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Evaluating the Impact of Weather Conditions on the Effectiveness and Performance of PV Solar Systems and Inverters

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Abstract

Solar photovoltaic (PV) systems have become an increasingly popular and environmentally friendly source of renewable energy. However, the performance and effectiveness of these systems can be significantly influenced by various weather conditions. This paper aims to evaluate the impact of weather conditions on the effectiveness and performance of PV solar systems and inverters. This paper utilizes a comprehensive dataset of solar irradiance, temperature, wind speed, and other weather parameters collected from multiple locations over an extended period. Various performance indicators, such as power output, efficiency, and reliability, are analyzed and compared under different weather conditions. The findings of this paper reveal the significant influence of weather conditions on the performance of PV solar systems and inverters. It is observed that variations in solar irradiance, temperature can lead to fluctuations in power output and efficiency. High ambient temperatures, for example, can negatively affect the performance of solar panels by increasing the operating temperature and reducing their conversion efficiency. These events can cause physical damage, reduce solar irradiance, and impair the functionality of inverters, leading to a decrease in overall system performance. The research outcomes presented in this paper provide valuable insights for system designers, engineers, policymakers, and investors in the renewable energy sector.

1. Introduction

Understanding how photovoltaic (PV) solar systems work and function in diverse environmental settings has become more important because of the rapid growth of PV solar systems as a renewable energy source. The effectiveness and productivity of PV solar systems are greatly influenced by the weather since it has a direct impact on the amount of irradiance and temperature. Weather-related variables can also have an impact on the efficiency of inverters, which transform the direct current (DC) generated by solar panels into usable alternating current (AC) for electrical equipment. For their design, operation, and maintenance to be optimized, PV solar systems and inverters must be evaluated for the effects of meteorological conditions. It makes it possible for scientists, engineers, and decision-makers to create plans that improve the overall effectiveness and dependability of solar energy systems. Additionally, knowing how weather factors affect PV solar system performance can help in the creation of precise forecasting models, which are important for efficient energy management and grid integration. The effectiveness and performance of PV solar systems and inverters under the influence of meteorological conditions are evaluated in this paper through a thorough comparison investigation. In this paper the impact of important meteorological factors such as solar irradiance, temperature, humidity, and wind speed on the energy generation capability and operational efficiency of PV solar systems by evaluating real-world data and carrying out controlled experiments. Additionally, the aim to investigate the relationship between weather conditions and inverter performance, taking into account elements like effectiveness, power output, and dependability. The study's conclusions are extremely pertinent to a wide range of solar energy industry stakeholders. Manufacturers and designers to create components that are resistant to the elements and to optimize system setups, which will improve durability and overall performance, can utilize the results. When deciding whether to integrate PV solar systems into the grid, energy planners and regulators can make educated choices by taking weather variations' effects on electricity generation patterns into account. The results of the research can also be used to create maintenance plans and forecasting models that will guarantee the long-term dependability and affordability of PV solar installations. Overall, by illuminating the complex interplay between weather, PV solar system performance, and inverter efficiency, this comparative study makes a significant contribution to the field of renewable energy research. We can accelerate the uptake of solar energy and ease the transition to a resilient and sustainable energy future by deepening our understanding of these dynamics. Photovoltaic solar panels generate energy based on their size, efficiency, and sunshine. Photovoltaic solar panels and placement are two other factors that can affect electric power generation .As well as the intensity of irradiation are significantly affect the productivity of photovoltaic panels [1,2]. The DC-to-AC solar power inverter, which is connected to the ac network in order to supply electricity to the user, is a crucial and efficient piece of equipment in these setups since it greatly affects the reliability with which the necessary energy is processed [3]. Photovoltaic Transformers contain a DC/DC booster transformer and a DC / AC inverter, these elements themselves are very important in giving solar energy systems high reliability to compensate for the processing of national grids [4]. The DC/AC inverter produces AC power with a power factor of 1 which is enhanced by the DC/DC converter of the solar array to match the maximum PowerPoint. In most cases, the power factor may be less than one and its value ranges from 0.7 to 0.9 depending on the type of load connected to the system [5, 6]. In addition, the inverter's efficiency can decrease with increasing input power, resulting in a lower output power [7, 8, and 9]. Heat affects the power of the inverter and its performance through the change of electrical resistance and internal losses of heat transformers, where the rise in heat can damage the inverter parts and reduce performance. Heat sinks, fans, and liquid cooling systems may help cool transformers to reduce losses and increase efficiency Therefore, cleaning and repairing the panels should be considered to improve their performance and lifespan. It is necessary for solar power plants to establish an effective solution for inverter ventilation that may lower the energy cost and ensure the photovoltaic power plant's dependability. [10, 11]. AC power from a solar photovoltaic system is typically calculated using the capacity factor or energy output over a day, month, or year. The capacity factor compares the measured power output to the theoretical maximum power output of the system when both are operating at full power. Power indicates the rate of energy production by a solar PV system, but it does not provide information on the total amount of AC power generated by the system. The most accurate method for determining AC power from a solar PV system is to use the system's power output, or energy produced over time [12,13,14].

2. Advancements in Photovoltaic Testing: An In-depth Examination of the PV Test System

The photovoltaic test system, commonly referred to as the PV test system, is a configuration created to examine and assess the performance and features of photovoltaic devices, such as solar panels or solar cells. It is utilized in photovoltaics-related research, development, manufacturing, and quality control procedures. The PV test system is made up of a number of components that are used to measure and analyze the electrical and optical properties of photovoltaic devices. The following are the main components frequently seen in a PV test system [15, 16]:

1-Light Source: To test photovoltaic devices, a consistent and regulated light source that mimics sunshine or a certain light spectrum is used. Depending on the needs of the experiments, this light source may be a solar simulator, xenon arc lamp, or LED array. Instruments used for measurement include those that measure voltage, current, power, and resistance, among other electrical properties. These could be electronic loads, source meters, or digital multi-meters [17, 18]. Under various test situations, this equipment record the electrical response of the solar devices.

2- Environmental Control: The PV test system may include environmental control devices to guarantee precise and repeatable testing. For the photovoltaic devices to operate at particular temperatures during testing, temperature control chambers or plates are included. Some systems also have the ability to manage humidity [19, 20].

3-Data collection System: During testing, a data collecting system gathers and records electrical and optical measurements. It could include tools for processing and analyzing the gathered data, such as data loggers, signal analyzers, or specialist software. Researchers or operators can assess the performance of the photovoltaic devices and compare several samples using this technique.

4-Software and Analysis Tools: Specialized software is frequently used to regulate test parameters, time measurements, and analyze test results. The management of the testing procedure, the display of test results, and the production of test reports are all made possible by this software.

