

## Performance Optimization of Solar PV System Utilized for Cooling System

Omar Hazem Mohammed<sup>1\*</sup>, Ziyad Tariq Al-Salmany<sup>1</sup>

<sup>1</sup>Technical Power Department, Technical Engineering College-Mosul, Northern Technical University, Mosul, Iraq

### Abstract

This work investigates the performance and energy effectiveness of a solar photovoltaic (PV) system used to provide a cooling system for a building in Iraq. To achieve the goal, simulations and optimization are utilized to find the economic feasibility of the building in Iraq. In addition, a comparative study is conducted to compare the economic feasibility of PV cooling based on two options. The first option depends on the conventional electrical grid to offer cooling for the Iraqi building. The second option relies on a solar PV system to provide the electrical power for cooling the same building. The major numerical analysis results revealed that using a PV system can save roughly 45% electrical power compared to the option when the electrical power is drawn from the conventional grid. For this reason, it is predicted that the PV system can save a higher level of greenhouse gas (GHG) emissions compared to the first option. The results of this research revealed that the cooling load of the building in Samawah, Iraq equalled 600 kW. The PV system required to operate the cooling of the Samawah building during summer equals 18 kW peak. Using a solar PV system would be more economically feasible than the electrical power drawn from the electrical grid. Utilizing PV cooling is considered beneficial for the environment as it can save GHG emissions that cause significant air quality problems and global warming.

**Keywords:** Solar PV system, cooling, Samawah, economic feasibility, GHG emissions.

Received on 14 February 2022, accepted on 05 June 2022, published on 08 June 2022

Copyright © 2022 Omar Hazem Mohammed *et al.*, licensed to EAI. This is an open access article distributed under the terms of the Creative Commons Attribution licence (<http://creativecommons.org/licenses/by/3.0/>), which permits unlimited use, distribution and reproduction in any medium so long as the original work is properly cited.

doi: 10.4108/ew.v9i39.1378

Abbreviation	Meaning
PV	Photovoltaic
R&D	Research and Development
GHG	Greenhouse Gas
USD	United States Dollar
LCOE	Levelized Cost of Energy
HOMER	Hybrid Optimization of Multiple Energy Resources
CLTD	Cooling Load Temperature Difference
CLF	Cooling Load Factor
RH	Relative Humidity
PSI	The Peak Solar Intensity at earth surface
HVAC	Heating, Ventilation, and Air Conditioning

### 1. Introduction

Challenges due to fossil fuel resources use are growing globally due to their numerous negative impacts on the environment, including global warming, climate change,

air and water pollution, and harmful greenhouse gas (GHG) emissions [1]. Knowing that these resources are not reliable as of their continuous cost fluctuations and intermittency [2-4]. Several scientists reported that 50% fossil fuel will run out globally by 2030. Based on this context, several research and development (R&D) efforts have been conducted to provide a practical and effective method of

\*Corresponding author. Email: [Omar.hazem@ntu.edu.iq](mailto:Omar.hazem@ntu.edu.iq)

energy with less environmental impact, lower cost, and higher sustainability. One of these innovative and efficient energy resources is the solar PV systems [5]. The global society witnessed an increased level of PV research through which effective PV modules with higher efficiency and electrical power performance were manufactured, offering larger PV market flexibility. Further, numerous nations worldwide adopted strategic energy mix future plan that enable the installation of utility-scale PV systems to mitigate the high electrical power consumption that depends on conventional resources (fossil fuels) and reduce the electrical bills. PV systems have numerous positive impacts due to their features [6-7]. Solar PV projects are characterized by their higher durability, longer lifespan, and less environmental effect compared to crude oil and coal. Solar PV systems are not only used to provide clean electrical power, but also for cooling [8-11]. Solar PV cooling is a new technology investigated in the last decades and several scholars reported its high potential and efficiency in offering cooling for numerous buildings depending on the solar PV electrical power. It can minimize the large electrical power consumption from the electrical grid and save GHG emissions by benefiting from solar radiation instead of using fossil fuel resources. Additionally, solar PV cooling can provide an alternative solution to diesel generators associated with higher operating and fuel costs by producing clean electrical power from sun beams [12].

