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M.Sc. in Mechanical Engineering

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INVESTIGATION OF THE EFFECTS OF COOLING AND DUST ACCUMULATION ON THE POWER OUTPUT AND EFFICIENCY OF PHOTOVOLTAIC PANELS

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BY

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Mechanical Engineering

Gaziantep University

Supervisor

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by

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I hereby declare that all information in this document has obtained and presented in accordance with academic rules and ethical conducts. I also declare that, as required by these rules and conducts, I have fully cited and referenced all the materials and results that are not authentic to this work.

Aisha Tareq Taher KOPRLE

ABSTRACT

INVESTIGATION OF THE EFFECTS OF COOLING AND DUST ACCUMULATION ON THE POWER OUTPUT AND EFFICIENCY OF PHOTOVOLTAIC PANELS

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In this study, experimental and numerical tests were performed on the conventional photovoltaic (PV) panels to investigate the effects of pulsed water spray cooling systems on the efficiency of the PV panels. The average outside temperature and solar radiation levels during the study were 39°C and 920W/m^2, respectively. Experimental results showed that the temperatures of the PV panel with dust and water-cooled system are 57.5°C, and 36.5°C, respectively. It is noted that the highest temperatures of the PV panel on which dust accumulated with different weights of 200 gr., 300 gr., 400 gr., and 500 gr., reached the levels of 57°C, 57°C, 60°C, and 63.4°C, respectively. It is investigated that the water-cooled PV system decreased the panel temperature to 34°C. The paired model developed analytically and numerically was solved using MATLAB software by using PV module equations, and the manufacturing data sheet to evaluate the overall performance of the panels. Simulation results indicate an increase in electrical efficiency from 19% for the dusty panel to 37% for the clean panel at 10:00 Am using the pulsed water spray system. In the case of the cooled and cleaned PV system with water, the open circuit voltage and short circuit current were increased by 8.5% and 6%, respectively. Experimentally, the overall efficiency of a cooling PV panel by pulsed spray system 13.7% while traditional PV panel efficiency was 13%.

Key Words: PV system, Accumulation of dust, Power, Efficiency, Pulsed-spray.

ÖZET

SOĞUTMA VE TOZ BİRİKİMİNİN FOTOVOLTAİK PANELLERİN GÜÇ ÇIKIŞI VE VERİMLİLİĞİ ÜZERİNDEKİ ETKİSİNİN İNCELENMESİ

KOPRLE, Aisha Tareq Taher
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Şubat 2023
53 sayfa

Bu çalışmada, darbeli su püskürtmeli soğutma sistemlerinin PV panellerin verimliliği üzerindeki etkilerini araştırmak için geleneksel fotovoltaik (PV) paneller üzerinde deneysel ve sayısal testler yapılmıştır. Çalışma sırasında ortalama dış sıcaklık ve güneş radyasyon seviyeleri sırasıyla 39 °C ve 920 W/m² idi. Deneysel sonuçlar, toz ve su soğutmalı sistem FV panelinin sıcaklıklarının sırasıyla 57.5 °C ve 36.5 °C olduğunu göstermiştir. 200 gr., 300 gr., 400 gr. ve 500 gr.'lık farklı ağırlıklarda tozun biriktiği PV panelin en yüksek sıcaklıklarının 57°C, 57°C, 60°C seviyelerine ulaştığı kaydedildi. sırasıyla ve 63.4°C. Su soğutmalı PV sistemin panel sıcaklığını 34 °C'ye kadar düşürdüğü araştırılmıştır. Analitik ve sayısal olarak geliştirilen eşleştirilmiş model, panellerin genel performansını değerlendirmek için PV modül denklemleri ve üretim veri sayfası kullanılarak MATLAB yazılımı kullanılarak çözüldü. Simülasyon sonuçları, darbeli su püskürtme sistemi kullanılarak sabah saat 10:00'da tozlu panel için %19 olan elektrik verimliliğinin temiz panel için % 37'ye yükseldiğini göstermektedir. Su ile soğutulan ve temizlenen FV sistemde açık devre gerilimi % 8.5, kısa devre akımı ise % 6 oranında artmıştır. Deneysel olarak, darbeli püskürtme sistemi ile soğuyan bir PV panelinin genel verimliliği %13.7 iken, geleneksel PV paneli verimliliği % 13'tür.

Anahtar Kelimeler: PV sistemi, Toz birikimi, Güç, Verimlilik, Darbeli püskürtme

"Dedicated to my family"

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First of all, praise be to my God, the Cherisher and the Sustainer of the World. A thesis work is a product of collective efforts and able guidance. A work has a life and spirits of its own. I believe that no work can achieve its ultimate objectives without proper guidance and support from others. I wish to express my heartiest thanks to my respected guides Assoc. Prof. Dr. Adem ATMACA, Department of Mechanical Engineering, University of Gaziantep - Turkey, who devoted their valuable time and provided enthusiastic guidance, advice and continuous encouragement, which were the constant source of inspiration for the completion of this thesis work. Whenever I requested to solve any of my problems, was one of the main supports during this period.

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LIST OFABBREVIATION

PV	Photovoltaic
CSP	Concentrated solar power
Isc	Short circuit current
Voc	Open voltage current
DI	De- inoized
CPV	Common procurement vocabulary
PVT	PV thermal
Re	Reynolds number
FEM	Finite element method
TE	Thermal electric
GA	Genatic algorith
CFD	Computational fluid dynamic
PCM	Phase change material
FF	Fill factor
Pmax	Maximum power

CHAPTER I

INTRODUCTION

1.1 Overview

The need to employ renewable energy sources is a critical issue with the rising energy demand, the finite availability of fossil fuels, and the increasing environmental damage. The technology for directly converting solar energy into electrical energy is known as photovoltaic panels (PV). People constantly strive to make their lives more pleasant, made possible by the accessibility and efficient use of energy. Iraq depends on power generation stations, and there are two types, non-renewable sources that rely on it mainly, and renewable sources from dams. Where owns nine thermal stations, the most significant being the AL-Bayji station 1320 MW and the AL-Shemal station 2100 MW, 25 Natural gas stations for the generation of electricity the essential Shatt-Basra station 1900 MW and AL-Anbar station 1642 MW, and eight renewable sources like dams most significant Musul dam 1050 MW and Haditha dam 660 MW. Iraq produces about 10,000 MW, which is not enough to meet the country's needs, so diesel generators were directed to fill the shortfall, which is a non-economical method.

Fossil fuels including coal, oil, and gas make up the majority of the sources of energy used by nations. Furthermore, if are not transformed into useable products, these kinds of raw fuels are no longer acceptable for usage. The conversion of fuels causes pollution, which damages the ecosystem and contributes to global warming [1]. More emissions will be produced and released into the atmosphere as a result, leading to extremely filthy weather. Researchers are constantly seeking alternate energy sources that operate with zero emissions because of the pollution issue.

Another factor is that it is forcing the energy sector to look for sustainable energy sources. The sun is the finest potential energy source for supplying all consumers on the planet with electricity. Many scientists and researchers from all the world are drawn to the ecologically energy source that derives from the sun, or solar energy [2] Two different types of energy can be generated from sunlight. PV cells produce the first kind of energy, which is electrical, while solar heating produces the second kind of energy, which is thermal [3]. The concept for a ground-mounted array is shown in Figure 1.1 [4].

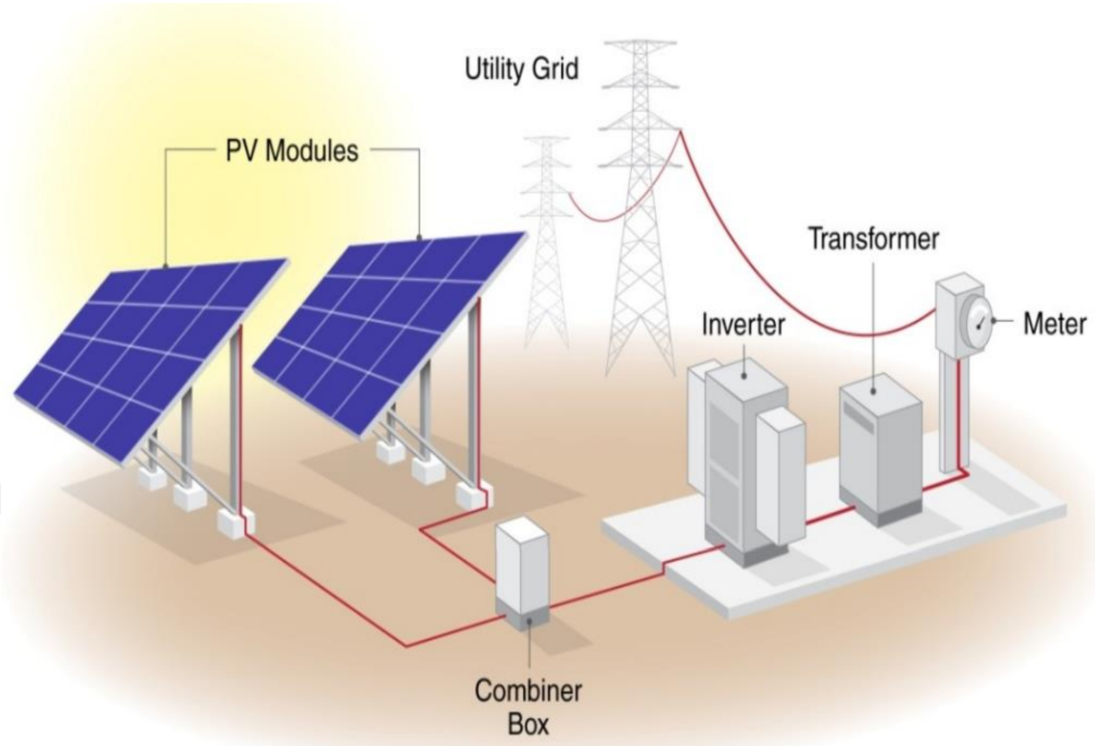

Figure 1.1 Major components of solar energy system (Ground-mounted array diagram).

1.2 Research Aim and Research Objectives

This study's aims to investigate the performance of PV panels using pulsed water spray cooling systems in the harsh environment of Iraq. Based on the locations where the relevant atmospheric conditions phenomena occur most frequently, modelers and engineers would be able to utilize this knowledge to choose the best sites for the construction of solar plants. The study was conducted practically using two models of the PV system and using MATLAB simulation system theoretically to evaluate the PV system's performance along the following axes:

1. Detailed experimental analysis of settled dust's effects on several no-concentrated PV module technologies.
2. Reduced the surface temperature of the water-cooled PV panel while contrasting it with the dusty PV panel.
3. Improved the PV panel's overall efficiency of the water-cooled and compare it with the dusty PV panel at the same time.

1.3 Thesis Layout

A thesis is built up of six chapters. The first chapter discusses the primary goals of the thesis and research. Chapter two provides a thorough review of the literature on solar concentrated PV technology, including information on the different cell types, performance improvement strategies, and cooling techniques. Additionally, it covers computational and experimental studies on how dust accumulation affects the properties of both concentrated and non-concentrated PV.

Chapter three describes the effectiveness of PV panels that cooled with distilled water and evaluate by using theoretic energy analysis equations. Chapter four presents a detailed experimental study on water-cooled PV conducted in Kirkuk/Iraq to establish a baseline for dust impacts in Iraq.

Chapter five discussion of the practical and the experiments conducted from 9:00 am to 5:00 pm during July and August, and the theoretical results obtained through the use of the simulation system (MATLAB). Chapter six, conclusions and future work of this research.

1.4 Photovoltaic (PV) cells

The solar cell has a long lifespan and requires no additional maintenance because none of its parts have moving parts. Solid-state technologies called PV cells directly turn sunlight into energy, without the aid of heat engine or other machinery. PV cells have the advantage of being easy to add more cells to increase the amount of energy produced. Almost the necessary energy may be developed from small units to megawatt power plants. Above all, PV cells have a high level of dependability and can be employed as independent production systems [5]. The PV cell is constructed of two thin layers of semi-conductor components and is built of a semi-conductor silicon material. The PV panel is composed of multiple connected, closed cells that are protected by a glass layer inside the PV cell and provide the required electrical power [6].

