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Department of Energy Engineering

The Impact of Environmental Conditions on the Performance of a 15 kw PV System Installed in Al-Musayab District

This Project was submitted to Energy Engineering Department/ College of Engineering – Al Musayab/ University of Babylon in Partial fulfilment of the requirements for the bachelor's degree

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SUPERVISOR CERTIFICATE

This project was submitted to the Energy Engineering Department, Faculty of Engineering – Al Musayab, University of Babylon, and has been accepted as fulfillment of the requirement for the Bachelor's degree under the supervision of:

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ABSTRACT

This research aims to study the effect of different environmental conditions on the performance of a 15 KW PV system, which was installed on the roof of the building of the Department of Energy Engineering in Al-Musayab Engineering College at the University of Babylon, IRAQ. The studied parameters include the accumulation of dust and airborne dirt (organic and inorganic) that reduces the amount of electricity generated by the system and the effect of temperature was also taken into consideration as the high temperature of the system negatively affects the system performance. This study was conducted for three months including December 2022 , March, and April 2023. At the beginning of the study, the system was cleaned and left to natural operating condition. Data of the system including temperature of the system, ambient temperature, solar radiation, and power of the system were collected in a sequential manner. Form the obtained data, it can be deduced that increasing the temperature of the system by one degree reduces the efficiency of the system by 0.69%. Dust accumulating on the surface reduces the efficiency by 3%. The cleaning cycle of the system was estimated to by 18 days to minimize the effect of dust.

Chapter One

Introduction

1.1 Introduction to solar energy

Solar energy is one of the fastest-growing sources of renewable energy in the world, and its position in the global energy production mix has been steadily increasing in recent years.). According to an IRENA report, global solar PV generation increased by a record 179 TWh in 2021 (a 22% rise) from the previous year. The global solar capacity amounted to 849 GW in 2021. Further, it accounted for 3.6% of the world's energy generation. Driven by concerns over climate change, as well as a growing recognition of the economic and environmental benefits of renewable energy, countries around the world have set ambitious targets for the adoption of renewable energy, with many investing heavily in solar, wind, hydroelectric, and other forms of clean energy. While solar energy currently accounts for only a small percentage of global energy production, its share is expected to continue growing rapidly as the cost of solar PV technology continues to fall and governments around the world implement policies to promote renewable energy. Fig 1.1 illustrates the world's energy consumption for 2021.

In reading the literature, it can be understood that PV performance can be significantly influenced by climatic conditions [1]. The studies show that the investigation of dust accumulation and its effects on PV output performance play an important role in the sustainable development of PV systems [2]. For instance, the power output of PV modules can be dropped up to 20% by a single dust storm [3] . Accumulation of dust on a glass cover of a PV system causes gradual reduction of a transmission coefficient [4], which then leads to the reduction of energy conversion efficiency. The average decrease in a crystalline photovoltaic module efficiency, corresponding to each micrometer of accumulated dust thickness, is equal to 25.5%/µm for naturally deposited dust[5].

Temperature plays a central role in the photovoltaic conversion process as long as it affects basic electrical quantities such as voltage and current of PV solar modules. The output power of a PV module depends on the temperature in which the solar cells operate. An increase in cell temperature contributes to a reduction in the power and therefore the efficiency of the PV module [6]. In a recent study from 2015 [7] carried out on analyzing the performance of a PV solar power plant connected to the grid of the Republic of Serbia that a temperature increase of 1°C reduces the energy yield of 0.31%.

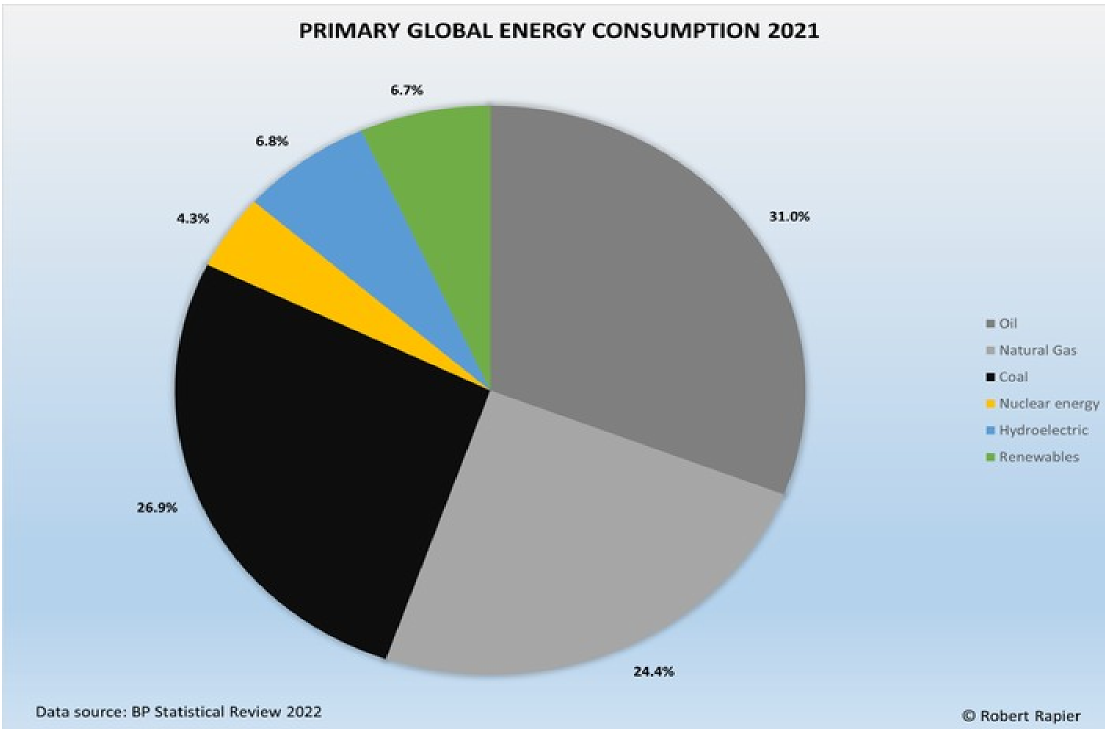


Figure 1.1 Global Energy Consumption of 2021[8]

1.2 Photovoltaic solar systems

Photovoltaic (PV) system is a type of renewable energy systems that converts solar energy into electrical energy using photovoltaic cells. Photovoltaic (PV) panels are the core component of PV systems that convert sunlight into electrical energy through the photovoltaic effect. The principle of operation of PV panels is based on the ability of certain semiconductor materials, such as silicon, to generate an electric current when exposed to light. The structure of a typical PV panel consists of several layers of materials, each with a specific function. The top layer is a protective layer that is designed to withstand weather and environmental factors. The next layer is the anti-reflective coating, which is used to reduce the amount of sunlight reflected from the surface of the panel. The active layer of the panel is the layer of semiconductor material that generates the electric current when exposed to sunlight. The back sheet is a protective layer that is designed to prevent moisture and other environmental factors from damaging the panel. Important parameters of PV panels include the power output of the panel, which is measured in watts (W), the efficiency of the panel, which is the ratio of the electrical power output to the solar power input, and the temperature coefficient, which is a measure of how the panel's power output changes with temperature changes [9].

