African Journal of Advanced Pure and Applied Sciences (AJAPAS)
Online ISSN: 2957-644X
Volume 3, Issue 3, 2024, Page No: 332-341
Website: *https://aaasjournals.com/index.php/ajapas/index*
معامل التأثير العربي 2023: (1.55) SJIFactor 2023: 5.689 ISI 2022-2023: 0.557
Special issue: First Libyan Conference on Technology and Innovation (LCTI-2024), Benghazi, Libya

The Effect of Water Vapor and Humidity on the Topcon Photovoltaic Cell

Abobaker Alansaryi [1*] and Abdulgader Alsharif [2]
[1] Mechanical & Renewable Energy Engineering Department, Higher Institute of Science and Technology, Aljofra, Sokna, Libya
[2] Department of Electric and Electronic Engineering, College of Technical Sciences Sebha, Sebha, Libya

تأثير بخار الماء والرطوبة على الخلايا الكهروضوئية ذات الاتصال المخمول بأكسيد النفق

أبوبكر الأنصاري *1، وعبد القادر الشريف2
1قسم هندسة الطاقة الميكانيكية والمتجددة، المعهد العالي للعلوم والتكنولوجيا، الجفرة، سوكنة، ليبيا
2قسم الهندسة الكهربائية والإلكترونية، كلية العلوم التقنية سبها، سبها، ليبيا

*Corresponding author: abubakeralansary@gmail.com

Received: March 01, 2024	Accepted: May 05, 2024	Published: May 30, 2024

Abstract:
The purpose of the study is to evaluate how water vapor, humidity, rain, moisture, and haze affected the Topcon photovoltaic cell's performance. The study discovered that poor weathering and high humidity have a negative impact on photovoltaic cells' and panels' performance. For instance, haze has a major impact on photovoltaic (PV) power generation. Quantitative studies on the impact of haze on photovoltaic power generation are scarce; however, as fine particulate matter concentrations increase, they become the main factor influencing solar irradiance and drastically reduce PV power generation. Due to the corrosion process, moisture and humidity can also cause photovoltaic cells and panels to deteriorate. Moisture intrusion is at the center of most degradation mechanisms that lead to PV module power degradation. Embedded moisture sensors, desiccant-stacked polyisobutylene sealants, encapsulants with improved moisture barrier and adhesion qualities, and PV designs with or without breathable back sheets are some of the techniques used to stop or reduce moisture ingression in PV modules. The study made several recommendations as well, such as placing the solar energy units at an appropriate inclination angle to maximize solar radiation and prevent the negative effects of rain and humidity, as well as shielding them from bad weather conditions, such as heavy rain and high humidity.

Keywords: Topcon, Humidity, Water Vapor, Photovoltaic Cell.

الملخص
يعد الغرض من هذه الدراسة هو تقييم كيفية تأثير بخار الماء والرطوبة والمطر والضباب على أداء الخلية الكهروضوئية (ذات الاتصال المخمول بأكسيد النفق) Topcon. وتوصلت الدراسة إلى أن سوء الأحوال الجوية والرطوبة العالية لهما تأثير سلبي على أداء الخلايا والألواح الكهروضوئية. على سبيل المثال، للضباب تأثير كبير على توليد الطاقة الكهروضوئية. وعلى الرغم من أن الدراسات الكمية حول تأثير الضباب على توليد الطاقة الكهروضوئية نادرة؛ فإن زيادة تركيز الجسيمات الدقيقة والضباب يؤثر على الإشعاع الشمسي ويقلل بشكل كبير من توليد الطاقة الكهروضوئية. وبسبب عملية التآكل، يمكن أن تتسبب الرطوبة أيضًا في تدهور الخلايا والألواح الكهروضوئية. ويحدث تسرب الرطوبة إلى داخل الوحدات مما يؤدي إلى تدهور طاقة الوحدة الكهروضوئية. وتعد أجهزة استشعار الرطوبة المدمجة، ومانعات التسرب المصنوعة من مادة البولي أيزوبيوتيلين المجففة، والمغلفات ذات حاجز الرطوبة المحسن وخصائص الالتصاق، والتصميمات الكهروضوئية مع أو بدون صفائح خلفية قابلة للتنفس، بعضًا من التقنيات المستخدمة لإيقاف أو تقليل تسرب الرطوبة إلى الوحدات الكهروضوئية. كما قدمت الدراسة في النهاية عدة توصيات تشمل وضع وحدات الطاقة الشمسية بزاوية ميل مناسبة لتعظيم الإشعاع الشمسي ومنع التأثيرات السلبية للأمطار والرطوبة، وكذلك حمايتها من الظروف الجوية السيئة باستخدام مواد العزل المناسبة.

