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RESEARCH & DEVELOPMENT CENTRE
PART OF MOHAMMED BIN RASHID AL MAKTOUM SOLAR PARK

Dubai Electricity & Water Authority

DEWA RESEARCH TRANSACTIONS

RESEARCH & DEVELOPMENT CENTRE

2023

Dr. Ali AlAleeli
VP - Research and Development

At DEWA's Research and Development Centre, our goal is to become a globally recognized platform for developing and demonstrating emerging solutions for future energy and water systems. We generate value for DEWA through innovative applied research to ensure that DEWA remains at the forefront of providing quality and reliable power and water services. We contribute to Dubai, UAE, and the Global community by disseminating knowledge and developing local research talent. We continuously innovate across five key research areas: solar, water, smart grid integration, energy efficiency, and fourth industrial revolution technologies (AI, IoT, robotics & drones, 3D printing, and advanced materials).

We operate under the following values:

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- We always LEARN AND GROW: We seize every opportunity to learn and grow. We push our boundaries and go beyond our comfort zone.

Dr. Sgouris Sgouridis
Director - Research Programs

The 2023 DEWA R&D Centre Transactions collection has reached a record 71 entries of Scopus-Indexed peer reviewed publications. Spanning all areas in our research portfolio, our researchers' efforts embody DEWA's vision to be a leading sustainable and innovative corporation. The rich tapestry of research collected in this volume is joined together by the common thread of being directly relevant to DEWA Business Units and to DEWA's stakeholders.

Although it is difficult to select among them, I would highlight the following publications in terms of leadership in their field and collaboration with highly recognized parties but also with DEWA's business units.

- As part of the Desert Standard Development, the "Mission profile concept for PV modules: use case - Middle east deserts vs temperate European climate" makes an important segmentation in close collaboration with Fraunhofer CSP.
- Another standard-oriented publication for creating appropriate KPIs to measure building energy flexibility, "Data-driven key performance indicators and datasets for building energy flexibility" in collaboration with International Energy Agency's Annex 82.
- Two journal papers continuing to support the in-house development of flow batteries focusing on flow field optimization and novel methods for estimating the battery's electrochemical impedance.
- A comprehensive lifecycle assessment of the PV reverse osmosis facility at R&D and the study of membrane fouling patterns from the same plant using optical coherent tomography in collaboration with Khalifa University.
- Record contributions with 24 papers in the DEWA organized IEEE MENA Solar Conference, including several Best Paper Awards.
- Several papers by the Smart Grid Integration team that involved recognizing as co-authors colleagues from DEWA Business Units for their contributions.

In summary, all publications in our 2024 Transactions volume highlight DEWA's commitment to innovation and applied research. As UAE and Dubai update and accelerate their Clean Energy roadmaps, the DEWA R&D team is well-placed to support these goals with technical expertise and customized solutions. We are confident that with the completion of the multi-disciplinary laboratory facilities, the attraction and retention of top talent, and leveraging the closer collaboration with DEWA Business Units, DEWA's R&D capabilities will become world-class and directly contribute to further enhancing DEWA's performance through adoption of innovative solutions.

I invite all DEWA employees to read through the abstracts and the papers that are of interest to them and reach out to R&D with their ideas on how to deepen our collaboration and involvement with the business of DEWA.

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PUBLICATIONS AND JOURNALS

SOLAR

PV Module
Most of the commercially available silicon based PV modules have a warranty of 25+ years.
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Laminator

40th European Photovoltaic Solar Energy Conference and Exhibition

Relevance of Pre-exponential constant and Activation energy in the degradation of encapsulant (EVA/TPO) in c-Si photovoltaic modules

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Abstract: Encapsulant discoloration is a significant cause of degradation in the Power conversion efficiency of solar modules. Evaluating the encapsulant's degradation under accelerated aging conditions and predicting the lifetime is critical. The current work reports the calculation of Activation energy to understand the discoloration of Ethylene Vinyl Acetate (EVA) and Thermoplastic Polyolefin (TPO) in C-Si Photovoltaic (PV) solar modules encapsulants using an indoor accelerated aging ultraviolet (UV) stress test of 244 days. Multiple modules are aged simultaneously at different temperatures in a single weathering chamber. The percentage change in short circuit current (Isc) per hour, Yellowness Index (del. YI), and Diffusion Coefficient(D) were used as the primary responses in the Arrhenius equation for the calculation of the activation energy. UV-365 illumination and Fluorescence imaging are used to identify the fluorophore generation in the encapsulant of PV modules. The values we got here for both EVA and TPO revealed the importance of pre-exponential constant along with activation energy and the methodologies reported here are unique and straightforward methods to evaluate the reliability and study the encapsulant degradation mechanisms using relatively less time and resources. Understanding the degradation characteristics can lead to the development of appropriate formulations/additives in EVA/TPO for better performance in different climatic conditions.

Keywords: Photovoltaic solar cell; Activation energy; Inverted grayscale; Fluorescence imaging;

Introduction:

Solar energy is a prominent source of renewable energy because of the availability of insolation throughout the year in some geographical locations. Rapid technological advances and industries make this area the most promising renewable energy technology. Despite technological advances, there are many hurdles affecting the reliability of PV modules. A major challenge is the degradation and delamination of module encapsulation which depletes the lifetime of solar modules [1]. Encapsulation is a crucial element of the PV module. Generally, a module consists of a top layer, typically glass, followed by solar cells sandwiched between two encapsulant layers, the back sheet, and the junction box. The life of a PV module is maintained by choosing the right components, and the encapsulant is a major part that needs to be carefully chosen due to its susceptibility to degradation [2]. Ethyl vinyl acetate (EVA) is a material that is used predominantly as an encapsulant. EVA undergoes thermal degradation and UV aging in the presence of weathering elements, affecting the PV module's overall efficiency [3]. Compared with other layers, this encapsulant has a high chance of degradation as soon as it is exposed to humidity, weather conditions, and UV radiation. Various additives such as UV absorbers, UV light stabilizers, and antioxidants are added to the polymer composition of EVA to protect the solar cell and increase its service life [4]. PV modules have an expected life of 25-30 years, meaning they must perform at 80% of their efficiency till the end of life [5]. In a study conducted by Gagliardi et al., modules set up in different regions of the world for 20 years were collected and studied. It was noticed that modules from hotter, warmer, and more irradiated zones suffered more EVA degradation than modules from other parts of the world [6]. While both high temperature and UV exposure play a role in the degradation of EVA, the extent of their contribution might not be the same. Kshitij Dolia [7] experimented with UV-cut and UV-pass EVA to determine the extent of discoloration under the same conditions for both. UV-cut EVA contains additives that absorb UV light below 360 nm, while UV-pass EVA allows the transmission of UV light to the cell. UV-cut EVA showed a high amount of discoloration. Although no discoloration was observed in UV-pass EVA, the complete delamination of the encapsulant was most likely due to the absence of adhesion-promoting additives in EVA.

Indoor accelerated activation energy testing involves putting the modules under various stresses and theoretically simulating the effect of years of usage. The activation energy calculated using this method is used in various empirical models that estimate the time to failure in outdoor conditions considering the weathering elements. David Miller et al. performed accelerated UV stress testing on various EVA-based encapsulants under different steady-state conditions to calculate the activation energy for encapsulant discoloration. The data were fitted by an Arrhenius relation, and the activation energy was estimated to be 30 to 60 kJ/mol (0.31 to 0.62 eV) [8]. TPO is gaining a lot of interest in the PV industry compared to EVA due to the lack of vinyl acetate

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Balancing Aesthetics and Performance of Colored Perovskite-Silicon Tandem Solar Cells through Simulation-Assisted Design

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***Abstract* — This research focuses on developing colored perovskite-silicon tandem solar cells that combine high efficiency with aesthetic appeal by employing a simulation-assisted design. Triple cation-based perovskite (CsFAPbIBr) is integrated with polished silicon heterojunction solar cells, considering variations in MgF_2 antireflective coating (ARC) properties and angle of incidence. The optimized device architecture, validated with experimental results, exhibits a baseline dark blue reflected color with promising J_{sc} and V_{oc} values. The produced spectrum of colors from parametric analysis of ARC shows a range of gamut from brown to blue to green. Maximum power penalty or loss is observed at 5.5% for the 4-terminal configuration under perpendicular light incidence relative to baseline. However, the power penalty increased to 8.6% for the 2-terminal device configuration for high saturation and vivid colors. Higher degrees of incidence angles result in colorful devices but increased performance losses. The study highlights the potential of colored tandem solar cells for applications such as building-integrated photovoltaics and power-generating-colored devices for displays.**