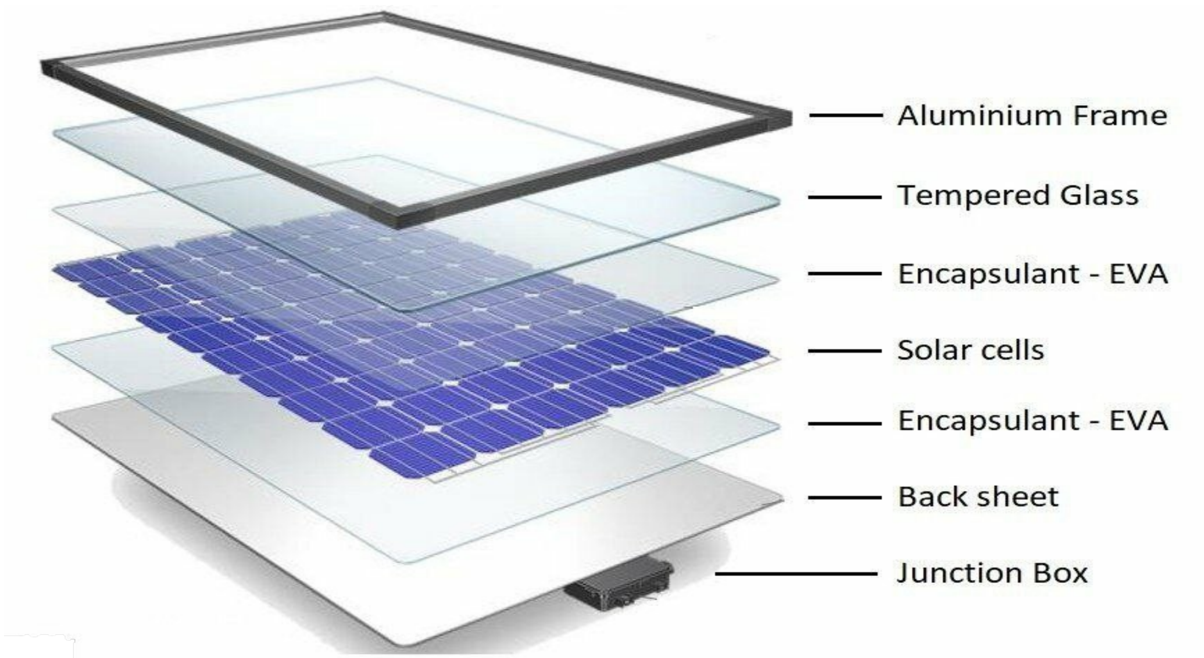


Figure 1.2 PV Panel Layout[10]

PV systems can be connected to the grid in two ways: as a grid-tied system or as an off-grid system. A grid-tied system is connected to the utility grid and can feed excess electricity back to the utility company. The components of such a system include PV panels, an inverter that converts DC power generated by the system to AC power and ensures the AC power is synchronized with the voltage and frequency of the grid, a bi-directional meter, and a circuit breaker that ensures the system is safely connected to the grid. An Off-grid system is not connected to the grid and is used to power standalone applications such as remote homes, cabins, or telecommunications systems. Such systems consist of PV panels, Batteries to store the energy generated, a charge controller that regulates the charging of the batteries and ensures the safety of the charging process, and an inverter that the energy stored in the batteries to AC power delivered to the load.

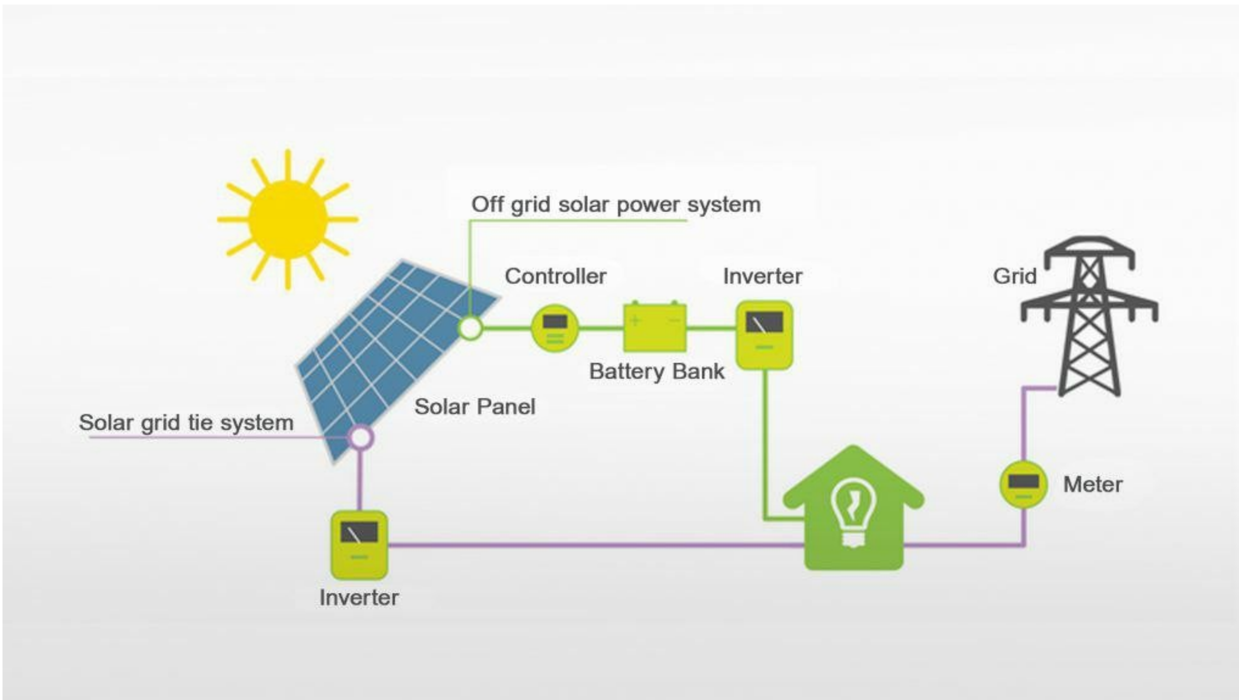


Figure 1.3 On-Grid and Off-Grid PV system layout[11]

1.3 The Temperature Effect on Solar Cell Performance

The panel surface temperature is a key environmental parameter that influences the performance of a PV panel by changing its electrical parameters, such as open circuit voltage (VOC), short circuit current (ISC), and maximum power output (PM). The solar flux heats the top surface of the solar cells; thus, the accumulation of thermal load leads to increases in the cell's temperature. In turn, this leads to a reduction in cell conversion efficiency. In general, PV panels are made of silicon semiconductor material and like all semiconductor materials, PV panels are also temperature sensitive. The panel surface temperature depends on the encapsulating material, solar radiation, atmospheric temperature, humidity, and wind speed [12]. As the temperature of the PV panel increases its VOC, and PM decreases. As a result of this, the overall performance of the PV panel reduces due to an increase in its surface temperature. The effect of Temperature on the Solar Cell I-V Curve and P-V curve is shown in Figures 1.4 and 1.5 respectively[13].