الكلمات المفتاحية: خلية توبكون، الرطوبة، بخار الماء، الخلية الكهروضوئية.

Introduction:

Since the best method for achieving interface passivation is to introduce a tunnel oxide layer between the substrate and poly-Si, the tunnel oxide passivated contact (Topcon) structure has received increased attention for the development of high performance solar cells. The bond between SiO in the tunnel oxide layer, which is impacted by the subsequent annealing, is clearly responsible for the quality of passivation of the tunnel oxide layer. The tunnel oxide layer was formed in the suboxide region (SiO, Si_2O, Si_2O_3) at the interface with the substrate. Subsequent annealing results in the formation of an oxygen-rich bond in the suboxide region, which enhances passivation quality. [1] On a p-type wafer, an oxide tunnel junction structure with a passivation characteristic of 700 mV or more (Voc) could be achieved to control the surface morphology, annealing profile, and acceleration rate. When samples were exposed to RTP annealing at temperatures higher than 900°C, the quality of their passivation quickly decreased. The physical characteristics and thermal stability of the thin layer must be taken into account in order to enhance the quality of passivation of the tunnel oxide layer. The Topcon silicon solar cell features screen-printed electrodes on both sides, a tunnel-SiOx/n +-poly-Si/ SiNx:H structure at the back, and a diffused front emitter made of boron. The currents at saturation Before printing the silver contacts, the Jo of this structure is 1.3 fA/cm 2 on a polished surface and 3.7 fA/cm 2 on textured silicon surfaces. The Jo of this structure increases to 50.7 fA/cm 2 on textured silicon surfaces after printing the Ag contacts, which is still manageably less for metal contacts. When this structure was used on Topcon solar cells, the cells independently produced a highest efficiency of 24.58% and a median efficiency of 23.91%. Interdigitated back-contact solar cells have improved their optoelectrical characteristics for both sides of contact, resulting in a conversion efficiency of up to 26%. [2] About 30% of the total energy coming from the sun is absorbed or reflected back by landmasses, clouds, and oceans. Higher humidity cities, such as Los Angeles and Hamburg, where average humidity ranges from 40 to 78%, produce a thin layer of water vapor at the front of the solar cell that faces the sun. There is a loss in absorption and reflection of the solar energy that actually reaches the solar cell. In addition to the 30%, there have been estimated losses of 15–30% of the energy. One of the effects of humidity was observed to be a decrease in the percentage of solar energy utilized, from approximately 70% to between 55 and 60% [3].

Background

The global photovoltaic (PV) market has been significantly impacted by tunneling oxide passivated contact (Topcon) solar cells. However, the module bill of materials that can be used is expensively limited due to its comparatively lower reliability when compared to Passivated Emitter and Rear Contact (PERC) solar cells. One important factor that is identified as contributing to the relatively low reliability of Topcon modules, especially at high temperatures and humidity, is the use of silver/aluminum (Ag/Al) paste for front-side metallization. But as of late, there has been a compelling alternative to traditional one-step cofiring: laser-assisted firing methods like laser-enhanced contact optimization (LECO), which combine conventional cofiring at relatively low temperatures with a subsequent laser treatment. Enabling higher power conversion efficiencies (PCE) is the primary motivation behind laser-assisted firing [4].

When selected impurities are tested at the cell level using damp heat testing at 85 °C and 85% relative humidity (DH85), the Joly wood Special Injected Metallization (JSIM) solar cells outperform the standard Topcon cells by a significant margin. Several investigations have brought attention to possible reliability problems that Topcon solar cells and modules may encounter when operating, especially in situations with high temperatures and humidity [5, 6, 8, 9]. Significant reductions in power output have been associated with damp-heat stress, which is typified by circumstances like the standard DH85 test (85 °C, 85% relative humidity) [7,10,11]. Studies highlight how susceptible Topcon cell front-side contacts are to damp-heat circumstances, which can result in serious contact problems following extended testing [5, 6].

The majority of degradation mechanisms that result in PV module power degradation are centered around moisture ingress. Moisture in EVA encapsulant can cause adhesion and optical losses, delamination and discoloration of encapsulants, corrosion of metal grids, and potential induced degradation. Among the methods used to find moisture intrusion in modules are dark lock in thermography, photoluminescence, ultraviolet fluorescence, and electroluminescence spectroscopy. There are several methods to prevent or detect moisture ingression in PV modules, including encapsulants with superior moisture barrier and adhesion properties, desiccant-stacked polyisobutylene sealants, embedded moisture sensors, and PV designs with or without breathable back sheets [12].