PV panels have no negative environmental effects because they don't emit any gases when they're in use. In addition, PV cells are favored over other renewable energy sources due to their easy of installation in a range of settings, such as public areas and surfaces, Figure 1.2 shows the PV cell producing electricity [7, 8].

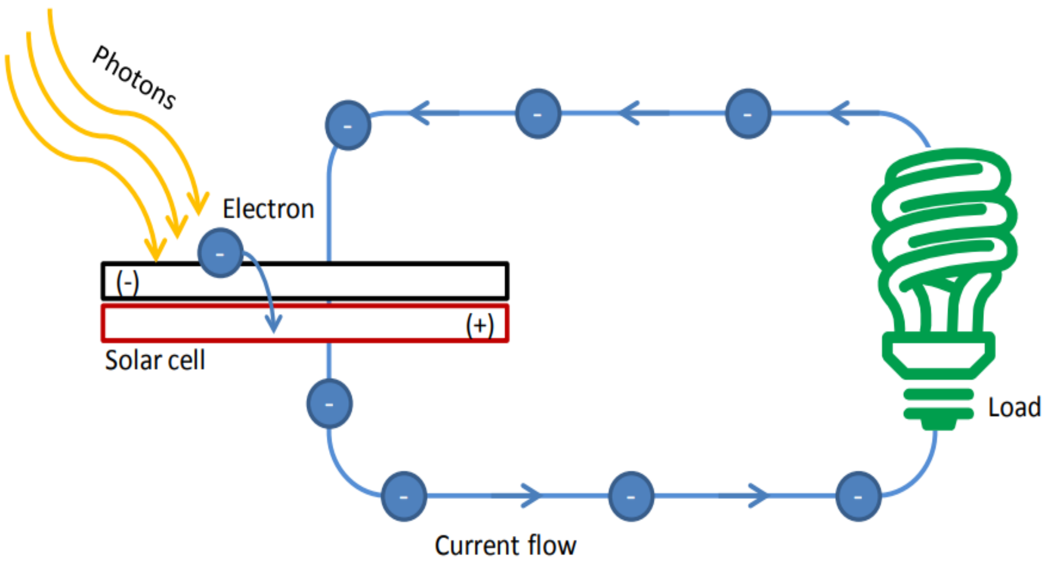

Figure 1.2 The PV cell generation of electricity.

1.4.1 Technical PV Panel Types

The PV cell can be divided into the following two categories:

1. The earliest kind of PV cell is made of crystalline silicon, which also contains crystalline lattice parts. The disadvantages of this type are impurities, although they are efficient compared to other varieties, ranging from (14–15%) and possibly even higher, they are effective. Mon-crystalline Silicon Cells are the name of this type. Compared to thin-film cells, which are immune to solar radiation and less efficient in low absorption environments, monoclonal silicon cells are more vulnerable to solar radiation. It has a greater relative cost since the production procedures are more complex, which raises the starting cost. In this kind, the impact of cell temperature on electrical efficiency is taken into account; as a result, when the cell temperature exceeds the standard by one degree, the cell's electrical efficiency decreases by 0.4-0.5%.
2. Polycrystalline silicon, produced by melting polycrystalline silicon, putting it into alloys, and chip-cutting such alloys using a lot of monocrystalline silicon, is used to construct other types of PV cells. This form of PV cell is produced at a lower cost than the first type since the manufacturing process is easier and less involved.

   However, it performs somewhat less well than the previous type. For two different types of PV modules, the influence of cell temperature on cell efficiency has the same coefficient, it has an efficiency of roughly (13–15%).

The standard conditions for determining the electrical efficiency of PV cells are solar radiation of 1000 w/m^2 and a cell temperature of 25 °C, which together produce the PV cell's finest degree of generation of electricity and its highest level of electrical efficiency. Because more than (80%) of solar radiation is not used in the generation of electricity, ultra-low PV has a poor conversion efficiency of no more than (9–20%) and most of the solar radiation energy is converted to thermal energy [9,10]. The PV cells' temperature rises as a result of this process, decreasing their electrical efficiency. High temperatures harm PV cells, which significantly reduces their output and lowers their electrical efficiency [11]. Calculations to estimate the value of employing solar cells and knowledge of the energy produced at various locations and loads are both essential in order to make the necessary adjustments for obtaining the proper electrical energy. The effect of temperature on the electrical efficiency of PV cells is depicted in Figure 1.3 [12, 13].

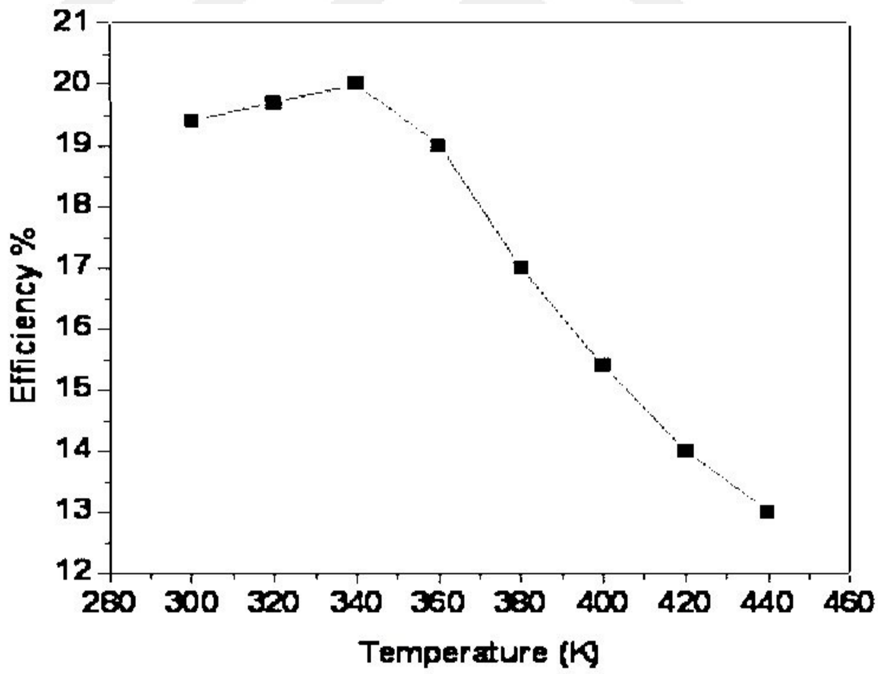

Figure 1.3 Impact of temperature on the PV cells' electrical efficiency.

3. panels made of crystalline silicon are more efficient than 3-A thin-film silicon PV cells. The original design and development of thin-film silicon panels, which have a higher power to (size/weight) ratio, for space application. Various PV cell types are depicted in Figure 1.4.

Figure 1.4 Types of PV panels.

1.4.2 PV Efficiency and Temperature Effects

The PV cell is designed to operate at (25°C) and (1000w/m^2) of solar radiation under normal operating conditions [16]. The best efficiency for turning solar energy into electrical energy is achieved by PV (20%). As the PV panels' efficiency decreases, their surface temperature sharply increases. PV panel surface temperature rise increase results in considerable energy loss. Different methods have been explored to lower the panels' surface temperatures, for each degree above 25 °C, PV panel efficiency drops by approximately 0.5% [17]. The electrical output of a solar cell panel can be increased by cooling it because cooling keeps the PV cells from overheating and damaging the panel. The relationship between efficiency and output power and temperature is inverse. An important key aspect that greatly affects a PV module's capacity to generate electricity is its operating temperature. To prevent a drop in electrical efficiency, the cooling fluid for the PV module can be either air or water. The removal of thermal heat and the lowering of light reflection "due to reduced refraction index" are two critical elements that boost the effectiveness of a commercial panel submerged in water [18].

1.5 Solar Energy

A carbon-free power source that is accessible everywhere is solar energy. Due to their location in or close to the solar belt, extensive sunny hours, and good insulation levels, several countries are well-positioned to benefit from solar technologies. The range of solar radiation over the world is depicted in Figure 1.3 [14]. Concentrated solar power (CSP) and photovoltaics (PV) are two alternative solar energy conversion methods that can be used to produce electricity. Concentrated solar power (CSP) and photovoltaics (PV) are two separate solar energy technologies that can be used to produce electricity [15]. CSP operates conventional turbines by producing heat from focused solar beams and steam. By combining their generating power with storage, CSP facilities have been able to produce electricity that can be stored and used for several hours after it is produced. Sunlight is converted directly into electricity using PV solar energy. Since Germany and later Spain expanded their use of PV systems around 2000, the demand for these systems has greatly increased [16]. Transmission facilities, rural phone stations, freestanding cathodic protection systems, and high-speed road emergency telephones are all applications of PV technology. The power of poly silicon panels has increased significantly (particularly in China), and this has been matched by a 75% drop in PV module pricing. In recent years, solar power capacity has increased significantly, and at the same time, its costs have been reduced. Additionally, this technology can be utilized to run irrigation pumps and drinking water pumps. In any country, the private sector general and the public must promote and publicize the usage of PV systems [17]. Because most rural region people require electrical energy to suit their needs. Depending on the user, solar energy will be useful in these locations [18]. The import of oil and gas will be greatly reduced by large-scale solar energy development. Solar energy might be the best alternative for these areas. Our reliance on fossil fuels will be decreased by using residential solar water heating and cooking equipment [19].

1.6 Iraqi Solar Energy

Solar radiation in Iraq is intense for extended periods; according to weather statistics, Baghdad receives roughly 3300 hours of intensity radiation every year. Iraq's solar brightness hours are incomparable to those of the majority of the world nations, including Spain, one of the more advanced countries in solar energy consumption. The solar radiation intensity per hour varies from 416 W/m² in January to 833 W/m² in June. Researches on using solar energy in Iraq began in 1973 , responding to the energy crisis brought on by the war that broke out in October of that year. The intensity of solar energy in Baghdad and other countries has been the focus of various investigations, many of which have resulted in equations [16]. During this time, the majority of the practical and theoretical work in this field was on investigating solar-powered freezers and water heaters. The findings of the Iraqi investigations in this field showed that theory and practice's conclusions were closely related. Studies and theoretical studies began with the development of theoretical models, such as a mathematical and numerical representation of solar water heaters [17, 18]. Iraqi researchers looked at the possibility of producing hydrogen for use in energy from high-concentration solar energy because it is thought to be an energy carrier and has a clean burning quality. Subsequent research has focused on introducing variables and weather aspects to solar power applications to generate power more effectively [19]. The Trobe walls were used by the researchers for more theoretical and experimental studies in the cold climate of Iraq [20, 21].

In various experiments, the industrial salt gradient pond has been effectively employed to store energy for use in a range of applications, heating agricultural greenhouses and increasing the output of solar distillates connected to the solar pond [22]. The outcomes of these investigations and tests revealed good precision in the statistics on solar radiation provided for each region of Iraq. Many of this research made use of the most recent mathematical relationships between temperature, humidity, and solar radiation period. In three locations in Iraq, relationships were discovered. Figure 3.3 shows a map of the annual and monthly solar radiation from 24 locations in the entire country of Iraq [23].

The experiment was unsuccessful because low-efficiency solar cells were used, and there was a buildup of dust on them as a result of their lack of maintenance (Every month for a few days, Iraq is characterized by a spike in the amount of dust). Streetlights were illuminated by PV cells [24].

PV cells are presently used sparingly and with low power to process electricity for individual homes, pump water for agriculture, and power telecommunication equipment in remote areas without easy access to the power grid. These elements have led to the widespread unsupported use of PV cells across Iraq. [25].