In [13], Chekkara et al. suggested an improvement of performance solar photovoltaic the connected in the grid for the water pumping system. The system consists of two controller stages, one for the maximum power point controller and the second for the fuzzy logic controller in which novel fuzzy membership is designed in an induction motor. Different samples were collected from the two sets of irradiances in the PV system and these samples were analyzed by duty ratio, additive conductivity and solar PV with a maximum power point tracking.

The authors in [14] provided new experiences for optimizing the design of photovoltaic cooling frameworks by analyzed the performance of a solar photovoltaic system, where spray cooling is applied to the cooling of photovoltaic cells, and the mathematical model of a solar photovoltaic power generation system was created by regarding the power consumption of the cooling system. The output power and electrical efficiency of the system were also compared under three cooling modes. The outcomes showed that spray cooling has more obvious advantages than water cooling at large concentration ratios and there exists an optimal spray flow rate that can optimize the net electrical efficiency. Thus, the optimal flow rate increases by increasing the concentration ratio.

Aljamali et al. [15], conducted an analysis to investigate the key contributions of solar thermal PV panels to provide cooling for buildings. The paper depended on a comprehensive literature review. They reviewed several articles and recent publications addressing the use of PV panels in cooling. Their literature analysis revealed that solar PV cooling is appropriate for small-scale applications

that require cooling. Furthermore, PV cooling is considerably efficient when there is abundant solar energy. However, when the weather is cloudy and no sufficient solar radiation exists, their efficiency in cooling can remarkably decline. Farajat et al. [16] carried out research to investigate the key role of solar PV system in providing cooling, depended on a comparative analysis. They compare the economic feasibility of two options to provide cooling. The first option is from the electrical grid, while the second option is from the PV panels. They collected temperature and solar radiation data to examine the PV system's potential to provide electrical power for cooling. Their comparative analysis results indicated that the cooling load required equalled 560 kW, while the electrical energy needed to power the cooling system equalled 224 kW. Further, findings confirmed that the cost of the electrical power using the PV system is forty percent lower than the power consumed from the electrical grid (for the first ten years). The payback period for the PV system equalled around five years.

Goyal, M., & Pandey, M. [17] investigated critical approaches to mitigate the energy consumption in buildings. The authors applied machine learning algorithms, including regression algorithm, random forest, extreme gradient boosting, and gradient boosting machine algorithms, to reduce the customer's electricity bill.

The study confirmed that using smart algorithms can reduce the energy consumption of a building without affecting consumers' thermal comfort. Mohammed et al. [18] carried out research to calculate the economic feasibility of an off-grid system consisting of solar PV system, hydro power turbines, and batteries to meet the electrical demand on Mosul residents in Iraq. O. H. et al. [19] relied on the HOMER optimization analysis to determine the profitability of the off-grid system. Their optimization analysis confirmed that the PV system capacity appropriate to match the Mosul residents' electrical demand (which is approximately 1.0 MW) equalled 5,000 kW, the hydroelectric turbines equalled 210 kW, the batteries number was 16,963, and while the converter capacity was 1,800 kW. In addition. They findings affirmed that the total system cost was 18.2 million USD, and the off-grid system can cover the peak load (1 MW) in Mosul, generating 8,000 kWh/day.