Moisture intrusion is one of the main variables that connects weather conditions to module degradation. High temperatures and humidity levels are conducive to this. A number of life-limiting processes, including corrosion and the majority of material deterioration in solar cells and modules, are highly dependent on ambient temperature and moisture ingress. Moisture ingress is affected by the characteristics of the polymeric materials and the module technology in addition to environmental and climatic factors [13].

Research Significance

The effect of water vapor and humidity on the TOPCON photovoltaic cell is a very important topic due to that solar energy is a renewable energy in today's world that seeks to use clean, renewable and pollution-free energy. Moisture infiltration typically occurs through the polymeric materials, module edges, and voids caused by handling, climatic conditions, and manufacturing stresses. When water enters a photovoltaic module, the moisture that builds up inside the module combined with additional weather-related stresses can cause various types of degradation in the module's components as well as other packing materials. Figure(1) displays the most prevalent failure modes and defects among these. A PV module impacted by moisture intrusion is depicted in Figure(2) [12].

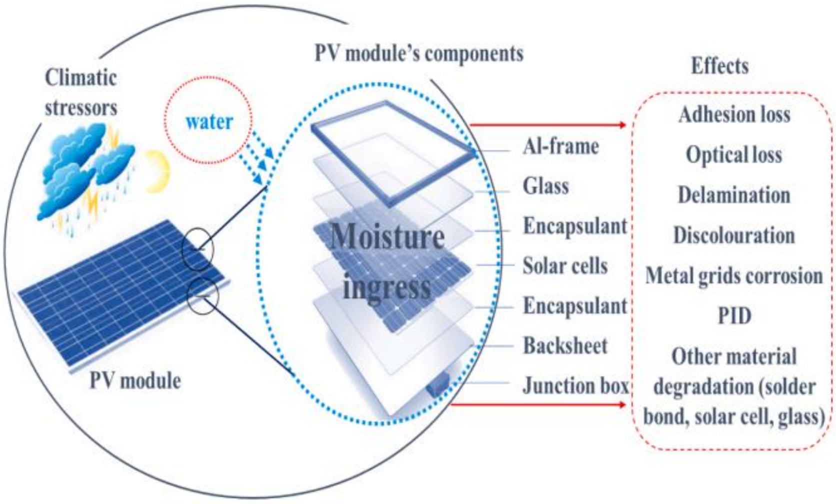

Figure 1: Defects and failure modes associated with moisture ingress in PV devices. Under environmental and/or climatic stressors (e.g., high humidity, temperature, and UV radiation), PV modules can suffer from moisture ingress which can lead to PV module degradation.

Figure 2: A typical moisture ingresses PV module showing signs of corroded metal grids, delamination and discoloration of encapsulants.

Research Question

The current research aims to assess the impact of water vapor and humidity on the Topcon cell. Therefore, the main research question is determined as the following:

Q1. What is the effect of water vapor and humidity on the Topcon cell?

Literature Review

It has been discussed the use of a tunnel oxide layer less than 2 nm thick to achieve passivated contact in sophisticated, high-efficiency silicon solar cells based on the full back surface field (BSF). Through interface passivation, the insertion of the tunnel oxide layer resulted in a significant improvement in the open-circuit voltage (Voc). A transition area, possibly a sub-oxide, was seen in the growth interface between the silicon substrate and silicon oxide layer during the growth of the oxide layer at a depth of roughly 0.75 nm. Transition region properties mainly influenced the properties of the tunnel oxide layer, which was less than 2 nm thick. Tunnel oxide layer passivation characteristics ought to be contingent upon the physical attributes of the oxide. The density of interface traps D_{it} is a crucial passivation parameter that is impacted by the oxide's stoichiometry, which is in turn greatly impacted by the conditions during fabrication and post-annealing. Due to hydrogen effusion on flat substrate surfaces, thin film blistering happens when heat treating a-Si: H thin films in order to crystallize and create doped layers. Regulation of the annealing profile and surface morphology are done in order to reduce this behavior. Additionally, for the sample annealed above 900 °C, the passivation quality of the passivated contact structure decreased [14]. Researchers in solar photovoltaics have invested sufficient time to enhance the performance of a number of high-efficiency crystalline silicon-based solar cell types, such as tunnel oxide passivated contact solar cells, interdigitated back contact solar cells, heterojunction with intrinsic thin-layer solar cells, and passivated emitter rear cells. Among these different types of high efficiency solar cells, tunnel oxide passivated contact (Topcon) solar cells are attracting more attention because they have a number of benefits, including easy access to raw materials, a straightforward process flow, the potential for high efficiency, etc. [15]