I. Introduction

Integrating solar energy sources into the built environment has become a pivotal goal in pursuing sustainable urban development. Photovoltaic (PV) modules hold great promise in meeting the energy demands of modern cities. However, the conventional appearance of PV modules often poses challenges to their seamless integration into architectural designs and urban landscapes. As a result, there is a growing interest in developing colored PV modules that combine high-performance energy generation with enhanced aesthetics, opening up new possibilities for sustainable architecture and urban planning. Coloring solar cells and PV modules offers a transformative approach to enhancing the visual appeal of renewable energy infrastructure.[1-3] Traditionally, the color of solar cells has been limited to the inherent black or dark blue hues of semiconductor materials used in their fabrication. However, recent advancements in materials science and device engineering have unlocked diverse avenues for introducing vibrant and customizable colors to solar cells and PV modules.[4] Various methods, such as spectral-selective coatings, colored glasses, pigmented films, and luminescent materials, have emerged as viable ways to achieve colored PV modules with some compromised electrical performance – power penalty.[5] The potential applications of colored PV modules are diverse and far-reaching. In the context of the built environment, these visually appealing solar cells can be seamlessly integrated into building facades, roofs, windows, and other architectural elements. By harmonizing with the design and color palette of structures, colored PV modules can catalyze the widespread adoption of solar energy solutions, transforming buildings into self-sufficient and environmentally conscious power-generating units.[5]

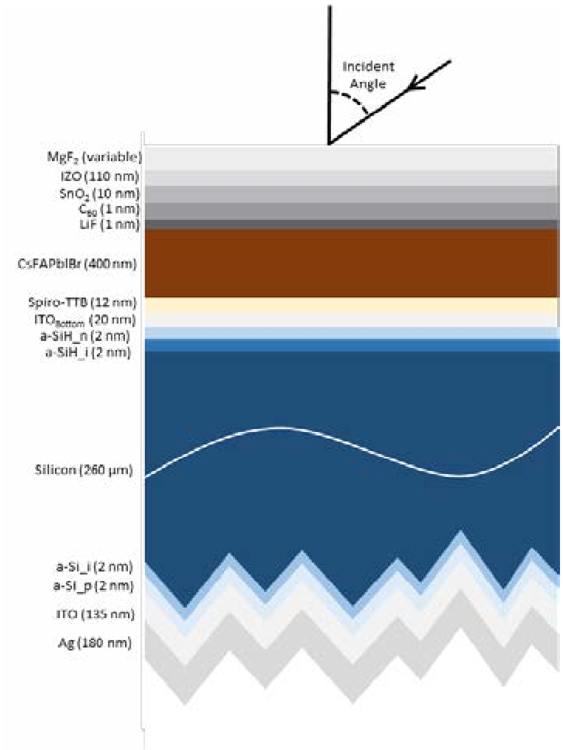

Fig 1. Schematic diagram of the perovskite/Si tandem solar cell with different thicknesses of MgF_2 ARC layers and light incident angle.

The advent of tandem perovskite-silicon solar cells represents a remarkable breakthrough in photovoltaic technology [6]. The combination of perovskite and silicon materials in a tandem configuration allows for the efficient capture of a broader range of the solar spectrum, resulting in significantly higher conversion efficiencies than traditional single-junction solar cells [7-8]. With this recent progress and

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IEEE

Characterization and Analysis of PV module defects and degradation mechanisms through use of Module External Quantum Efficiency.

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***Abstract* — This paper proposes a module-level external quantum efficiency (m-EQE) technique to analyze optical losses in photovoltaic (PV) modules caused by common degradation mechanisms and defects. The effectiveness of m-EQE is compared to conventional methods such as illuminated IV and UV-F imaging. Measurements of m-EQE, IV, and UV-F are taken on three different modules, two exposed to a desert climate for seven years and one kept indoors. The analysis shows that the aged modules experience a decline in performance, particularly at lower wavelengths as correlated by m-EQE, which corresponds to the UV-F degradation patterns observed. The m-EQE technique has proven to provide an edge in defects analysis and is an easy-to-use, verifiable, and standardizable method for analyzing module-level optical losses.**

I. Introduction

There is no doubt that the increasing global demand for energy in recent years has led to a surge in renewable energy growth, particularly in solar energy. Hence, solar energy, in the form of photovoltaics (PV), has become a critical source of energy production worldwide. However, the areas where the solar resource is found in abundance also coincide with harsh desert conditions that accelerate the degradation of PV modules [1]. For instance, the Mohammed Bin Rashid (MBR) Solar Park currently generates 2.027 GW using solar PV plants due to the large amounts of solar irradiance, however, the area is also home to harsh winds, high temperatures, and more than double the amount of UV radiation [2]. Therefore, it becomes clear that understanding and quantifying the degradation mechanisms and defects of solar panels is vital to its mitigation or avoidance in all forms, and in extension, improving the contribution and dependence on solar PV energy in the worldwide energy production scene. One such method pertains to the optical losses aspect of PV defects and degradation, which constitutes the use of External Quantum Efficiency (EQE) as a measure to identify and characterize intrinsic and extrinsic optical losses throughout the layers of a PV cell. While EQE is commonly used on PV cells for theoretical purposes, it is rarely used on the module-level to test the final product: the PV module. This paper aims to present a module-EQE (m-EQE) methodology that can achieve that. The study also aims to use this method to test desert-fielded PV modules that are already installed, as a more practical application of m-EQE that can possibly be utilized in testing, analyzing defects, and PV module standards.

II. Literature Review

Despite the fact that EQE is a reliable means of determining both intrinsic and extrinsic optical losses caused by defects and degradation mechanisms in photovoltaic (PV) modules, there has been a lack of extensive research on this aspect in the literature. This may be due to the limited availability of module-level EQE procedures and analysis techniques, as most studies have focused on cell-level EQE analysis, which only tests the intrinsic losses caused by material and construction choices. In contrast, module-level EQE analysis is performed on fully developed PV modules and aims to determine the extrinsic optical losses that are experienced in outdoor conditions. Although both approaches are important for PV module performance, the latter has often been overlooked.

However, recent literature has shown a growing interest in module-level EQE analysis, suggesting that this method is gaining attention in the scientific community. For instance, Luo et al. applied their own technique of module EQE on bifacial PERC modules, and successfully correlated the observed PID degradation to EQE loss at higher wavelengths (800-1200 nm specifically), inferring that the degradation affected the rear side, and recommends reinforcement of such areas in the module [3]. Another instance is where Yurrita et al. attempted to verify the effectiveness of using ultraviolet additives to protect solar modules from UV radiation through the use of module EQE and IV, proving that an improvement was successfully observed [4]. Other authors discuss the aspect of optical losses and how the chosen encapsulation plays a large role, through use of spectral response tehcniques [5].

Moreover, various techniques were developed in recent years in an attempt to properly quantify module EQE, with varying degrees of success [6]-[7]. Perulli et al. used a unique technique of Photoluminescence (PL) and Photocurrent (PC) mapping to calculate EQE from such readings, using fluorescence maps to detect different layers of solar cells [8] However, it is vital to note that no one specific accepted method is used universally, and none of the methods are streamlined and standardized. This paper aims to change the current dynamic by proposing an easy-to-use, verifiable, and standardizable method to the field.

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Consolidation of Temperature Coefficients of Perovskite-based Absorbers

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***Abstract* — This paper focuses on the temperature dependent band gap of perovskite semiconductors and its impact on the optoelectronic properties of perovskite-based photovoltaic devices under real operating conditions. Despite the significant progress in perovskite solar cells (PSCs), understanding their behavior in practical settings is crucial due to the unusual temperature-dependent effect of bandgap. Unlike traditional semiconductors, the band gap (E_g) of perovskites increases with temperature. Although the bandgap temperature dependence for traditional solar cells is well-documented, there is a lack of literature review and single-source data for existing perovskite absorbers. Accordingly, this study consolidates scattered data from literature to provide a comprehensive dataset of temperature coefficient-dependent band gaps of perovskites. The collected data is categorized based on cations and halides, material morphology, and temperature ranges. By presenting this consolidated data, the research aims to facilitate the development and optimization of single junction and multijunction perovskite devices, ultimately contributing to the advancement of efficient and stable perovskite-based photovoltaic technologies for various applications.**