5-Safety features: When working with electrical systems, especially during testing processes, safety is of the utmost importance. To prevent accidents or harm to the equipment or employees, the PV test system includes safety measures such circuit protection devices, grounding mechanisms, and insulation protections. Depending on the intended application, budget, and user needs, a PV test system's precise setup and capabilities may change. The ability to perform tests under various sun irradiation levels, spectral mismatch correction, IV (current-voltage) curve tracing capabilities, and other features may be added to advanced systems. The electrical efficiency of PV panels can be significantly impacted by temperature. The electrical efficiency of the PV panel diminishes as the solar cells' temperature rises. For every degree that the temperature of the PV cells rises, (Stropnik & Stritih, 2016) claim that the electrical efficiency of PV panels can drop by 0.4% to 0.65%. Additionally, Radziemska Stropnik & Stritih (2016) discovered that for every 1°C increase in temperature above 25°C, the electrical efficiency of PV panels reduces by 0.08%, resulting in a 0.65% decline in power output [21]. Significant power losses in PV systems may also result from PV cell degradation effects. Kaplani (2012) talks about the degrading effects seen in field-aged PV cells that might lead to a decline in effectiveness and performance. The study measures temperature degradation effects in different PV module components using IR thermography and digital picture processing [22]. Based to this study's findings, there is a connection between the cause of electrical performance degradation and the impacts of that degradation that IR thermography was able to detect. The effectiveness of PV modules can also be impacted by low light levels. a study by Firth et al. (2010), PV module efficiency is drastically decreased under low solar irradiances [23]. According to the study, there is a significant decline in PV module efficiency at low light levels, which is supported by the efficiency values seen at low solar irradiances. The efficiency of PV cells must be increased through effective thermal management. In a study published in 2019, Shittu et al. explore the possibility of cooling PV cells using a flat plate heat pipe. The research demonstrates that the flat plate heat pipe successfully lowers the temperature of the solar cells, improving electrical efficiency [24]. The numerical analysis contrasts the electrical performance of PV-only, PV-thermoelectric, and PV-thermoelectric-heat pipe systems in order to show the latter's superior efficiency. The design and optimization of PV systems can boost their efficiency in addition to temperature and thermal control. The Wind Driven Optimization (WDO) algorithm is suggested by Mathew et al. (2018) as a method for precisely determining the parameters of a double diode model of solar PV systems. According to the study, the WDO method may deliver optimum values with fewer mistakes, enhancing the precision and adaptability of PV system electrical modeling [25].

3. *PV Mathematical Model and efficiency evolution*

The mathematical model of a photovoltaic (PV) panel is typically based on the principle of the current-voltage (I-V) characteristics of a solar cell it can be seen in figure 1.

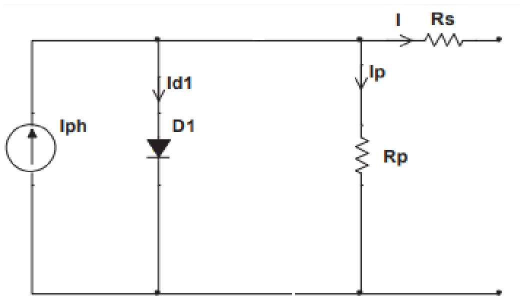


Figure 1. Circuit diagram of single-diode model PV model

The power output under various operating conditions can be calculated using the I-V curve, which depicts the relationship between the current output and the voltage across the terminals of the PV panel. The commonly used mathematical model for a PV panel is the single-diode model, which includes a diode component to account for the nonlinear behavior of the solar cell. The single-diode model's equation for the I-V relationship of a PV panel is given in [26]:

$$I = I_L - I_o\left(exp^{\frac{V+I\times R_S}{n\times V_T}} - 1\right) - \frac{(V+I\times R_{S)}}{R_{sh}} \qquad (1)$$

Where I is the PV panel's output current, IL is the light-generated current (photocurrent), Io is the diode's reverse saturation current, V is the panel's output voltage, Rs is its series resistance, n is its ideality factor, VT is its thermal voltage (roughly 25.7 mV at room temperature), and Rsh is its shunt resistance. The nonlinear I-V equation is typically solved iteratively to determine the current and voltage values that satisfy the equation for a given set of parameters and operating conditions. A mathematical model for a photovoltaic (PV) system can be described using various equations and parameters. Here's a simplified model that represents the basic behavior of a PV system: Solar Irradiance: The amount of sunlight falling on the PV panels is represented by the solar irradiance (G) in watts per square meter (W/m²). It can vary throughout the day based on factors like weather conditions and time of year. Temperature: PV panels are affected by temperature, which affects their efficiency. The panel temperature (T) in degrees Celsius (°C) can be measured or estimated. Output Power: the product of solar irradiance, panel efficiency, and the surface area of the PV panels give the output power (P) of a PV system [27]. It can be expressed as:

$$p = G \times \eta \times A \qquad (2)$$

Where: G is the solar irradiance in W/m², η is the panel efficiency (a decimal value), A is the surface area of the PV panels in square meters (m²) Panel Efficiency: The panel efficiency (η) represents the ability of the PV panels to convert solar energy into electrical energy. It depends on the panel technology, temperature, and other factors. Panel efficiency is typically provided by the manufacturer or can be determined through experimental data. Electrical Energy: The electrical energy produced by the PV system over a given period of time (E) is the integral of the output power with respect to time [28]:

$$E = \int P(t)\, dt \qquad (3)$$

Where $P(t)$ represents the instantaneous power output at time t. System Losses: In real-world conditions, PV systems experience various losses, such as losses due to wiring, shading, dirt on panels, and inverter inefficiencies. These losses can be considered as a factor (L) that reduces the effective output power:

$$P_{eff} = P \times L \qquad (4)$$

Where P_{eff} is the effective output power, and L is the loss factor (a decimal value).

To evaluate the efficiency of a photovoltaic (PV) system, you can use various mathematical models. Here's a general approach to assess the efficiency of a PV system using some common metrics: Performance Ratio (PR): The performance ratio represents the overall efficiency of the PV system by comparing the actual energy output to the expected energy output. It is calculated as the ratio of the actual energy generated (E_{actual}) to the theoretical maximum energy that could be generated by the system under standard test conditions ($E_{\text{theoretical}}$) [29].

$$PR = \frac{E_{actual}}{E_{theoretical}} \qquad (5)$$

The theoretical energy output can be estimated by multiplying the system's peak power (P_{peak}) by the number of hours of sunlight ($H_{sunlight}$) during the evaluation period

$$E_{theoretical} = P_{peak} \times H_{sunlight} \qquad (6)$$

Energy Conversion Efficiency (η): The energy conversion efficiency measures the ability of the PV system to convert sunlight into usable electrical energy. It is calculated by dividing the actual energy output (E_{actual}) by the total solar irradiance ($I_{sunlight}$) incident on the PV panels during the evaluation period [30].

$$\eta = \frac{E_{actual}}{I_{sunlight}} \quad (7)$$

The total solar irradiance can be obtained by integrating the solar irradiance over the evaluation period.