Currently, the most important work in silicon photovoltaic research and development is bridging the performance of poly silicon passivating contacts and developing a blatant passivating contact that is scientifically feasible. Crystalline silicon solar cells are the industry standard in the solar industry. Double-sided contacted cells are the preferred option for industrial production because they are less complex and exhibit higher efficiency than interdigitated back-contact cells. Avoiding the front side layer, which is essential for the bi-directional cell's exceptional opto-electrical properties and provides lateral charge carrier transportation. As a result, the conversion efficiency is 26.0%. The back of this cell has a p-n junction in the form of a full-surface passivation contact of polysilicon, in contrast to standard industrial cells, which have a p-n junction at the front. A thorough examination of the power loss reveals that these cells balance the usual transport losses, recombination losses, and transport losses of electrons and holes. Systematic simulation studies have shown the potential and superiority of these rear junction solar cells by establishing some fundamental design guidelines with efficiencies exceeding 26% for future silicon solar cells [16].

As an evolutionary improvement over the existing mainstream PERC, formation of an interfacial tunnel oxide capped by the polysilicon (poly-Si) layer is one of the most promising ways to realize carrier-selective contacts. In order to move this cell concept from laboratory research to industrial manufacturing, the PV industry is currently exploring a variety of technologically viable options. This paper develops cost-driven strategies for the industrial production of Topcon-based solar cells based on an evaluation of alternative process routes based on future alternative process technologies that are expected to be developed and currently in production. The techno-economic evaluation indicates that the increased capital and operating expenses necessary for the Topcon concept are dispersed unevenly along the process value chain, with a sizable portion occurring during the diffusion/annealing and metallization stages. However, Topcon-concepts are still found to be economically competitive in terms of levelized cost of electricity (LCOE) when compared to bifacial PERC under the given assumptions, provided that a minimum absolute gain in cell efficiency ($\Delta\eta > 0.55\%$ for most-conservative scenarios and > 0.40% for most-progressive scenarios, respectively) can be maintained [17].

The impact of post-crystallization annealing in different atmospheres on the quality of surface passivation of tunnel oxide passivated contact (Topcon) for solar cells made of crystalline silicon (c-Si) is examined. By annealing at moderate temperatures between 300°C and 700°C in a mixture of water vapor and nitrogen atmosphere, the results offer a novel approach to enhance the surface passivation of the as-crystallized Topcon structure. In comparison to the so-called forming gas annealing, the wet nitrogen significantly reduces the single-side reverse saturated recombination current density (J0) to 3.8 fA/cm³ and improves the implied open circuit voltages (iVoc) from 700–710 mV to approximately 730 mV on average. Furthermore, it is ensured that the contact resistivity will be used in the high-efficiency c-Si solar cell by its continued low values of approximately 5 mΩ.cm². The enhanced surface passivation resulting from water vapor annealing is attributed to hydrogen incorporation, as demonstrated by secondary ion mass spectroscopy (SIMS). This is consistent with the logical belief that passivates the defects in the oxide and c-Si interface region. This work suggests a straightforward and affordable method to enhance the Topcon structure's surface passivation, which is appropriate for the production of high-efficiency c-Si solar cells [18].

Due to possible moisture degradation, Dutch scientists have reported a higher degradation risk for n-type Topcon cells with EVA encapsulant. Damp heat tests show that n-type cells are more susceptible than p-type cells due to front-side metallization. To evaluate the effect of various encapsulation materials on performance losses in bifacial PV modules, researchers at the Netherlands Organization for Applied Scientific Research (TNO) have carried out a number of damp heat tests. Three encapsulant materials used in PV module production were compared by the scientists in their study "Corrosion effects in bifacial crystalline silicon PV modules; interactions between metallization and encapsulation," which was published in Solar Energy Materials and Solar Cells. These materials are ethylene vinyl acetate (EVA), polyolefin elastomers (POE), and thermoplastic polyolefins (TPO). According to the research team, POE and TPO, in contrast to EVA, do not release any acidic components; therefore, they may be more effective against acid-induced corrosion than EVA. This observation was made in earlier studies. It takes a while before significant field degradation can be seen, so there is currently no concrete proof that using these materials will increase module durability in the field. Comparing TPO encapsulants to EVA and POE, the research group claims that testing revealed that hydrophobic and chemically inert TPO encapsulants offered the best level of protection against moisture-induced degradation. Additionally, it showed that compared to their p-type counterparts, the front-side metallization of the tested n-type Topcon cells is more vulnerable to degradation caused by moisture or acid. Compared to other combinations of cell types and encapsulants, it can be concluded that the particular combination of n-type Topcon solar cells with EVA is likely a higher risk one. In fact, it is best to avoid using EVA in conjunction with metallization that is highly susceptible to corrosion. Alternatively, building more corrosion-resistant n-type PV panels should be aided by the application of the more corrosion-resistant metallization types found to Topcon solar cells [19].