Kharrich et al. [20] executed research to develop a novel algorithm that helps offer higher efficiency and good power quality of renewable energy systems with higher economic feasibility. To achieve their study goal the study implemented Quasi-Optimizational Bonobo Optimizer algorithm to calculate the profitability and cost of energy of a renewable energy system comprising (PV system, wind turbine, batteries, and diesel generator). They conducted a comparison between their novel algorithm and other methods including invasive weed optimization, artificial electric field algorithms, and Harris Hawks optimization to validate their work. Their analysis results revealed that their Quasi-Optimizational Bonobo Optimizer algorithm provided optimum design of the renewable energy system and an optimum economic feasibility,

indicating a net present cost of 110,807 USD, while the LCOE was 0.1053 USD/kWh. Mohammed O. H. et al. [22] developed a linear programming algorithm to determine the optimal size and power generation amount of a hybrid PV-wind-tidal systems to offer electrical clean power for remote area (Ouessant Island, France). The authors relied on analyzing the design and cost of energy for three possible scenarios. The first scenario off-grid system of one renewable source: PV, tidal, or wind, integrated with batteries with full-time operating duration. The second scenario is off-grid system of one renewable source: PV, tidal, or wind, integrated with batteries with part-time operating duration. The final scenario is more than one renewable energy source but with part-time operating duration. Their linear programming algorithm results revealed that these three scenarios were the most feasible solutions in terms of power generation, state of charge compared to other configurations and designs.

Kharrich et al. [21] investigated the economic feasibility of a hybrid system (PV, wind, batteries, and diesel generator) to provide electrical power in two cities: Rabat, Morocco, and Baghdad, Iraq. Kharrich et al. [22] depended on the particle swarm algorithm to analyze the economic feasibility of the two systems and determine the optimized size of the hybrid energy system. Their analysis findings revealed that the hybrid energy system installed in Baghdad is more feasible compared to the hybrid system in Rabat, using the similar hybrid energy systems components. Also, results indicated that the total system cost in Baghdad was 31,000 USD, while the total system cost in Rabat was 43,000 USD.

## 2. Materials and Methods

### 2.1 Method

This research is initiated by conducting a literature review of facilities cooling via solar PV technology. Following this step, the weather conditions of Samawah province were reviewed and determined. After this step, the Iraqi cooling load requirements are assessed. Based on the data collected, the design of PV air conditioning system is conducted. Then, the economic feasibility of this design is evaluated. Finally, results are modified and validated. Figure (1) presents the research methodology.

### 2.2 Weather Conditions of Al-Samawah

Al-Samawah is characterized by hot weather in summer and cold winter [23]. This region has higher temperature values in summer as indicated in Figure (2).

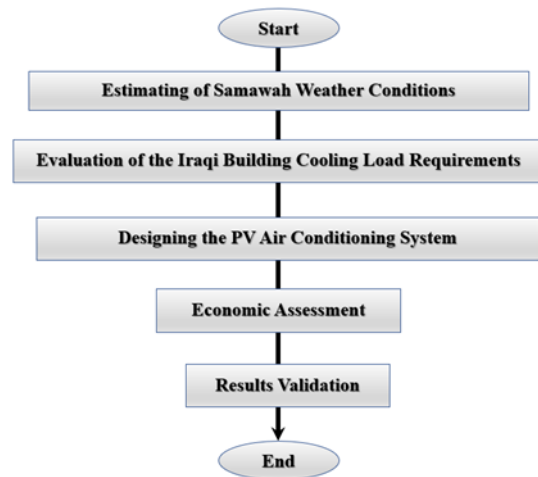


Figure 1. The research methodology flowchart.

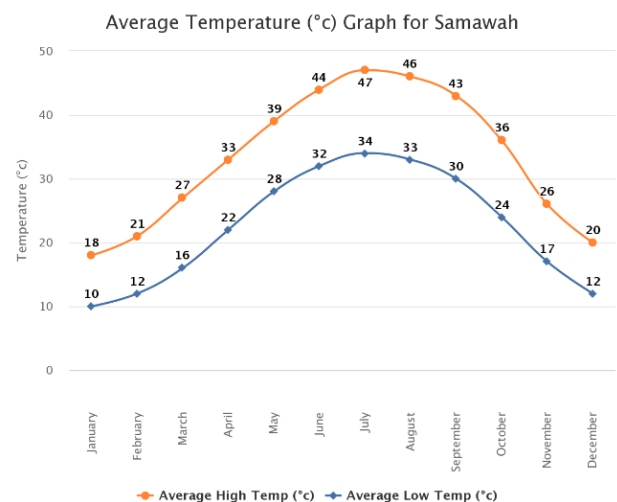


Figure 2. Samawah average maximum and minimum temperature of 2021 [24].