1.7 Problem Statement

The efficiency of PV modules increased at (25 °C and 1000 W/m^2) although the efficiency of PV panels was influenced by the temperature of the cells. The module efficiency decreases with each increase in PV cell temperature. A range of (13-20%) of solar radiation can be converted to electrical energy, and the solar irradiation that the PV cells absorbs is transformed into undesirable thermal energy, which raises cell temperature and lowers efficiency. PV panels main problem is a loss in cell performance and efficiency brought on by an increase in cell reference temperature. To overcome this limitation, there is a strong motivation to reduce cell base temperature via heat transmission and removal processes in the quickest and simplest manners.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

To improve the production efficiency of PV panels, many theroretical and practical investigations have been done. Understanding the various scientific approaches to the cooling system for (PV) panels is essential to become familiar with the various cooling strategies. One of the most popular and applied used technologies is the use of water.

2.2 Previous Studies Investigating the PV Panels Without Cooling

There are many researches calculated the PV efficiency values. The experimental and theoretical investigation using PV system software on the effect of the performance of PV panels according to climatic conditions in Malaysia. The experimental data run recorded from 9:00 am to 5 pm. The research found that solar panels electrical efficiency drops by (5%), on average, for every 10°C increase in temperature over their normal operating temperature. It was also discovered during the study that variations in solar radiation intensity cause changes in the solar panels temperature, with the experiment estimating that the lowest electrical power is (79.5W) at a temperature of (65°C) and that the greatest power Electricity was recorded by (100W) at a temperature of (25°C). by (49.43%) degrees. Thus, it has been demonstrated by both approaches that as the temperature rises, the open circuit voltage drops, resulting in a fall in the solar panel's electrical efficiency [26].

The impact analyzed of varying the surface temperature of PV panels on electricity efficiency using the (PCID) tool. Utilizing crystalline silicon PV cells with thicknesses ranging from (1 m) to (100 m), numerous experiments were conducted at high temperatures ranging from (20 °C) to (80 °C).

Studies indicate that while the short circuit current (ISC) rises with temperature, the open circuit voltage (VOC) and filling factor (FF) drop as temperature rises (100 m) and rises (20 °C) [27].

2.3 Previous Studies Investigation of the PV Panels Cooled By Water

In many studies, The PV panel cooling facility uses the spraying water technique to consume less water. The temperature decreased (from 45 °C) to (35 °C) [19]. The solar cells surface temperature was discovered to have dropped to 18°C when using the third strategy, which combines back cooling with film cooling. The second method of cooling is direct contact backwater attachment. It demonstrates that the daily energy production of the cooled PV module has improved by a factor of up to 22%, 29.8%, and 35% in comparison to the non-cooled PV module for the film, back, and integrated film-back cooling modules, respectively. It was discovered that the cells surface temperatures dropped to 25°C. By using an infrared camera, the experimental results were acquired [20].

The effects of spraying water over the solar panels front face It is being researched how to clean them and lower the surface temperature. The results showed that the PV performance may be improved by 9.5% by adding a thin water coating to absorb the heat [21]. The electric efficiency can be enhanced by 8.5, 12-14, and 8 %, by creating a collector and an absorber that is attached to the back and end of the coolant, respectively [22, 23]. In various depths of water in a pool was submerged the monocrystalline silicon panel was. In comparison to PV panels without any cooling devices, According to data analysis, electrical efficiency has grown by 11% at 4 cm of water level, although the growth ratio only reaches 15% at that depth [24].

A passive cooling method was designed as a media cool by using rainwater and a gaseous expansion device for rainwater distribution. The passive cooling solution improved by 8% of the PV panels electrical efficiency, which decreased the temperature of the cells. The amount of solar energy that the gas got after being thermally expanded by it determines how much water it forces to flow up the solar panels [25]. The thermal transmission fluid circulates inside and outside of the absorber tube, cooling the concentrator cells to improve output on both sides. A new model is introduced for the liquid of PV parabolic during the collector and the concentrated immersion cooled method. The liquid is utilized on all of the panel's edges to cool PV cells. Results show that fluid inside the annulus can more easily carry heat since it is stronger on both sides of the cells [28].

The electrical performance of a PV panel is sensitive to operating temperature and can be significantly affected when the cell temperature begins to rise. The result demonstrates that cooling the PV panel is more efficient from the front side than from the back and may also improve optical efficiency by cleaning up dust and other contaminants from the PV surface. using various water cooling strategies, the performance of the PV module will be determined. The results were contrasted with those from PV panels that weren't cooled, as well as front, back, and double cooling [29].

Water spray technology has been used to cool solar cell panels. Instead of continuously spraying water on the PV cells' surface, the effectiveness of this method was examined. According to the findings, solar cells' electrical efficiency has increased by 17% [30].

The contrast between the various cooling fluid immersions. An isolated liquid, organic fluids, and deionized water are all used during the immersion. The results demonstrated an increase in electrical efficiency to 14.9% [31].

The study investigated the mechanism of dust adhesion and separation using the modeling and also examines the temperature change caused by the air-blowing procedure. The use of an efficient cooling method can significantly increase the efficiency of PV systems. Research and testing are being done on a compressed air-based regulating system that can simultaneously clean and cool solar PV panels. However, these systems use a large amount of water, which can be a big problem for large-scale PV plants. A regulation system that will maximize PV generation can be made using dynamic models of compressed air release. This study uses PV arrays serving a dry site and uses an empirical test to evaluate the increased power generation resulting from the cleaning and cooling effects [32].

The thermal behaviors and electrical performance of the absorber combined with the back of the PV panel were utilizing a technique model in three dimensions study of a solar collector based on the finite element method (FEM) technique using the COMSOL program. At 0.0256 kg/s, the mass flow rate, the PV panel produces electrical power and temperature of 59.434 W and 23.845 °C, respectively. According to the findings, as the flow rate increases, collector temperature (PVT) falls, increasing the quantity of power produced by the PV panel [33]. An increase in electrical efficiency is dependent on cooling methods, the kind and size of the module, location, and season, and often results in a 3-5% increase in overall efficiency. Both the front and back sides employed water spray technology. The power output on only the front side was measured at 40.1 W, and the output on the back side was found to be at 39.9 W [34].

In this research, 20 nozzles are installed, 10 of which are on each side to spray water using nozzles on the monocrystalline PV module. From 52 °C, the average plate temperature was lowered to 24 °C. Potency rose by 14.15 percent. The installation of the rear nozzles is parallel to the front nozzles, and the surface are set at an angle of 40 degrees to provide a shaded effect for the frame. The nozzle assembly enables efficient water mist distribution. Water mist is distributed more widely on surfaces thanks to wicker [35].

Moreover, water-cooling technology on the top and back of the solar panel have been used and direct water cooling used to cool the front panel as wel, while pipes connected to a water reservoir cooled the back. The findings demonstrated a drop in cell temperature from (50 to 39 C°) [36].

In India, the researcher looked at how cooling affected the panels front surface in the summer and winter. According to the findings, the efficiency of power is between (11–14%) in the winter and (9–12%) in the summer [37].

Study of the conversion tools effectiveness and the impact of lowering the cell surface temperature. A water spraying method was employed with four different nozzle types that had different diameters (2, 3, 4, and 5 mm). The outcomes showed that a nozzle with a 2 mm diameter reduced the cell's temperature down to (50%) of its starting point [38].

In this study, the electrical, thermal, and energy capacities of the PVT were examined for mass flow rates between 0.025 kg/s and 0.083 kg/s in dynamic tropical environment, the effectiveness of a commercial PV thermal system (PVT) was assessed using mass flow rate effects. However, smaller than the PV's exergy efficiency (13.0-12.75% for irradiances of 710-790 W/m^2) for irradiances below 790 W/m^2, and the inverse was also true. Additionally, the PV thermal efficiency, which ranged from 38.8 to 43.1%, was below average. when compared to experimental (non-commercial) PVT systems, its energy-saving efficiency was typically above 50%.

Additionally, from the findings of the experiment, an expression was created and provided between the temperature of the PVT module and the water flow rate [39].
Four different cooling fluids, including water, water vapor, nano-silica water (SiO2-H2O), and nano-silver water (Ag-H2O), were used to reduce the PV module's surface temperature and boost system efficiency. The findings also revealed that using water, SiO2-H2O, and Ag-H2O for cooling boosted the system's efficiency by 13.09%, 16.17%, and 20.68%, respectively, compared to using natural airflow. Additionally, the usage of water, SiO2-H2O, and Ag-H2O reduced the surface temperature of the PV module by 1.77 °C, 9.76 °C, and 13.17 °C, respectively, compared to the air-based natural flow cooling [40].

The investigation uses computational and experimental research to look at the decrease in PV panel temperature operating using an air-cooled heat sink. High amounts of solar irradiation can cause an increase in operating temperature, which can harm the efficiency and lifespan of PV panels. A perforated aluminum plate placed on the rear of the PV panel is the suggested heat sink. The working temperature of the PV panel was discovered to have drastically dropped, and its electrical performance had much increased. CFD analysis in the heat sink model with a 1.5 m/s airflow velocity and a 35 °C temperature under 1000 W/m^2, heat flux revealed that the average of the PV panels temperature reduced from 85.3°C to 72.8°C. The PV panel's maximum power point and open-circuit photovoltage (V_{OC}) both increased as a result of the heat sink's reduction in temperature, by 10% and 18.67%, respectively. [41].
To prevent uneven cooling over the PV panel's surface. In this work, a cooling technique based on a jet impingement device is proposed for (PV) strings. This study recommends water jet impingement cooling as a feasible technique for evenly cooling PV panels based on the meteorological data for the Middle Eastern region. The comprehensive cooling method includes optical, radiation, thermal, electrical, and jet cooling models. To evaluate the impact of cell temperature on the PV string using average heat transfer correlations, a comprehensive thermal model based on the energy balance technique is also constructed. This work develops a jet impingement cooling model for PV strings and performs heat transfer calculations for both single and multiple jet nozzles in order to forecast the cell temperature, power production, and conversion efficiency of PV strings. The results show that jet cooling is more effective, has a lower minimum cell temperature, and maintains a more stable temperature

[42].This research presents an experimental performance assessment of a converging channel cooling system designed to achieve low and uniform temperatures on the surface of a PV panel. Temperature distribution at various converging angles was looked at with the CFD program. The temperature profile standard deviation was used to determine the two-degree angle of the converging channel heat exchanger. The temperature distribution for cooled PV showed a nearly uniform temperature profile when the average cell temperature dropped from 71°C to 45°C. Thermal properties were discovered to be sensitive to the PV system performance. The maximum power output increased from 11.9 W to 16.2 W when convergent cooling was used and the cell temperature was significantly reduced to 2S.8°C by using convergent cooling. To ensure that cells function effectively at low temperatures with even temperature distribution in severely hot or cold weather, the following cooling system may be utilized [43].

Experimental studies of several PV panel cooling techniques. Phase change material (PCM), thermoelectric (TE), and aluminum fins were the cooling methods employed. $CaCl_2 \cdot 6H_2O$ is one PCM that is widely used to cool PVs, and a PCM with a melting point higher than the surface temperature of the PV panel is the other. PV panel surface temperatures and output powers were compared utilizing various TE material counts (6, 8, and 12) and aluminum fin arrangements. The PCM, which is notch-chosen suitably, was discovered to have insulating features in the PV panel and to increase the panel's temperature while decreasing its output power. When the best cooling techniques were used under the same climatic conditions, the PV with fin system generated the most power (47.88W), whereas the PV with PCM generated the least power (44.26W) [44]. This research examined at whether it was possible to recover the electrical efficiency that the PV panel had lost due to its high temperature. It was a (PV/T) system built to work with a thermal tank filled with paraffin attached to the PV module. High-efficiency hybrid (PV/T) systems that can both heat water and cool PV modules have been suggested by many scholars. A heat exchanger with a nanofluid flowing across it is located inside the paraffin. It is possible to boost the electrical efficiency of PV modules, attracting more investment and speeding up the commercialization of the technology. The examination took place in Baghdad, Iraq, during the weather of May. The suggested PV/T system's electrical efficiency was compared to that of comparable systems from the literature. The electrical efficiency of the suggested system was 13.7%, therefore it increased [45]. The research examined the performance of a commercial polycrystalline silicon PV module under experimental conditions in the arid environment of Iraq. Temperature variations have an impact on the PV module's output parameters. Most parameters drop negatively as module temperature rises. The temperature of the PV module and its electrical characteristics were monitored. The PV's temperature ranged from 35.2 C at 7:00 am to 69 C at 2:00 pm, according to the data gathered. At noon, when sun irradiation was 961 W/m^2, the highest electrical power was recorded at 123 W.