I. Introduction

Organic-inorganic hybrid perovskites have shown tremendous optoelectronic properties, which makes them ideal for a wide range of applications, including thin-film solar cells, light-emitting diodes, and perovskite lasers.[1-5] Because of these excellent properties, a lot of research efforts have been made to achieve 26% photoconversion efficiency (PCE) of the perovskite solar cells (PSCs) in just over a decade, which is highly comparable with the Si solar cells.[6] However, PSCs suffer from instability issues as the organic cations in the perovskite composition are highly volatile and vulnerable to moisture and temperature. Therefore, compositional engineering strategies such as replacing the organic cations with Cs, iodide with bromide, and Pb with other metal cations have been implemented, improving the compositional stability, and increasing the perovskite bandgap.[7] The increase in bandgap makes them suitable for the perovskite/Si tandem solar cells, which recently delivered a PCE of 33.7%.[6]

Despite this tremendous progress, understanding the operation of PSCs in real operating conditions is crucial because temperature dependence band gap $[\![(E]\!]\_g = f(T))$ plays a key role in determining the optoelectronic performance of solar cells in real operating conditions. Unlike conventional semiconducting absorbers, one interesting aspect of perovskite is that the E_g of perovskites increases with increasing temperature, resulting in better thermal resistant performance via increased open circuit voltages.[8] Similarly, the short-circuit temperature coefficient of the perovskite/Si tandem solar cells can be either positive or negative or a mixture of both depending on the current mismatch, location solar spectrum, and operating temperature range.[9] In general, most semiconductor bandgaps narrow proportionately while operating within the solar cells' operating temperature spectrum. Yet, the relationship between bandgap and its temperature dependence is not universally consistent. In certain cases, bandgaps even increase with temperature. Notably, the band-edge states of perovskite semiconductor compounds are reversed, with the conduction region consisting of p-like states and the valence region comprising of s-like states. Remarkably, this irregular inverse order leads to an increase in bandgap with rising temperature for these materials, contrary to the trend observed in most tetrahedral traditional materials.

With the progress in perovskite-based solar cells, a few literatures have been reported estimating the temperature coefficient of these absorbers, especially to determine the energy yield of devices. Currently, the data for the temperature dependence of bandgap (E_g) is scattered in the literature. Therefore, in this work, we have consolidated all perovskite material data collected from published reports and grouped by cations-based and halide-based, with different material morphology and temperature ranges.

II. Methodology

In this study, the methodology involved a comprehensive literature search using prominent repositories like SCOPUS, Web of Science, and IEEE, with specific keywords such as "Temperature coefficient + perovskite," "band gap temperature dependence + perovskite," and "temperature + bandgap + perovskite" to gather relevant data on the temperature dependence of band gap energy in perovskite materials. This search yielded 15 pertinent documents containing the required data. Subsequently, the extracted information was consolidated and categorized based on the nature of perovskite materials. The temperature-dependent band gap energy values (Eg) were extracted from these documents and organized according to different perovskite types. Additionally, graphs from literature

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Discoloration Effect on Performance of PV Modules Installed in Middle East Hot Desert

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***Abstract* — The discoloration of encapsulant material is one of the major degradation modes in PV modules. This paper aims to analyze and identify the discoloration patterns forming on PV modules due to encapsulant material degradation at three different tilt angles. It was observed that the tilt angle directly influences the discoloration patterns formation in the PV modules. In the UV fluorescence images, modules installed at 25° tilt angle showed maximum discoloration in comparison to other tilt angles. The discoloration of encapsulant material directly influences shortcircuit current in the PV modules. The average annual degradation rate of short circuit current (Isc) for the frame pattern is 0.155%/year and the filled pattern is 0.273%/year. The rate was maximum at 25° tilt angle for both frame and filled patterns. Additionally, the Raman spectra also exhibited a direct relationship between discoloration and fluorescence background as 25° tilt angle showed maximum intensity. Overall, this study helps in finding the discoloration modes of the PV module's bill of materials at different tilt angles and can thereby be used to modify the encapsulant materials for desert PV module applications.**

Keywords: Encapsulant, Discoloration pattern, Degradation, Fluorescence, PV modules.

I. INTRODUCTION

The Middle East desert regions are significantly increasing the number of PV modules being installed in desert climates due to the immense exposure to solar irradiation. Deserts receive ample sunlight for a major part of the day unobstructed and this has piqued the attention of the PV comunity [1]. The crystalline silicon (c-Si) PV technology is dominating the existing PV industry. In c-Si module technology, the module is composed of various layers such as solar glass, encapsulant material, solar cells, interconnects, backsheet and junction box. These PV components are simply called bill of materials (BOM) [2]. Any module installed in outdoor conditions encounters performance degradation over time. In desert regions, PV modules exhibit different degradation modes due to differences in BOM [3]. Desert climate is characterized as harsh and displays extreme day and night temperatures, high UV irradiation, dry conditions, and high soiling. The harsh conditions of the desert climate are a concern for the reliability and bankability of PV modules.

Among all the materials, an encapsulant is a crucial component for the efficient functioning of the PV modules for long-term operation in the field. The degradation modes shown by encapsulant are discoloration, delamination, and bubble formation. This leads to a reduction in the performance of the PV module before meeting the 25-year warranty given by the manufacturer. In all these modes, discoloration is the major concern in desert climates [4]. Discoloration substantially reduces the number of photons reaching solar cells and can reduce the performance of PV modules. Multiple visual observations over the years in desert areas have led to the conclusion that encapsulant discoloration and metalization oxidations are severe issues for PV modules [3]. UV irradiance is the major source for the discoloration of encapsulant material [5]. Based on field results, it is recommended that the test protocol should include specific test sequences to address the encapsulation discoloration and delamination changes caused by desert UV irradiance and thermal stresses [3].

This paper aims to analyze and identify the discoloration patterns forming on PV modules due to encapsulant material discoloration. This study helps in finding the encapsulant degradation modes at different tilt angles and can thereby be used to modify the encapsulant materials for desert PV module applications.

II. DETAILS OF EXPERIMENTATION

The c-Si PV modules were installed at Dubai Electricity and Water Authority (DEWA) R&D Center within the MBR Solar Park, Dubai, UAE. Rows of PV modules were installed at three tilt angles of 5°, 25°, and 90° and named R1, R2/R3, and R4 respectively. Two types of defects such as encapsulant discoloration and backsheet chalking/cracking have been identified in PV modules after 7 years of outdoor field exposure in desert conditions. The encapsulant discoloration patterns were observed and recorded. The formed discoloration patterns were observed by UV-FL imaging, where the modules are illuminated under the UV light to produce fluorescence images. The imaging was carried out in outdoor desert conditions during the nighttime. Raman Spectroscopy was conducted to find the encapsulant discoloration-induced fluorescence

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Dust and Sand Analysis in Solar Parks

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***Abstract* — Due to their exceptional solar irradiance levels and minimal cloud cover, desert regions have emerged as prime locations for the deployment of photovoltaic (PV) systems, such as the installation at the Mohammed bin Rashid Al Maktoum Solar Park (MBR Solar Park). High temperatures can lead to hot air rapidly rising and forming a spinning column of air known as "dust devils" carrying fine sand particles and debris several meters into the air. In this work, we designed a sand trap device to collect sand from different heights, especially during dust devils. Additionally, sand was also collected from different locations around Dubai from both modules and ground to analyse the particle size distribution. This study assisted the assessment of distinct abrasive effects associated with coarse and fine sand particles during sandstorms, thereby improving our understanding of their impact on PV modules installed in arid regions.**

***Keywords* — PV Solar Parks, Sand and Dust, Scanning Electron Microscopy, Particle Size Distribution.**

I. Introduction

Desert regions are increasingly emerging as potential locations for large-scale photovoltaic (PV) power plants due to their high solar irradiance and low cloud coverage. However, one of the challenges of operating PV systems in desert areas is the accumulation of dust or sand particles and other contaminants on the PV panels, which can significantly reduce the system's energy output and efficiency. The soiling effect caused by dust deposition on the PV panels depends on numerous factors, including the type and amount of dust, the climatic conditions, and the design and orientation of the PV modules [1].

Monitoring and analyzing the characteristics of the sediments that accumulate on the panels is critical to maintaining the efficiency and performance of PV systems in desert areas. Dust analysis can provide valuable information on the composition, size distribution, and optical properties of the deposited particles, assisting in developing effective cleaning strategies and optimizing the design and operation of PV systems. Additionally, dust analysis can provide insights into the sources and transport mechanisms of the dust, which can help identify potential mitigation measures to reduce dust deposition on PV panels [2].

Several recent studies have focused on analyzing dust for PV systems in desert areas. These studies have employed various dust sampling and characterization techniques, including gravimetric analysis, scanning electron microscopy, X-ray diffraction, and spectroscopic analysis. The results of these studies have shown that the characteristics of the dust vary significantly depending on the location, season, and meteorological conditions and that the dust can significantly impact the energy output and efficiency of PV systems [3].