Figure (2) illustrates the maximum temperature values recorded in June, July, and August. While the minimum temperature values of Samawah are registered in January, February, and December.

It is concluded from Figure (3) that the precipitation rate reaches a maximum value in November, while in June, July, and August, there is no precipitation.

Figure (4) indicates Samawah's maximum and average wind speed in 2021. This shows the speed ranges between 10 and more than 30 miles per hour. The maximum wind speeds are recorded in June, while the minimum wind velocities are registered in January. Finally, Figure (5) shows the solar irradiation of Samawah.

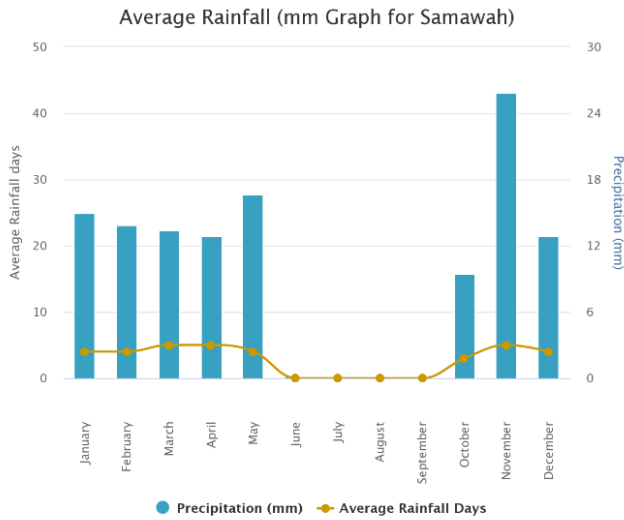


Figure 3. Samawah precipitation rate and average rainfall days[24].

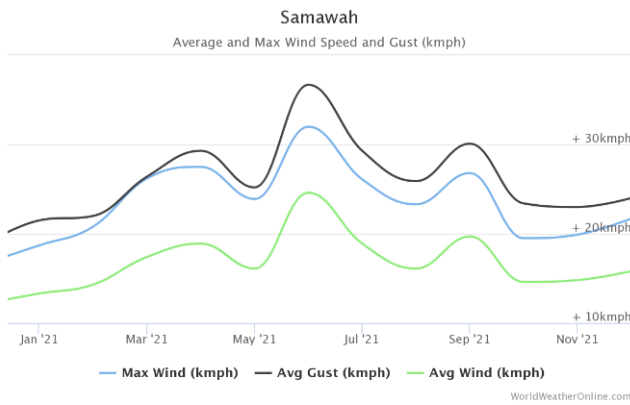


Figure 4. Samawah maximum and average wind speed in 2021[24].

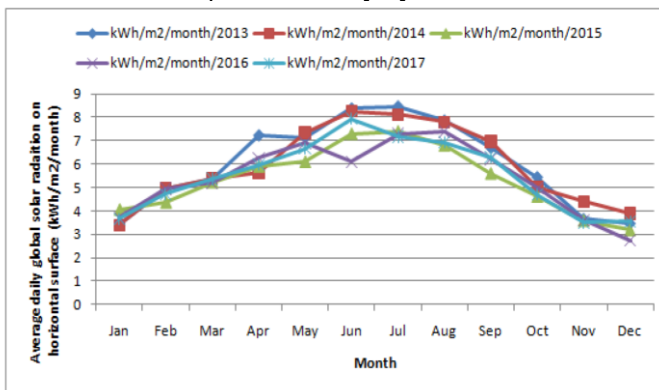


Figure 5. Samawah solar irradiation[25].

It is inferred from Figure (5) that Samawah is also characterized by higher solar radiation in June, July, and August reaching a maximum value of 8 kWh/m<sup>2</sup>/day. While the minimum solar radiation equals around 3 kWh/m<sup>2</sup>/day in January and December.