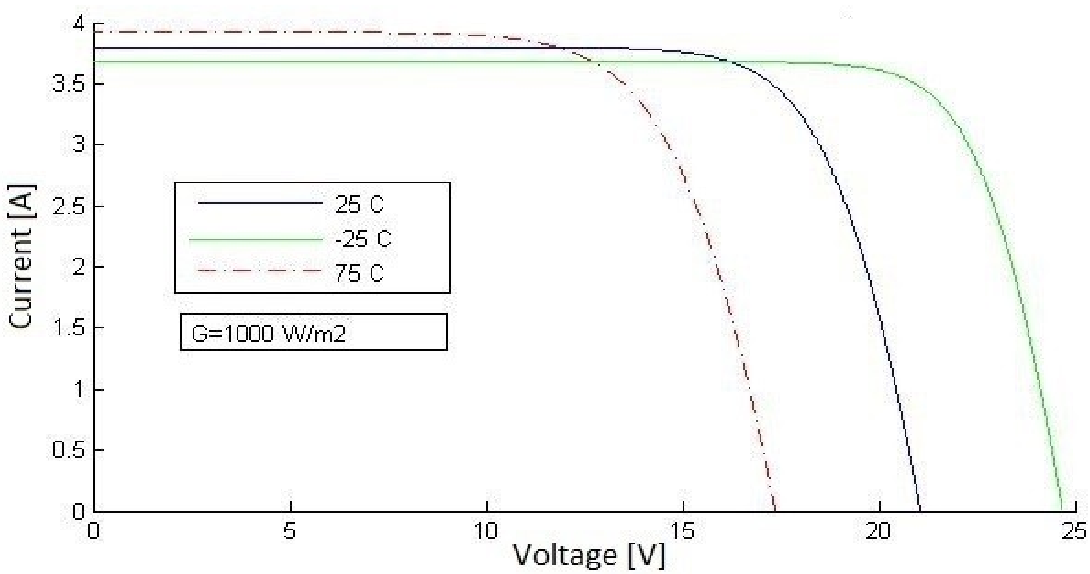


Figure 1.4 Effect of Temperature on Solar Cell I-V Curve[14].

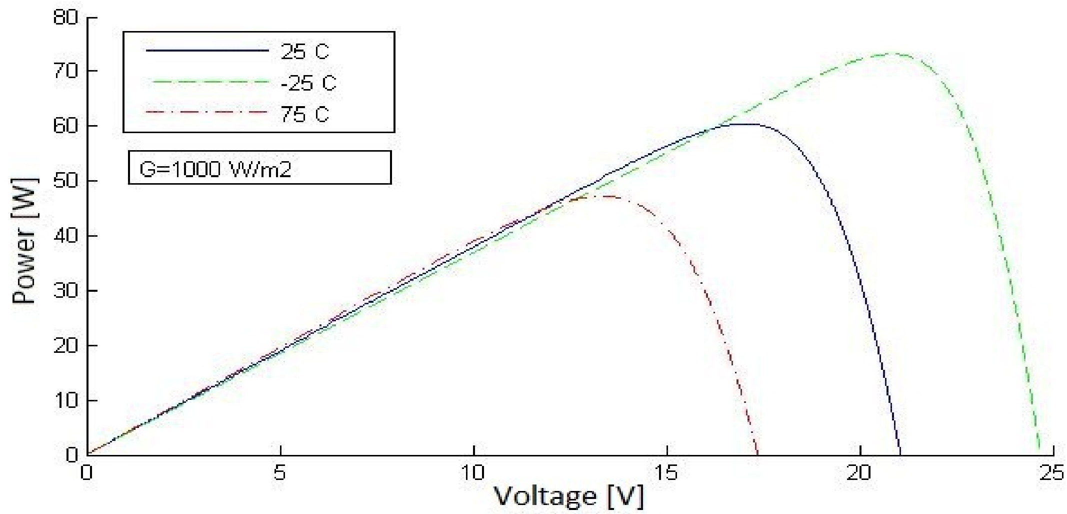


figure 1.5 The Effect of Temperature on the P-V Curve [14]

1.4 Effect of Dust on PV Solar Panels

Photovoltaic power plants require massive grounds, so they are generally built in open areas such as deserts and wastelands. In these places, surrounding areas are empty, and the general configuration of the ground surface is mostly sandy soil, so the PV surface is very easy to be covered with dust, especially in stormy weather. Therefore, it is very important to study the effect of dust on the operating characteristics of photovoltaic systems and improve the efficiency of photovoltaic power generation.

The major impact of dust accumulating on PV panels is that dust settles directly on the solar photovoltaic panels, blocking the cells from the sun’s rays. In general, the upper structure of the photovoltaic panel is a glass cover plate made of toughened glass with a transmittance of over 91%. When the dust accumulated on the glass cover-plate, the dust obscured the light irradiating PV, so that the transmission of the glass cover plate weakened and the actual amount of solar radiation received by PV is reduced. When the solar light spreads to the PV-covered dust, some of the solar light intensity is absorbed by the dust and turns into heat, another part of the light intensity is scattered on the surface of the dust, and only a part of the light intensity is injected into the glass cover plate and received by PV. this is the reason why the PV photoelectric effect weakened. [15]

Despite its instantaneous effect on the performance of PV systems, the corrosion effect of dust causes permanent damage to PV panels. Dust particle size is very small, generally between 0.001~0.01 mm. From the point of view of chemical composition, atmospheric dust is mainly oxides, among them, SiO_2 is the highest, accounting for 68%~76% As time grows, the glass cover plate which mainly consisted of silica can react with acid or alkali. Then the surface of the glass cover plate becomes uneven and the diffuse reflection increases. So, the propagation uniformity of the solar light in the glass cover plate is damaged, and the PV generating capacity is affected [16].

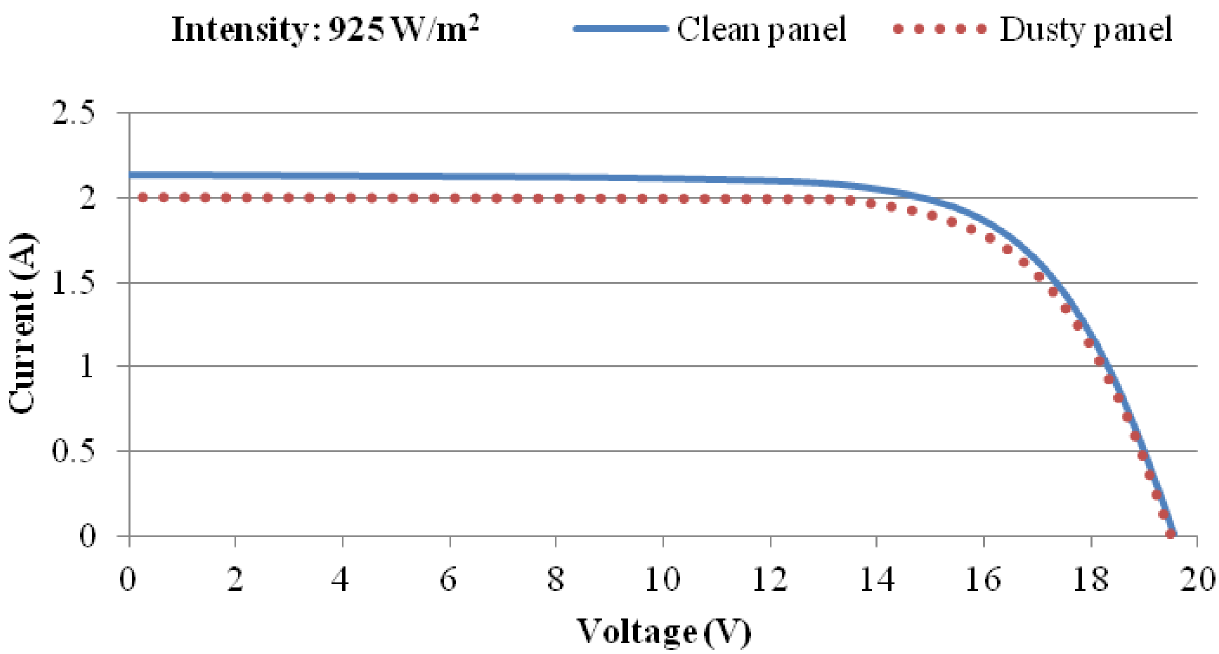


Figure 1.6 I-V characteristics at an insolation of 925 W/m2.[17]

1.5 The Project Objectives

This research aims to investigate the effects of cell temperature and dust accumulation on the performance of a 15kw PV solar system, which was installed on the roof of the building of the Department of Energy Engineering in Al-Musayab Engineering College at the University of Babylon, IRAQ. This can be done by measuring and analyzing the effect of the above parameters on the actual performance of the system.

