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The effect of Kuwait's climate on the efficiency of solar cells in the electricity production network (a theoretical study)

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Abstract

This research aims to demonstrate the climate impacts in Kuwait on the efficiency of solar cells in the electricity production network, and to analyze climate constraints and problems related to the use of solar energy in electricity production. The study specifically aims to demonstrate the impact of high temperatures and the potential effects of sand and sandstorms, and certainly to find potential technical solutions. To increase the efficiency of solar cells in Kuwait's climatic environment, based on the importance of the topic as it is an addition to engineering studies, as it highlights the benefits of using solar energy in producing electricity, and through the use of the descriptive approach and the analytical approach, several results were reached, the most important of which was, The high temperature under which solar panels operate is one of the most important factors that affect their productivity, and The methods of installing solar cells may affect their exposure to solar radiation, which affects the efficiency of electricity production, The study recommends using smart prediction systems based on AI and programming these systems to operate only when temperatures rise above certain levels to save energy. We also recommend using machine learning to perform preventive and regular maintenance and monitor the performance of solar panels.

Keywords: Solar energy, Climate effects, Temperature, Solar radiation, Sandstorms

1. Introduction:

Energy management became important in the field of energy production, after the energy crisis occurred in 1970 due to severe shortages in supply, as well as during the October War in 1973, when the Arab countries stopped exporting oil. Energy management can be defined as the integrated processes in energy production, in addition to the services accompanying its production, as well as energy conservation and reuse.

The topic of the impact of Kuwait's climate on the efficiency of solar cells in the electricity production network was identified by many researchers, who explained the existence of many obstacles that limit effective energy management. He pointed out many of the obstacles facing, including the climate obstacles facing energy facilities, Institutional obstacles include many factors, including the lack of clear tasks for facilities, as well as the lack of qualified and trained personnel to manage various energy projects in various climatic conditions. They also include behavioral obstacles in energy management, and the possibility of exploiting the available capabilities to a great extent.

The state-owned Kuwait National Petroleum Company has completed a study on the establishment of 100 fuel stations that operate partially with solar energy over the next 5 years, with the first 20 stations being completed in 2017, As well as the Kuwait Engineering Factory for Solar Energy, which is an example of initiatives in this field, as well as the project Street lighting powered by solar energy, charging golf cars, mobile transformers, solar heaters, flashlights, freezers, and refrigerators, and opening a school that consumes solar energy to generate electricity is an initiative to establish 90 other schools to spread the experience in Kuwait, and Kuwait, whose electricity production alone consumes about 3 billion dinars annually, or 9% of With the total value of its oil revenues, it intends to produce 15% of its energy needs through renewable energy in 2030.

1.1. Research problem

The problem of current research into the exceptional climate impact lies in the impact on the efficiency of solar cells in the electricity production network, the economic cost of producing electrical energy in Kuwait and keeping pace with developments in the field of alternative energy in the world due to the availability of oil with huge reserves.

1.2. Research questions

The study's questions revolve around the reality of the impact of Kuwait's climate on the efficiency of solar cells in the electricity production network, as well as the reality of power

generation plants and the expected results in the event of managing and designing power generation plants using solar energy under climate conditions, the current conditions for implementing renewable energy projects in Kuwait, and the view of decision makers. Renewable energy projects, climate constraints, problems related to the use of solar energy that face decision-makers, the reality of the infrastructure necessary to implement projects using solar energy, and the research questions are as follows:

1. How do high temperatures affect the energy conversion efficiency of solar cells?
2. What are the possible effects of sand and sandstorms on solar cell performance?
3. What are the potential technical solutions to increase the efficiency of solar cells in Kuwait's climate environment?

1.3. Research objective

The research aims to explain the climate impacts in Kuwait on the efficiency of solar cells in the electricity production network, and to analyze climate constraints and problems related to the use of solar energy in electricity production. The study specifically aims to:

1. Explain the effect of high temperatures on the energy conversion efficiency of solar cells.
2. Illustrate the potential effects of sand and sandstorms on the performance of solar cells.
3. Finding potential technical solutions to increase the efficiency of solar cells in Kuwait's climate environment.

1.4. Research importance

The importance of the research derives from the importance of the topic as it is an addition to engineering studies, as it highlights the benefits of using solar energy to produce electricity by implementing projects that have low emissions in the environment and provide clean energy, in addition to identifying the necessary requirements to find potential technical solutions to increase the efficiency of solar cells in Kuwait's climatic environment.

1.5. Research Methodology:

The descriptive approach and the analytical approach were followed, since the nature and specificity of the research imposed the following of these approaches by studying and analyzing the most important topics related to the impact of Kuwait's climate on the efficiency of solar cells in the electricity production network.

2. Literature review:

Alshawaf, M., et al. (2020). Solar PV in Kuwait: The effect of ambient temperature and sandstorms on output variability and uncertainty.

In this study, the performance of a 2000 MW solar PV plant operating under the weather conditions in Kuwait is simulated using a Monte Carlo approach, the study showed the significant impact of sandstorms and dust accumulation on the cells, as longer lasting sandstorms (12 h and more) reduced the total daily solar irradiation by up to 60%. Moreover, the presence of dust on the solar cells causes a decrease in energy production by 100%, and the more stable and reliable supply of power during the months of June to September, and the certainty of the power output improves in the summer and declines during the winter.