Additionally, the average electrical efficiency peaked at roughly 7:00 in the morning, at 16.6% with a sun intensity of 318 W/m^2. It was determined that the fill factor may reach a maximum of about 76% [46].

The hybrid PV solar energy collection system in Dohuk city is being studied for seven months by experimental and digital means. Data on temperature, water mass flow rate, wind speed, and sun intensity are all included in the study.

Transient processes with constant thermophysical characteristics and heat transfer coefficients are modeled mathematically in one dimension. The PV/T collector's overall efficiency reaches its best point in May 2019 (72.01%), and it reaches its lowest point in January 2019 (63.1%). When compared to a PV solar collector system, the electrical efficiency of the cooling approach increases to roughly 3% [47]. The performance of both the system and standard water-cooled (CPV) concentrated photovoltaic (CPV) system was investigated experimentally and numerically in this work. For the PV panel, electricity efficiency increased from 14.2% to 17% with the use of reflectors and water cooling.

In the instance of the water-cooled CPV system, the short circuit current (Isc) and open voltage current (Voc) increased by 9% and 5.2%, respectively. The ambient temperature throughout the experiments was 32.6 °C, and the average sun radiation was 930 W/m^2. Additionally, MATLAB/Simulink modeling for PV modules is made using production data sheets and equations.

The final panel temperatures of concentrated PV systems and PV water-cooled concentrated systems are, respectively, 57.5°C, 64.1°C, and 36.5°C, according to empirical studies. Additionally, the CPV system and water-cooled CPV system each saw improvements in their power output of 10.65% and 24.4% (effectively 23%). [48].

2.4 Studies the Impact of Dust Accumulation on PV Panels

In the PV industry, research and development have often focused on solar radiation analysis, efficient operating techniques, design, and system sizing. In previous studies, panel modeling and I-V characteristics were used to examine the PV module. However, these works do not account for important factors or outside factors that can have an impact on the PV system. For PV-powered devices, solar cell efficiency is a critical design consideration. Frequently, there isn't much room to integrate solar cells. Cell efficiency may potentially come to serve as a primary system feasibility requirement [49]. The buildup of dust on solar panels, known as soiling, lowers CSP systems' optical efficiency. Over a 108-day dry period in the summer, the site's efficiency was seen to drop from 7.2% to 5.6%. Figure 2.1 shows how a PV panel has accumulated dust. However, a following rain event brought the efficiency back to 7.1%, recovering the majority of the lost efficiency. The variations in the efficiency of a sizable commercial installation (86.4 kWdc) throughout 2010 were measured using information on rain events captured at a nearby weather station (3.4 km away), satellite data on solar resource, and satellite data on solar resource variability. It was found that daily soiling losses were 0.21% [50].

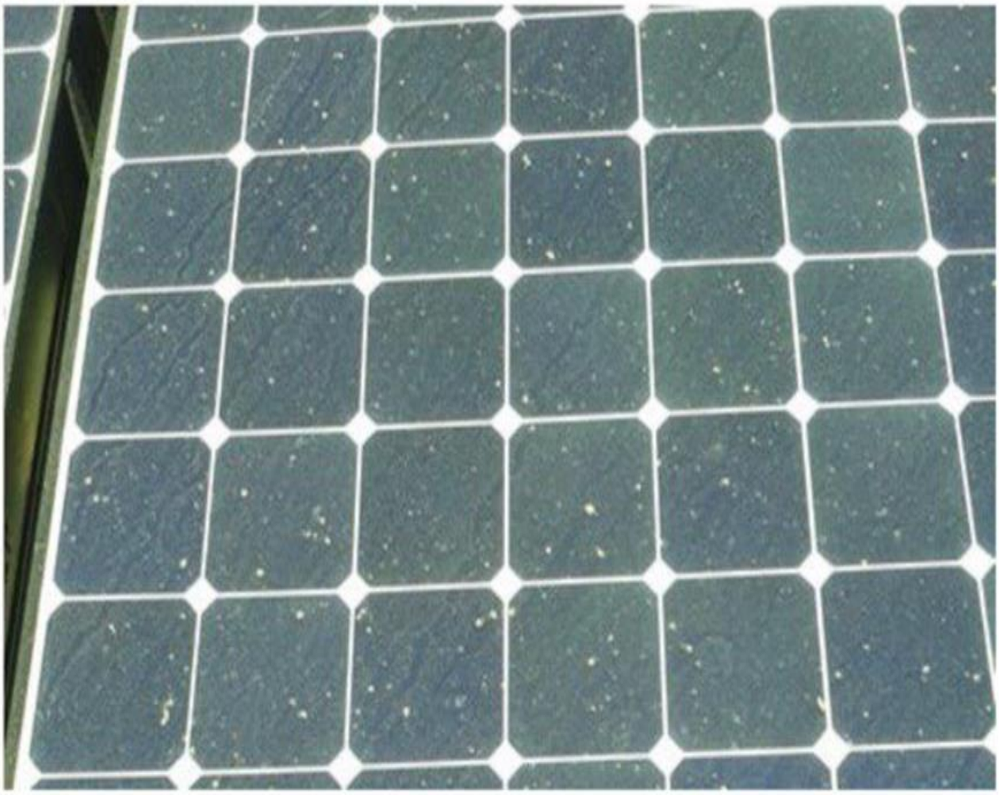

Figure 2.1 Dust accumulations on PV panel.

The production of energy from clean and sustainable sources is largely concerned with environmental challenges (pollution and global warming), growing fossil fuel prices, and shortage of fossil resources. However, due to their low efficiency, PV Solar systems that produce electricity are not yet commercially viable.

In addition, the PV module performance is also impacted by other elements, particularly environmental ones like dust, hail, humidity, and temperature as well as installation-related ones like installation site, tilt angle, and altitude. It is necessary to create a method to protect the PV module against hailstorms.

Also provides a summary of the current understanding of the hailstorm's effects on the PV module and suggests further investigation into the causes of dust deposition impacts on the surface of the PV module, the thermal properties, and the electrical of the PV module. The current evaluation also contains historical and current investigations of various mitigation approaches to help in choosing the optimal option for dust cleaning [51].

PV cells' output performance may be adversely affected by the particles that have accumulated on solar panels because they can absorb and distribute solar energy. It is possible to correctly forecast how particles will affect the PV module by modeling the power distribution of the external electromagnetic field of particle deposition irradiated by solar radiation and then designing the necessary equipment to lessen its adverse effects.

In this research, offer a fresh viewpoint, suggesting that the accumulation of particles of the right size can concentrate the sun's incoming irradiation in the direction of travel. Based on this finding, the proposed an innovative method to enhance the power output of the PV system and decrease the negative effects of deposition. Our numerical findings demonstrate that when the thickness of solar glass in conventional solar panels is decreased to 1.5 mm, it is realistically possible to acquire more than 10 times higher incoming solar power in the forward direction from the light-concentrating effect of deposition. Additionally, some unique cladding designs can be created to take advantage of this beneficial effect and manufacture more effective solar panels [52].

2.5 Cleaning Techniques of the PV Cells

It is essential to implement mechanical cleaning methods to improve the PV module's performance in regions where dust is a major issue, such as North Africa and the Middle East. In regions with little dust deposition, like the United States and Europe, rain, wind, and snow are more successful at progressively cleaning up the air [53]. Cleaning methods involving mechanical means include brushing, blowing, and wiping.

A self-cleaning mechanism is built into the architecture of the single-axis solar tracking system. You can use electricity and technology to control this system [54]. The method to clear particles of accumulated dust, as shown in Figure 2.2, includes directing a hose from the water's flow to the PV panel surface.

To achieve the requisite high pressure with this method, a lot of water must be used, as well as pumps. In contemporary cleaning techniques, compressed water is occasionally combined with a specific chemical. It increases dust removal's effectiveness. Additionally, it results in a significant water loss is possible, and chemical buildup on the PV edges is also a possibility. When high-pressure water pumps are used, a portion of the solar energy generated is consumed, lowering the efficiency. A hot PV could cause a thermal shock, but there is also a danger that water pipes could clog or even burst. When drops of water fall, they will unquestionably be cooler than the plate's surface. Typically, PV cleaning is finished at midday. In addition to cleaning the PV, water helps cool it rainwater is used. The difficulty of using water in locations with limited supplies is a drawback of this technology.

On the PV surface, Using water at temperatures close to the PV temperature and letting water tanks get heated by the sun are traditional ways to prevent heat shocks. It has been determined that water is the most effective cleaning method for PV, particularly now that air stagnation and the crucial period for dust particle deposition have begun. When used in PV stations with large amounts of space, this technology may be highly expensive.in places where there is a shortage of water [55].

The temperature of the PV backside was the foundation for the researchers' automatic water control system. In hot and dry environments, water was used to clean and cool PV, and the effectiveness of this unit was compared to the effectiveness of the unit without cooling or cleaning. The water spray washed the PV surface, by bringing the temperature of the PV down to a level that was nearly equal to the ambient temperature, [56].

Figure 2.2 Automatic water cleaning system using solar panels.

2.6 Observations from Previous Studies

The researchers stated goal was to boost the electrical efficiency of the PV panels by implementing several forms of cooling systems, throughout this chapter as evidenced by the demonstration of the most relevant works using cooling systems. Some of the studies were conducted theoretically using simulation systems such as (MATLAB and ANSYS Software), and some of them were done practically under the climatic conditions of different cities at different times of the year, while others are theoretical and practical. From these studies, the PV panel surface temperature and electrical efficiency were also calculated. In addition, most of the research was aimed at finding the most efficient design to improve performance by cooling the panel and cleaning it from dust. In this chapter, we will study the measurement of the PV system performance with two tests. The first test investigates the consequences of raising the panel's surface temperature and lowering it with water using a pulsed water spray. The second test examines the effects of dust collection with various weights and similarly cleans the panel by spraying.

CHAPTER III

MATERIALS AND METHODS

3.1 Introduction

In this chapter, the performance of PV panels that were cooled with distilled water was assessed using the theoretical equations of energy analysis. In addition to using PV equations for the electric side, such as the open circuit voltage (V_{OC}), the short circuit current (I_{SC}), and the fill factor (FF), on the hybrid PV panels.

3.2 Mathematical Analysis of the Solar Cell

PV cells are semiconductor devices that use solar energy to generate electricity. The method involves dividing the electron-hole pairs produced at the p-n junction by the light quanta. This serves as the basis for how solar cells produce an electric current. [57].

The solar cell's ability to produce energy is affected by many things:

- When intensity of incident light increases, it means that consequently the electric current increases.
- Cell Area an increase in the cells surface area increases the current it produces.
- The incident inclination the choice of the incidence angle helps to improve the solar cells performance efficiency.

The performance of the solar cell is determined by several factors:

- Determine the short-circuit current for every silicon PV panel at any temperature using the mathematical relationship. [58].
- Open circuit voltage (Voc), the (Voc) decreases as the temperature of the photovoltaic panel increases significantly.
- Short circuit current (Isc), the (Isc) increases slightly as the solar panel's surface temperature rises, although it is calculable for every silicon PV panel at any temperature using the mathematical relationship[58].
- Efficiency η_e, electrical efficiency is the ratio of the maximum electrical power value to the solar irradiation energy that may be generated by a PV panel.

$$\eta_e = \frac{P_{Max}}{A \times G} \tag{3.1}$$

Where $P_{Max} = I_m x \times v_m$

- The fill factor (FF), is calculated as the ratio of the solar cell's maximum power P_{Max} to its output of (Isc) and (Voc) [59].

$$FF = \frac{P_{Max}}{I_{SC} \times V_{OC}} \tag{3.2}$$

The effect of parameters on the cell is divided as follows in Figure 3.1 [57], external parameters, internal parameters, and output parameters.

