M. R and Mohamed, M. A (2019), Energy performance analysis of on-grid solar photovoltaic system-a practical case study. *International Journal of Renewable Energy Research (IJRER)* 9, 3, 1292-1301.

Satsangi P, GS SB and Saxena AK. (2018, Performance analysis of grid interactive solar photovoltaic plant in India. Energy for Sustainable Development 47, 9-16.

Sundaram S and Babu JS (2015), Performance evaluation and validation of 5 MWp grid connected solar photovoltaic plant in South India. Energy conversion and management 100, 429-439.

Syahindra KD, Ma'arif S, Widayat AA, Fauzi AF and Setiawan EA (2021), Solar PV system performance ratio evaluation for electric vehicles charging stations in transit oriented development (TOD) areas. In E3S Web of Conferences, 231, 02002. EDP Sciences.

Vikraman VK., Kumar DP and Mahendiran R (2020), Performance analysis of 3 kWp rooftop grid-connected solar photovoltaic system in an urban house of southern India. Journal of Agricultural Engineering 57, 1, 56-62.

Yildirim MA, Cebula A, Sułowicz M (2022), A cooling design for photovoltaic panels–Water-based PV/T system. Energy 256, 124654.

Zubeer SA. and Ali OM (2021), Performance analysis and electrical production of photovoltaic modules using active cooling system and reflectors. *Ain shams engineering journal,* 12, 2, 2009-2016.