Ayedh Alqahtani, et al. (2024). Electricity Generation in Kuwait using Sustainable Energy Sources – A Focus on Solar Photovoltaic Systems.

This study aimed to explore solar photovoltaic (PV) systems. And the efforts made by the Kuwaiti government to reduce dependence on electricity from fuel and oil, and to benefit from solar radiation, especially to reduce the electrical load in the summer. The study mentioned the most prominent photovoltaic energy projects, the most prominent of which are Shagaya Renewable Energy Park, Sidra 500, MEWR and MPW Head Office Buildings, the study focused on the temperature coefficient of thin-film PV is less than that of polycrystalline PV, which makes it more tolerant to higher temperatures, as well as the necessity of creating a live database that would be created and would allow the development and enhancement of PV projects in Kuwait.

Al-Enezi, F.Q. et al. (2011). Visibility and Potential of Solar Energy on Horizontal Surface at Kuwait Area.

In this paper, the authors are identifying and analyzing the geographical and temporal variability of solar energy inside Kuwait. The fundamental solar models are modified to estimate and identify daily and hourly solar radiation on horizontal surfaces on the basis of the more readily available meteorological data. The presented results prove that Kuwait has an abundance of solar energy capability in terms of almost cloudless atmosphere for nine months and twelve hours solar time a day over the year, this makes Kuwait suitable for producing photovoltaic energy instead of traditional power plants.

Yaqoub E. Althuwaini, (2023). Soiling Effect and Remedial Measures of Solar Photovoltaic System Performance in Kuwait.

The study aimed to explore the potential of solar energy projects in Kuwait, a location characterized by high dust levels and an average of 9.4 hours of daily sunshine. A soiling map of Kuwait was created using PVsyst software, and a theoretical and mathematical model for a 100 MW solar PV power plant was developed based on various environmental and technical

parameters. The model, tailored to Kuwait's conditions, revealed that without any mitigation strategy, over 25% of the total generated electricity could be lost annually. Efficiency losses could rise by approximately 50% during seasons with sandstorms and high soiling rates, The study also examined the impact of cleaning methods on energy production. Both manual and automatic cleaning significantly increased energy production, from 112,092 MWh to 207,300 MWh. Manual cleaning reduced energy costs by 4.9%, while automatic cleaning resulted in a 17.34% higher energy-saving cost compared to a system without cleaning. Additionally, the payback period of the solar PV system was reduced from 9.22 to 7.86 years with the use of an automatic cleaning system. Based on these findings, the study recommends the implementation of an automated cleaning system for solar PV installations in Kuwait to maximize energy efficiency and reduce costs.

Zainab Al-Hamza (2023), Improving the Efficiency of Solar Cells.

This research discusses the applications of using solar cells and their types, which are in addition to their main role in producing electrical energy, and its application to residential buildings, a number of factors and considerations are concerned with the design of photovoltaics in buildings and the selection of their systems. Also, through our study of the research, we noticed several results that there are many factors that affect the efficiency of the cells, namely (short circuit current, open circuit voltage, filling factor, and temperature), In order to increase the efficiency of the cells and reduce the cost of the voltage system, we recommend that the study study ways to improve the performance of the solar cell from Through the change in the parameters of the cell, solar concentrators, and Vernel lens, it also shows the types of concentrators and the factors affecting them.

Othman Ali, (2022), Improving the operation of silicon solar cells.

The study dealt with improving the operation of silicon solar cells and calculating solar radiation in the city of Khartoum. The study aimed at ways to improve the operation of silicon solar cells. The problem of the study stemmed from the intense need to use solar energy and develop the work of silicon solar cells. The study was conducted at Omdurman Islamic University over a period of three years. The importance of the study arises from the fact that solar energy is available and free from negative effects. The experimental method was used to conduct the study. The study reached several results, the most important of which is that the energy generated from solar cells is energy free of negative effects and the work of solar cells can be improved. It appeared that there is an inverse relationship between the efficiency of solar cells and temperature,

and there is a relationship between the efficiency of solar cells and the angle of inclination of the solar cell. The study recommends further research into the relationship between cell efficiency and tilt angle.

Dhi Thamer Eid, (2022) Solar cells.

This research discusses the applications of using solar cells, which are in addition to their main role in producing electrical energy, and its application to residential buildings. A number of factors and considerations are concerned with the design of photovoltaic cells in buildings and the selection of their systems. Using the analytical approach, the study concluded that solar cells convert sunlight directly into electrical energy, taking advantage of the electronic properties of a certain type of material known as semiconductor materials. In the past, their use has been limited to equipping remote areas with small amounts of power. Now, more and more widespread use of the applications of these cells appears if their prices continue to fall in the current form. The study also recommended preparing power for household needs in the form of spaces connected to the power supply network. It seems practical from an economic standpoint, especially with the new technologies that are now in the research and development stage, and that technology thin films using semiconducting materials are a candidate technology for producing solar cells that are expected to not decrease in cost.

Swapnil Dubey, et.al (2013) Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review.