This paper presents a methodology for examining airborne sand particles that have the potential to accumulate on photovoltaic (PV) modules during sandstorms or periods of high wind as well as the sand already deposited on the modules. This can help analyse these particles' effect when deposited on the PV Module.

II. Background

Wind speed is critical in the atmosphere's transportation and deposition of sand particles. The wind is the primary cause of the movement of sand particles in the air, and it determines their speed and direction. Therefore, measuring wind speed is crucial for analyzing sand and understanding its behaviour. Wind speed measurement is particularly important in PV systems in desert areas to understand particle deposition dynamics on PV panels.

Dust accumulation on PV panels can cause a significant reduction in energy output and efficiency, and wind speed can affect the rate and pattern of dust deposition on the panels. In general, higher wind speeds can enhance the removal of dust particles from the panels, while lower wind speeds can increase the deposition of dust particles on the panels [4].

Measuring wind speed can also help identify dust sources and pathways of dust transport in the atmosphere. Wind can transport dust particles over long distances, which originate from various sources, including natural and anthropogenic sources. By determining the direction and speed of the wind, we can obtain insights into the potential sources of dust and the pathways of dust transport onto the PV module. A *dust devil* is a cone-shaped whirlwind with its apex near the ground surface and its base some distance above it. They are small, rapidly rotating air columns made visible by the dust, dirt, and debris they pick up from the ground. They are usually about 10-50 feet (3-15 meters) wide and up to several hundred feet (over one hundred meters) tall. The origin of the dust is typically local and does not affect the trajectory of the dust devil. Studies have shown that many factors often complicate and affect the trajectory.

In flat desert areas, dust devils have been commonly reported to be stationary, settling over a small topographic for an

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Enhanced Defect Detection in Desert-Exposed PV Modules through Three Imaging Techniques

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Abstract — **The Middle East has witnessed a surge in solar installations; however, the region's severe desert climate leads to premature defects and power degradation in photovoltaic (PV) modules, thereby causing issues related to reliability. This paper presents the results from the application of three pivotal imaging techniques, namely electroluminescence, dark lock-in thermography, and UV-F imaging. These methodologies were employed for the spatial evaluation of defects in PV modules exposed to desert environmental conditions over a span of 7 years at the DEWA Research and Development (R&D) center, Dubai. The findings substantiate the efficacy of these techniques in tandem to identify and analyse defects. The techniques were found to be useful for detection of an array of defects including; encapsulant discoloration, different types of cell breakages, and disruptions in the finger connections, and other related cell defects. This approach offers a quick and effective defect detection in field-deployed PV modules.**

I. Introduction

The Middle East is likely to continue to play a large role in the worldwide expansion of solar energy capacity, and several countries in the region, notably the United Arab Emirates, Saudi Arabia, and Jordan, have made significant investments in solar PV in recent years. The potential of solar photovoltaic (PV) technology in the Middle East is expected to increase significantly as technological advancements progress and costs decline.

Nevertheless, the harsh desert climate conditions in the desert have prompted growing apprehension regarding the efficacy of solar photovoltaic (PV) modules. Various factors can contribute to the occurrence of flaws and degradations within solar modules, hence resulting in long-term reliability and durability concerns [1]. These factors include high solar irradiation, UV dosage, ambient temperature, significant fluctuations between day and night temperatures, and the accumulation of sand-dust [2-11]. Encapsulation deterioration is frequently documented in the literature [12]. The primary stressor identified in this regard is the high solar irradiance and UV dosage.

There are several useful techniques for identifying defects that are created during harsh outdoor conditions. Preliminarily, IV (current-voltage) analysis is used to detect the overall power degradation in modules during outdoor exposures. It provides insights into which electrical parameter has degraded, offering indicative clues about the type of defect or the primary mode of degradation. Nonetheless, imaging techniques are invaluable for pinpointing the spatial location of defects that contribute to the decline in electrical performance.

In purview of this, there are different imaging techniques, like electroluminescence imaging (EL) in which electric current is applied to a solar module, leading to the generation of light due to the radiative recombination of carriers. By carefully analyzing the intensity and distribution of the emitted light, various issues such as cracks, defects, and degraded areas in the solar panel can be identified [13].

EL imaging technique is extensively used in the real-time production processes of the solar cells to identify process induced defects like grain boundaries. In addition, mechanical damage to the wafer (microcracks), fingers and other electrical contacts can be detected by this technique[14].

Dark Lock-in Thermography (DLIT) technique has not seen widespread adoption in PV module investigations, in comparison to its use in solar cell defect analyses. It has been predominantly used for localization of electrical defects such as shunts [16]. Recently, the use of DLIT technique has been demonstrated for detection and characterization of module packaging and soldering defects [16].

Furthermore, Ultra-Violet Fluorescence (UV-F) imaging is one aspect of a set of measurement methods

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Enhancing Durability of PV Modules in MENA Region: The Hot Desert Test Protocol

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***Abstract* — IEC 61215 type approval testing has assisted in enhancing the overall durability of PV modules, but its design is better suited for moderate climates, as most known failure modes have been observed in such conditions. The MENA region is emerging as a preferred site for GW-scale PV power plants with low solar electricity prices, where a one-size-fits-all approach to approval testing is inadequate. In the MENA region, PV modules are exposed to hot-dry or hot-humid climates, with high temperatures, low to moderate humidity, high UV irradiation, sandstorms, and high soiling rates being the key challenges. Therefore, there is a need to modify and/or add to existing tests and protocols to account for harsh desert conditions.**

I. INTRODUCTION

The Middle East is home to numerous solar power plants that generate electricity using photovoltaic (PV) modules [1]. However, currently, there is no standardized method for testing the durability of these modules in hot desert regions, where high module temperatures, high UV irradiation, sandstorms, and high soiling rates with sand particles pose major challenges. Two approaches have been proposed for designing desert test cycles to address this gap. The first approach involves modifying selected sequences from the IEC 61215 standard to account for the unique effects of desert environments, such as higher UV exposure at elevated temperatures and an upward shift in the temperature range of temperature cycling tests at higher ramp rates. The second approach involves developing additional test sequences that can reproduce the failure modes and defects observed in these regions. Based on field results, it is recommended that the test protocol should include specific test sequences to address the encapsulation browning effects and metallization changes caused by thermal and mechanical stresses. These findings are discussed in more detail in publications [2]-[4]. Two major test sequences are proposed to evaluate the performance of large-scale utility-scale power plants that feature mono-facial or bifacial modules, fixed or single-axis mounting configurations, and regular cleaning using robotic systems; the Desert UV test and the Desert mechanical load test. These tests aim to simulate the extreme environmental conditions in the desert region and reproduce the observed defects. In summary, a standardized method for testing the durability of PV modules in hot desert regions of the Middle East is needed to ensure that they can withstand the environment's unique challenges while maintaining reliable performance. The proposed approaches and test sequences are intended to fill this gap and provide a more accurate evaluation of the modules' durability in the region.

Over a period of seven years, a field exposure and monitoring study was conducted on 30 different types of PV modules at the outdoor test facility (OTF) at the DEWA R&D center, situated within the 5GW MBR solar park in Dubai, UAE. The study identified discoloration of the encapsulant as the primary mode of deterioration, followed by metallization defects.

II. DESERT UV STRESS SEQUENCE

In this scenario, two types of defects, encapsulant discoloration and backsheet discoloration and cracking, have been identified in PV modules after 7 years of outdoor field exposure in desert conditions. To simulate these defects, two test legs have been devised. The first test leg aims to replicate the encapsulation browning and photobleaching process through a desert UV test sequence. This test involves exposing the front and back sides of the module to a special UV test with a total of 60kWh/m^2 at 80 °C, followed by a damp heat test as specified under the IEC 61215 standard, as shown in Fig. 2. Fig. 1 provides a helpful schematic on the formation of encapsulation browning.