Fill Factor (*FF*): The fill factor quantifies the efficiency of the PV system in utilizing the available power from the solar cells. It is calculated as the ratio of the maximum power output (P_{max}) to the product of the open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}).

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} \quad (8)$$

The maximum power output can be obtained by multiplying the voltage at the maximum power point (V_{mp}) and the current at the maximum power point (I_{mp}). This simplified mathematical model captures the basic principles of a PV system. However, it's important to note that more sophisticated models can be developed by considering additional factors such as tilt angle, azimuth angle, spectral response, and the effects of partial shading. Additionally, models can also incorporate battery storage systems or grid connections for a more comprehensive representation of PV system behavior. These metrics provide an overall assessment of the efficiency of a PV system. However, keep in mind that for a thorough evaluation, additional aspects like temperature, shading, system losses, and module degradation need also be taken into account.

4. Methodology

PV inverters placed in countries with temperate climates may function differently than those installed elsewhere. Within considering this, the primary goal of this paper is to demonstrate that the Iraqi standard is unsuitable for use in inverters intended for installation in Equatorial climates. After this fact has been established, the goal of developing a new weighted efficiency formula for the Equatorial climate can be realized see figure 2. The following tasks are completed in order to achieve these objectives:

1- Collecting irradiance data from weather stations in an Equatorial environment for a year.

2- Using the acquired data, run an inverter with a PV array (Matlab simulation).

3- Measuring the power input and output.

4- Recalculate the inverter's data.

5- Developing the Equatorial climate weighted efficiency formula

6- Testing the formula using data from a real-world PV system.

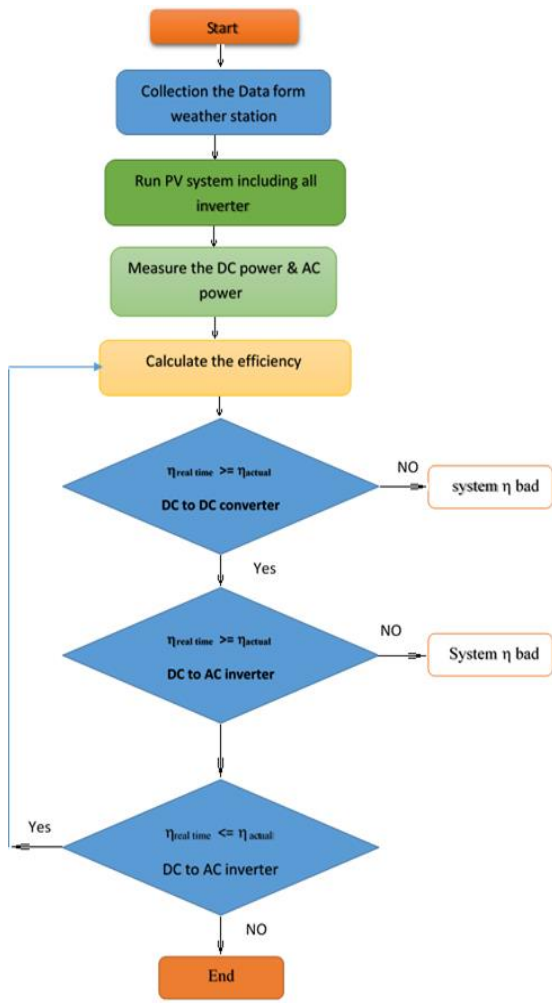


Figure (2): Flowchart of the proposed methodology

5. Simulation and experimental Results

To simulate a PV panel based on a mathematical and simulation model shown in figure 3, we can use the single-diode equivalent circuit model. This model represents the PV panel as a current source in parallel with a diode, a series resistance, and a shunt resistance. Here's a step-by-step guide to simulating a PV panel using this model [30].

Maximum power output (Pmax): The maximum power that the PV panel can deliver under standard test conditions. Open-circuit voltage (Voc): The voltage across the terminals of the PV panel when no current is flowing.

Short-circuit current (Isc): The current flowing through the PV panel when the terminals are shorted.

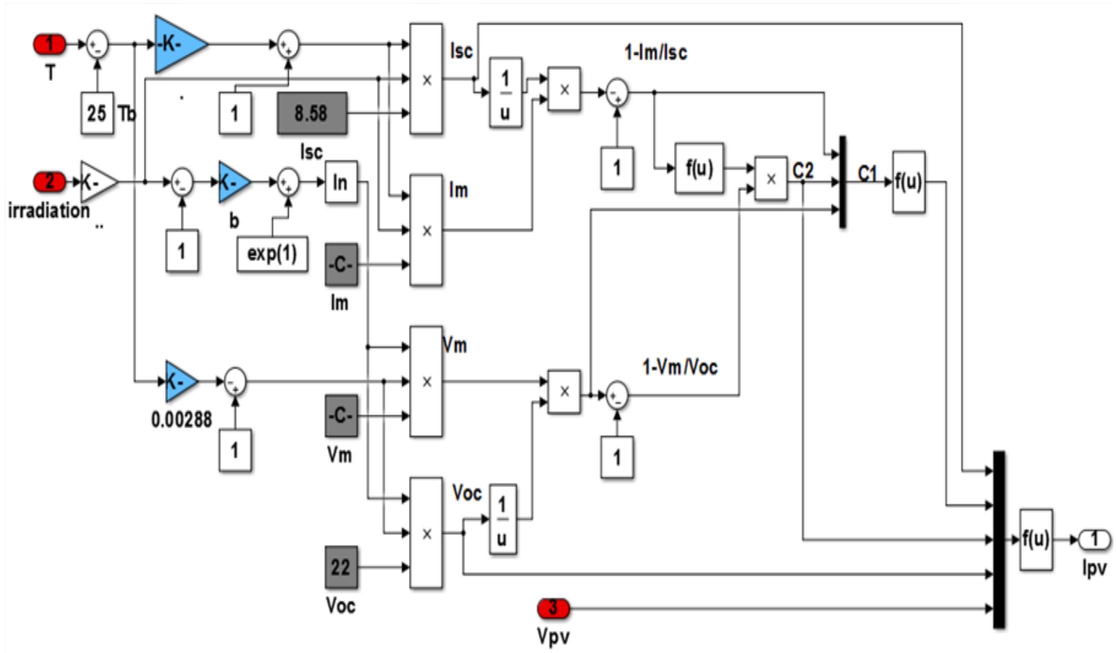
Nominal operating cell temperature (T): The temperature at which the panel's characteristics are measured. Determine the single-diode model depend on Eq. (1). Calculate the diode saturation current (Io):