Chapter Two

EXPERIMENTAL WORK

2.1 Introduction

This research was conducted for evaluating the effect of dust and temperature on the performance of the 15 kW PV system. The following sections describe the details of the experimental set-up, measuring and auxiliary devices, and experimental procedure.

2.2 The Experimental Setup

An attempt has been made to evaluate the performance of a 15kw grid-connected PV system that was installed on the roof of the building of the Department of Energy Engineering at Al-Musayab Engineering College at the University of Babylon with geographical coordinates of 32.78°N latitude and 44.29°E longitude. The system consists of 44 polycrystalline PV panels having a total area of 86 m2 with 340W each along with a 17.5% maximum efficiency. The properties of the PV panels are listed in Table 2.1. The system is characterized by four south-facing arrays, each array consisting of 11 panels tilled by 30°. as shown in Figure 2.2. A 15kw inverter(Sunny Tripower 20000TL) having an efficiency of 98.4% was implemented. The specifications of the inverter are illustrated in Table 2.1

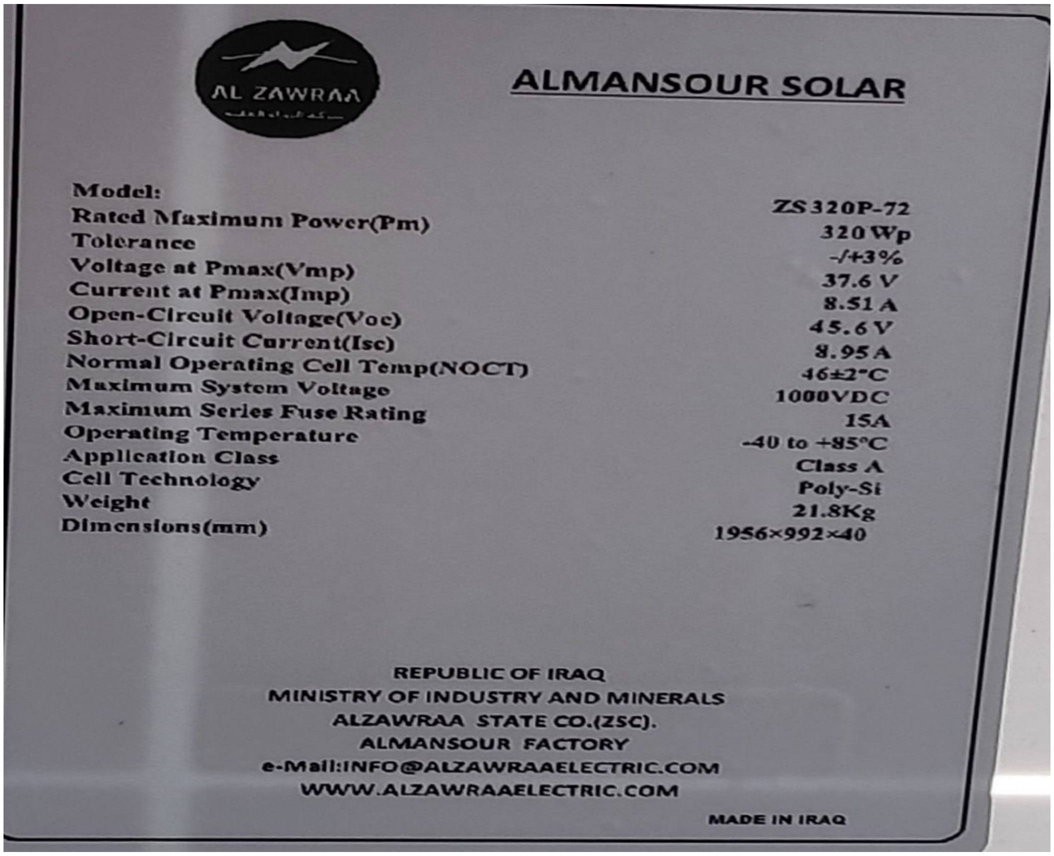


Figure 2.1 The Specifications of The PV Module at Standard Conditions (25c̊, 1000w/m2)

Figure 2.2 The PV System

Table 2.1 Specifications of SUNNY TRIPOWER 20000TL Inverter.

Description	Property
SUNNY TRIPOWER 20000TL	Inverter Model
20440 W	Maximum DC power input
1000 VDC	Maximum input voltage
320 V to 800 V	MPPT operating range
2/A:3;B:3	Number of independent MPP inputs
20000 W	Maximum AC power output
29A	Maximum AC output current
3/N/PE;220V/380V 3/N/PE;230V/400V 3 / N / PE; 240 V / 415 V	Nominal AC voltage
98.4%	Efficiency

2.3 The Measuring Devices

In this section, the instruments that were used to collect data in our study are introduced. These instruments were carefully selected based on their accuracy, precision, and suitability for measuring the various parameters involved in the performance analysis of the PV system. The instruments are TES 1333R solar meter, EXTECH SDL200 temperature recorder, and thermocouples. All of these instruments are available in the laboratory of the college, and their selection was based on their compatibility with the PV system and their ability to collect reliable and accurate data.

Thermocouple 2.3.1

A K-type thermocouple is a temperature sensor that measures the temperature of a PV system by utilizing the thermoelectric effect. It consists of two different metal wires, namely Chromel and Alumel, which are welded together at the measuring junction. When the junction is exposed to heat, it generates a voltage that is proportional to the temperature difference between the measuring junction and the reference junction[18]. The voltage generated is then converted into temperature units using a thermometer or data logger. Three PV modules were utilized, with 6 K-type thermocouples placed in the Middle of the front and back faces of the three

PV modules. The range of operation of the utilized thermocouple is from -40 c° to 230 c° with ±0.1c° accuracy.

2.3.2 Solar Meter

The TES 1333R thermometer is a solar meter used to measure solar radiation. It has an accuracy of ±10 W/m^2 and measures solar irradiance in W/m^2. The device is lightweight, compact, and easy to use, making it suitable for measuring solar radiation on a PV system. The thermometer was used to measure solar radiation in five different locations on the PV system. The average value of the measurements was considered to assess the solar radiation's impact on the performance of the PV system. The instrument is shown in Figure 2.3.