The study aimed to investigate the impact of operating temperature on the performance of silicon-based solar cells and photovoltaic (PV) modules. Methodologically, the study involved analyzing various correlations from existing literature that describe how temperature affects PV systems, including free-standing frames, PV-thermal collectors, and building-integrated arrays. The results indicated that electrical efficiency and power output are linearly dependent on operating temperature, with higher temperatures leading to decreased performance due to increased internal carrier recombination rates. It was found that performance ratios generally decrease with latitude due to temperature effects, while high-altitude regions like the southern Andes, Himalayas, and Antarctica exhibit higher performance ratios due to lower temperatures. The study recommends that PV modules with lower sensitivity to temperature are more suitable for high-temperature regions, whereas those more responsive to temperature changes are better for low-temperature areas. Additionally, the geographical distribution of photovoltaic energy potential should consider the effects of irradiation and ambient temperature on PV system performance.

Jehad Adeeb, (2019), Temperature Effect on Performance of Different Solar Cell Technologies.

The study aimed to evaluate the variations in the performance of different solar cell technologies in relation to temperature in Amman, Jordan. Methodologically, the study involved collecting field data from a weather station and three PV systems (Poly-crystalline, Mono-crystalline, and Thin-film) with identical design parameters from the Test Field Project at Applied Science Private University, Shafa Badran, Amman, Jordan. The analysis included calculating the estimated specific energy yield (kWh/kWp) for the three PV systems based on measured solar irradiance and technical specifications of the installed panels and inverters. The actual energy yield at different temperatures over one year was then compared with the estimated values to determine deviations and calculate actual temperature coefficients for energy yield. The results indicated that thin-film solar panels are less affected by temperature, with a temperature coefficient of -0.0984%, compared to -0.109% for Mono-crystalline and -0.124% for Poly-crystalline panels. The study recommends using these findings in the preliminary design steps, particularly in selecting the appropriate solar cell technology for specific locations based on their average temperatures. Additionally, since solar cell performance directly impacts the overall economics of the project, selecting the proper technology is crucial for optimizing performance and cost-efficiency.

Nourredine Bouaouadja, et.al (2000), Effects of sandblasting on the efficiencies of solar panels.

The study aimed to investigate the impact of sandstorms on the efficiency of photovoltaic solar panels used for electrification, water pumping, and communications in inaccessible regions, such as southern Algeria. The methodology involved examining the effects of sandblasting duration on solar panel efficiency. The glass-protected solar panels, designed for such purposes, are frequently exposed to sandstorms, particularly in spring when wind speeds can reach up to 120 km/h and last approximately 48 hours. The study noted that small sand particles (average size <120 µm) are lifted high into the atmosphere, while larger particles (average size >120 µm) remain closer to the ground. Results indicated that solar panel efficiency decreases during sandstorms, and some efficiency losses are permanent due to erosion damage to the protective glass. The findings highlight the importance of developing more robust protective measures for solar panels in regions prone to sandstorms to maintain their efficiency and longevity.

3. Theoretical Framework

3.1 Solar cells and their types

Renewable energy is one of the modern scientific fields, but interest in it may date back to the beginning of the 1930s, when thinking about it depends on providing materials and devices that have the ability to convert the energy of the sun and wind into electrical energy (generating electricity). A substance called (selenium) has been discovered. which is greatly affected in its electrical resistance when exposed to light, and this discovery was just a coincidence because the basis of the research was only to find a material with high electrical resistance in order to extend communications cables at the bottom of the Atlantic Ocean, in addition to the use of wind energy in Europe to produce energy. For mills in the past. Interest in solar energy was renewed in the early 1950s with the development of high-quality chips with geometric shapes that had the ability to convert sunlight into electrical energy, but they were Very high cost. (Lohmann, 2018)

Solar panels are the visible part of the solar system that is installed on the roof of the building and generates electrical energy. The solar panel is solar cells grouped together that produce direct current electricity that can be used to operate some equipment or stored in batteries that can be recharged and used. More than once, the power of these cells is measured in watts. Here, small panels start from 2 watts or 32 watts until they reach billions of watts for large buildings and factories. To clarify the mechanism of operation of solar panels, you must know the basic component of the solar system, which is the solar cell. Solar panels consist of the following components: (solar cell - solar module - solar array). (Haupt, et al. 2018)

The importance of solar energy comes from its consideration as the most important renewable energy source during the current century, because traditional (fossil) energy is threatened with depletion, as well as with the catastrophic effects it creates on the Earth's environment in terms of pollution and a rise in the Earth's temperature, which has caused climate changes in the Earth's atmosphere. Therefore, the efforts of many countries are directed towards investing in solar energy, allocating the necessary amounts to develop products and research on exploiting solar energy as one of the most important sources of alternative energy to oil and gas.