### 2.3 General Description of the Iraqi Building

The Cooling load required for the Iraqi building is 600 kW. Location: Samawah, Iraq. The overall building area equals 1,000 square meters. The surface area of each window: 3 meters in length × 2 meters in height (6 m). Type: Double Glazing.

Occupancy: 30 individuals in each Department (4 departments, 4 floors). Working hours: from 9:00 am to 4:00 pm. (CLTD/CLF) method is implemented to determine the cooling for Samawah building. It is a common approach with higher practicality and effectiveness in evaluating cooling load of facilities [3]. HAP software was also used to calculate the cooling load. Outdoor dry bulb temperature = 39 °C  
 Outdoor wet bulb temperature = 27 °C  
 Indoor design temperature value = 25 °C  
 Outside relative humidity (RH) = 40%  
 Average wind speed = 5.7 m/s.

Figures (6) and (7) describe the internal and external Iraqi building's style according to the specifications defined in section 2.3.

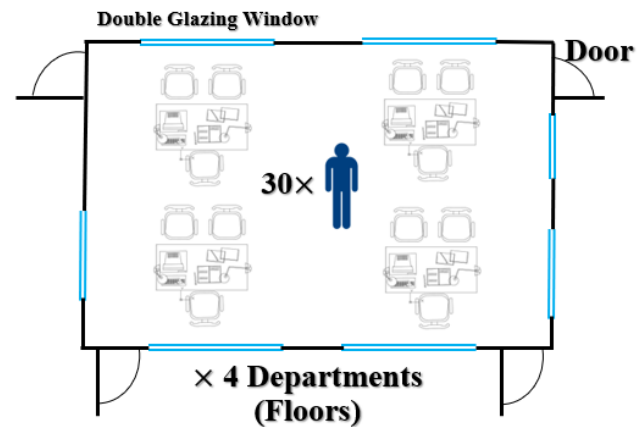


Figure 6. The internal Iraqi building style.



Figure 7. The external Iraqi four storey building style.

## 2.4 Design of the PV System

Based on the cooling load determined via (CLTD/CLF) approach and HAP software, the size of the PV system depend on the maximum cooling load required in summer which is 600 kW. To compute the PV system size, PVSS, equation (3.1) is utilized: Jogunuri et al.[26]

$$PVSS = \frac{E_{DL} \times PSI}{\eta_{SB} \cdot K_{Loss} H_{Tilt}} \quad (1)$$

Where  $E_{DL}$  is the daily energy load (kWh),  $PSI$  is peak solar intensity at earth surface ( $\text{kW}/\text{m}^2$ ),  $\eta_{SB}$  is the efficiency of the system balance,  $K_{Loss}$  is the Loss factor related to the high temperature amounts and dust,  $H_{Tilt}$  is the mean daily tilted solar irradiation ( $\text{kWh}/\text{m}^2/\text{day}$ ).

$\eta_{SB}$  is evaluated via the relationship:

$$\eta_{SB} = \eta_{Converter} \times \eta_{Wires} \quad (2)$$

Where  $\eta_{Converter}$  is the efficiency of the system converter,  $\eta_{Wires}$  is the efficiency of the system wires.  $K_{Loss}$  is computed via the expression [27]:

$$K_{Loss} = (1 - T_{Losses}) \times (1 - D_{Losses}) \times (1 - PV_{Losses}) \quad (3)$$

Where  $T_{Losses}$  is the losses related to higher temperature amounts,  $D_{Losses}$  is the losses due to the soiling and dust, and  $PV_{Losses}$  is the PV panel tolerance.