$$I_o = \frac{I_{sc}}{exp^{(V_{oc}/(n \times V_t)} - 1} \quad (9)$$

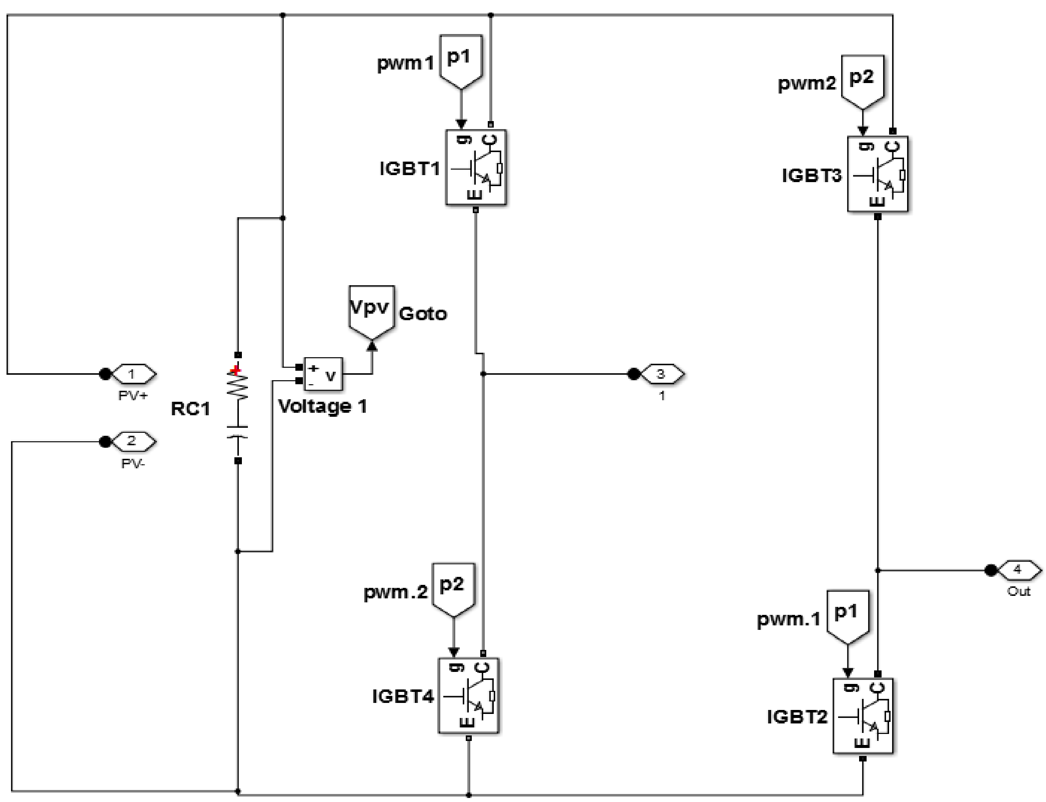
Calculate the light-generated current (Iph):

$$I_{ph} = I_{sh} \times \frac{G}{G_{ref}} \times (1 + \alpha \times (T - T_{ref}) \quad (10)$$

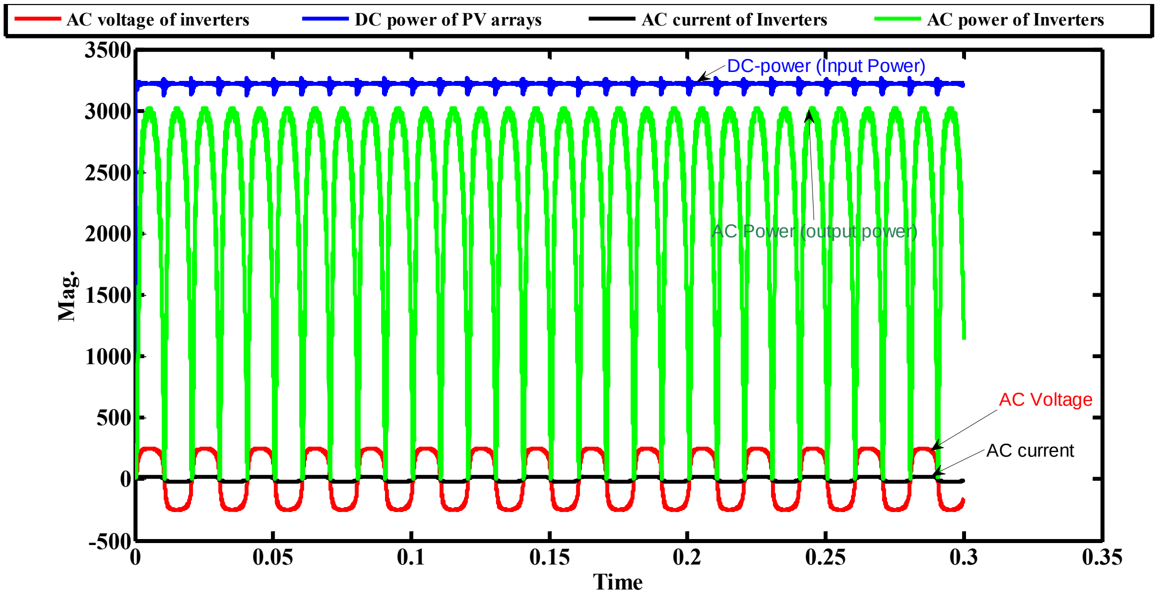
Where G is the solar irradiance, Gref is the reference solar irradiance (typically 1000 W/m2), is the temperature coefficient of current, T is the cell temperature in Kelvin, and Tref is the reference temperature (typically 25 degrees Celsius), n is the diode ideality factor, Vt is the thermal voltage (KT)/q, and q is the electron charge. Implement the equations in a programming language or a simulation tool Simulink of Matlab, and numerical methods like Newton-Raphson are used to solve the equations iteratively for different values of V and I. Temperature fluctuations affect photoelectric system output power depending on the photoelectric material, system design, and operating conditions. It can determine how temperature affects photoelectric system performance, though the flowing parameters: Bandgap Energy, The minimum energy required for an electron to travel from the valence band to the conduction band in photoelectric materials. Bandgap energy decreases with temperature. The material absorbs more photons, increasing system output power. Carrier Density: Temperature affects a photoelectric material's free electrons and holes, which generate electricity. Thermally produced charge carriers improve output power at higher temperatures. Electrical Resistance Temperature affects photoelectric material electrical resistance. As temperature rises, some materials become more resistant, reducing system output power owing to energy losses. Thermal Expansion: Thermal expansion or contraction of system components might impact optical element alignment and system performance. Misalignments impair light absorption and output power. Efficiency and Degradation: Higher temperatures increase thermal energy, which degrades photoelectric material and lowers efficiency. If the temperature exceeds the material's acceptable range, this effect is crucial. To determine how temperature changes (40°C, 45°C, 25°C, 30°C, and 35°C) figure 4 and figure 3 affect a photoelectric system's output power.