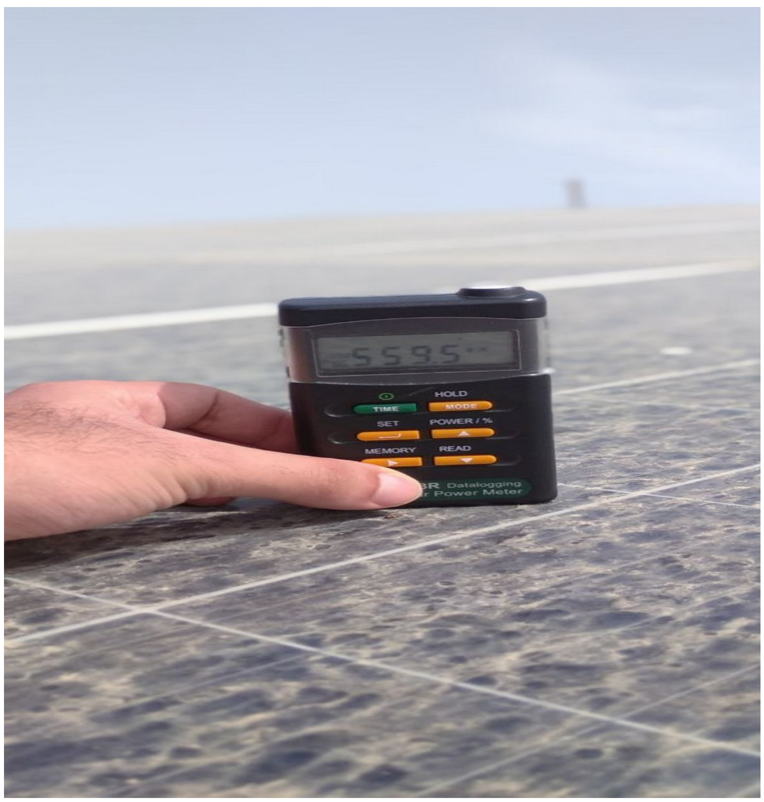


Figure 2.3 Solar Meter

2.3.3 Temperature recorder

The EXTECH model SDL200 thermometer was used to record the solar cell temperature. as shown in Figure 2.4. It is capable of recording temperature data from four different channels simultaneously with an accuracy of ± (0.4 % + 1°C), allowing for a comprehensive evaluation of a PV system's performance. The thermometer utilizes K-type thermocouples to measure temperatures, which are known for their high accuracy and stability. The device is equipped with a large backlit display, with a user-friendly interface that provides real-time temperature readings, making it easy to monitor temperature changes over time.

Figure 2.4 Temperature Recorder

2.4 The Experimental Procedure

The system was carefully studied over three months including December 2022, March, and April 2023. Under natural operation conditions, the cell temperature, solar irradiation, ambient temperature, and dust accumulation rate were measured. The PV system cleaned and measurements carried out sequentially. The system was left to operate under the effect of the three naturally induced factors namely, Temperature, Solar irradiation, and Dust accumulation rate. The natural phenomena, rain, and dust storms had poured out some disturbance during the data collection process which has been taken into consideration. The effect of dust on the performance of the PV system was monitored visually by leaving the system without cleaning until the performance starts to decrease.

Solar irradiation was recorded using TES-1333R solar meter, as mentioned in Section 2.3.2. The device was placed perpendicularly to the surface of the 30° inclined cell. Measurements were done on five different locations on the PV system to ensure representative data. The average value of the obtained data was taken into consideration.

The cell temperature is measured by 6 k-type thermocouples over three PV modules. The temperature of each module was measured with two thermocouples located in the Middle front and back of the panels. Data were recorded using a 4-Channel temperature recorder (EXTECH SDL200), as addressed in Section 2.3.3. The effects of temperature and dust on the PV system performance were experimentally investigated.

The dust accumulation rate was visually inspected and its effect was measured by comparing the production of the system under relatively high dust covering the surface of the panels with the production of the clean system under approximately similar operating conditions of temperature and solar radiation.

2.5 Summary

This chapter describes the effect of dust and cell temperature on the performance of the 15 kW on-grid PV system, which was installed on the roof of the Department of the energy engineering building at the College of Engineering / Al-Musayab / University of Babylon.

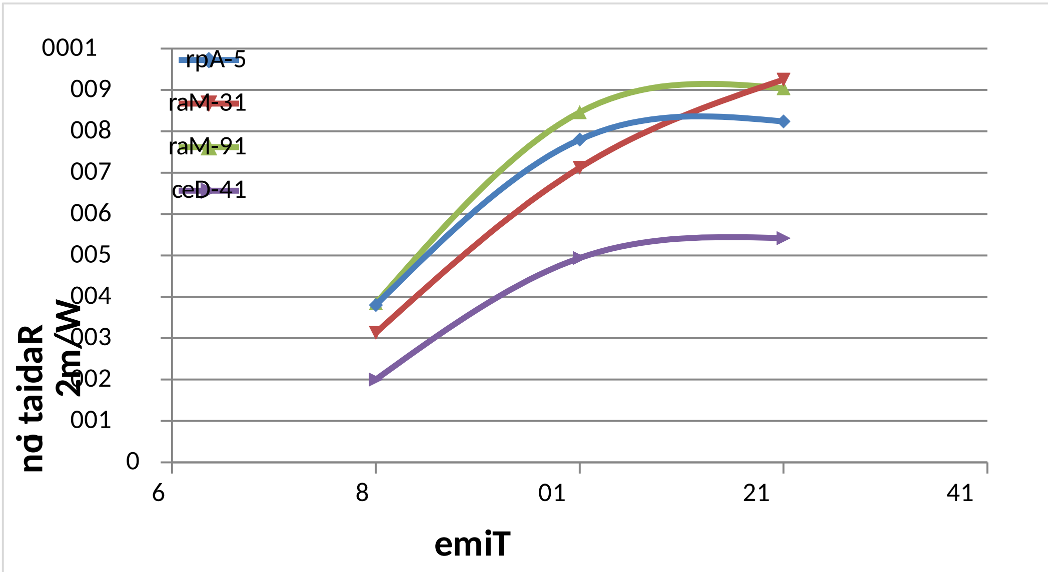
CHAPTER THREE

RESULTS AND DISCUSSION

In this chapter, the experimental results will be discussed for the 15 kW PV system. The system was studied under natural operation conditions at the same location and the same angle of inclination. Data were obtained daily from 8:30 AM to 1 PM for the months of December, March 2022, and April 2023. Readings were of power, temperature, and solar radiation taken every two hours as shown in Appendix A. The discussion in this chapter will be based on the results obtained during the mentioned period.

3.1 Incident Solar Radiation Results

The amount of energy produced by the photovoltaic panel is directly proportional to the intensity of solar radiation. An increase in the intensity of radiation means greater gains in energy. Certain days have been selected to quantify the behavior of the system during the mentioned period. The selected days provide a representative and diverse set of data that captures the range of performance and behavior of the PV system under various conditions. These days are March 13, March 19, April 5, and December 14. The incident solar radiation was measured and the collected data are shown in Fig. (3.1). During the experiments, it can be observed that the incident solar radiation divers due to seasonal conditions where it's higher in March and April than in December. It generally increases within the period of (9:30 AM to 1:30 PM) with some fluctuations due to the presence of clouds from time to time.



.Figure 3.1: Solar Radiation with Time during specific days

The power output of the system is mainly dependent on the incident radiation which increases when radiation increase and decreases when radiation decreases. Figure 3.2 illustrates the power capacity of the system corresponds to the solar radiation values shown in Figure 3.1.