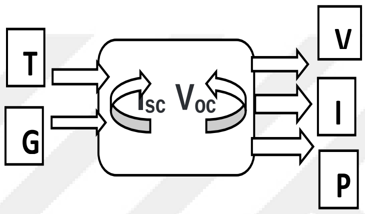

Figure 3.1 Output parameters, input, and internal parameters of the solar cell.

3.3 Mathematical Modeling of the Solar Module

Researchers and professionals used PV cell models to describe the behavior of these cells. The basis for a computer simulation of an actual system is modeling, Computer codes are created from mathematical models defining the system's properties for use in the simulation process. [60]. A single diode is used in the model, which also includes series resistance and resistance to conversion. It is coupled in parallel to a light-generated current source (I_{sta}) as in Figure 3.2 [61].

The basis for the cell's operation is the manufacture of solar cells using semiconductor materials such as silicon. It takes careful processing to produce a positive electric field on one side and a negative electric field on the other on a tiny semiconductor wafer. When light radiation hits the solar cell, it causes the electrons in semiconductor materials to become separated from their atoms. If electrical conductors are connected to the positive and negative sides, forming an electrical circuit, electrons can be caught as electricity. The diode turns the current created by the photon generated by the cell by p-n into electricity. The result of this procedure is an open circuit voltage (Voc). These procedures are converted into mathematical equations (Equations 1, 2, 3, and 4) that create a mathematical model that is simple to utilize in the simulation process and compatible with the building blocks in the library. Simulink in MATLAB [61،62]. The aim of simulating the solar cell model's mathematical equations is to confirm how an increase in cell temperature (the research issue) affects the result.

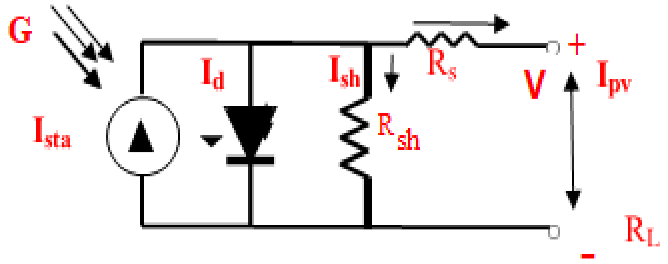

Figure 3.2 Equivalent circuit model of a PV cell.

Photocurrent Equation:

$$I_{sta}=\frac{G}{Gn}[I_{1+}\ K_i(T-T_n)] \tag{3.3}$$

Since:

Ista is the photocurrent

G is the radiation

Gn is the nominal radiation

Ki is the current temperature coefficient

I_l is the short circuit current

T is the absolute temperature in Kelvin

Tn is the reference temperature (298 K)

Diode Current Equation

$$I_d=I_{rs}\left(\frac{Tn}{T}\right)^3 exp\left(\frac{q*Ego}{B*K}\left\{\frac{1}{Tn}-\frac{1}{T}\right\}\right) \tag{3.4}$$

where Id is the saturation current and Ego is the material band gap energy.

Reverse Current Equation:

$$I_{rs}=\frac{I_{sc}}{exp\left(\frac{V_{oc}}{a+V_t}\right)^{-1}} \tag{3.5}$$

Where I_{rs} is the reverse saturation current, V_t thermal voltage, and α is the ideality factor.

Load Current Equation:

$$I_{pv} = I_{sta} - I_d - I_{sh} \tag{3.6}$$

Where I_{pv} is the output current of the solar panel.

Thermal Voltage Equation:

$$V_t = \frac{(T * K * N_s)}{q} \tag{3.7}$$

Where Vt thermal voltage, K is the Boltzman constant, Ns is the number of cells in series, and q is the electronic charge.

Equations (3.4 – 3.8) represent the mathematical behavior of the cell. The theoretical analysis of the physical processes involved in cell operation served as the foundation for the mathematical modeling in the environment (MATLAB/Simulink). The theoretical study allowed for the formulation and translation of mathematical models that characterize the system's attributes into subsystem components for use in the simulation process [62]. The Simulink environment represents the physical processes of these parameters as subsystems, which are regarded as blocks with independent inputs and outputs and connected to other subsystems to build the system. To simulate the dust deposition effect on solar panel surfaces. However, in this study, equations are used to determine the PV module's electrical properties, as voltage and current should be known before calculating the electrical efficiency. The output characteristics of the PV module are calculated using the MATLAB/Simulink software and the PV module equations to achieve electrical modeling. The first step in the simulation procedure is to convert the operating temperature from Celsius (°C) to Kelvin (K) using the reference's data sheet under standard test conditions (STC) (25 °C and 1000 W/m^2), as illustrated in Figure 3.3.

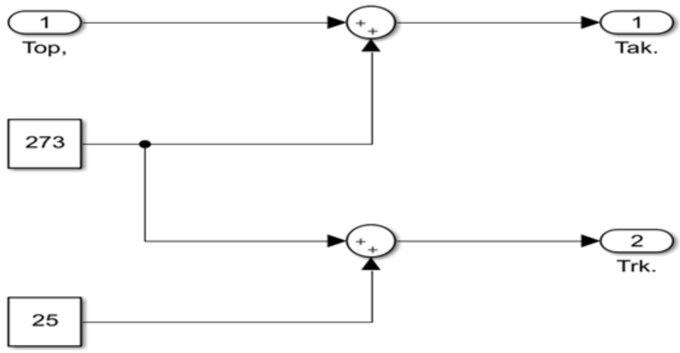

Figure 3.3 Conversion of temperature from degree (°C) to (K).

The Simulink model of the solar panel is then created by combining the block diagrams for the following PV model equations, Figure 3.4, shows the final PV model developed using Simulink, which uses temperature and irradiation as inputs and produces voltage output (Vpv) and current output (Ipv) as results. Finally introduces electrical equations like (Voc), (Isc), (FF), and electrical efficiency.

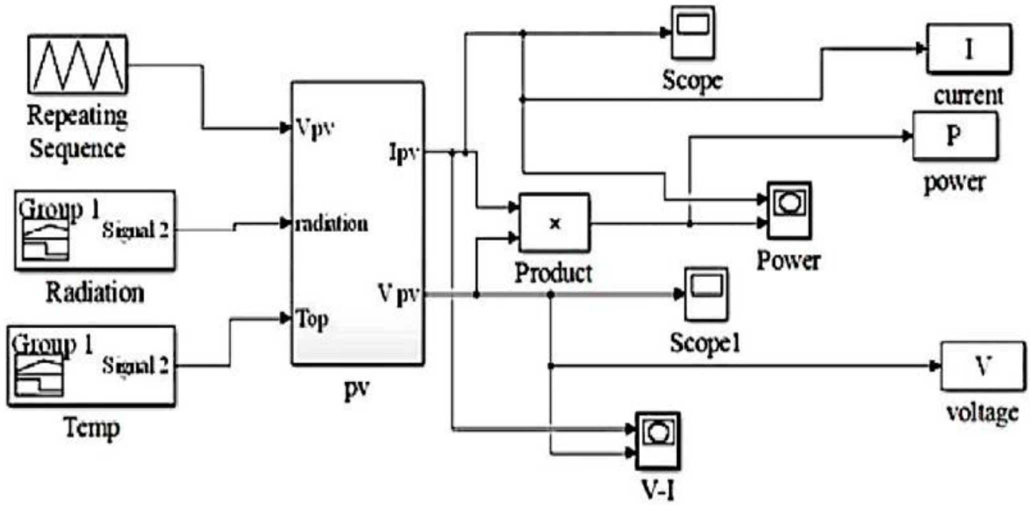

Figure 3.4 Simulink module of the (PV) panel.

CHAPTER IV

EXPERIMENTAL SETUP

4.1 Introduction

In this chapter, the entire experimental work will be described starting with the construction of the test platform and its features, tools used for data acquisition, cooling system, PV panels, modification, and evaluation of properties. This system is tested under different test conditions to evaluate the distinct performance of each system.

4.2 Experimental Setup

The study was conducted at Al-Kitab University, north of the city of Kirkuk/in Iraq (latitude 35.46˚, longitude 32.9˚), where two identical PV panels with technical specifications were placed on the roof of a building (16 m) above ground level, where the PV panels were installed on an inclined base at an angle (30°) above the horizon. The work was carried out in July and August through a series of experiments, where the first, second, and third experiments compared the effectiveness of the water-cooled PV system with that of the base system. In the fourth experiment, water was used to clear and cool the panel surface of dust, and its impact on the PV system's performance with the base system that collects dust of varying densities was examined. In the water cooling system, the PV panel temperature decreases by using water as a working fluid, and includes all necessary and appropriate equipment. The schematic diagram of the experimental set-up is shown in Figure 4.1.

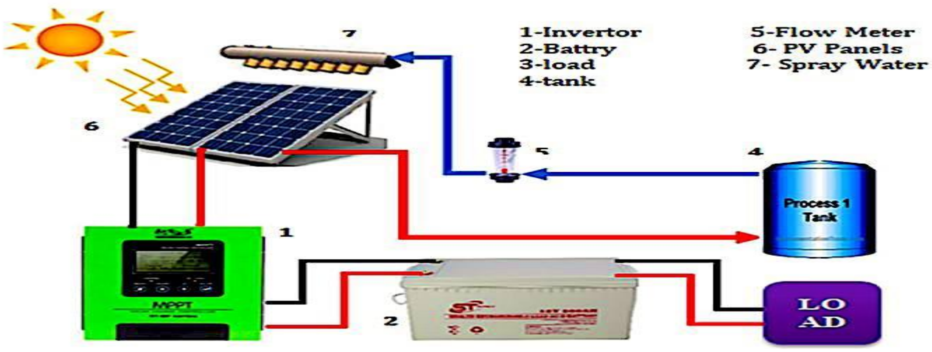

Figure 4.1 The experimental setup's schematic diagram.

4.2.1 Build the Experimental Device

The experimental device contains two test systems, the first of which is to cool and clean the surface of the board with distilled water through nozzles installed on the surface of the board from the top, and the other system is the system on which dust accumulates, which is considered a foundation system. The entire structure was fixed to a steel frame, as illustrated in Figure 4.2. The nozzle tube was placed inside a plastic tube to spray the water equally and vertically on the surface of the panel and also for the direct contact of water with the surface of the panel as shown in the Figure 4.3

Figure 4.2 The experimental setup.

Figure 4.3 Install the nozzle on the surface of the solar panel.

4.2.2 Photovoltai (PV) Module

Two identical PV panels of 250 Wp each, with dimensions (1.64 m length and 0.992 m width) of the polycrystalline type consisting of 60 cells, were used. The devices were installed with a PV system using a sun simulator as shown in Figure 4.4

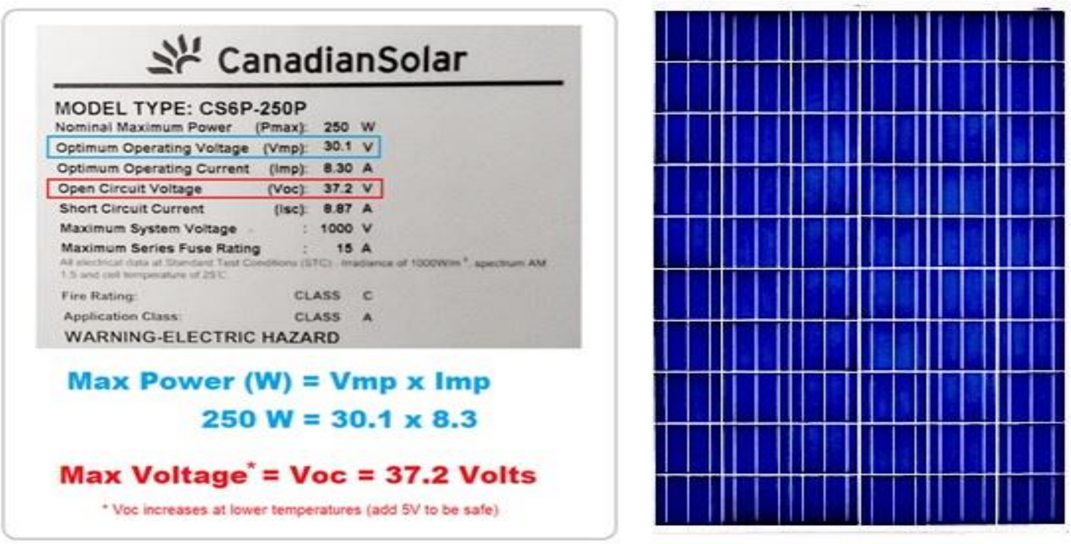

Figure 4.4 PV panels type polycrystalline.