Figure 1. Process of encapsulation browning and photobleaching that results in frame or filled discoloration patterns

The M1 step presents the unaged encapsulant with additives. Depending on the amount of UV exposure and module temperatures, discoloration of M1 can occur at varying rates. In the OTF study, all modules displayed

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Optical Properties of 3D-Printed Solar Panel Front Cover Using Clear Resin

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***Abstract* — In this paper, we investigated the optical properties of 3D-printed resin and its potential as an alternative option for solar panel front cover, as well as extending it to other applications. We 3D -printed 6 coupons (Size: 5 cm x 5 cm x 0.3cm) and developed six test procedures that differed between manual/automated sanding, level of sandpaper grits, and method of applying the polishing compound. Transmittance test was conducted across different stages of each experiment. Our results revealed that the highest transmittance achieved was 88% (procedures 2 and 4), due to polishing the coupon after each sanding process. In addition, the clarity of the surface was the highest for both procedures; clear of scratches and smooth in comparison to the other 4 test procedures. These results provide an insight into the potential of using 3D printed materials such as clear resin as an alternative option for solar panel front cover.**

Keywords— photovoltaic module, components, front cover, solar glass, 3D printing, clear resin, desert conditions

I. Introduction

Additive manufacturing, also known as three-dimensional (3D) printing, is the process of constructing three-dimensional objects by layering material in accordance with a digital model [1]. The technology has advanced rapidly over the years and has been employed in numerous applications across various fields, among them is solar energy industry [2].

Due to its low cost, high precision, and design flexibility, 3D printing is a promising technique for the prototyping and production of solar cells. Several studies have investigated the use of 3D printing to construct the different layers of a solar cell, including the photoactive layer, metallic connections, and transparent conductive oxide layer [3-5]. For intricate designs such as interconnects for monolithically series-connected solar cells, inkjet printing technology and rotary screen printing technology have been utilized [6]. Microcell arrays with ultra-thin semi-transparent layers are potential replacements for flexible organic cells with comparable efficiency [7]. Furthermore, 3D-printing has been utilized to address one of major challenges of silicon cells which are silver based electrodes [8–10]. According to above studies, 3D printing can produce uniform, high-quality layers with optimum form, conductivity, and material adhesion.

Additionally, 3D printing technologies is not limited to solar cells only. It has been utilized to further improve photovoltaic (PV) and photo-thermal conversion efficiency of PV modules. Dye-sensitized solar cell modules have been developed with 3D-printed concentrators, enhancing their photovoltaic efficiency from 5.48% to 7.03% [11].

The front cover of the solar panel, which is typically made of glass, is an essential component of the solar panel; it protects the solar cells and plays a role in preserving their efficiency over time. The cover glass should be highly transparent, resilient, and impervious to environmental factors. In addition, the cover glass must not compromise the performance of the solar cells. Traditional manufacturing processes for solar panel coverings are expensive and lack design flexibility [12].

3D printing technology enables the construction of customized and intricate geometries [1], which can improve the efficiency of solar panels. Furthermore, 3D printing offers the benefits of cheaper and quicker prototyping as well as simpler customization. Experimenting with 3D printing for solar panel front covers could therefore contribute to the development of cost-effective and efficient solar panels, thereby promoting the widespread adoption of solar energy as a renewable energy source.

The motivation behind experimenting with 3D printing solar panel front cover using resin is to explore new ways that could reduce the cost and improve the efficiency of solar panels.

This paper demonstrates the experiment that we have developed with the purpose of testing the optical properties i.e. transparency of 3D-printed samples produced using clear resin.

II. Methodology

We selected clear resin from FormLabs for the purpose of the experiment due to its transparency characteristic. We utilized Stereolithography (SLA) 3D printing technology to print 6 sample coupons. We printed 4 samples coupons of size 5cmx5cmx0.3cm, and 2 samples coupons of size 5cmx5cmx0.2cm.

As shown in Fig. 1, the 3D-printed sample coupon using clear resin achieved a see-through but not transparent/glass-like surface. Therefore, prior to starting post-processing, we immersed each coupon in a bag of clear resin dipped in a beaker of hot water at 80 ° C for 10 mins, followed by washing it for 6 minutes using isopropyl alcohol to remove any residual resin that can distort the final shape or attract impurities to the surface of the coupon. Finally, we cured the sample by exposing it to UV light for 4 minutes in order to harden the resin.

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Plasmonic $Au@SnO_2$ Core-Shell Hybrid Electron Transport Layer for Highly Efficient Planar Perovskite Solar Cells

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***Abstract* — Plasmonic nanoparticles play a pivotal role in enhancing both the optical and electrical properties of photovoltaic devices. Herein, we report the incorporation of $Au@SnO_2$ into the SnO_2 electron transport layer (ETL), which can simultaneously improve the efficiency of the n-i-p planar perovskite solar cells (PSCs). The PSCs with 1 v% $Au@SnO_2$ ETL significantly enhanced the power conversion efficiency (PCE) of the PSCs from 16.23% to 18.43% due to the improvement in short-circuit current density (J_{sc}) and fill factor (FF). Moreover, the Au@SnO2-based hybrid ETL significantly reduced the nonradiative recombination losses and improved the carrier transport and extraction at the ETL/perovskite interface.**

I. Introduction

In just over a decade, PSCs have shown tremendous potential in photovoltaics due to their excellent photoelectrical properties, power conversion efficiency (PCE), low cost, and ease of fabrication process for small and large-scale photovoltaic devices. [1] Therefore, continuous research efforts have been made to improve the PCE of PSCs from 3.8% to 25.8%. [2,3] Also, the band gap of the perovskites can be tuned from 1.17 eV to 2.24 eV through compositional engineering. [4] Furthermore, the softness and excellent tolerance to defects make them suitable to be used as a top cell for tandem solar cells on various substrates without any need for lattice matching. [5] Therefore, many research efforts have been made to integrate PSCs on Si to fabricate Si/perovskite tandem solar cells and recently achieved the highest PCE of 33.2%. [6] However, organic-inorganic compounds of the perovskites are highly vulnerable to oxygen, moisture, temperature, and electrical biasing, which significantly impedes the long-term stability of the PSCs. In this context, several strategies, such as improving the crystallinity of the perovskite, electronic properties of perovskite, ETL, and hole transport layer (HTL), and passivating the interfaces, have been employed. [4], [7]

Interestingly, incorporating plasmonic nanostructures into the carrier transport layers has been proven to be very effective in improving the PCE of the PSCs as the metal nanostructures exhibit surface plasmon resonance, which improve the optical absorption and electron management in the perovskite layer. [8] Among several metal nanostructures, gold nanoparticles (Au NPs) exhibit both superior thermal and chemical stability and highly localized surface plasmon resonance in the visible to the near-infrared range, which can improve the charge carrier dynamics in the PSCs. In 2013, Snaith et al. reported the enhancement in the photocurrent of PSCs by incorporating $Au@SiO_2$ core-shell NPs inside the Al_2O_3 matrix. The photocurrent enhancement was attributed to the decrease in the exciton binding energy of the perovskite layer rather than improving the light absorption. Later, several research efforts have been made by embedding Au NPs in various dielectric materials such as SiO_2, TiO_2, and MgO to improve the charge carrier dynamics of the PSCs.[9] However, there is rare research investigating about the plasmonic effect of Au nanoparticles embedding in SnO_2, though SnO_2 is the most common material used as ETL for the n-i-p planar PSCs.

In this study, we applied $Au@SnO_2$ core-shell NPs as ETLs to fabricate n-i-p structured planar PSCs. The core-shell NPs were mixed with the conventional aqueous SnO_2 solution and directly deposited on the ITO substrates. The PSCs with the $Au@SnO_2$ core-shell NPs reduced the non-radiative recombination and improved the carrier transportation at the interface. Thus, the J_{sc} and FF of the PSCs with $Au@nO_2$ core-shell nanostructures were significantly improved, which enhanced the PCE from 16.23% (w/o $Au@SnO_2$ core-shell) to 18.43%.

II. Experiment

The materials used in this study were purchased from commercial sources and used as received. The n-i-p planar PSCs were fabricated with a device structure of ITO/SnO_2 or SnO_2+$Au@SnO_2$/ $FA_{0.95}MA_{0.05}PbI_{2.85}Br_{0.15}$/Spiro-OMeTAD /Au. The $Au@SnO_2$ core-shell NPs were synthesized as previously reported. [10] The 1.4 M perovskite solution was prepared by dissolving PbI_2 (613.13 mg), $PbBr_2$ (25.70), FAI (228.8 mg), MABr (7.84 mg), and MACl (37.81 mg) in DMF and DMSO (4:1) and ultrasonically stirred for at least 12h. First, the ITO substrates with a resistance of 15 Ω/sq were sequentially cleaned with detergent solution, DI water, acetone, and isopropanol (IPA). After the cleaning and drying, the substrates were treated with ozone (O_3) plasma for 20 min. The plasmonic hybrid ETLs were prepared by adding 1 vol% of the as-prepared $Au@SnO_2$ core-shell NPs into the 2.25% aqueous SnO_2 solution and spin-coated on the ITO substrates at 4000

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PV MODULES SAND AND BRUSH ABRASION TESTING

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***Abstract* — For the qualification and benchmarking of PV modules for hot desert operation, a test sequence for sandstorm and cleaning durability testing is introduced. A test sequence based on sand and brush abrasion testing of IEC 62788-7-3 is under evaluation using blowing sand testing, sand trickling testing, and a cleaning robot test-stand. The change in short-circuit current of PV modules, roughness, transmittance and reflectance of glass surfaces and samples are measured. Coaxial microscopy is used to describe the abrasion process of the front glass texture and the anti-reflective coating.**

***Keywords* — PV Modules Abrasion, Sand Abrasion, Brush Abrasion, Module Cleaning, Coaxial Microscopy**

I. Introduction

More and more PV systems are being installed in deserts with hot-dry climates. Higher module temperatures, ultraviolet radiation, sandstorms and soiling with dust are the main challenges. In this work, the abrasion effect of blowing sand is investigated and compared with modules in operation with cleaning and in the Cleaning Test Facility at the DEWA R&D Center which is located at the 5 GW MBR Solar Park in Dubai.