(a) PV system simulation



(b) inverter



(c) Simulation output

Figure (3): (a) Block diagram for PV panel system , (b) DC to AC inverter and (c) simulation output

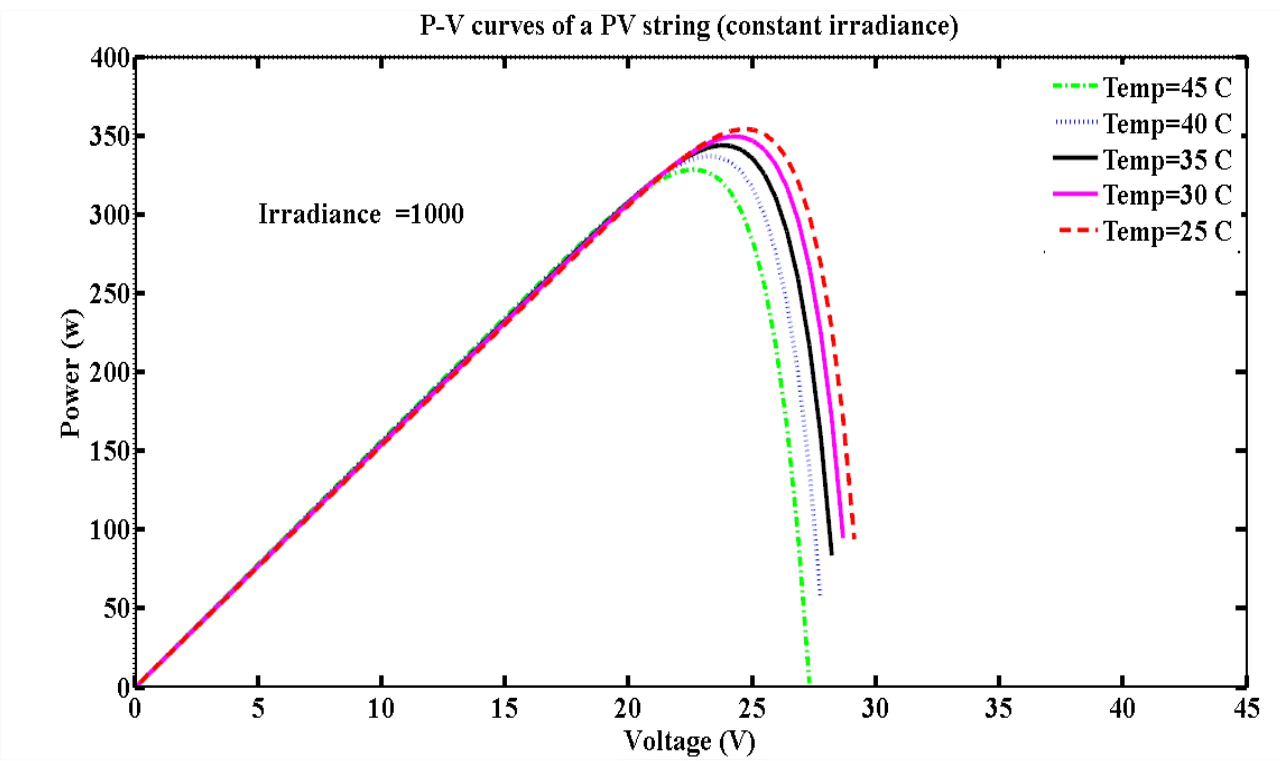


Figure (4): Effect of the temperature on output power of PV panel

The angle at which sunlight hits the surface of a photovoltaic (photovoltaic) system determines its output. Photovoltaic modules generate more electricity when sunlight hits them at the right angle see figure 5, the deviations from this optimal angle decrease efficiency and output. Therefore, the optimal angle is usually for photovoltaic systems oriented perpendicular to the sun to enhance energy production. The tilt angle, or ideal angle, depends on the location, season and output of the system. In the northern hemisphere, the ideal angle is Latitude Plus 10-15 degrees. Moreover, direct and diffuse radiation the photovoltaic system receives both direct radiation (sunlight that hits the photovoltaic module directly) and diffuse radiation (sunlight scattered in the atmosphere). The angle of incidence affects both components differently. Direct radiation works best when the photovoltaic module is perpendicular to the incoming rays, while diffuse radiation is less dependent on the angle. On the other hand incident angle Modifier (IAM) is the ratio of the effective radiation of the module surface to the natural incidence (direct sunlight hits the module vertically). Logon Management calculates the effective radiation unit using the cosine angle of incidence. Off-angle unit performance improves with higher IAM. One of the important things to consider is out-of-angle injury losses: when sunlight hits a photovoltaic module, multiple losses occur. These losses include higher reflection, shading by adjacent modules, module impedance losses, and longer light path lengths through the semiconductor material. Reduced output due to low energy conversion efficiency. It is also important to take care of tracking systems modules in photovoltaic systems can track the path of the sun. Tracking systems improve the angle of incidence and power output. Two-axis trackers can adjust the azimuth angles (East and West) and height (up and down), while single-axis trackers rotate the units from East to West. The angle of impact of the fall on the output of the photovoltaic system varies depending on the technology, design and ambient conditions. Detailed simulations and calculations can reveal how the angle of incidence affects certain photovoltaic systems.