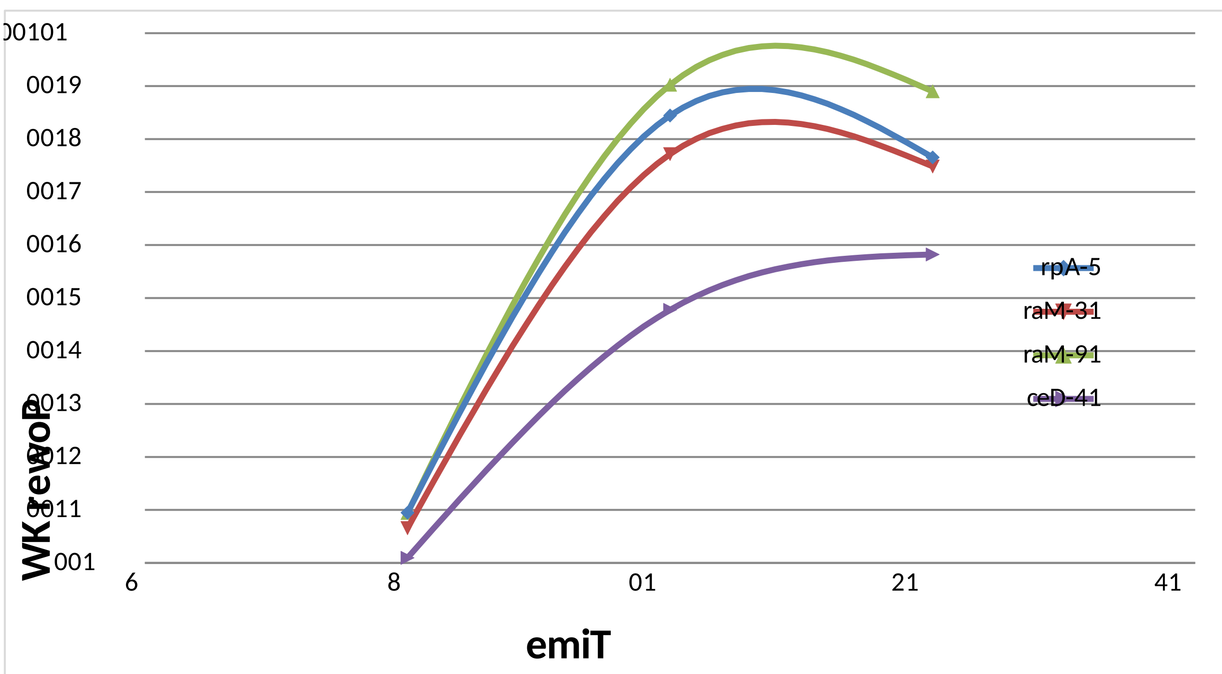


Figure 3.2 Power with Time

3.2 The effect of temperature on solar panel efficiency

Through the results obtained on (March 29) from 9 Am to 1:30 Pm, it was found that the temperature of the system at 10 AM is 33 Celsius and the efficiency was 13.39%, while as the temperature increased at 1 pm to 40 Celsius and the efficiency decreased 8.41%. From these results, we conclude that increasing the temperature of the system by 1 degree reduced the efficiency by 0.69%. as shown in Fig. (3.3).

Increasing the temperature of the solar cell (silicon) negatively affects its performance. With the increase in temperature, the current increases slightly, and the cell voltage decreases even more, so the production capacity decreases and the efficiency decreases. Semiconductors are sensitive to heat. Increasing the temperature leads to a decrease in the band gap and thus the parameters of the semiconductor are affected. The energy of the electrons increases and the energy needed to break the bond between the electrons and the nucleus decreases. This leads to an increase in current and a decrease in voltage when the temperature rises. The efficiency of the system is calculated using the following equation

$$\eta = \frac{p}{G_T A\, 44} \times 100\%$$

P(w): the power of the system, GT: The Irradiation in W/m2, A: Area of the panel (1.9492 m2)

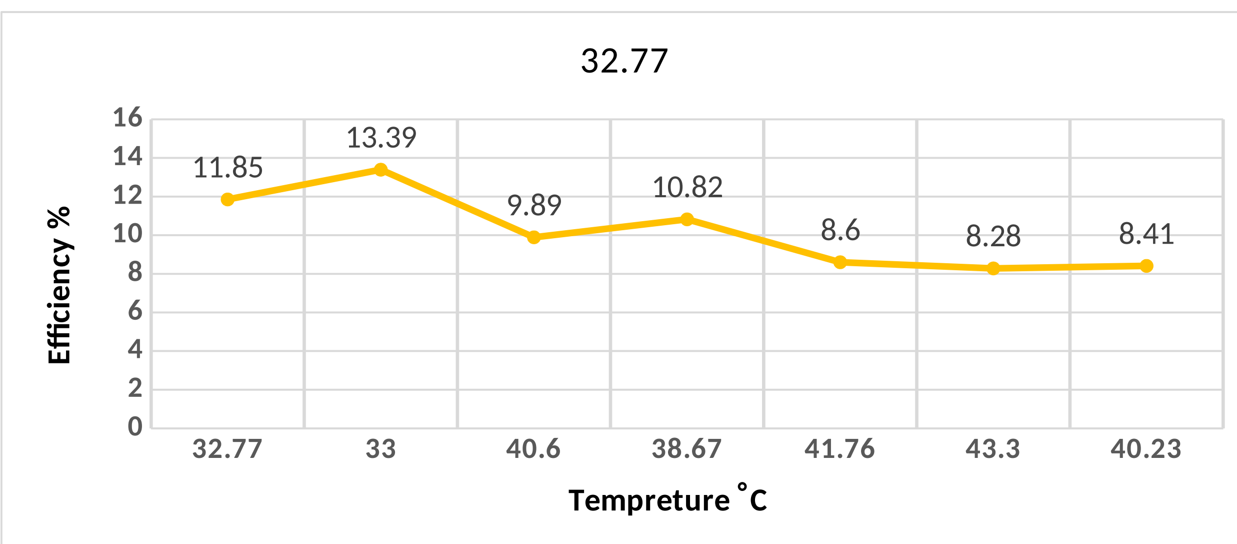


Figure 3.3: Efficiency vs Temperature for the day of March 29

The Temperature, Solar radiation, and Efficiency of the cell are interconnected quantities. The increase in solar radiation increases the efficiency while increasing the temperature at the same time, which leads to a reduction in the power capacity, thus the efficiency. This behavior is illustrated in Figure 3.4. It can be noted that the efficiency starts to increase as the solar radiation increases until it reaches a maximum of 13.4% with a temperature of 32 ℃ at 10 AM then it starts to decrease where the effect of temperature is significant.