The largest share in research and applications has been given to the field of converting solar energy into electricity, which is known as Photovoltaic and this source. Of energy is the hope of developing countries for development, as the availability of electrical energy has become one of the most important key factors for creating infrastructure in them, and the production of electricity from solar energy does not require centralized generation, but rather it produces energy and is used

in the same region or place, and this saves a lot of cost in transportation. And transportation. (Reikard, et,al. 2017)

This method relies mainly on converting sunlight into electrical energy, and there are many materials in nature used in the manufacture of solar electric cells, which are combined with a specific electrical and engineering system to form what is called a solar panel, which in turn is exposed to sunlight at a certain angle to produce the largest amount of electricity, and despite Solar energy has taken an important place among the alternatives related to renewable energy, but the extent of its benefit is linked to the presence of sunlight throughout the time of use, similar to traditional energy, and therefore it seems that what is required (in addition to developing the electrical and thermal conversion of solar energy) is the development of a technology for storing that energy to benefit from it. During the period of occultation of solar radiation. There are several technical methods for storing solar energy, including thermal, electrical, mechanical, chemical, magnetic, etc. storage. (Haupt, et al. 2018)

3.1.1 Types of solar cells:

- Monocrystalline silicon cells.

These panels are made of pure silicon gem cut into few strips, this type is characterized by more space-saving, the longest-lived of all types, high cost and high efficiency. And this type withstands higher temperatures (Aldousari, 2022).

- Polycrystalline silicon crystals.

It is characterized by the presence of several small crystals within the material, Polysilicon is less expensive to produce compared to single-crystalline silicon, It lasts for long periods due to its hardness, Its efficiency is lower than Monocrystalline silicon, It is more affected at high temperatures,

- Randomized solar cells.

This type relies on creating irregular nano- or micro-structures to scatter light in ways that increase the likelihood of it being absorbed within the photovoltaic material, it improves light absorption, is suitable for different lighting angles, and is more effective throughout the day and in changing lighting conditions. Despite its inexpensive cost in manufacturing, it has poor long-term performance.

3.2 The effect of high temperatures on the energy conversion efficiency of solar cells

The efficiency of solar panels is affected by temperature, specifically the temperature coefficient of solar panels, which is the percentage change in power output for each degree Celsius rise in

temperature. Most solar panels have a temperature coefficient between 0.5% and 0.8%, which means that for every degree Celsius increase in temperature, the power output decreases by that percentage. This is because solar panels work by converting sunlight into electricity, and high temperatures can cause the materials in the panels to expand and generate heat, reducing their ability to efficiently convert sunlight into electricity. In addition, high temperatures can degrade the electrical properties of materials in solar panels, reducing their efficiency. (Lohmann, 2018)

The temperature at which solar panels operate is one of the most prominent factors that affect their productivity. Since the temperature of solar cells in the field varies greatly during the day, it is necessary to know and understand the effect of temperature on their performance, and this effect is evident through the decrease in electrical voltages. (0.4) millivolts per degree Celsius at a temperature of (25°C). The reason for this is that the solar cell needs a short-wave beam, that is, within the ultraviolet band and light rays, because the photons within them are strong and are the ones that generate electrical voltage. As for the long-wave rays (under (red) which contributes to raising the temperature of the solar cell, as it has been shown that there is a direct correlation between the daily average temperature and the rate of decrease in voltage in the solar cells. The daily average temperature and the amount of decrease in voltage show a trend toward increase starting from the month of January, which reached Its value is (282.8 K), and the rate of voltage decrease for the same month reached (2.38 mmV), then the temperature rates rise to reach their highest value during the month of August (313.7 K), considering that the temperature that achieves the highest efficiency is (25 C), equivalent to (298 K). (Haupt,et al. 2018)

3.3 Potential effects of sand and sandstorms on solar cell performance

The panels work by relying on sunlight, through the solar cells inside these panels. These cells contain a semiconductor silicon material, Si, which is responsible for generating electrical current. When the silicon crystals are exposed to sunlight, the electrons inside these crystals move, and this leads to the generation of a continuous current. It is transmitted through the wires of special devices, which then convert it into alternating current capable of operating electrical appliances. Dust and dirt can accumulate on the surface of these panels and form a layer that prevents light from reaching the solar cells, thus causing a malfunction of the panels. Therefore, the process of cleaning the panels must not be neglected. (Reikard, et,al. 2017)

The dust phenomenon is an atmospheric phenomenon that cannot be controlled to a large extent. It is a frequent occurrence, and can be repeated in one day. This means that the productivity of panels installed in such environments can decrease completely, and the matter can get worse if it

is combined with accumulated dust and waste. Engines of cars, vehicles, and birds, which contain various organic materials and elements. When all of these materials accumulate on the solar panels, they can create an insulating layer on the surfaces of the panels, thus preventing the transmission of light into the solar cells. This layer cannot be cleaned easily except in the presence of water. (Naegele, et al. 2019)

3.4 Analysis of climatic conditions in Kuwait on the efficiency of generating electricity from solar cells

3.4.1 High temperatures

In solar power generation system, the effect of solar cell temperature in Kuwait is one of the main factors affecting the power generation efficiency of the system. The current research shows that when the operating temperature of solar panels is 25 degrees, their output power is maximum, and when the temperature is higher or lower than 25 degrees, the output power will decrease as the temperature increases or decreases. (Lohmann, 2018)