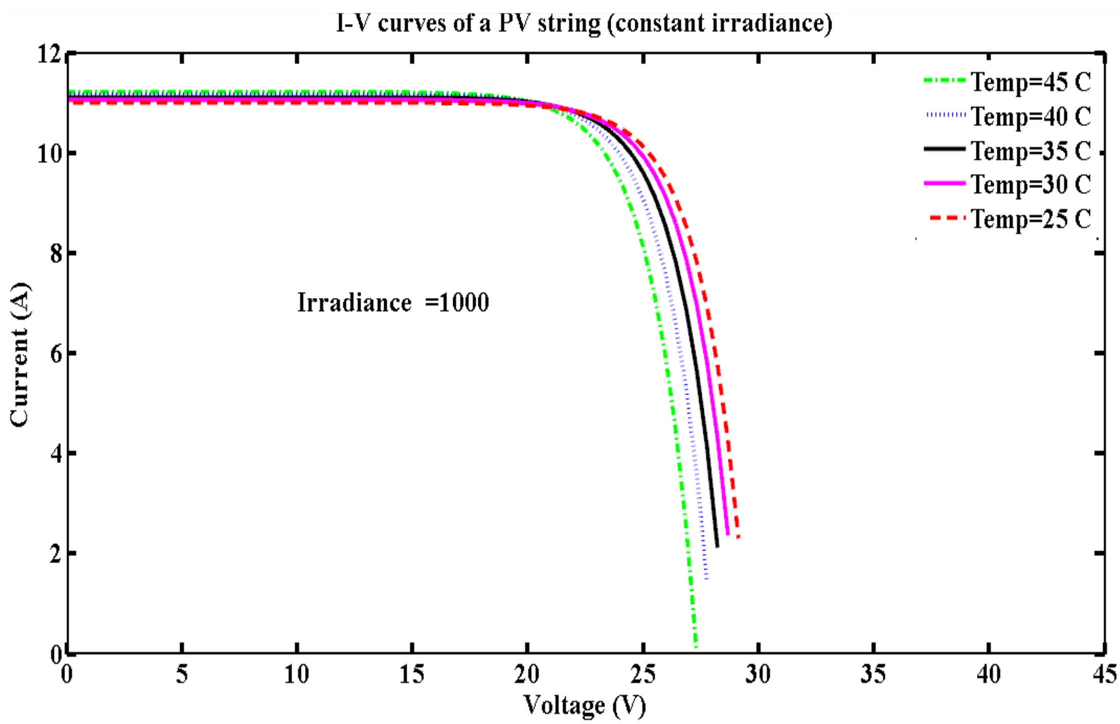


Figure (5): Effect of the temperature on output current of PV panel.

5. Practical results from a photovoltaic system

The practical results of a PV system in Baghdad would depend on these factors. Generally, in areas with high irradiation levels like Baghdad, PV systems have the potential to produce a significant amount of electricity. However, it's important to consider other factors like temperature, humidity, and local regulations that might affect the system's performance and overall energy output. Figure 6 shows the monthly local sun radiation on horizontal surfaces for the climatic zones analyzed. The illustration figures 7(A, B, C, and D) additionally shows the monthly local Sun Radiation on Horizontal Surfaces for each climatic zone. The computations started here. A solar panel's output is most affected by clouds. Solar photovoltaic (PV) output and grid-tied inverter output fluctuate due to cloud cover. PV generator power curves resemble solar radiation (E) intensity curves (Figure 7). The DC current signal and solar radiation intensity shown in figure 6 (recorder accuracy). Figures (8) (A, B, C, and D) illustrate that the four inverter's efficiency are (82.2711%, 82,844%, 81,133%, and 87,044%) respectively that are related to the sun's radiation intensity The calculation process used in extracting the efficiency of the inverter is to measure the power output of the inverter and the power input to it. This simple calculation process gives me a wide field in analyzing the efficiency of the inverter in working conditions in this paper touched only on the

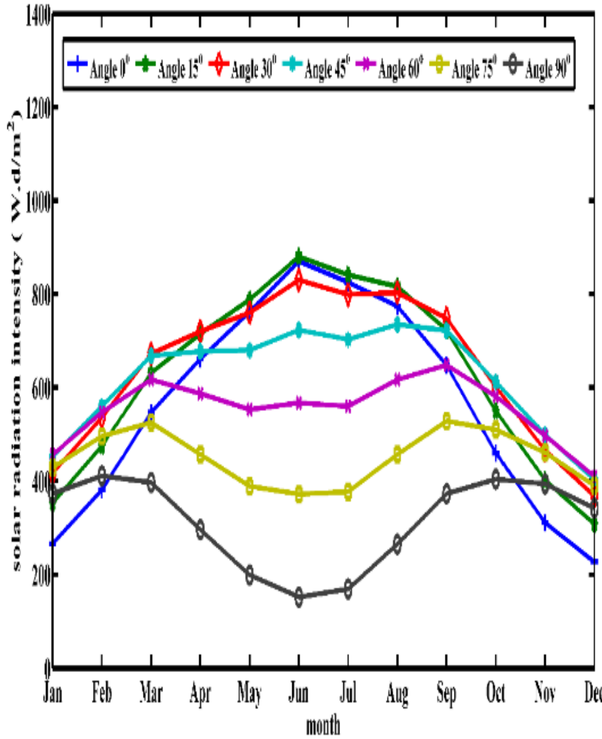


Figure (6): The effect of the angle of sun Irradiation

calculations of the efficiency of the inverter in adverse weather conditions in a specific area in Baghdad. Table (1) shows the experiment's inverter's efficiency is proportional to the effectiveness.

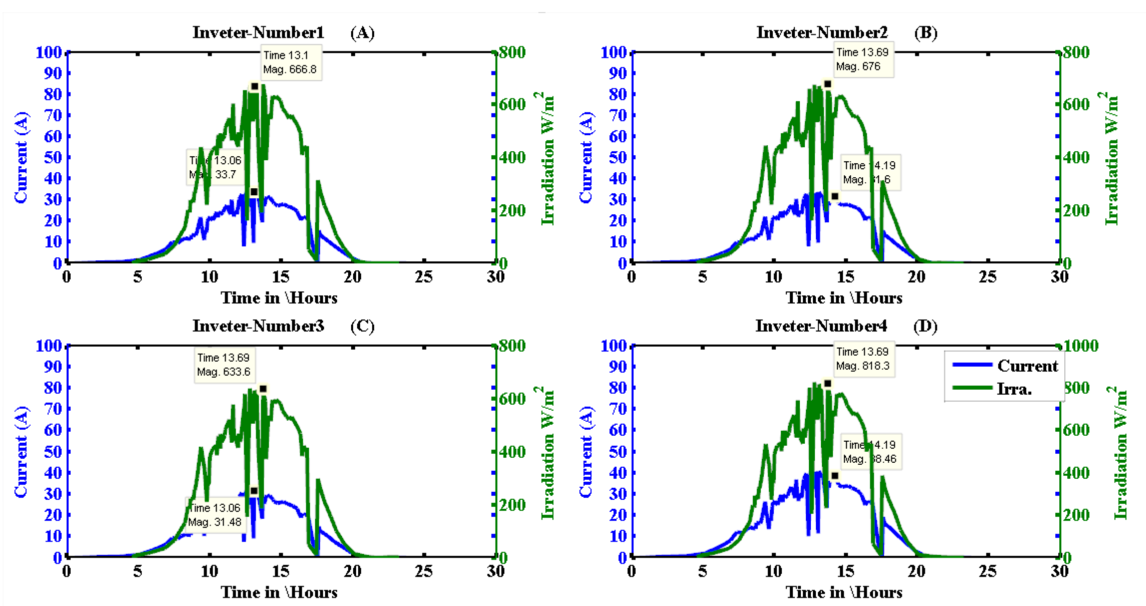


Figure (7): DC current variation of the PV-Inverters generator as a function of solar irradiance