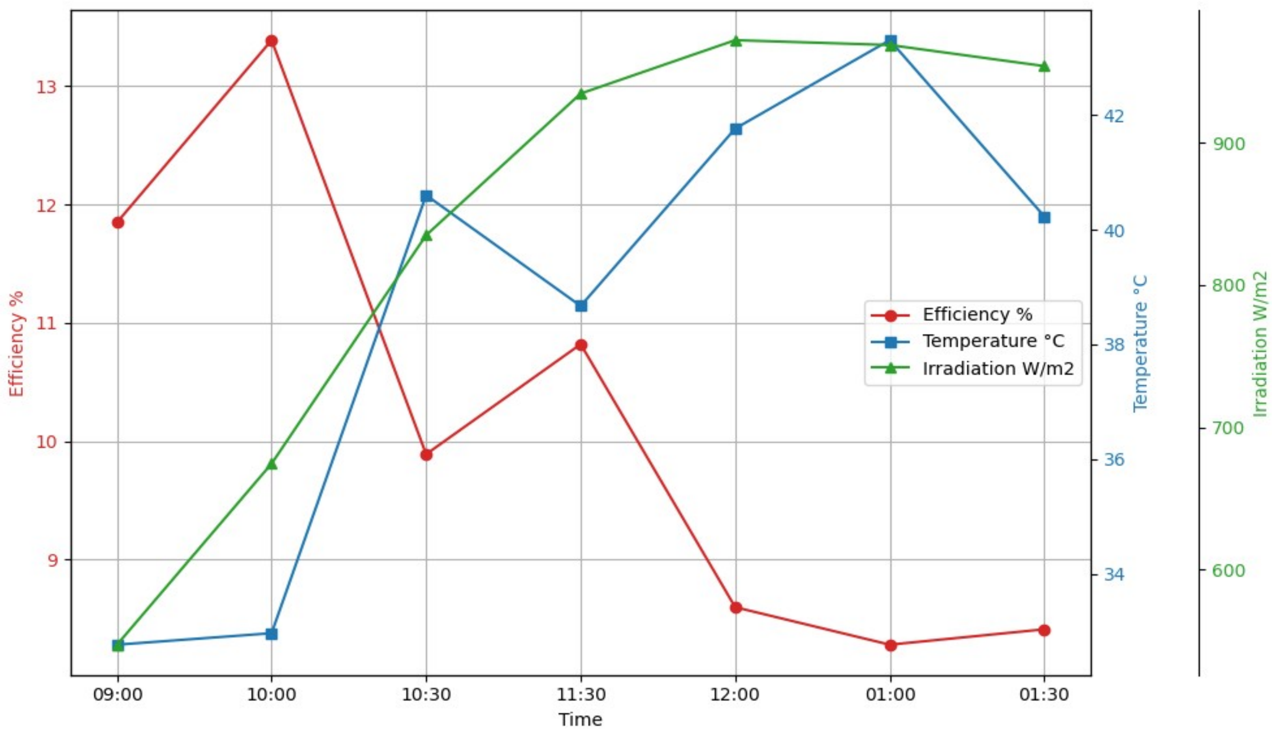
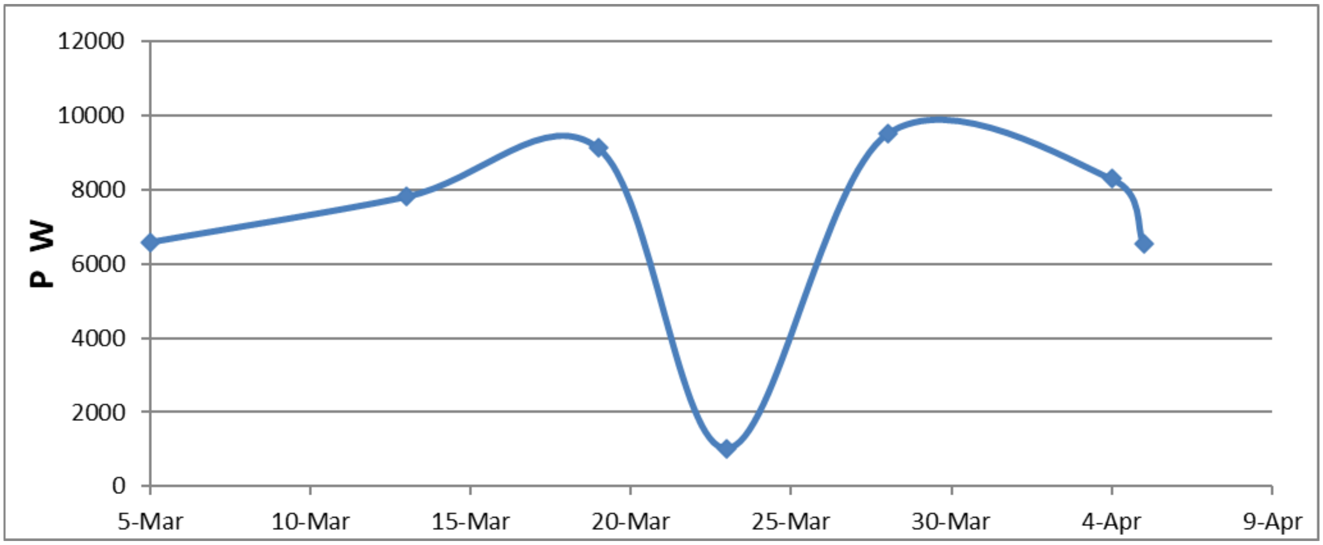


Figure 3.4: Efficiency, Temperature, and Solar Irradiation with Time

3.3 The Effect of Dust on Solar Panel Efficiency

The dust accumulation rate was visually inspected and its effect was estimated by comparing the data of the system when a significant amount of dust was accumulated to the conditions when the system is relatively clean under approximately the same temperature and solar radiation, it has been found that the cleaning cycle of the PV system is every 18 days. as shown in Fig. 3.5 (The data of this figure are attached in Appendix A).



.Fig. 3.5: The power with the dust accumulation density during the specified period

Figure 3.5 shows the behavior of the system efficiency during the period from March 5 to April 6. It should be mentioned that the system was cleaned on March 5 and left the dust to be accumulated on the surface. Fluctuations in the efficiency of the system during the period from 5 to 22 March are due to fluctuations in temperature and solar radiation. In the period from 22 to 28 March, the system encountered a significant reduction in efficiency with sufficiently similar conditions to those days before the mentioned period. This reduction can be attributed to the dust accumulated on the surface leading to a reduction of solar radiation imparted to the surface. Efficiency enhances on March 28 due to the presence of rain during this day whereas the efficiency drops again on April 2 after a relativity thick layer of dust has been formed as a result of a dust storm.

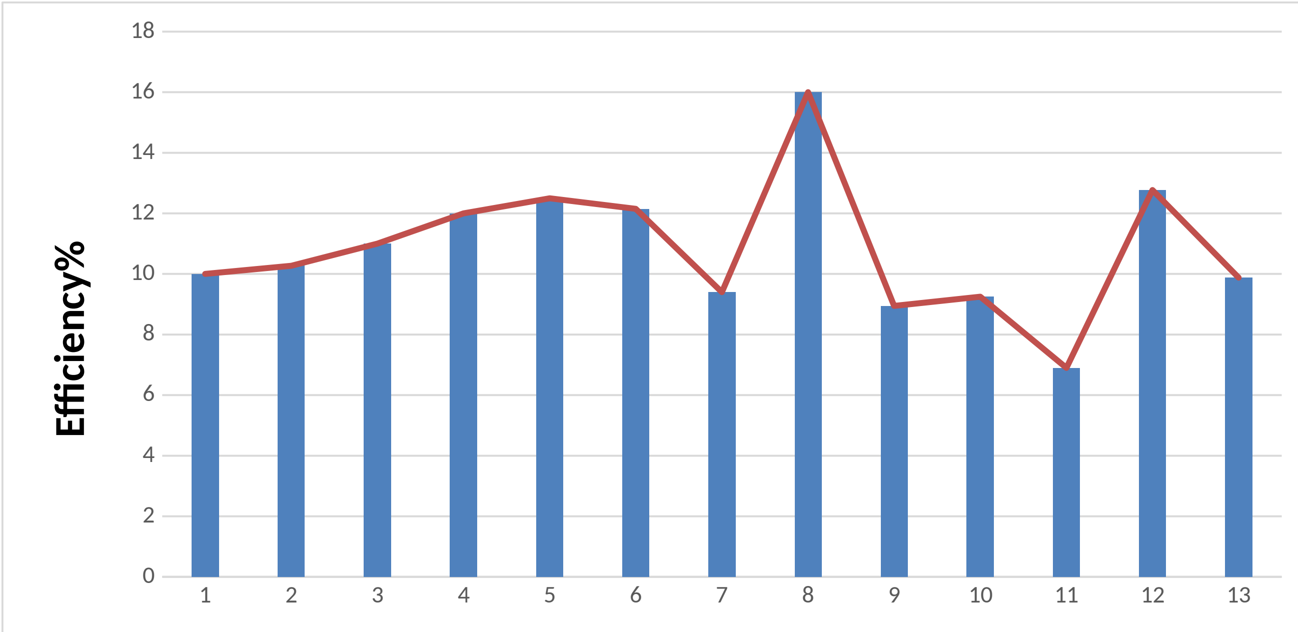


Figure 3.6 Efficiency behavior with dust accumulating on the surface of the system