4.3 Measuring Devices and Sensors

To record the outcomes of the experimental work under the system requirements, a collection of measuring tools and sensors is used. Each device has been calibrated, and the next sections will discuss each of its functions and specifications.

4.3.1 Solar Power Meter Device

A digital radiation intensity meter (SM 206) was used, as shown in Figure 4.5 to measure the amount of solar radiation hitting the PV panels throughout the experimentation time.

Figure 4.5 The solar radiation meter.

Table 4.1 List of characteristics of the solar power meter device.

Specifications	**Value**
maximum reading	2000W/m^2
Accuracy	Typically,within±10W/m^2
Angular accuracy	cosine corrected <5% for angle <60º
Sampling time	0.25 sec
Operating Temperature	(0 -50)ºC, Humidity, below (80%)RH

4.3.2 Clamp Meter

The clamp meter device was used to measure the current and voltage produced by the PV panel at a varied load ranging from zero ohms to the highest possible value of resistance to determine the maximum electrical power for the PV panel performance in both the absence and presence of cooling for the PV module system. While measuring current in a short circuit, the PV panel load is linked in series, and when measuring voltage in an open circuit, it is connected in parallel. According to Figure 4.6, the clamp meter utilized in the experiment is of the (UNI-T) UT 203 type.

Figure 4.6 Clamp meter.

4.3.3 Thermocouples Sensor

A digital thermometer with a K-type thermocouple was used to record temperature information at numerous locations at various PV module placements as shown in Figure 4.7. A temperature range of (-50°C to +70°C) can be measured by the sensor with an accuracy of ±1.

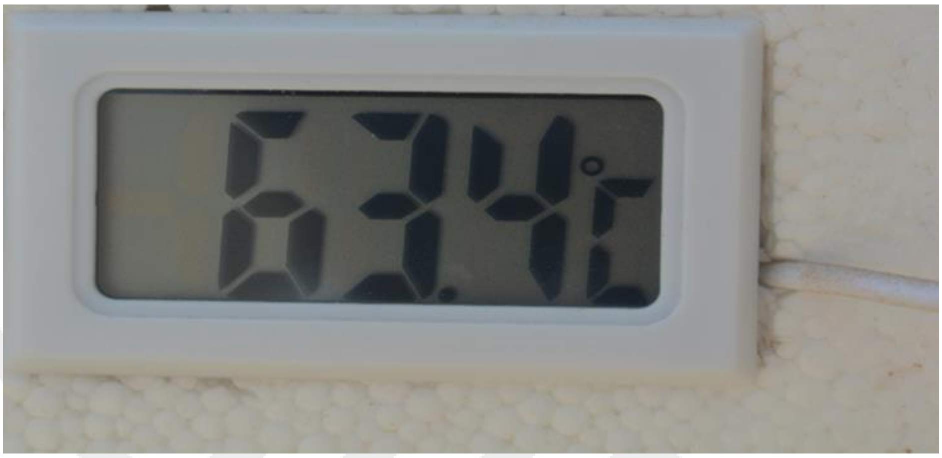

Figure 4.7 Thermocouple sensors.

4.3.4 Rotameter

Rotameter is used to calculate the volumetric flow rate of water passing through a Cu tube that is oscillating. Figure 4.8 shows. Rotameters were calibrated and had a measuring range of 1 LPM to 7 LPM for the experiment.

Figure 4.8 Rotameter.

4.3.5 Anemometer

Anemometer is used to determine the surroundings temperature around it. The Anemometer of the AM-4206 M type has two components. The first part has buttons for altering and selecting the measuring unit as well as a reading digital monitor. The air velocity in the second section is controlled by a fan and a temperature sensor. The device is shown in Figure 4.9.

Figure 4.9 Anemometer AM-4206M device.

4.3.6 Solar Charger Controller

Solar charger device used to control variation voltage outputs according to solar exposure level from the solar panel to 12V DC to charge the battery as shown in Figure 4.10.

Figure 4.10 Solar Charger.

4.3.7 Invertor

The inverter used during the experiments is a local product of the (Baghdad Factory brand), it is used to raise the mode and level of electricity from 12V DC to 220V AC as shown in Figure 4.11.

Figure 4.11 Inverter.

4.3.8 Battery

The battery system used during the experiments has a 12V D/C voltage with 150 A/hr of current capacity. The system, which supplies the generated electricity from PV panels to the inverter, is presented in Figure 4.12.

Figure 4.12 The battery.

4.4 The Dust

Accumulation of dust, soot, or other particles causes PV panels to decrease in efficiency, resulting in a decrease in the amount of energy produced and loss of income for its operators. Because the solar panels are exposed to weather and environmental conditions similar to the amount of dust deposited on the building's roof, the dust has gathered on the PV panel's surface. To determine the amount of dust accumulated on the surface of the panel, it was collected by determining an area of the roof of the building equal to the area of the solar panels. The dust weights were converted into thicker layers, and different weights of 200,300,400,500 grams were used to find out the effect of the PV panel's performance, as shown in Figure 4.13, with dust samples. Table 4.2, shows the thickness of the dust layers used in the study.

Figure 4.13 Dust samples.

Table 4.2 Thickness of the dust layers.

Dust	Thickness of dust
Dust 1	0.077 mm
Dust 2	0.011 mm
Dust 3	0.15 mm
Dust 4	$0.1879e^{-2}$ mm

4.5 Operation Method

The steps for cooling the PV panels to make the system operate properly are given as the following:

1. Clean the experimental device.
2. Run the device until it to a steady state.
3. Recording and analyzing the findings of the reading using a range of tools to capture data using theoretical equations, demonstrating the relationships, and discussing the outcomes.
4. Measuring the ambient temperature and solar irradiation of the system every hour from 9 am to 5 pm.

CHAPTER V

RESULTS AND DISCUSSION

5.1 Introduction

This chapter discusses the theoretical and practical findings from the experiments conducted from 9:00 am to 5:00 pm in July and August using the MATLAB/ simulation software. The performance of PV panels was examined through tests in this chapter to see how temperature and dust buildup affected their efficiency. Furthermore, the modeling was validated by comparing simulation and experimental studies with the spray cooling system.

5.2 Numerical Results

5.2.1 PV Module Performance Under Different Irradiation Levels

The simulation is run at 1000 W/m^2, 800 W/m^2, 600 W/m^2, 400 W/m^2, and 900 W/m^2 irradiation intensities. preserving the other variables' values. Results from the simulation under standard test conditions are given at a temperature of 298 K and 1000 W/m^2, which precisely match the manufacturer's specifications. These simulated test results include the module's efficiency and fill factor, among other performance metrics. It is discovered that irradiation greatly influences maximum output power. The open circuit voltage does, however, only slightly rise as the irradiation changes. Simulated I-V and P-V characteristics of a module are shown in Figure 5.1 and Figure 5.2.

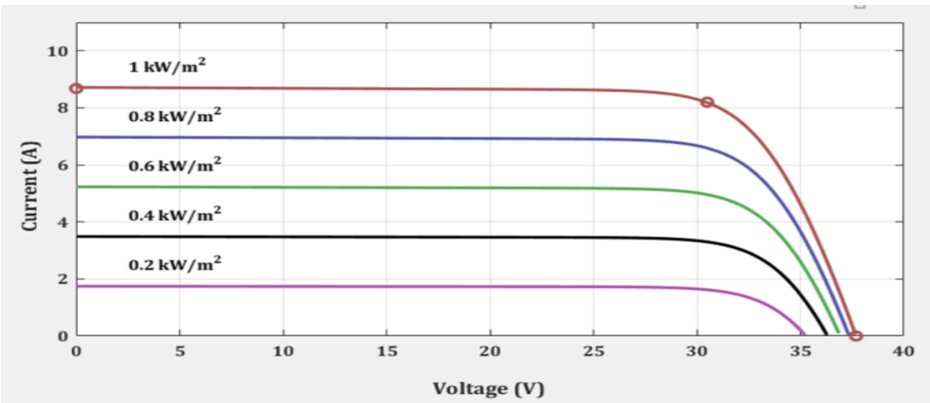

Figure 5.1 (I-V) characteristics for various solar irradiation conditions

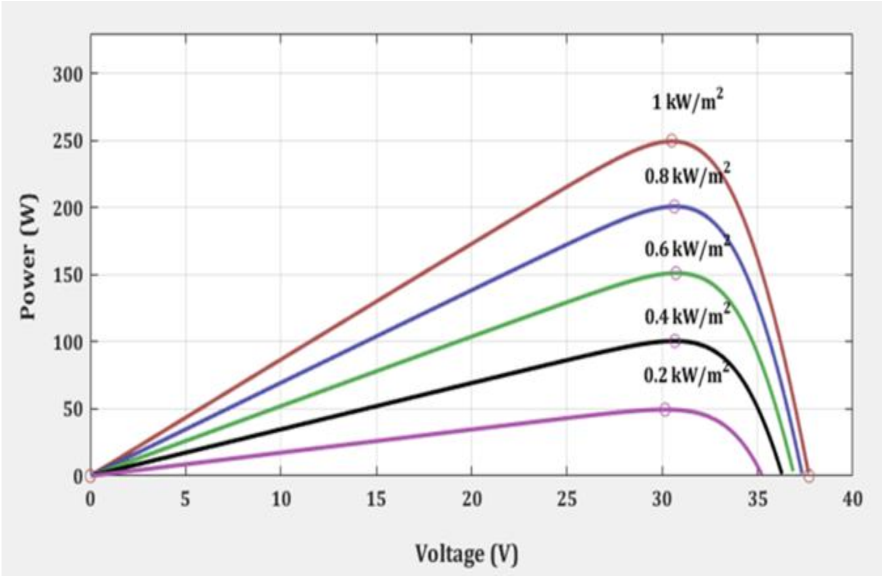

Figure 5.2 (P-V) characteristics for different levels of solar irradiation.

5.2.2 The Effects of Ambient Temperature

A PV module's performance is significantly impacted by its temperature. High temperatures lower the power production of PV modules even though they are less crucial than sunlight length and intensity. The PV cell's short-circuit current increases as the operating increasing temperature, but the maximum power output decreases. Net power drops at high temperatures because the rise in output current is significantly smaller than the decrease in voltage. Figures 5.3 and 5.4 display how the ambient temperature affects the maximum power output, voltage, and current of solar cells. In general, when the temperature rises, a PV module's efficiency decreases.