Currently, there is no suitable standardized method for testing the abrasion resistance of PV modules and solar glass under sandstorm conditions. For PV modules used in arid and harsh environments, a qualification test should include a sand abrasion test due to the locally occurring sand and dust laden winds, and a dry-cleaning resistance test as more and more PV surfaces are freed from the light obscuring dust load using automated and waterless cleaning systems (cleaning robots).

Qualification testing of PV modules for arid climate conditions must include a sand abrasion test and a dry-cleaning resistance test.

The anti-reflective coating of the most micro-textured solar glass varies in thickness (approximately 100 nm on average) on the hills and valleys due to the application technique (roller coating process) [1], [2]. This can be seen by looking at the anti-reflective layer under a coaxial RGB microscope and observing the resulting color. In most cases, the layer is thicker on the hills than in the valleys.

The appearance of the ARC layers can vary greatly from manufacturer to manufacturer.

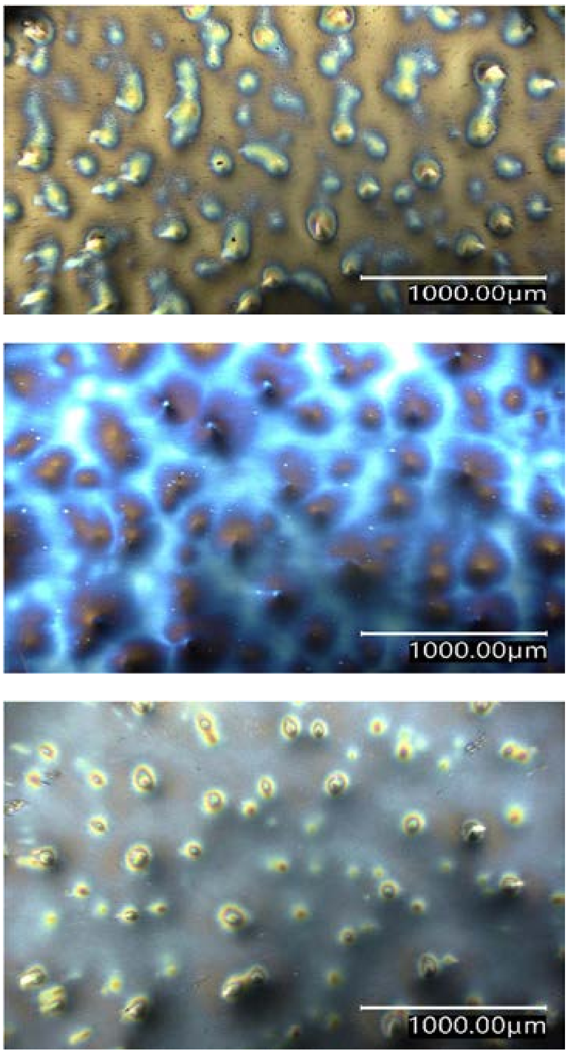

Fig. 1-3: Different ARC coatings on different commercial PV modules viewed with coaxial microscopy imaging.

Sand abrasion is caused by the partial removal of the anti-reflective coating and the formation of cracks, which induces the chipping of the glass materials. The destructive effects of the sand impact on the glass surface and glass coating can be seen in Fig 5 after conducting the blowing sand test.

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PV MODULE CLEANING UNDER HOT DESERT CONDITIONS

Creating Test Standards for PV Module Cleaning

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***Abstract* — The Cleaning Test Facility (CTF) is located at DEWA's research center near the MBR solar park in Dubai. The CTF will provide the opportunity to test different robots on different module types that have been or could be installed in the different sections of the MBR solar park. The CTF offers the opportunity to test different cleaning equipment, PV modules with different anti-reflective and/or anti-soiling coatings, and different test procedures under different operating parameters. The CTF consists of four fixed tables facing south and eight single-axis tracking tables moving from east to west. Each table has four strings of 16 modules. The various tests will evaluate the impact on the panels through optical methods, performance analysis, infrared thermography, and UV fluorescence. Cleaning equipment will also be evaluated for efficiency and reliability. The goal of the research project is to develop test procedures for standardized evaluation of cleaning systems.**

I. Introduction

Solar energy is one of the most promising sources of clean and renewable energy, especially in the Sunbelt regions where there is an abundance of solar radiation, including the United Arab Emirates (UAE) and the emirate of Dubai. The annual global horizontal irradiation (GHI) in the UAE is estimated to be around 1900 - 2300 kWh/m2, making it a highly favorable place for the deployment of solar photovoltaic (PV) plants. However, adverse climatic conditions in Dubai that involve the deposition of dust on PV modules combined with extremely low yearly precipitation can negatively affect the performance of PV modules. The effect known as soiling results in noticeable losses in the annual energy yields of utility-scale projects.

Much research focused on assessing the effect of dust accumulation on PV performance. However, there are no studies that comprehensively evaluate the various cleaning methods considering the harsh conditions of Dubai. In this project a grid connected PV demonstration plant (166 kWp) will be used to test the performance and reliability of different cleaning systems. The systems that will be tested include both commercial and pre-commercial systems: robotic cleaning, semi-automatic brush cleaning methods, etc. The long-term performance, reliability and durability of the different cleaning systems will be investigated in depth. This will include examining the PV module glass and coating abrasion, analyzing the optical transmittance and reflectance behavior, and microstructural damage pattern with the various cleaning methods.

In October 2020, DEWA R&D started a project to investigate the performance and reliability of PV modules and of cleaning devices under hot desert conditions, culminating with the implementation of the Cleaning Test Field (CTF). The main goal of this proposed project is to use the Cleaning Test Field (CTF) and apply intensive experimental testing to develop novel test methods.

Several cleaning methods have been developed and commercialized in the market to mitigate the effect of dust soiling. Those methods are categorized into mechanical, electrical, and chemical self-cleaning. Each method has certain disadvantages and advantages attached to its application on the cleaning PV modules and the different front glass coatings.

Mechanical cleaning methods that include manual applications, semi-automatic and robotics cleaning, are used at a commercial level. The manual cleaning methods can be dry or wet and require workforce and cleaning brushes. Manual cleaning is ineffective for the cleaning of large power plants due to being labor intensive and time-consuming methods. In addition, in the case of wet manual cleaning, the use of water in massive quantities is a big concern, especially in arid regions. The robotic cleaning methods and semi-automatic, specially designed cleaning vehicles or cleaning systems that are connected to commercial vehicles are widely used nowadays for large power plant and there are several types and design exists in the market [1].

Truck-mounted cleaning systems consist of a brush attached to a truck or other vehicle, which drives between the PV module rows. Normally, the brush is located on a crane jib, which places it over the PV module. Each machine has its own system for controlling the pressure of the brushes on the PV modules to avoid any structural damage to the PV modules. With this type of cleaning system, distance and tilt angle deviations between module-mounting structures do not constitute a problem. For the vehicles to reach the PV modules, a minimum distance is required between the rows. This depends on the device and ranges from 2.5 to 3 meters. In addition, a maneuvering area at the end of the rows is necessary so that the

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Retrofitting the translation equations of the one-diode model for photovoltaic modules

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Abstract **— One of the most common approaches to estimate the photovoltaic parameters under varying environmental conditions is to first extract these parameters at a reference condition, usually at standard test conditions (STC). The temperature and irradiance dependance of each of these STC parameters is then calculated using a set of translation equations. Although the translation equations are based on device physics, the biggest disadvantage of this approach is that the constants in the translation equations are not universal for different photovoltaic technologies. To address this limitation, a unified fitting approach has been proposed, which not only extracts the five photovoltaic parameters but also adjusts the constants of the translation equations. The proposed method exhibits a marked improvement in the fitting accuracy for the measured I-V curves of the module.**

Keywords **— Photovoltaic, One-diode model, Electrical model, Translation equations, Parameters fitting, I-V curves.**

I. Introduction

Over the years, photovoltaic (PV) technologies have made significant progress, which has led to improved efficiencies, reduced costs, and increased deployment of solar energy systems. Each PV technology has a different underlying chemistry, based on the materials and processes used for its construction. These factors make each PV technology different from the other. In fact, even under extremely controlled environments, the PV cells produced within the same batch exhibit slight variations in their current-voltage (I-V) characteristics [1,2]. Due to this reason, the PV industry often implements binning to segregate similar performance PV cells into one set, so to reduce power losses in the PV module due to I-V characteristics mismatch.