For crystalline silicon (c-Si) solar cells, metallization has always been and continues to be a crucial area of development, along with wet processing, junction formation, and passivation. Because of the close relationship between the race to reach the 25% cell efficiency milestone (Figure 3), and the development of metallization approaches during the early 1940s and 2000s. For industrial-type c-Si cells, the primary metallization methods are based on the use of plated contacts, evaporated contacts, screen-printed contacts, or alternative printing techniques. Crucially, as metallization approaches based on screen-printed contacts continue to advance, some metallization techniques or approaches have fallen out of favor while others have been re-discovered [20].

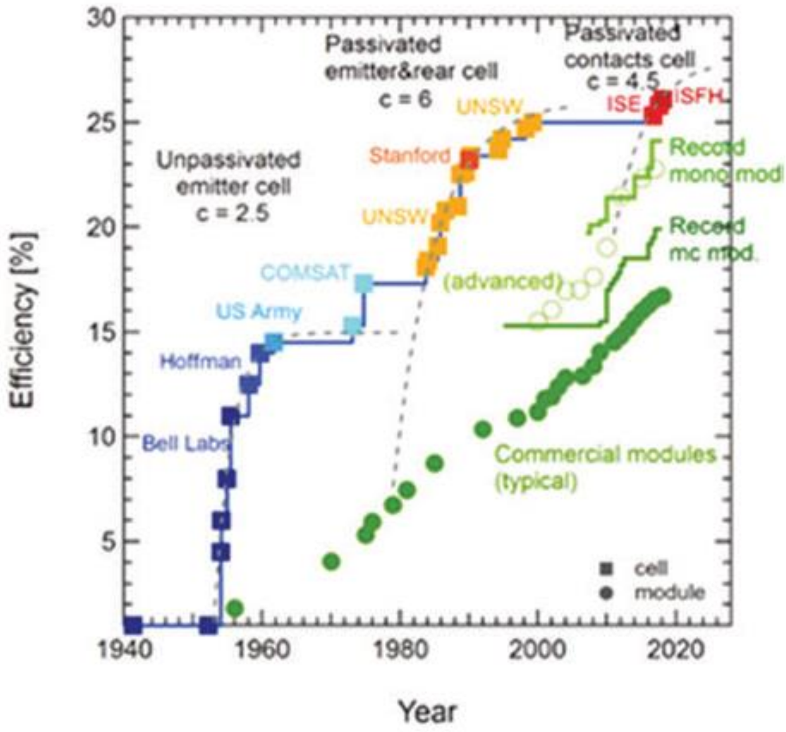

Figure 3: Evolution of the efficiency of champion laboratory c- Si solar cells (square symbols), record modules (green solid lines) and typical commercial modules (circle symbols) over time.

Heterostructures, such as silicon heterojunction back contact solar cells have led to the current 26.7% world record efficiency [22].