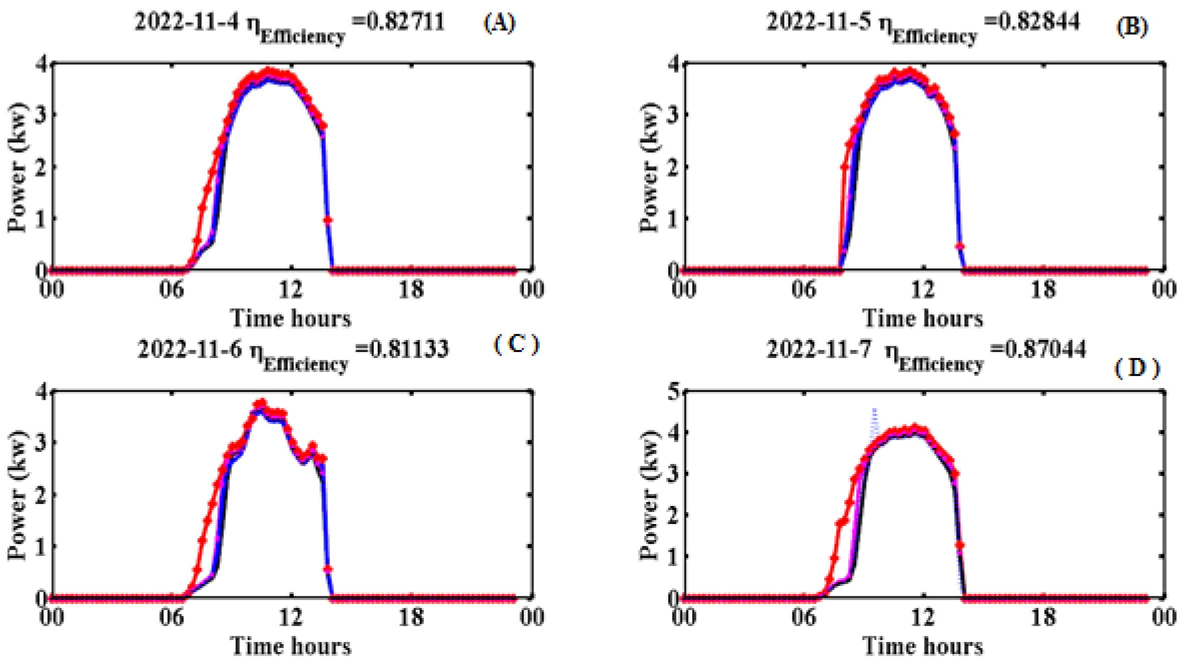


Figure (8): variation of the PV-Inverter power generator as a function of solar irradiance (E) on 4/5/6-7/11/2022

Table (1): Sun irradiation coefficients and inverter efficiency.

Statistic	Irradiation date 2022-11-4	Irradiation date 2022-11-5	Irradiation date 2022-11-6	Irradiation date 2022-11-7
Min	0.8569	0.8034	0.7569	1.0390
Max	678.8056	636.3802	698.8506	823.0518
Mean	366.0201	343.1439	386.1211	443.7994
Median	422.4720	396.0675	437.6539	512.2473
Mode	0.8569	0.8034	0.83427	1.0390
Std	209.5544	196.4573	210.5884	254.0847
Rang	677.9486	635.5768	632.7046	822.0127
efficiency	83%	82%	81%	87%

Solar panel irradiation does not affect DC/AC inverter efficiency only, but the design, quality, and technology determine inverter efficiency. Solar irradiation affects solar panels, wiring, inverters, and other components. Solar energy capture and conversion determine system efficiency.

Conclusions

Irradiation has a substantial impact on the efficiency of photovoltaic (PV) inverters. Inverters are electronic devices that transform the direct current (DC) generated by solar panels into alternating current (AC), which can then be utilized to power loads or supplied back into the grid. An inverter's efficiency is defined as the ratio of DC power output to AC power. Irradiation, or the amount of sunlight or solar radiation received by the PV system, is critical in determining the system's overall performance and efficiency. The PV panels create more electricity when the irradiation level is high, resulting in a greater DC power input to the inverter. In this case, if the inverter is constructed and tuned for higher levels of irradiation, it can work more efficiently and convert a greater proportion of the DC power into AC power. When the irradiation level is low, such as when it is cloudy or overcast, the PV panels generate less electricity, resulting in a reduced DC power input to the inverter. In such cases, the inverter's efficiency may suffer when it runs outside of its ideal range, resulting in decreased conversion efficiency and potentially lower power output. Manufacturers use a variety of approaches and technology to enhance inverter efficiency throughout a wide range of irradiation levels. Advanced maximum power point tracking (MPPT) algorithms, voltage optimization methodologies, and enhanced circuit designs are examples of these. When selecting and sizing inverters, PV system designers and installers must consider the projected irradiation levels in a specific region. The system can achieve higher overall efficiency and performance by selecting inverters that are appropriate for the projected irradiation range. To summarize, irradiation has a major impact on the efficiency of inverters in PV systems. The selection of an appropriate inverter that is suited for the projected irradiation levels is critical to ensuring optimal conversion of DC power to AC power, resulting in increased energy production and system performance.

References

[1] Photocatalytic efficiency of titania nonylphenol ethoxylate composite thin films under solar irradiation. (2022, January). Focus on Surfactants, 2022(1), https://doi.org/10.1016/j.fos.2021.12.010

[2] Hellström, B. (2004, September). Derivation of efficiency factors for uneven irradiation on a fin absorber. Solar Energy, 77(3), 261–267. https://doi.org/10.1016/j.solener.2004.06.002

[3] García-Rodríguez, V. H., Pérez-Cruz, J. H., Ambrosio-Lázaro, R. C., & Tavera-Mosqueda, S. (2023, March 7). Analysis of DC/DC Boost Converter–Full-Bridge Buck Inverter System for AC Generation. Energies, 16(6), 2509. https://doi.org/10.3390/en16062509

[4] Chen, R., & Zhang, J. S. (2014, November 20). Half Load-Cycle Worked Dual Input Single Output DC/AC Inverter. Journal of Power Electronics, 14(6), 1217–1223. https://doi.org/10.6113/jpe.2014.14.6.1217

[5] Serban, E., Pondiche, C., & Ordonez, M. (2019, March). Modulation Effects on Power-Loss and Leakage Current in Three-Phase Solar Inverters. IEEE Transactions on Energy Conversion, 34(1), 339–350. https://doi.org/10.1109/tec.2018.2879217