The maximum dust accumulation density was recorded on April 2 after a dust storm, where a relatively thick layer of dust accumulated on the surface leading to a significant reduction in the efficiency of the system. Maximum efficiency recorded on April 2 was 9.35% with solar radiation of 921W/m2 and temperature of 31 ℃. A comparison of dusty system efficiency of clean system efficacy is shown in Figure 3.7.

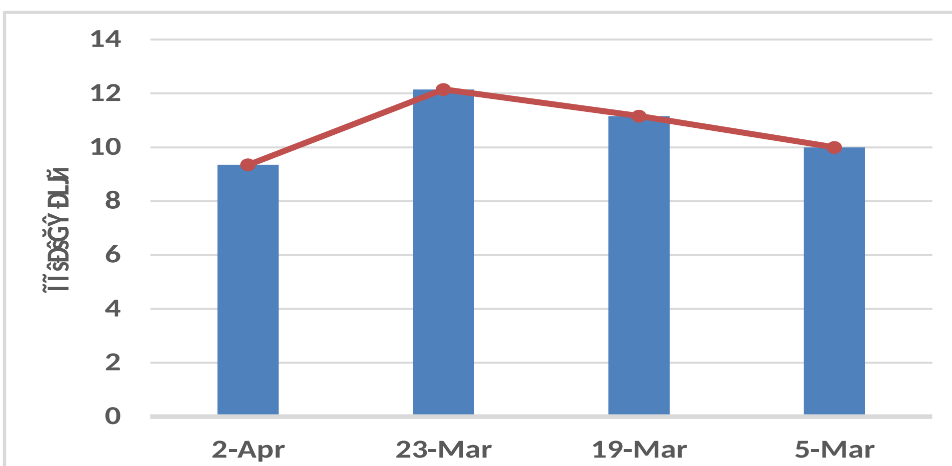


Figure 3.7 Efficiency comparison between dusty and clean system

Forming a layer of dust on the surface of the solar panel reduces the number of photons absorbed by the photovoltaic panel, thus reducing the number of electrons transmitted between the poles of the panel, which leads to a decrease in the amount of energy produced by the solar panel. Through the obtained results, the maximum efficiency reduction due to dust accumulating on the surface is 3%.

Chapter Four

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The project aims to study the effects of temperature and dust on the performance of a 15-kw solar system, which was installed on the roof of the Department of energy engineering building at the College of Engineering / Al-Musayab / University of Babylon. The performance of the system was evaluated under natural operating for three months. Accordingly, the following conclusion can be drawn from the obtained results.

1. The readings showed that increasing the temperature of the system by one-degree reduces the system efficiency by 0.69%.

2. Dust accumulation on the solar cells surface reduces the system efficiency by 3% .
3. It is recommended to clean the system every 18 days to minimize the effect of dust.

4.2 Recommendations

To reduce the accumulation of dust on the panels, we recommend one of the following approaches: mainly: (1) manual or automated cleaning of the solar system every 18 days and (2) searching the possibility of coating the solar panels' surface with anti-soiling nano-coating.

For further investigation and research, it is recommended to utilize the features of real-time data of the system provided by the inverter software. to compare the experimental results with the simulated results.

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Appendix A

March 13

EFFICIENCY %	POWER W	G_T W/M^2	TEMPERATURE ℃	TIME
2.8	756	313	24.76	**8:30**
12.8	7816	712	35.8	**10:30**
9.55	7584	925	45.26	**1:00**

March 19

EFFICIENCY %	POWER W	G_T W/M^2	TEMPERATURE ℃	TIME
3.16	1042	384	24.3	**8:30**
12.57	9124	846	30.76	**10:30**
11.16	9000	940	33.5	**1:00**

April 5

EFFICIENCY %	POWER W	G_T W/M^2	TEMPERATURE ℃	TIME
3.98	1300	380	24	**8:30**
12.77	8544	780	37.5	**10:30**
10.97	7754	824	41.2	**1:00**

December 14

EFFICIENCY %	POWER W	G_T W/M^2	TEMPERATURE ℃	TIME
1.19	196	200	19.4	**8:30**
11.51	4875	493.8	34.5	**10:30**
12.74	5921	541.67	31.6	**1:00**

March 29

EFFICIENC % Y	POWER W	GT W/M2	TEMPERATURE ℃	TIME
11.85	5566	547	32.77	9:00
13.39	7750	675	33	**10:00**
9.89	7089	835	40.6	**10:30**
10.82	8679	935	38.67	**11:30**
8.6	7167	972	41.76	**12:00**
8.28	6882	969	43.3	**1:00**
8.41	6881	954	40.23	**1:30**

April 2

EFFICIENCY %	POWER	GT W/M2	TEMPERATURE ℃	
7	3400	202.4	20.133	**8:30**
9.6	3932	395.8	23.933	**10:30**
7.3	2189	133.8	28.166	**1:00**

March 5

EFFICIENCY %	POWER	GT W/M2	TEMPERATURE ℃	
16	494	342.9	25	**8:30**
10	6588	748	30.83	**10:30**
8	6711	871	41	**1:00**

March 22

EFFICIENCY %	POWER	GT W/M2	TEMPERATURE ℃	
9.58	1475	179	18.6	**8:30**
12.15	7651	734.2	31.3	**10:30**
8.54	3767	237	27.9	**1:00**

Data of Figure 3.5

EFFICIENC % Y	POWER	¿ $W/m2$	TEMPERATURE ℃	
10	6588	748	30.83	**MAR-5**
12	7816	712	35.8	**MAR-13**
12.5	9124	846	30.76	**MAR-19**
1.6	1023	728	33.7	**MAR-23**
13	9504	800	32	**MAR-28**
6.9	8295	989.8	36.8	**APR-4**
12.77	6544	780	36.567	**APR-5**

Data of Figure 3.6

EFFICIENCY %	POWER	¿ W/m	TEMPERATURE°C	*DAY*
10	6588	748	30.83	*5-MAR*
10.27	6330	718.2	29.18	*9-MAR*
11	8410	832	45.7	*12-MAR*
12	7816	712	35.8	*13-MAR*
12.5	9124	846	30.76	*19-MAR*
12.15	7651	734.2	31.3	*22-MAR*
9.4	6504	800	31	*28-MAR*
16	7750	674	32.9	*29-MAR*
8.946	5377	700.8	31.53	*30-MAR*
9.25	7309	921	30..93	*2-APR*
6.9	8295	989.8	38.8	*4-APR*
12.77	8544	780	37.567	*5-APR*
9.88	8075	952.2	35.43	*6-APR*