The performance of several types of high efficiency crystalline silicon-based solar cells, such as passivated emitter rear cells, heterojunction with intrinsic thin-layer solar cells, interdigitated back contact solar cells, heterojunction with interdigitated back contact solar cells, and tunnel oxide passivated contact solar cells, has been improved by the research in solar photovoltaics. Tunnel oxide passivated contact (Topcon) solar cells are becoming more popular among these high-efficiency solar cells because they have a number of benefits, including easy process sequencing, raw material availability, and high efficiency potential [15].
Achieving high photovoltaic (PV) integration in electrical grids has become one of many nations' strategic goals in recent years. In order to entice the private sector to invest in PV-related projects, numerous governments have implemented incentive-based policies. However, non-governmental organizations won't fund these kinds of projects unless they have a positive net present value (NPV). The authors of this study look into how open burning in Sumatra causes haze to affect PV systems in Malaysia. Malaysia has instituted a feed-in tariff (FiT) mechanism in order to increase the installation of renewable energy sources, as it is a developing country. When compared to many similar countries, Malaysia has a much higher FiT rate and a longer purchase agreement, which makes it a preferred destination for PV system investments. On the other hand, haze and other environmental disruptions have a detrimental effect on PV system yield. The transboundary haze episode that affected Kuala Lumpur from September to October 2015 decreased the power generated by photovoltaic systems by 17.8% [24].
The generation of photovoltaic (PV) power is significantly affected by haze. There aren't many quantitative studies on how haze affects PV power generation, but when fine particulate matter concentrations rise, it becomes the primary factor affecting solar irradiance and significantly lowers PV power generation. In order to examine the weight factors of the effects of haze on irradiance, this study suggests using the enhanced method of the degree of grey slope incidence. The effect of haze on the amount of irradiance is explained by the exponential-linear model. Additionally, the quantitative loss of PV power due to haze is the main focus of the PV system model. It is possible to determine the losses resulting from haze on PV power generation in 2017 and 2018 by modeling and analyzing data samples of PV power generation in Hangzhou, China. In 2017 the losses were 5.25 ± 1.19 % and 6 ± 1.16 % of the original PV power generation, respectively. In addition to being a crucial component in the forecasting and scheduling of PV power generation, the quantitative analysis of haze on PV power can serve as a solid foundation for the economic assessment of new PV systems [25].
The number of solar photovoltaic (PV) systems being installed is rising quickly as a sustainable energy source, but environmental factors like dust, bushfire smoke, and urban haze can cause low irradiance conditions and soiling. This review looks at how haze affects PV performance, highlighting important findings and pointing out apparent gaps in the literature. Apart from the serious health risks posed by dust storm particles, bushfire smoke, and industrial exhaust fumes, the primary effect of these haze sources is a reduction in sunlight, which can reach up to 80% in certain situations. PV operators experience significant annual revenue losses due to pollution-related haze in numerous cities across the globe. Additionally, tracking systems and concentrated PV systems are most impacted by haze's severe effects on direct irradiance. All of these haze-related technical effects point to the necessity of carefully tailoring PV systems for particular sites. Furthermore, it is obvious that eco-friendly international initiatives like COP26 and air pollution control laws like China's national air pollution policies should be used in order to boost the world's PV output. To identify associated challenges and suggest workable strategies, more research is required. This research should include indoor experiments, forecasting future implications of aerosols on PV energy conversion, and performing energy policy analysis [26].
Due to the uncontrolled and unethical burning of a neighboring country, a dense haze and toxic smoke have recently covered the surrounding area in Malaysia. The devastating open-burning incident began in Indonesia in 1997 and had a significant impact on most ASEAN nations, particularly Singapore and Malaysia, their neighbors. Because of this, the alternative energy source known as photovoltaic (PV) technology experiences a notable reduction in energy production. This is because sunlight is blocked in this situation. The six hours of claimed good sunshine have reduced to no more than two hours, and things get worse when the Air Pollution Index (API) reaches 200, which is an extremely unhealthy level. This study incorporates some findings from field data collected from 1 kWp PV generators installed in Malaysia, which show the daily energy decrease that the generators operated during this unfavorable weather condition. It is discovered that a significant reduction in energy is observed at a power output of 0.43 W for every 1 API point increment. In order to support the adoption of PV technology in the ASWAN region, this value provides such tangible evidence of additional factors that should be taken into account in PV modeling [27].
Through dropwise condensation or rain falling on their cover, droplets can affect the performance of solar photovoltaic (PV) cells. This study explores this effect experimentally. Dew formation is common in a variety of climates, including semi-arid areas that are ideal for the installation of PV cells. Because of optical effects, droplets on the surface of solar cells can have a negative impact on the efficiency and generation of power within the cell. In order to cover semi-transparent glass covers, acrylic droplets with a contact angle of 25° to 77° and a surface area coverage of 19% to 49% were prepared, either with or without surface treatments. Commercial polycrystalline silicon solar cells with dry and droplet-covered glass covers had their current vs. voltage curves measured at incidence angles ranging from 0° to 85° while solar irradiation was simulated. The droplets had no

effect on PV cell performance for incident angles θi ≤ 30°. Nevertheless, the presence of droplets resulted in a significant decrease in the PV cells' maximum power and energy conversion efficiency for incident angles θi > 30°, especially when it came to large droplet contact angles and/or surface area coverage. The reason for this decline in performance was that the light from the incident source was refracted through the droplets rather than being completely absorbed by the solar cell at the cover/air interface. The study also demonstrates that, depending on the actual weather, the hourly energy production of PV cells can drop significantly with the formation of dew. These findings emphasize how crucial it is to choose a long-lasting hydrophilic solar cell cover [28].