Using equation (1),  $PSI$  is  $1 \text{ kW}/\text{m}^2$ . Before using equation (1), equation (2) is used to find  $\eta_{SB}$ . System's wire losses are evaluated as (99.4%). The cable losses equal 0.2%, 0.6%, and 1.7% for cable cross-sections  $10 \text{ mm}^2$ ,  $4 \text{ mm}^2$ , and  $1.5 \text{ mm}^2$ , respectively. Kolantla et al. [28], reported that the efficiency of modern converters equals (98.32%). Therefore, the system's balance efficiency  $\eta_{SB}$ , amounts to 97.7%. Maghami et al. [29], stated that dust makes losses in the PV generation by 4.7%. Through the experimental investigation, Abbood et al. [30], mentioned that the annual temperature loss equals (10.18%). Cipriani et al. [31], reported that the PV modules tolerance reaches around (10%). Substituting these values in equation (3), gives a  $K_{Loss}$  of (0.77). The average annual value of  $H_{Tilt}$  obtained by Ali [32], is  $7.58 \text{ kWh}/\text{m}^2/\text{day}$ . Substituting the values of  $E_{DL}$  (assuming that it equals  $100 \text{ kWh}$  (average)),  $PSI$ ,  $\eta_{SB}$ ,  $K_{Loss}$ , and  $H_{Tilt}$  in equation (1) leads to 17.54 kilowatts or 18 kW for safety purposes.

## 3. Results and Discussions

The results indicated that the mean temperature range between 18 and  $47 \text{ }^\circ\text{C}$ . Also, it revealed that the precipitation rate reached a maximum value in November, while there was no precipitation in June, July, and August.

Furthermore, research outputs affirmed that Samawah's wind speed ranges between 10 and more than 30 miles per hour. The maximum wind speeds are recorded in June, while the minimum wind velocities are registered in January. Moreover, it confirmed that Samawah is characterized by higher solar radiation in June, July, and August reaching a maximum value of  $8 \text{ kWh}/\text{m}^2/\text{day}$ . While the minimum solar radiation equalled roughly  $3 \text{ kWh}/\text{m}^2/\text{day}$  in January and December. It should be noted here that the results showed that the cooling system requirements are 600 kW, while the solar PV system required to meet this load equalled approximately 18 kW.

On the other hand, the research results showed that using a solar photovoltaic energy system is more economically feasible than the electrical energy drawn from the electrical grid. This is due to its abundance in the site under study and the availability of ideal conditions for generating electric power. It is one of the promising future energy sources and has the lowest cost, especially in the long run. Besides, utilizing PV cooling is greatly beneficial for the environment. It can replace GHG emissions that cause significant air quality problems and global warming when the electrical network is used.

The results of this study are consistent with the findings of Farajat et al. [16]. The comparative analysis results indicated that the cooling load required equalled 560 kW, while the electrical energy needed to power the cooling system equalled 224 kW. As the cost of electrical energy using the PV system is forty per cent lower than the power consumed from the electrical grid. While the payback period of the PV system is about five years.

On the other hand, the results of this research are not consistent with the results of Aljamali et al. [15], which found that solar PV cooling is suitable for small applications that require cooling, in addition to the fact that solar PV cooling for buildings is not efficient, practical or profitable for large buildings. This may also depend on the site under study, the type of buildings, and the method of insulation used in those buildings. This is what we differ with them and the opposite of what we found in this research, as cooling is very effective for large buildings, less expensive and with good efficiency.

## 4. Conclusions

This work investigates the performance and energy effectiveness besides the economic feasibility of a solar photovoltaic (PV) system used to provide a cooling system for a building in Samawah, Iraq. Based on the analysis conducted in this work, the majoring findings can be summarized in the following paragraphs:

The cooling load of the building in Samawah, Iraq, equalled 600 kW. The PV system required to operate the cooling of the Samawah building during summer equals 18 kW peak. This means that the solar PV system will reduce the consumption of a lot of traditional energy and replace it with clean renewable energy.

Using the solar PV system would be more economically feasible compared to the electrical power drawn from the electrical grid. Utilizing PV cooling is considerably beneficial for the environment as it can save GHG emissions that cause significant air quality problems, global warming and a lot of environmental damage in Iraq.

Finally, based on the conclusions obtained from this work, we can recommend the following:

1. Integration of other renewable energy sources which can provide more electrical energy without using the electric grid.
2. Conducting the same analysis of PV cooling principles but for another facility in Samawa.
3. Implementation of photovoltaic cooling design for another region in Iraq.