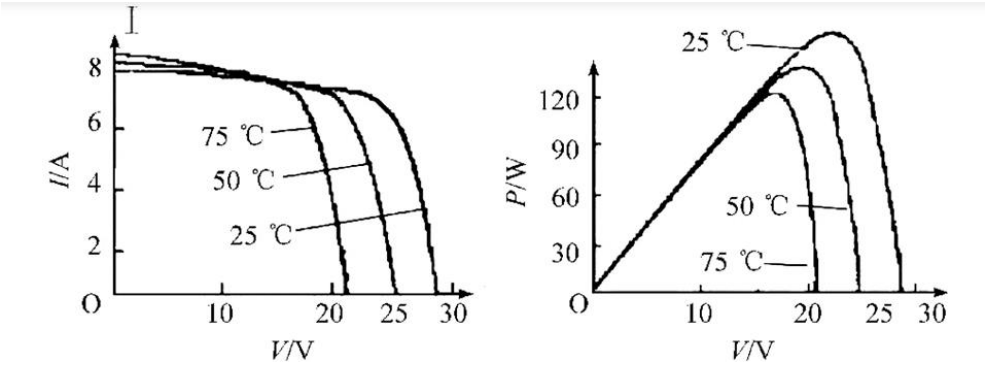

Fig. 1: I-V solar cell characterized under temperature effect

One interesting point that most people don't realize is that solar systems perform less as the temperature rises in Kuwait and will produce about 20% less energy than their peak on any given day. This is why a solar system will never reach its peak output at any one point in time. Appropriate during spring or fall in Kuwait. (Nasrallah, et al. 2001) Generally, the system produces more energy units during the summer months due to the length of the days. The temperature in Kuwait can affect how electricity flows through an electrical circuit by changing the speed at which the electrons move, because solar panels They work best in certain weather and temperature conditions. Engineers in Kuwait are designing ways to improve the efficiency of solar panels that operate in non-optimal temperature conditions. This may involve designing cooling systems that use outside air, fans and pumps. (Haupt, et al. 2018).

The State of Kuwait enjoys a hot climate, which gives a degree of solar radiation suitable for photovoltaic cells. In return, it generates a high temperature, which affects the efficiency of the solar cell, as the temperature is inversely proportional to the efficiency of the solar cell. In the following figure, we note the temperatures by month for the years 2022-2023

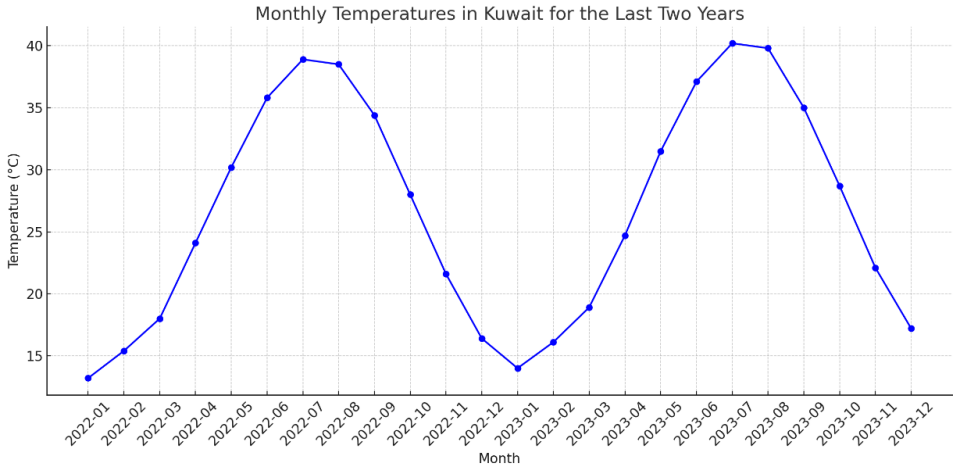

Fig. 2 temperature degree 2022-2023 (weather atlas, 2024)

We note that temperatures in May, July, June, and August are high compared to October, December, January, February, And march. Here factors come into play that must be taken into account to provide high production efficiency based on the change in load, high energy demand in the summer, and uncertainty in the winter. The installation system, ventilation, wind, dust, and type of solar cell also play important factors in the temperature of the cell when operating.

All these factors are taken into account when designing a PV power generation system including Normal Operating Cell Temperature (NOCT), whereas the average decrease in efficiency is about 0.4-0.5% for each degree Celsius exceeding the optimum operating temperature (NOCT).

3.4.2 Solar radiation

Solar radiation is radiant (electromagnetic) energy coming from the sun. It provides light and heat to the Earth and energy for photosynthesis. This radiant energy is essential for the metabolism of the environment and its inhabitants. The three relevant bands, or bands along the solar radiation spectrum, are ultraviolet, visible and infrared. Of the light reaching the Earth's surface, infrared makes up 49.4%, while visible light provides 42.3%, with ultraviolet making up just over about 8% of total solar radiation. Each of these ranges has a different impact on the environment.

The temperature of the photovoltaic cell in Kuwait has a significant impact on the performance of solar cells. It is very important to note that as the temperature rises, the power output of the photovoltaic cell decreases.

The temperature of the photovoltaic module also affects its efficiency in Kuwait. (Nasrallah, et al. 2001) In general, the efficiency of the silicon photovoltaic module will be reduced. Crystallinity increases by about 0.3-0.5 percent for each degree Celsius increase in temperature. The effect of varying temperatures does not have a very significant effect on current. But this can be seen in the decrease in the voltage of the photovoltaic cell, as a result of which the ability of the photovoltaic cell to generate electrical energy decreases. (Al-Shammari, 2013).