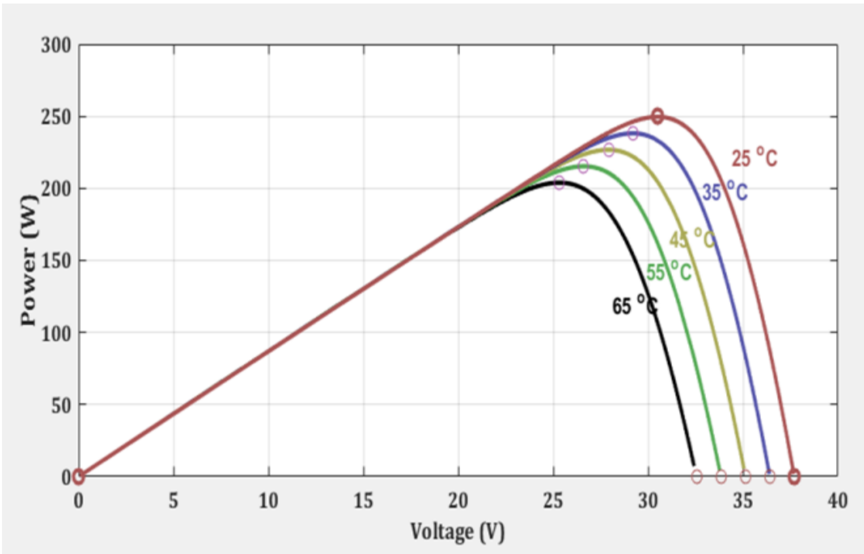

Figure 5.3 Effect of temperature on PV characteristics with power.

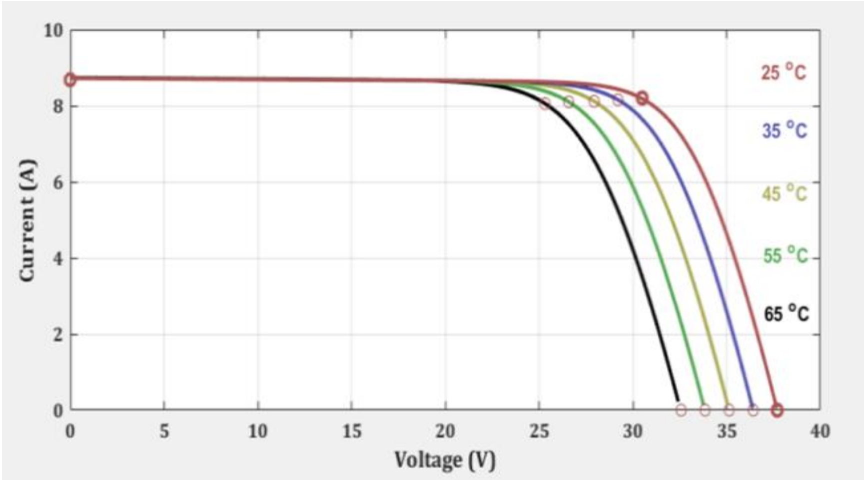

Figure 5.4 I-V characteristic with different temperatures.

5.2.3 The Effects of Dust Deposition

From the simulation of the numerical results, it was determined that the PV module's performance is adversely impacted by dust accumulation on its surface, as shown in Figures 5.5 and 5.6. Solar panels' overall performance is impacted by the phenomenon of dust accumulation in a desert environment. Therefore, dust that has formed on solar cell surfaces reflects a significant quantity of solar radiation. The panels' net absorbed solar radiation is reduced. This issue can be resolved by installing a cleaning mechanism that aids in preventing dust accumulation on the solar panels. As a result, The energy output and efficiency of PV systems will be impacted by this reduction.

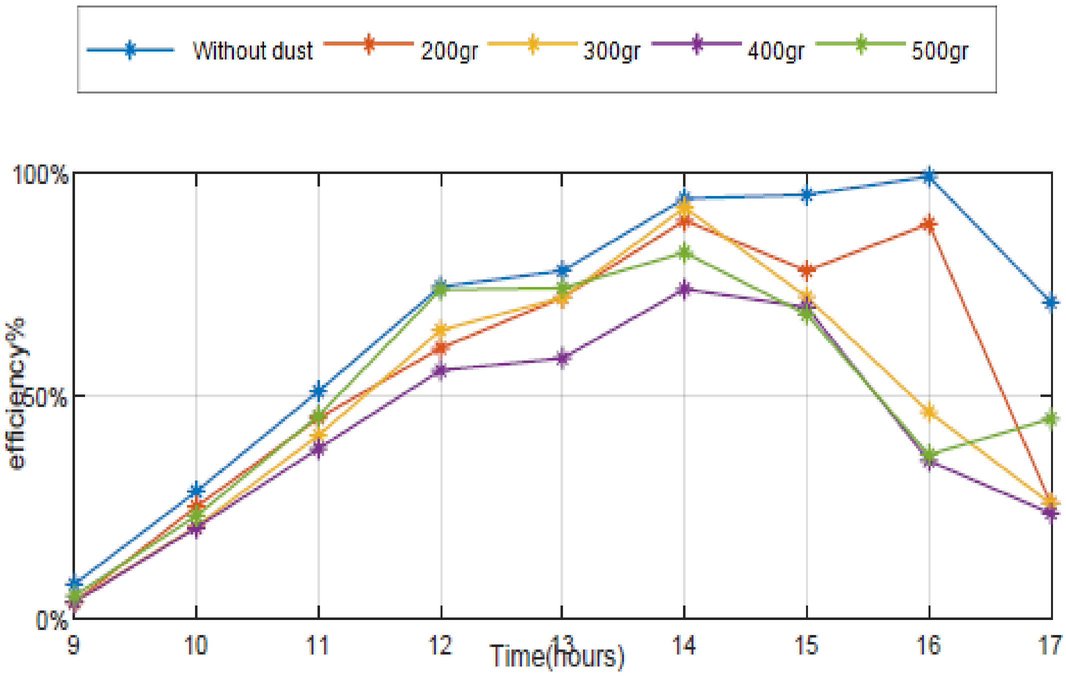

Figure 5.5 Numerical efficiency characteristics with varying dust weight.

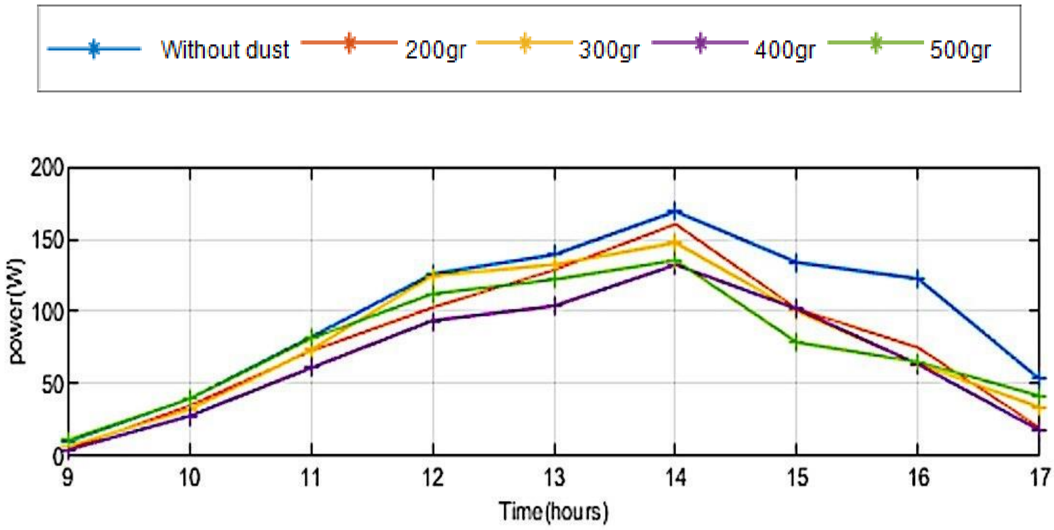

Figure 5.6 Numerical power characteristics with varying dust weight.

5.3 Experimental results

5.3.1 The Effects of Cooling on the Power and Efficiency of Cell Temperatures

Due to the lower temperatures of the cooling process using this water cooling system, the current work has been able to increase the rate of power generation by up to 10% while decreasing the PV panel's temperature by up to 17°C, which is a significant improvement given that most solar panels can only convert around 20% of the solar energy that is exposed to electricity. Figures 5.7 and 5.8 show how the cells' capacity and efficiency are affected by the cooling process; as a result of the cooling process' lower temperatures, the cells' capacity rises, and their efficiency rises.

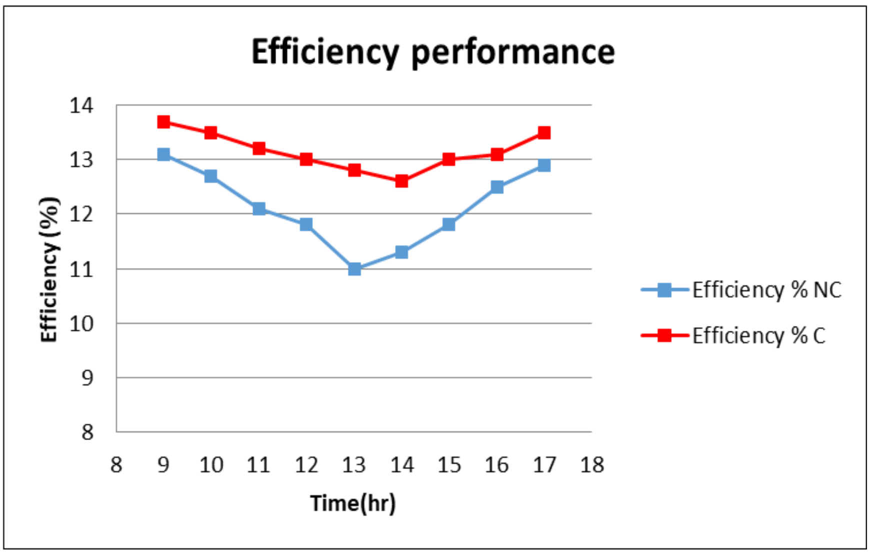

Figure 5.7 Efficiency with time.

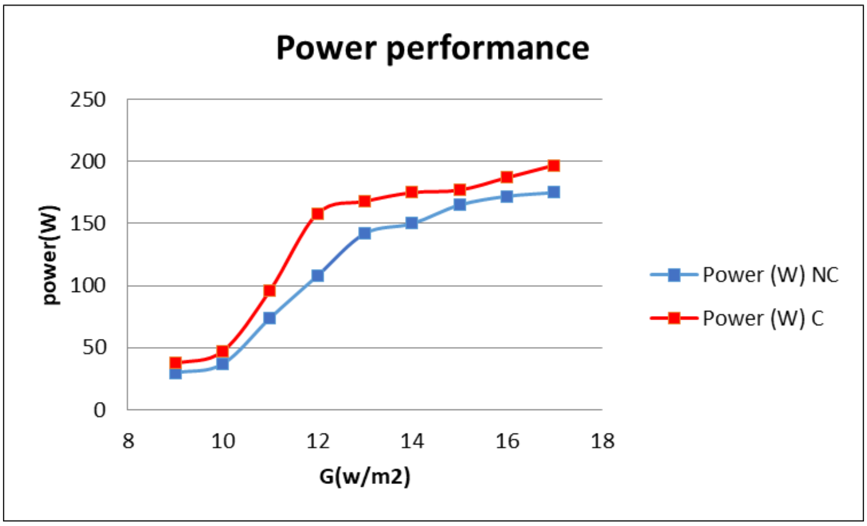

Figure 5.8 power with time.

5.3.2 Ambient Temperature Effects on PV Performance

The temperature of the surrounding area harms the solar panel's ability to produce electricity; the greater the temperature of the panel, the more noticeably the voltage value we get from it falls. While the value of the current slightly rises, which can be neglected. Increasing the ambient temperature will increase the temperatures of solar cells (silicon). Heat is less of an issue for thin cells (thin film) than it is for (monocrystalline) cells, as shown in Figure 5.9.