To maximize the energy/power yield from a PV system, one is required to understand the I-V characteristics of the PV system. The I-V characteristics of the PV system can both be measured or simulated. To simulate the I-V characteristics or to extract valuable information from the measured I-V curves, numerous electrical models, with varying degree of complexity, have been developed. For traditional Si solar cells, these models include, but are not limited to, one-diode, two-diode and three-diode variants [3,4].

The choice of PV model depends on the desired level of accuracy and the specific requirements of the analysis or application. The one-diode model is commonly used for quick estimations and system design, while the two-diode and three-diode models are preferred for more detailed analysis, optimization, and research. Each model has a different number of unknown parameters and many approaches have been presented in the literature to determine their optimal values [5].

Whichever model is chosen, the traditional approach to PV parameters identification and performance estimation proceeds in two steps: First, the PV parameters of the system are extracted under a specific reference condition, usually at the standard test conditions (STC); Second, the PV parameters under varying field operating conditions are calculated based on the dependence of each parameter on irradiance and the module temperature. The equations used to translate these parameters to other operating conditions are referred to as the "translation equations" [6–9].

The biggest disadvantage of the traditional approach is that the constants appearing in these translation equations, Eqs. (2)-(7), are used as fixed values for all types of PV devices. This leads to erroneous estimates of the PV parameters, and consequently mimicking wrong I-V characteristics [10,11]. As these PV parameters are also used for diagnostics of the PV system, incorrect parameterization would lead to wrong predictions about the health of the system [12].

In this work, a new unified fitting approach has been developed and implemented, where both the PV parameters and various constants of the translation equations are tweaked to improve the fitting accuracy of the one-diode model.

II. One-Diode Model

A one-diode model is a mathematical representation of the electrical characteristics of a PV module. It is commonly used to simulate the behavior of the PV systems and analyze their performance. As shown in Fig. 1, the one-diode equivalent electrical circuit model consists of a single diode, a current source, a series resistance, and a shunt resistance. In Fig. 1, I_L is the illumination current, I_D is the diode current and I_{sh} is the shunt current.

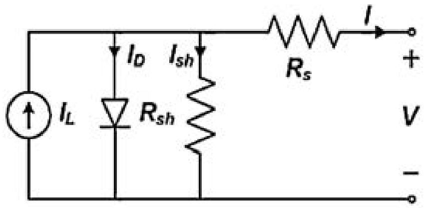

Fig. 1 One-diode equivalent electrical model of a PV module.

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Forecasting global horizontal and direct normal irradiation in the Arabian Peninsula: Sensitivity to the explicit treatment of aerosols

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Abstract

Global horizontal (GHI) and Direct Normal Irradiation (DNI) predicted using an operational three-dimensional atmospheric meteorology-chemistry model and a triple-nesting configuration over the Middle East with a focus on the hot desert climate of UAE is presented. The model runs every day, providing solar radiation components and air quality variables with a temporal step of one hour and a horizon of 72 hours. The model performance was assessed with measurement data of solar radiation from a ground monitoring station in Dubai (UAE) collected over one year, from January to December 2022, of representative and distinct meteorological regimes. We have examined the ability of the model to forecast GHI and DNI values under the RRTM (Rapid Radiative Transfer Model) and different shortwave downward radiation parameterizations. On an annual scale, the GHI and DNI displayed a mean rMBD of 0.51% and 18.7% and rRMSD of 21.6% and 69.7% respectively. The introduction of advanced treatment of aerosols dramatically improves the model performance in predicting GHI and DNI.

Keywords: solar radiation; desert dust; NWP model; Middle East, WRF-Chem, RRTM, aerosol

1. Introduction

The Middle East and North Africa (MENA) region has abundant solar resources and is implementing plans for renewable energy (Nematollahi, Hoghooghi, Rasti, & Sedaghat, 2016, Sgouridis, S. et al, 2016). The demand for electricity keeps rising in large urban environments of MENA, and the need for diversification from conventional energy production is now pushing for methods to reduce carbon emissions towards more sustainable development (Munawwar & Ghedira, 2014). Several solar resource assessment and feasibility studies for concentrated solar power plants (CSP) and photovoltaic plants (PV) have recently been carried out in the Middle East (Charabi & Gastli, 2010; Liqreina & Qoaider, 2014; Mokri, Aal Ali, & Emziane, 2013; Zell et al., 2015). Several research studies over the Middle East have shown that PV systems offer the most reliable and stable solution for primarily hot and humid environments (Pomares, 2017;). Therefore, accurate predictions of Global Titled Irradiance (GTI) derived from solar components of GHI, DNI and Diffuse Horizontal Irradiation (DHI) and local ground albedo in the region are of fundamental importance for efficient grid-connected PV establishments.

Accuracy in determining the expected solar irradiance and electricity production from solar power plants is essential for reducing grid integration costs and for more effective electricity grid management. Unlike wind power, solar radiation predictive capabilities are still nascent. GHI and DNI forecasting are traditionally conducted using various modeling approaches, including statistical models, models based on satellite data and sky cameras, and numerical weather prediction (NWP) models. The forecasting target horizon and spatial and temporal resolution determine the optimum modeling approach. For forecasts over the first minutes up to approximately 1-2 hours ahead of time (nowcasting), time series of solar irradiance can be provided by statistical approaches based on measured solar radiation data and sky cameras at a specific location (Hugo T.C.PedroCarlos F.M.Coimbra & Hugo T.C.Pedro, 2012; Mellit & Pavan, 2010). For forecasts from ~2 hours up to ~5 hours ahead (short-term forecasting), approaches based on the detection of cloud motion derived from satellite remote sensing are used to infer intra-hour solar irradiance with often high spatial and temporal resolution (Chow et al., 2011). The most valuable tool for GHI and DNI forecasting from 6 hours up to several days ahead is a Numerical Weather Prediction (NWP) model.

NWP models inherently include a radiative transfer model that is used to predict GHI and DNI through dynamic modeling of the troposphere. (R. J. Zamora, 2003; Robert J. Zamora et al., 2005) evaluated the hourly GHI predictions of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) (Grell, Jimy, & David, 1994) and the National Center for Environmental Prediction (NCEP) Eta Model in certain locations in the USA and reported model errors on the order of 100 Wm^{-2} for high aerosol loadings. The ability of MM5 to predict hourly solar irradiance was also studied by (Heinemann, Lorenz, Girodo, & University, 2006), who found a relative root

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Modelling Dust Emissions for Solar Resource Forecasting

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***Abstract* — Dust simulations over the Arabian Peninsula using the WRFChem model are presented. Results are validated against observed AOD and DNI. A sensitivity analysis is conducted by altering the proportionality constant of dust flux to 1, 0.5 and 0.25 (Dust_1, Dust_0.5 and Dust_0.25 respectively). In addition, a cold start simulation is included to show the effect of ignoring background dust concentration (Dust_1_cold). Results from Dust_0.25 performed best in terms of AOD and DNI. The cold start simulation Dust_1_cold highlighted the need to include background concentration in the simulations as it represents far-field sources in addition to accumulation from recirculation in the region.**

I. Introduction

The Weather Research and Forecasting Model with Chemistry (WRFChem) is a fully coupled atmospheric weather forecasting and atmospheric chemistry and transport model. It includes options for paramterising dust emissions and its subsequent impact on aerosol optical depth (AOD), horizontal visibility, surface radiation and cloud microphysics.