The higher solar radiation increases the potential power output of solar cells, the accompanying rise in temperature decrease their efficiency. The effect of cell temperature on I-V characteristics is illustrated in Figure 2. The figures show the effect of temperature variation (25°C, 50°C, 70°C) on the I-V characteristics of continuous radiation for G = 1 sun.

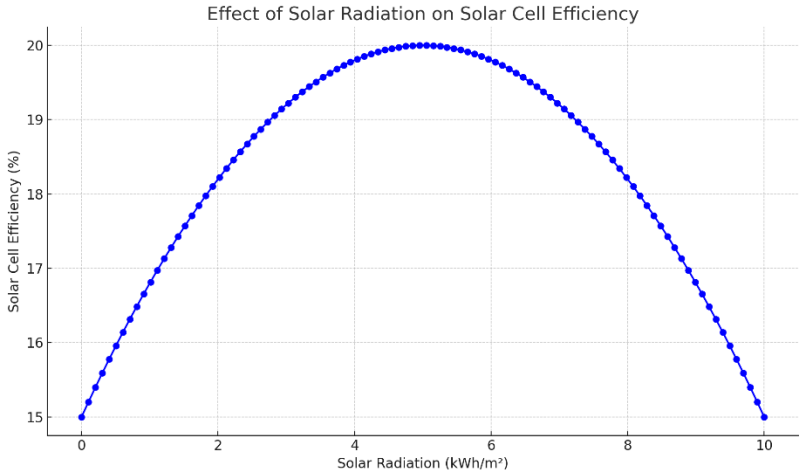

Fig. 3 effect of solar radiation on solar cells efficiency.

Figure (3) shows that the greater the solar radiation, the higher the temperature of the cell, which leads to a decrease in efficiency. Since Kuwait enjoys high solar radiation, the need to regulate the efficiency of energy production becomes important to maintain regular demand, according to the study of Al-Enezi, F.Q. et al. (2011) The peak of solar radiation occurs during the months of May, July, and June of the year, and from 11 a.m. to 3 p.m., which requires the design of systems to improve efficiency to work automatically.

According to a study conducted by Muhaisen, et al. (2016) that Kuwait has a geographical location rich in solar radiation and that most areas of Kuwait are suitable for the installation of photovoltaic power plants. As show in Figure 4

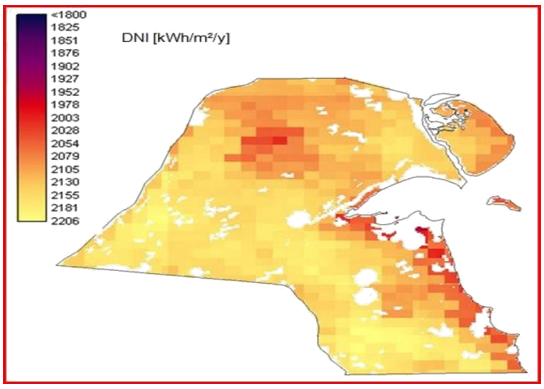

Fig 4. Solar image map of Kuwait. (Muhaisen, et al., 2026)

3.4.3 Dust and sand storms

Dust and sand storms greatly affect the efficiency of solar cells, and neglecting regular cleaning of solar cells may lead to a loss of 100% efficiency. Many factors play in the formation of a layer of dust on the surface of solar cells, capillary, van der Waals force, electrostatic, and particle-weighing. forces and humidity in dry environments.

This phenomenon exists in most desert environments, but varies depending on the location and the type of dust scattered. The hours of dust scattering may increase over a long period. For example, in Kuwait City, the dusty weather condition lasts for 27% of the hours of the day, from May to August, which causes... Lack of visibility sometimes. Dust has the property of accumulating on exposed surfaces, creating a layer on top of it. Previous study reports indicate that there are other factors that cause the continued accumulation of dust. The most dramatic are gravitational forces, wind speed and direction, and surface wetness. Gravity increases the amount of dust falling and depositing it on the surfaces of the panels, aided by slow wind movement, while high wind speed helps remove dust if the wind is in the appropriate direction. (Lohmann, 2018) Al-Hattab, K. (2022) study showed that 40% of Kuwait's dust comes from Iraq, This gives an indication that the northern regions of Kuwait are more exposed to dust than the southern regions, which necessitates plans for afforestation and the selection of appropriate sites for photovoltaic power plants. According to an experimental study conducted by Al-Dousari, A., et al. (2020) done in Kuwait to get the effects of dust on the transparency of a glass plate revealed for 38 days found the following outcomes. For a tilt angle of 0˚ (horizontal), the decrease in transmissivity was around 64%; for tilt angles of 30˚, 45˚, and 60˚, the decrease in transmissivity was around 38%, 30%, and 17%, respectively. Which gives an idea of the magnitude of the effect of neglecting to clean the solar panels on the loss of transparency due to the penetration of photons into the solar cell.

Sandstorms cause the greatest damage to solar cells and cause imbalance in meeting loads and demand. By studying the time series of storms in Kuwait provided by meteorological centers, proactive solutions can be made and preparations for that. Below is a figure showing the concentration of sand storms by month for the 2022-2023 years.