[6] Meng, Z., & Chen, L. (2020, November). Theoretical maximum efficiency and higher power output in triboelectric nanogenerators. Energy Reports, 6, 2463–2475. https://doi.org/10.1016/j.egyr.2020.09.009

[7] aifullin, E. R., Vankov, Y. V., Bazukova, E. R., & Maryashev, A. V. (2018, July). Evaluation of heat transporting losses due to changes of insulation properties during operation. Journal of Physics: Conference Series, 1058, 012061. https://doi.org/10.1088/1742-6596/1058/1/012061

[8] Das, R. S., & Jain, S. (2013, August). Experimental performance of indirect air–liquid membrane contactors for liquid desiccant cooling systems. Energy, 57, 319–325. https://doi.org/10.1016/j.energy.2013.05.013

[9] Kotomchin, A. N., & Sinelnikov, A. F. (2020, August 28). Installation for maintaining the operating temperature of electrolytes when restoring machine parts with electroplated coatings. The Russian Automobile and Highway Industry Journal, 17(4), 500–511. https://doi.org/10.26518/2071-7296-2020-17-4-500-511

[10] Jeykishan Kumar, K., Sudhir Kumar, R., & Bhattacharjee, T. (2021, June 12). Alternate method for evaluating power-temperature derating characteristics of grid tie solar photovoltaic inverter. Sādhanā, 46(3). https://doi.org/10.1007/s12046-021-01646-9

[11] Hao, X., Shan, S., Gao, N., Chen, G., Wang, Q., & Gu, T. (2023). Performance analysis of a novel combined cooling, heating and power system with solar energy spectral beam splitting. *Energy Conversion and Management*, *276*, 116500..

[12] SIMULATION OF INVERTER FOR PROTOTYPE MODULE OF SOLAR PHOTOVOLTAIC (PV) SYSTEM. (2018, January 5). International Journal of Recent Trends in Engineering and Research, 3(12), 228–234. https://doi.org/10.2383/ijrter.2017.3561.7nutu.

[13] Kersam, S. S. (2022). Design and Implementing of a Buck Dc-To-Dc Converter into the DC Motor's Speed Controller in Matlab/Simulink. Anbar Journal of Engineering Sciences, 13(2).

[14] Ali, H. M., Abbas, A. K., & Salih, W. M. (2022). Methodologies Employed to Cool Photovoltaic Modules for Enhancing Efficiency: A Review. Anbar Journal of Engineering Sciences, 13(2).

[15] Hammadi, S. H., & Mohammed, A. H. (2014). Application of earth tube heat exchanger and solar chimney for natural cooling system in Basrah City. Journal for Engineering Sciences, 23-32.

[16] Alsheekh, M., Najim, S. E., & Sultan, H. S. (2021). Experimental, Theoretical and CFD Validations for Solar Powered Atmospheric Water

Generation Using Thermoelectric Technics. Basrah Journal for Engineering Sciences, 21(2).

[17] Hannun, R. M., Najim, S. E., & Khalaf, M. H. (2014). The Parameters Change with Different Operation Conditions of Solar Chimney Power Plant Model. Basrah Journal for Engineering Science, 14(2).

[18] Siddiq, A. I., Fadhel, H., & Anwar, M. O. (2023). Automatic PV Array Reconfiguration under Partial Shading Conditions. NTU Journal of Renewable Energy, 4(1), 36-46.

[19] Ahmed, O., Baker, G., & Ahmed, A. (2023). An Experimental Study to Improve the Performance of a Solar Still Using Solar Collectors. NTU Journal of Renewable Energy, 4(1), 47-56.

[20] Jasim, M. A., Ahmed, O., & Alaiwi, Y. (2023). Performance of solar stills integrated with PV/Thermal solar collectors: A review. NTU Journal of Renewable Energy, 4(1), 97-111.

[21] Firth, S., Lomas, K., Rees, S. (2010). A Simple Model Of Pv System Performance and Its Use In Fault Detection. Solar Energy, 4(84), 624-635. https://doi.org/10.1016/j.solener.2009.08.004

[22] Kaplani, E. (2012). Detection Of Degradation Effects In Field-aged C-si Solar Cells Through Ir Thermography and Digital Image Processing. International Journal of Photoenergy, (2012), 1-11. https://doi.org/10.1155/2012/396792

[23] Mathew, D., Rani, C., Kumar, M., Wang, Y., Binns, R., Busawon, K. (2018). Wind-driven Optimization Technique For Estimation Of Solar Photovoltaic Parameters. IEEE J. Photovoltaics, 1(8), 248-256. https://doi.org/10.1109/jphotov.2017.2769000.

[24] Shittu, S., Li, G., Zhao, X., Akhlaghi, Y., Ma, X., Yu, M. (2019). Comparative Study Of a Concentrated Photovoltaic-thermoelectric System With And Without Flat Plate Heat Pipe. Energy Conversion and Management, (193), 1-14. https://doi.org/10.1016/j.enconman.2019.04.055.

[25] Stropnik, R., Stritih, U. (2016). Increasing the Efficiency Of Pv Panel With The Use Of Pcm. Renewable Energy, (97), 671-679. https://doi.org/10.1016/j.renene.2016.06.011.

[26] Terrang, C. D., Sodipo, B. K., & Abubakar, M. S. (2023). PV MODULE SINGLE–DIODE MODEL, PARAMETER EXTRACTION OF POLYCRYSTALLINE AND AMORPHOUS SOLAR PANEL. Science World Journal, 18(2), 301-307.

[27] Thanikanti, S. B., Kumar, P., Devakirubakaran, S., Aljafari, B., & Colak, I. (2023). A dynamic mismatch loss mitigation algorithm with dual input dual output converter for solar PV systems. Solar Energy Materials and Solar Cells, 251, 112163.

[28] Habib, S., Jia, Y., Tamoor, M., Ans Zaka, M., Shi, M., & Dong, Q. (2023). Modelling, Simulation and Experimental Analysis of a Photovoltaic and Biogas Hybrid Renewable Energy System for Electrification of Rural Community. Energy Technology.

[29] Fan, S., Wang, X., Cao, S., Wang, Y., Zhang, Y., & Liu, B. (2022). A novel model to determine the relationship between dust concentration and energy conversion efficiency of photovoltaic (PV) panels. Energy, 252, 123927.

[30] Chaichan, M. T., Kazem, H. A., Al-Waeli, A. H., Sopian, K., Fayad, M. A., Alawee, W. H., ... & Al-Amiery, A. A. (2023). Sand and Dust Storms' Impact on the Efficiency of the Photovoltaic Modules Installed in Baghdad: A Review Study with an Empirical Investigation. Energies, 16(9), 3938.