Methodology

Methodology indicates to the scientific approach that the researcher uses to conduct the research. Qualitative approach will be used in this paper due to the lack of data collection through questionnaire.

The focus of qualitative research is on emotions, concepts, or experiences. Finding patterns that can lead to testable hypotheses is the primary objective of data collection, which is often conducted using narrative techniques. In the initial stages of a study, educators employ qualitative research methods to identify trends or novel viewpoints. Qualitative research is a methodology designed to collect non-numerical data and generate insights. It is either semi-structured or unstructured and is not statistical. It is based on information obtained through a research methodology that answers the question of why [23].

Findings

Through reading, revision and analysis of previous studies, the researcher extracted some findings related to the impact of moisture, humidity and water vapor on the Topcon photovoltaic cell due to its exposure to weather and environmental conditions and unstable weather, especially in high humidity conditions. The bulk of previous studies indicate that the haze, rains, moisture and high humidity, in addition to bad weather conditions, have bad effects on the performance of photovoltaic cells and the quantity of electric power generated [24, 25, 26].

Many attempts have been tried to protect photovoltaic cells from adverse effects of environmental conditions and bad weather and enhancing their electric power generating performance. On a p-type wafer, an oxide tunnel junction structure with a passivation characteristic of 700 mV or more (Voc) could be achieved to control the surface morphology, annealing profile, and acceleration rate, which can lead to better performance and protective effect. When samples were exposed to RTP annealing at temperatures higher than 900°C, the quality of their passivation quickly decreased. The physical characteristics and thermal stability of the thin layer must be taken into account in order to enhance the quality of passivation of the tunnel oxide layer [2].

At the front of the solar cell facing the sun, higher humidity cities like Los Angeles and Hamburg—where average humidity ranges from 40 to 78%—produce a thin layer of water vapor. The amount of solar energy that really reaches the solar cell is lost through reflection and absorption. Apart from the 30%, an estimated 15-30% of the energy has been lost. Humidity was found to have an impact on the amount of solar energy used, which decreased from about 70% to between 55 and 60% [3].

The use of silver/aluminum (Ag/Al) paste for front-side metallization is one significant factor that is identified as contributing to the relatively low reliability of Topcon modules, particularly at high temperatures and humidity. However, recent developments have produced a strong substitute for conventional one-step cofiring: laser-assisted firing techniques such as laser-enhanced contact optimization (LECO), which combine a laser treatment after conventional cofiring at relatively low temperatures. The main goal of laser-assisted firing is to enable higher power conversion efficiencies (PCE) [4].

Studies highlight how susceptible Topcon cell front-side contacts are to damp-heat circumstances, which can result in serious contact problems following extended testing [5, 6].

Moisture intrusion is at the center of most degradation mechanisms that lead to PV module power degradation. Moisture in EVA encapsulant can lead to potential induced degradation, adhesion and optical losses, encapsulant delamination and discoloration, and metal grid corrosion. Dark lock-in thermography, photoluminescence, ultraviolet fluorescence, and electroluminescence spectroscopy are a few techniques used to detect moisture intrusion in modules. PV designs with or without breathable back sheets, desiccant-stacked polyisobutylene sealants, embedded moisture sensors, and encapsulants with improved moisture barrier and adhesion properties are some of the techniques used to stop or identify moisture ingression in PV modules [12]. One of the primary factors linking weather patterns to module deterioration is moisture intrusion. This is facilitated by high humidity and temperature levels. Temperature and moisture intrusion have a significant impact on several life-limiting processes, such as corrosion and most material deterioration in solar cells and modules. In addition to environmental and climatic factors, the properties of the polymeric materials and the module technology also have an impact on moisture ingress [12].

Tunnel oxide passivated contact (Topcon) solar cells are gaining more attention among these various varieties of high efficiency solar cells due to their many advantages, which include simple raw material access, a simple process flow, the potential for high efficiency, etc.[15]

Dutch scientists have reported a higher degradation risk for n-type Topcon cells with EVA encapsulant due to potential moisture degradation. Tests using damp heat demonstrate that front-side metallization makes n-type cells more vulnerable than p-type cells. Several damp heat tests have been conducted by researchers at the Netherlands Organization for Applied Scientific Research (TNO) to assess the impact of different encapsulation materials on performance losses in bifacial PV modules [19].