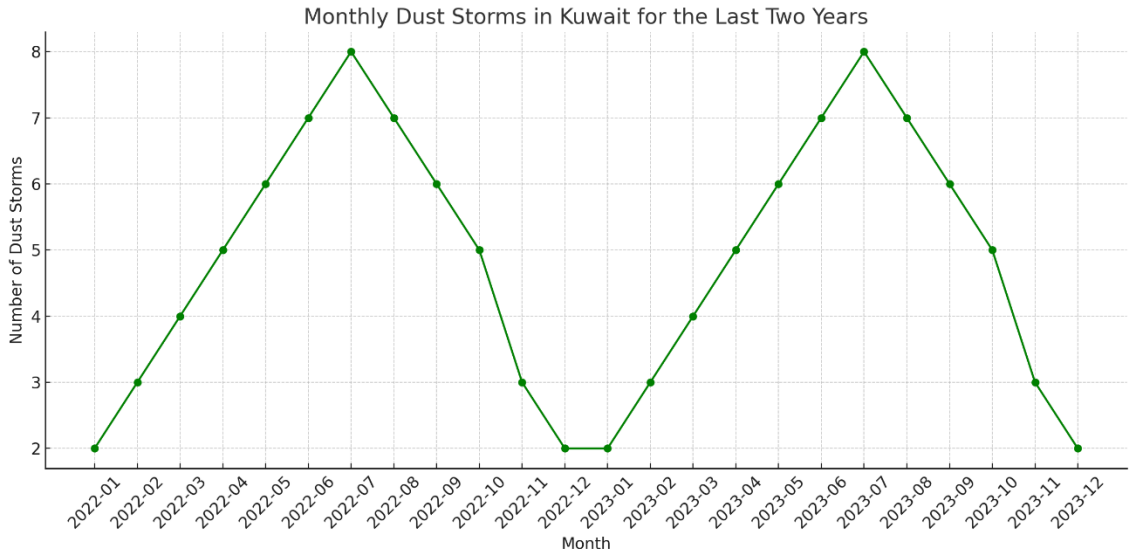

Fig. 5 number of dust storms (1-2022 to 12-2023) source (weather atlas, 2024)

From the figure above, we notice that sandstorms are more severe in May, July, and June, and decrease in January and December. Through smart learning and machine learning, the variables of storms can be predicted and precautionary solutions can be developed. As the experimental measurements made by A. Aldihania. et al. (2014) for HIT PV panel in Kuwait has shown that the accumulated dust over a period of 12 months can lead to a maximum loss in power output of 16% at noon for the July month.

3.5 Potential technical solutions to increase the efficiency of solar cells in Kuwait's climate environment

Studies indicate that solar panels are designed to withstand heat, snow, rain and wind, but their ability has limits, which means that climate change in Kuwait is putting more pressure on them and pushing them towards decomposition faster. (Al-Shammari, 2013)

Scientists are seeking to develop new technologies in Kuwait that contribute to exploiting sunlight with the aim of relying on it as a source of renewable energy, which saves us from using fossil fuels (oil, gas and coal), and contributes to preserving the environment and reducing harmful climate changes (Bracale, et,al. 2015), And this can benefit from experiences from neighboring countries with a similar climate, such as the UAE and Saudi Arabia.

Temperature is the main cause of decomposition of solar panels, and with Kuwait's temperatures rising further, we must take into account the risk of decomposition when purchasing solar panels, should be more careful when choosing a new location for a solar farm, to ensure that their modules have less chances of failure due to deterioration. (Naegele, el al. 2019)

Solar panel cooling systems can be classified into two types: passive and active cooling technologies, based on the energy source used. Passive solar panel cooling technologies rely on the idea of removing the heat generated from the panel without adding external capacity based on systems added to the solar station, through heat transfer media such as air, water, and other materials, while the idea of Active solar panel cooling techniques is based on the use of external energy و such as installing a fan or pump in the solar station. (Naegele, et al. 2019)

The most common and easiest water-cooling techniques for solar panels is the method of spraying water mist on the surface of the solar panels, to cool it directly by installing a tube on top of the panel to spray water on a regular basis, and this is the method used mainly to clean the panels of any dirt and dust attached to them, However, relying on water in Kuwait may be inappropriate as it is a desert place. (Bracale, et al. 2015)

There is also no doubt that the other common problem facing solar cells is the problem of accumulated dust that hinders the entry of light into these cells, so the dust reduces production and the sector incurs losses that threaten production in this field and investment in it, There are also other climatic factors, such as humidity, movement and speed of the wind, as they are factors that help the main effect of the operating temperature of the photocell and the transmittance of light into the cell, and these factors can be taken together to improve the overall efficiency of the photocell.