## References

- [1] J. Kotcher, E. Maibach, and W.-T. Choi, "Fossil fuels are harming our brains: identifying key messages about the health effects of air pollution from fossil fuels," *BMC Public Health*, vol. 19, no. 1, pp. 1–12, 2019.
- [2] D. Helm, "The future of fossil fuels—is it the end?," *Oxf. Rev. Econ. Policy*, vol. 32, no. 2, pp. 191–205, 2016.
- [3] N. Abas, A. Kalair, and N. Khan, "Review of fossil fuels and future energy technologies," *Futures*, vol. 69, pp. 31–49, 2015.
- [4] Kharrich M., Mohammed O.H., Akherraz M. "Assessment of renewable energy sources in Morocco using economical feasibility technique", *International Journal of Renewable Energy Research*, Vol. 9 (4), pp. 1856 - 1864, 2019.
- [5] N. A. Utama, A. M. Fathoni, M. A. Kristianto, and B. C. McLellan, "The end of fossil fuel era: Supply-demand measures through energy efficiency," *Procedia Environ. Sci.*, vol. 20, pp. 40–45, 2014.
- [6] Kharrich, M., Mohammed, O. H., Mohammed, Y. S., & Akherraz, M. "A review on recent sizing methodologies for hybrid microgrid systems." *International Journal on Energy Conversion*, vol. 7 (6), pp. 230 - 240, 2019.
- [7] Hattu, Edwin PD. "Colling System Application In PV Module Toward Output Voltage And Current PV Module." *ICESC 2019: Proceedings of the 1st International Conference on Engineering, Science, and Commerce, ICESC 2019, 18-19 October 2019, Labuan Bajo, Nusa Tenggara Timur, Indonesia*. Vol. 46. European Alliance for Innovation, 2019.
- [8] Suherman, S., et al. "Water and heat-sink cooling system for increasing the solar cell performances." *EAI Endorsed Transactions on Energy Web* Vol.7, No.27, 2019.
- [9] A. Albatayneh, M. Jaradat, M. Al-Omary, and M. Zaqout, "Evaluation of Coupling PV and Air Conditioning vs. Solar Cooling Systems—Case Study from Jordan," *Appl. Sci.*, vol. 11, no. 2, p. 511, 2021.
- [10] R. Romano, P. Siano, M. Acone, and V. Loia, "Combined Operation of Electrical Loads, Air Conditioning and Photovoltaic-Battery Systems in Smart Houses," *Appl. Sci.*, vol. 7, no. 5, p. 525, 2017.
- [11] M. Kharrich, O. H. Mohammed, and M. Akherraz, "Design of hybrid microgrid PV/Wind/Diesel/Battery system: case study for rabat and baghdad," *EAI Endorsed Trans. Energy Web*, vol. 7, no. 27, 2020.
- [12] Velmurugan et al., "A Review of Heat Batteries Based PV Module Cooling—Case Studies on Performance Enhancement of Large-Scale Solar PV System," *Sustainability*, vol. 14, no. 4, p. 1963, Feb. 2022.
- [13] C. Manideep and M. V. Priya, "Improvement of Performance In Grid Connected Solar Photovoltaic For Water Pumping System Using Induction Motor," *2022 International Conference on Business Analytics for Technology and Security (ICBATS)*, pp. 1-5, 2022.
- [14] ZHAO, Yulong, et al. Performance analysis of a solar photovoltaic power generation system with spray cooling. *Case Studies in Thermal Engineering*, vol. 29, 2022.
- [15] N. M. Aljamali, L. H. Khadum, and A. A. Jabbar, "Applications of Cooling Systems via Using Solar Thermal-Photovoltaic Panels: Literature Review".
- [16] S. M. Farajat and M. Abu-Zaid, "Design a solar power air conditioning system for the engineering building at Mutah University," *Glob. J. Eng. Technol. Adv.*, vol. 5, no. 1, pp. 008–017, 2020.