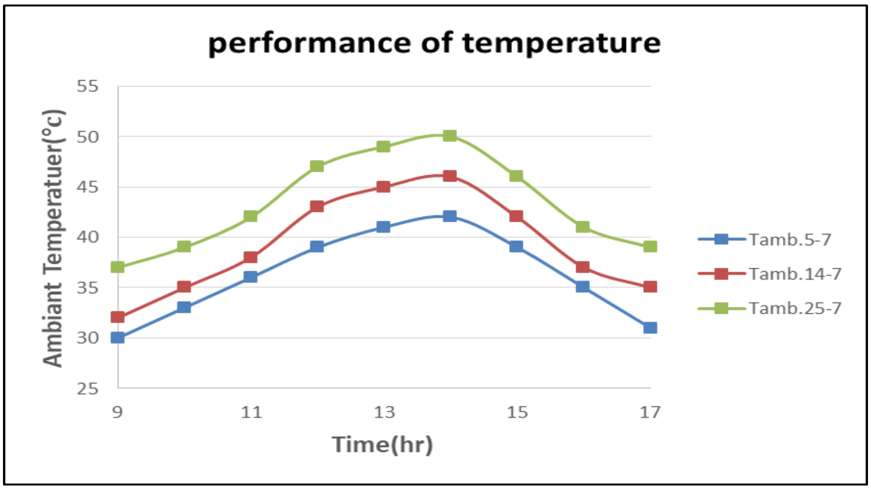

Figure 5.9 Ambient temperature with time.

5.3.3 The Cooling Effect of PV Panel Surface Temperature

The ambient temperature and the amount of sunshine typically affect the temperature of solar panels that generate power, whereas the effectiveness of solar panel energy generation is more closely related to the sunlight's intensity, which can be impacted by temperature and other environmental factors.

Obviously, PV solar panels convert sunlight into electricity, so its assumed that the more sunlight the better. However, this is not always the case because sunlight also contains invisible infrared rays that carry heat. As a result, assumed that solar panels will perform well if they receive a lot of light, their efficiency may decline as they become hotter, see Figure 5.10.

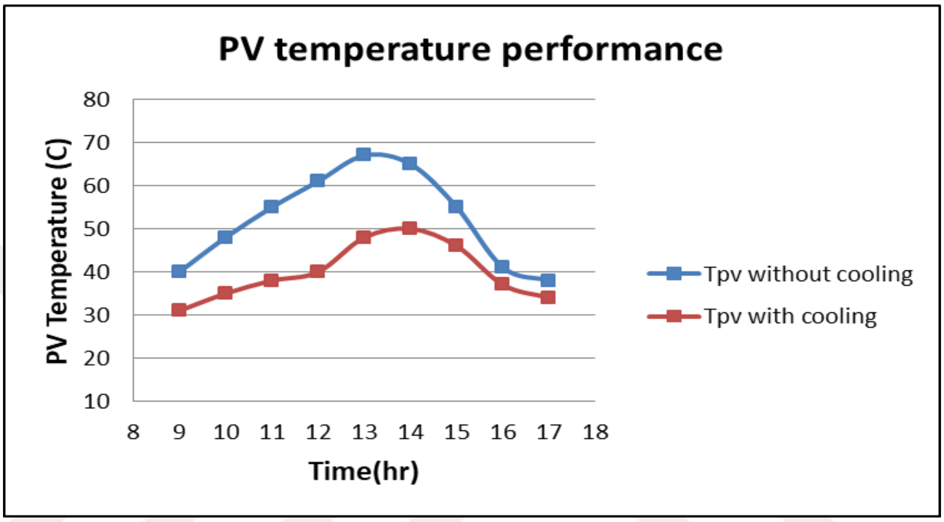

Figure 5.10 PV temperature with time.

5.3.4 Dust Accumulation's Impact on PV Performance at Different Weights

The issue of dust collection has a significant impact on solar panels' overall performance. An important amount of solar irradiation is scattered when dust constructs on the surface of solar cells. Consequently, the panels' net incident solar radiation is reduced. As a result, this decline will have an impact on PV systems' ability to produce electricity and their effectiveness. The use of a cleaning system that aids in lowering dust accumulation on the solar panels can assist offset this issue. To investigate and comprehend the detrimental effects of lowering solar irradiation received by the cells, six solar radiation sensors were employed and installed together with PV panels and local weather data. According to preliminary findings, as dust built on the PV cells over time, the solar radiation that they were able to detect gradually dropped from 1% to 12%. To prevent this decrease and to make sure that incident solar irradiation is at its highest level during the appropriate weather condition, it is advised to clean the PV cells occasionally, see Figures 5.11 and 5.12.

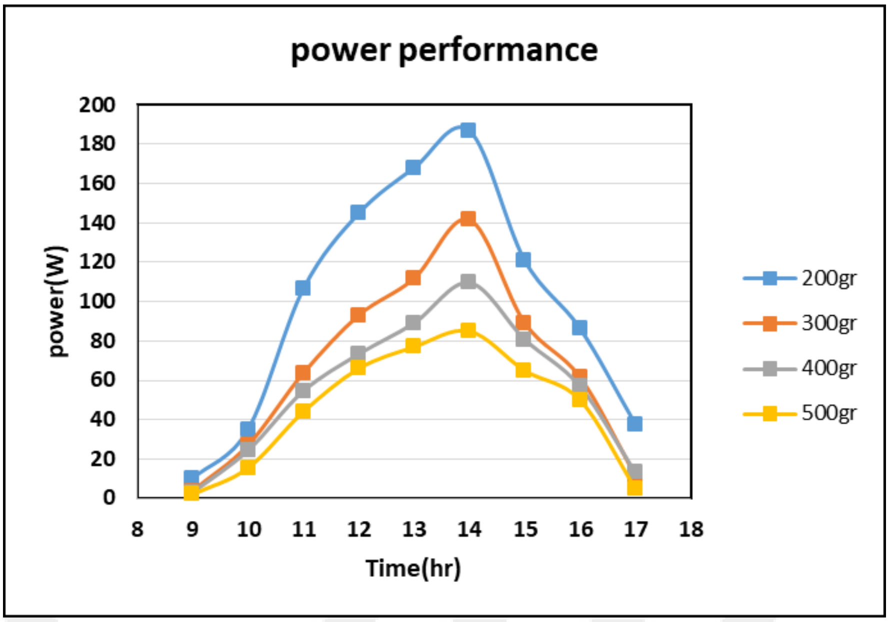

Figure 5.11 power performance.

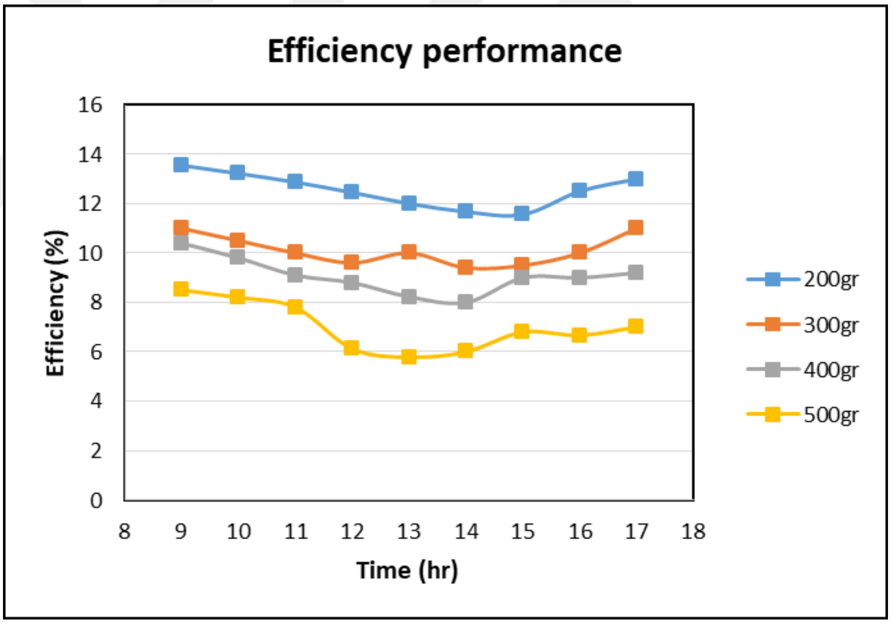

Figure 5.12 Efficiency performance.

5.4 The Effects of Solar Radiation on Cell Performance

When there are clouds in the sky, the solar radiation drops to 100 W/m^2 or 400 W/m^2 as seen in the accompanying curve. The graph shows that the panel's current output is quite low at 200 W/m^2, within 2 amps. , the voltage just slightly decreases. At 1000

W/m^2, the panel current is 9.8 amps., while the panel voltage only increases by a tiny amount. Thus, an increase in watts per square meter causes a rise in the panel's productivity, whereas a decline causes a fall in the panel's productivity, see Figure 5.13.

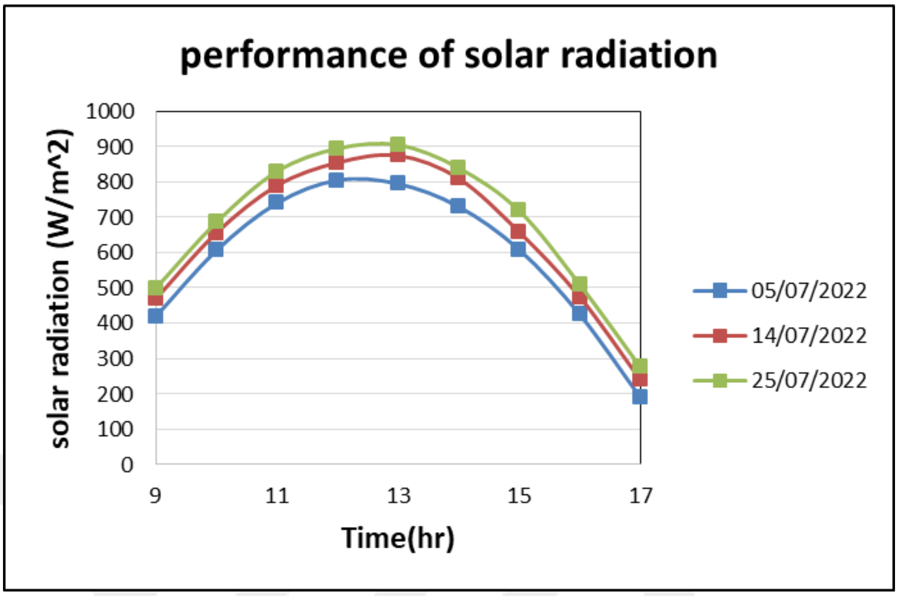

Figure 5.13 Solar irradiation with time day.

CHAPTER VI

CONCLUSION

In this study the performance of PV panels have improved, by utilizing a pulsed spry cooling system that was created for PV panels under the weather conditions of Kirkuk/Iraq, using numerical and experimental investigations. The performance of the solar panel is greatly influenced by the surrounding area, and the front surface of the PV module, in addition to environmental variables such as temperature, wind, humidity, and dust deposition.

To determine the general effectiveness of PV systems, the paired model was created and numerically solved using the MATLAB program. The PV panel's front surface is cooled by water flowing from an atomizer. To determine the impact of various parameters on the panel efficiency, the difference in surface temperature of the panels has been measured under a variety of conditions. The experimental research was used to validate the PV panel numerical model. It was found that the outcomes of the experimental investigation and the theoretical study only differed by 2.3%. The results produce the following conclusions:

- The simulation results indicate that adopting the spray water cooling system enhanced electrical efficiency from 12.2% to 16%.
- The PV panel's ability to cool corroborated the increase in power; the highest measured output power was 198 W.
- The pulsed spray cooling system's cooled PV panels had the maximum electrical efficiency of 13.7%, whereas the traditional PV panels had the highest electrical efficiency of 13%.
- The dusty panel's maximum power output value on July 22 was 187 W, and the dusty PV panel's lowest power output value was 85 W for a panel with 500 gr. of dust.
- Cleaning by a pulsed water spray system greatly affected to performance of PV panels. The efficiency of the panel accumulated by 200 gr of dust on the surface

- of the PV panel, was less effective than the rest of the weights, and this indicates that cleaning the surface of the plate continuously improves the performance of the cell and thus increases its life

To select the best areas to build a PV system, several conflicting variables must be considered. The amount of electrical energy generated decreases as a result of the accumulation of dust and dirt on the photovoltaic panels, which reduces their efficiency. Therefore, it is very important to clean the photovoltaic systems continuously. Using a water spray system is the easiest and cheap way to remove dust, which improves the efficiency of the photovoltaic panel by cooling and cleaning the surface of the panel at the same time.

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