Based on the summary of what was mentioned, the researcher presents proposed solutions that will increase the efficiency of solar cells under the climatic conditions in Kuwait as follows:

- **Choosing the type of solar cell:** Choosing the appropriate photovoltaic cell requires conducting an experimental study in more than one area in Kuwait over a long period of time, more than a year, to obtain accurate and practical results, according to a study (Ahmed Hamza, et al., 2017) the energy performance, environmental impact, and cost assessments. of one MWp plant using the main 2017 market available photovoltaic technologies under hot climatic conditions for the state of Kuwait is carried out The PV modules technologies used are the monocrystalline, polycrystalline, and thin-film with cell types of cadmium telluride (CdTe) and CdS/CdTe semiconductor;

The main study conclusion is that the thin-film cadmium telluride (CdTe) technology has the yearly average right energy cost performance parameters, and it can be recommended For use under Kuwait climate condition, Third generation solar cells can also be used as perovskite cells and Phase Change Materials – PCM.

- **Using Automatic Passive Cooling:** Automatic Passive Cooling can be used to reduce the temperature and exploit resources, such as water cooling, air cooling, and convection that passes air underneath to enhance natural cooling, as well as the use of solar cells with built-in cooling, smart shade control systems, as well as the use of hybrid systems with wind energy for active cooling to maintain Load balance.

- **Using smart automated cleaning systems:** Althuwaini, 2023 indicates that automatic cleaning resulted in a 17.34% higher energy-saving cost compared to a system without cleaning, and Total cleaning costs for manual cleaning systems were 130% higher than for automatic cleaning systems. Manual cleaning systems are expensive and unsustainable compared to automated cleaning systems, such as the use of water mist sprayers programmed to operate automatically, nanomaterials that repel dust and moisture, vibration technology, and the use of drones For large panels.

- **Using artificial intelligence and machine learning techniques:** The use of artificial intelligence and machine learning systems in smart monitoring and optimization according to weather conditions constitutes a very important factor in improving the efficiency of photovoltaic energy production, and improving proactive maintenance such as: predictive models for performance and preventive maintenance, sun tracking systems, improving heat distribution within the solar system, and reducing hot spots that can To reduce efficiency, analyze climate data based on the climatic history of the region.

- **Using of hybrid systems:** Integrating solar energy systems with other energy sources such as wind or thermal energy ensures the continuity of energy generation and improves the efficiency of the overall system, eliminating the problem of uncertainty, especially in winter or under extreme weather conditions in summer, and using smart energy management systems through machine learning to manage energy flow. Improving energy conversion efficiency based on changing climate conditions, ensuring efficient energy distribution and grid stability.

4. Conclusion

Kuwait is located in a Harsh climate in terms of high temperature, dust and sandstorms, but that does not prevent the trend towards generating electrical energy from photovoltaics, as experiences

can be taken in the Kingdom of Saudi Arabia, Saudi Arabia and the Emirates, which have worked on the great development of clean photovoltaic energy and which have a climate similar to the climate in Kuwait.

Kuwait plans to cover 15% of its electrical energy needs from renewable energy, which will provide approximately 400 thousand barrels of oil per day from generation stations, as in the long term the need for renewable energy sources becomes necessary.

In this research, we talked about the effect of Kuwait's climate on the efficiency of solar cells in the electricity production network, and the importance of the effect of high temperatures, solar radiation, and dust on the surfaces of solar panels, and this was confirmed through the findings of previous scientific investigations. Finally, we discussed methods and ways to cool and clean these panels.

5. Results:

- The high temperature under which solar panels operate is one of the most important factors that affect their productivity.

- In solar power generation system, the effect of temperature of solar cells in Kuwait is one of the main factors affecting the efficiency of power generation.

- Dust and sandstorms block and affect the solar cells' absorption of solar rays, which affects the efficiency of electricity production.

- Other climatic factors, such as humidity, wind speed, and ventilation, are factors affecting cell temperature and efficiency.

- The optimal design of the production site, the electric farm, and the cell inclination angle improves exposure to solar radiation and increases efficiency

- The use of smart automated cooling and cleaning systems is important in improving the efficiency of solar cells, and benefiting from applications of artificial intelligence and machine learning in forecasting, preventive maintenance, and managing the stability of the grid.

6. Recommendations

The researcher recommends the following:

- Conducting long-term experimental studies on the types of solar cells on the market to determine the optimal type to work with high efficiency under the climatic conditions in Kuwait.

- Using modern third and fourth generation solar cells integrated with self-contained cooling and cleaning systems.

- Using smart automatic cooling and cleaning systems to effectively cool and clean the panels.

- Using artificial intelligence techniques to enable cooling and cleaning systems to operate under specific conditions, to save energy.

- Install self-cleaning systems that operate periodically to clean the panels from dust and sand, or use transparent protective covers that can be easily removed and cleaned to protect the solar panels.

- Choose locations for installing solar panels away from areas highly exposed to sandstorms, or provide barriers to protect from the wind.

- Design the ventilation system under the panels to improve airflow and natural cooling, i.e. raise the panels at a suitable angle to increase airflow and reduce dust collection.

- Using the machine learning to Conduct preventive and regular maintenance and continuously monitor the performance of solar panels to detect any decline in performance due to high temperature or dust accumulation.

- Using self-charging laser dust cleaning robots, automating their work after dust storms or periodically based on forecasting systems.

- Investing in research to develop new materials and technologies to improve the efficiency of solar panels in the harsh climate conditions of Kuwait.

- Creating an information Database for photovoltaic energy projects for studies and researchers, independent websites for renewable energy production projects, and publishing data for investors and energy companies.

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