- [17] M. Goyal and M. Pandey, "Extreme Gradient Boosting Algorithm for Energy Optimization in buildings pertaining to HVAC plants," *EAI Endorsed Transactions on Energy Web*, p. 164562, 2020.
- [18] O. Hazem Mohammed, Y. Amirat, and M. Benbouzid, "Economical evaluation and optimal energy management of a stand-alone hybrid energy system handling in genetic algorithm strategies," *Electronics*, vol. 7, no. 10, p. 233, 2018.
- [19] O. H. Mohammed, "Optimal Hybridisation of a Renewable System to Fulfill Residential Electrical Load: In Mosul, Iraq," in *2018 Third Scientific Conference of Electrical Engineering (SCEE)*, 2018, pp. 209–213.
- [20] M. Kharrich et al., "Development and implementation of a novel optimization algorithm for reliable and economic grid-independent hybrid power system," *Appl. Sci.*, vol. 10, no. 18, p. 6604, 2020.
- [21] O. H. Mohammed, Y. Amirat, M. Benbouzid, S. Haddad, and G. Feld, "Optimal sizing and energy management of hybrid wind/tidal/PV power generation system for remote areas: Application to the Ouessant French Island," in *IECON 2016-42nd Annual Conference of the IEEE Industrial Electronics Society*, 2016, pp. 4205–4210.
- [22] O. H. Mohammed, Y. Amirat, and M. Benbouzid, "Particle swarm optimization of a hybrid wind/tidal/PV/battery energy system. Application to a remote area in Bretagne, France," *Energy Procedia*, vol. 162, pp. 87–96, 2019.
- [23] D. Q. H. Abd and A. K. Abdulkareem, "Study the Daily Behavior of Rainfall over Iraq," in *Journal of Physics: Conference Series*, 2020, vol. 1660, no. 1, p. 012068.
- [24] "Samawah Climate Weather Averages," *WorldWeatherOnline.com*. <https://www.worldweatheronline.com/samawah-weather/al-muthanna/iq.aspx> (accessed Feb. 13, 2022).
- [25] R. A. Mejeed, S. S. Oudah, and R. Y. Abed, "Design of solar photovoltaic pressurized drip irrigation pumping system at Al-salman District in Samawa Governorate," *Int. J. Power Electron. Drive Syst.*, vol. 10, no. 3, p. 1628, 2019.
- [26] S. Jogunuri, R. Kumar, and D. Kumar, "Sizing an off-grid photovoltaic system (A case study)," in *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, 2017, pp. 2618–2622.
- [27] H. M. Hashim, E. Sokolova, O. Derevianko, and D. B. Solovev, "Cooling Load Calculations," *IOP Conference Series: Materials Science and Engineering*, vol. 463, p. 032030, Dec. 2018.

- [28] D. Kolantla, S. Mikkili, S. R. Pendem, and A. Desai, "Critical review on various inverter topologies for PV system architectures," *IET Renew. Power Gener.*, 2020.
- [29] M. R. Maghami, H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad, and S. Hajighorbani, "Power loss due to soiling on solar panel: A review," *Renew. Sustain. Energy Rev.*, vol. 59, pp. 1307–1316, 2016.
- [30] A. A. Abbood, M. A. Salih, and A. Y. Mohammed, "Modeling and simulation of 1mw grid connected photovoltaic system in Karbala city," *Int. J. Energy Environ.*, vol. 9, no. 2, pp. 153–168, 2018.
- [31] G. Cipriani, V. Di Dio, A. Marcotulli, and R. Miceli, "Manufacturing tolerances effects on PV array energy production," in *2014 International Conference on Renewable Energy Research and Application (ICRERA)*, 2014, pp. 952–957.
- [32] F. A. Ali, "Optimum Tilt Angle of Photovoltaic Panels for Some Iraq Cities," *J. Univ. Babylon Eng. Sci.*, vol. 26, no. 1, pp. 155–163, 2018.