Compared to other combinations of cell types and encapsulants, it can be concluded that the particular combination of n-type Topcon solar cells with EVA is likely a higher risk one. In fact, it is best to avoid using EVA in conjunction with metallization that is highly susceptible to corrosion. Alternatively, building more corrosion-resistant n-type PV panels should be aided by the application of the more corrosion-resistant metallization types found to Topcon solar cells [19].

Among these high-efficiency solar cells, tunnel oxide passivated contact (Topcon) solar cells are gaining popularity due to their many advantages, which include simple process sequencing, readily available raw materials, and the potential for high efficiency [20].

Haze and other environmental disturbances reduce the yield of PV systems. The transboundary haze episode that hit Kuala Lumpur in September and October 2015 resulted in a 17.8% drop in the power produced by photovoltaic systems [24].

The generation of photovoltaic (PV) power is significantly affected by haze. There aren't many quantitative studies on how haze affects PV power generation, but when fine particulate matter concentrations rise, it becomes the primary factor affecting solar irradiance and significantly lowers PV power generation. In order to examine the weight factors of the effects of haze on irradiance, this study suggests using the enhanced method of the degree of grey slope incidence. The effect of haze on the amount of irradiance is explained by the exponential-linear model [25].

Recommendations

Based on the review and analysis of previous studies on the subject and the results reached, the study proposes a number of recommendations, including the following:

- Protect solar energy units by placing appropriate insulation materials in order to protect them from bad weather factors, especially heavy rain and high humidity.
- Place the solar energy cells at an appropriate inclination angle in order to avoid the bad effects of humidity and rain and to make the most possible use of the sun’s rays.
- Conducting more future experimental studies in order to determine the effect of high humidity and water vapor on the performance of solar electricity generation units.
- More involvement of the private sector and non-governmental organizations in the process of producing electrical energy through renewable sources to preserve the environment.
- The use of TF4N mass production adhesive film with improved paste can reduce DH degradation to about 2%.
- Sintering annealing technology with TF4N and low aluminum or no aluminum pastes can solve the degradation issue, bringing the performance of mono-facial modules close to bifacial products.

Limitations

The research has some limitations that could limit its effectiveness and the potential for its findings to be widely used. These limitations include the research relying on previous studies and not relying on basic data collected and analyzed by the researcher, or relying on laboratory experiments to measure the effect of water vapor and high humidity on solar electricity generation units, especially the modern type called the tunnel oxide passivated contact (Topcon) structure. Limitations also include the lack of previous studies that were relied upon.

Implications

The research includes a number of theoretical and practical implications for this study. The theoretical implications include explaining the importance of conducting experimental studies that address the problem of the negative impact of humidity, water vapor, and unstable weather on the performance of electrical power generation units from sunlight. This also includes focusing on appropriate means to protect these units and maintain the highest possible performance by reducing the risks exposed to them. The practical implications include the need for companies working in the field of solar energy to benefit from this research in order to improve their experience and reduce the problems they face.

Conclusion

The study aimed to assess the impact of water vapor, humidity, rains, moisture and haze on the performance of Topcon photovoltaic cell. The study found that high humidity and bad weathering conditions have adverse effects on the performance of photovoltaic cells and panels. As an example, the generation of photovoltaic (PV) power is significantly affected by haze. There aren't many quantitative studies on how haze affects PV power generation, but when fine particulate matter concentrations rise, it becomes the primary factor affecting solar irradiance and significantly lowers PV power generation. Moisture and humidity can leads also to degradation of photovoltaic cells and panels due to corrosion process. The majority of degradation mechanisms that result in PV module power degradation are centered on moisture ingress. Moisture in EVA encapsulant can cause adhesion and optical losses, delamination and discoloration of encapsulants, corrosion of metal grids, and potential induced degradation. Among the methods used to find moisture intrusion in modules are dark lock in thermography, photoluminescence, ultraviolet fluorescence, and electroluminescence spectroscopy. There are several methods to prevent or detect moisture ingression in PV modules, including encapsulants with superior moisture barrier and adhesion properties, desiccant-stacked polyisobutylene sealants, embedded moisture sensors, and PV designs with or without breathable back sheets. The study also offered a number of recommendations including protecting solar energy units by placing appropriate insulation materials in order to protect them from bad weather factors, especially heavy rain and high humidity, in addition to placing the solar energy cells at an appropriate inclination angle in order to avoid the bad effects of humidity and rain and to make the most possible use of the sun's rays.

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