The first term in the dust flux equation represents the dust source strength, or potential dust emission. The methods for calculating the source strength term vary and have returned similar but different results [1-3] [Cao2015, Walker2009, Ginnoux2012]. A pragmatic solution to this is the inclusion of a proportionality constant, which acts as a scaling parameter, to the dust source strength term. It is common practice for users to tune the dust source strength based on the observation in their study area [4-6] [e.g Ukhov2020, Zhao et al., 2013; Kumar et al., 2014; Flaounas et al., 2017; Rizza et al., 2017]. In this paper we present a sensitivity analysis of the scaling parameter term to dust emissions, which is assessed against AOD observations.

II. Model Set-Up and Data

WRFChem v4.4 was run at a 12 km resolution using a single domain from 1-30 June 2019. Dust emission is controlled by the Air Force Weather Agency (AFWA) dust scheme. Our simulations are based on recent updates to the dust emissions scheme which include corrections to the dust flux calculation [7][LeGrand2018], dust size distribution and aerosol optical depth calculation [5][Ukhov2020,]. The model was run in a operational mode, being initialized at 00 UTC every day with 0.25° Global Forecast System (GFS v??). The model was run in the so called “warm start” mode (except for day 1, which is run in “cold start” mode), meaning that the atmospheric dust from the previous days simulation is used as initial conditions. The domain covered the whole of the Arabian Peninsula, which is sufficiently large enough to represent major sources of dust in the region and limits the need for including dust sources in the boundary conditions. A composite time series is created for the final analysis with the observations. In this composite, the first 30 hours of the forecast is used, while the first first 6 hours are disregarded as spinup. This means that a 24 hour period from forecast hour 7 to 30 is used from each day to create the composite time series.

Model results are validated against observations from the Outdoor Test Facility (OTF) at the Dubai Electricty and Water Authority Research and Development (DEWA R&D) centre (24.77 °N, 55.37 °E). Observations include AOD from a Cimel Sun Photometer and direct normal irradiation (DNI) from a pyrheliometer.

Model scenarios are summarized in Table I.

TABLE I

WRFChem model scenarios

Scenario	Scaling param	Warm/Cold start
Dust_1	1	Warm
Dust_1_cold	1	Cold
Dust_0.5	0.5	Warm
Dust_0.25	0.25	Warm

III. Results and Discussion

The average observed AOD during June 2019 was around 0.4 with a maximum just over 1 on 21 June (Fig. 1a). The peak AOD corresponds to DNI around 500 W/m^2, the lowest value observed in June. Model scenario Dust_1 simulated maximum AOD of 3.5 around the same period on 22 June, with a corresponding DNI of less than 200 W/m^2. The DNI from Dust_1 is equivalent to observed overcast conditions, meaning the sun would be blocked by the dust, and is indicative of overactive dust emission in the simulation. Analysis of the simulation revealed that the peak model AOD (indicated by the red circle in Fig. 1a) was associated with dust emission and transport from the Syria/Iraq region (red circle in Fig. 1c). These dust events can take more than 24 hours to travel from the source region to the OTF, and are therefore not present in the Dust_1_cold simulation. The difference in AOD between Dust_1 and Dust_1_cold highlights a two things. Firstly, the peaks in AOD in Dust_1_cold are due to source regions that are closer to the OTF. Secondly, the AOD drops to near zero, between peak AOD as there is no background dust in the initial conditions. Thus, AOD from Dust_1 is assumed to be due to

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Self-Thermometry of PV Panels

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Abstract*—During field operations, it is an unfortunate reality that over time, the temperature sensors of the PV panels get detached, damaged, or miscalibrated. Since the performance and reliability of a panel are determined by panel temperature (T_{mod}), a complementary/alternate approach is needed. In this regard, the Sandia model can be used to predict panel temperature, if the model parameters are calibrated by site-measured historical data. However; this is often impossible because historical data may not be available. In this study, we show that by merely incorporating the panel's electrical efficiency (degrading over time) into the equation, the panel temperature can be predicted with precision, obviating the need for calibration. Based on an analysis of more than 100 different PV panels installed at the outdoor test facility of DEWA R&D (Dubai, UAE), we show that the generalized model anticipates the actual temperature within 3.1 ˚C (worst case). The approach offers a new paradigm where the panel serves as its own thermometer and flags when the temperature sensor malfunctions.

Keywords*—PV panel, Outdoor testing, Thermal model, Empirical model, Temperature Sensors.

I. Introduction

Time-dependent power production is the most crucial metric for evaluating the performance and reliability of a solar farm. Its evaluation requires several parametric inputs, one of which is the operating temperature (T_{mod}) of the PV panel, which may be determined either experimentally or via a thermal model. Indeed, the power (and ultimately the efficiency) decreases linearly and the lifetime decreases exponentially with T_{mod}. Therefore, it is critically important to monitor T_{mod} of a PV panel.

The T_{mod} can be measured by mounting various types of temperature sensors (i.e. thermocouples) at the back of the panel (IEC 67724-1). Typical sensors have a broad range (from 40 to 130 °C), high accuracy (~0.5 °C), and excellent stability (less than 0.1 °C per year). Unfortunately, despite careful installation, it is common to find the sensors damaged, degraded, or miscalibrated over time. In this regard, we suggest that the thermal model of the panel can be used as an alternative "thermometer" of the panel.

In the literature, various thermal models have been reported. Some models rely on empirical correlations [1,2], and deduced analytical equations using the heat equation [3], while others use comprehensive models developed by means of numerical techniques [4,5]. Based on the geometry of the PV panels and the boundary conditions they are typically subjected to, numerical models are better fitted for accurately estimating the PV panel temperature, especially under rapidly varying ambient conditions in the field [6–8]. Fortunately, in the literature, many empirical equations have been shown to provide adequate estimates of the PV panel temperature, such as the Faiman [2] and the King's (or Sandia) model [1].

In this study, we will determine PV panel temperature for 100 plus PV panels of different types and configurations installed at the outdoor test facility of DEWA R&D in Dubai, UAE (shown in Fig. 1). We will compare two approaches for model-based self-thermometry. In the traditional approach, we will derive the empirical constants of the Sandia model by fitting the local field data. For the proposed approach, we will generalize the Sandia Model (with default parameters) by accounting for the panel's electrical efficiency but obviating the empirical fitting [9].

Fig. 1. More than 100 different types of PV panels were installed at the outdoor test facility (OTF) of DEWA R&D, Dubai, UAE.

II. Model Improvement

The following equation is used for estimating the PV panel temperature using the Sandia model [1]:

$$T_{mod} = \text{POA} \times e^{a+b\times ws} + T_{amb} \tag{1}$$

Here, POA is the incident plane of array irradiance, ws is the wind speed and T_{amb} is the ambient temperature. As shown in TABLE I, the empirical constants a and b depend on the panel type and its configuration.

TABLE I. Sandia Model Default Parameters [1]

Panel Type	Mount	a	b
Glass/cell/glass	Open rack	-3.47	-.0594
	Close roof mount	-2.98	-.0471
Glass/cell/polymer sheet	Open rack	-3.56	-.0750
	Close roof mount	-2.81	-.0455
Polymer/thin-film/steel	Open rack	-3.58	-.113
22X Linear Concentrator	Tracker	-3.23	-.130

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Temperature and Energy Yield Study of Façade Building Integrated PV Modules in Hot Desert Region

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***Abstract* — In this study, a comparative analysis was conducted for building integrated PV (BIPV) modules. The DEWA BIPV Cube, installed in 2017, is an example of applying passive cooling techniques in BIPV. It features a double-skin façade that allows natural ventilation conditions for the back side of PV modules. Temperature and energy yield were measured continuously on two different module types, crystalline Si (C-Si) and Cu(In, Ga)(Se, S)$_2$ (CIGS). C-Si modules have lower module operating temperatures than CIGS modules. The maximum temperature for both types was slightly above 70°C (Level 1 of IEC TS 63126). C-Si modules still obtain higher energy yields, although C-Si has a higher temperature coefficient. The results of this study indicate that C-Si modules have lower power degradation rates in facades with about 1%/year, while CIGS modules degrade up to three times faster than C-Si modules.**

***Keywords* - BIPV, Energy yield degradation, C-Si, CIGS, Module temperature study, Desert climate, and Vertical Façade.**

I. Introduction

Integrating PV modules in buildings, known as Building Integrated Photovoltaics (BIPV), is one of the promising solutions to the energy problems in recent years. It offers the option of electric energy generation and self-consumption in the same building; this, when accompanied in energy-efficient buildings, will result in a balance between energy requirements and generation, known as the Net/Near Zero Energy Building (NZEB) concept [1].

BIPV is the use of PV modules as double-functioning building elements [4]. One function is to generate electricity; the second function is to act as a building's envelope elements. The buildings categorized as medium-rise or high-rise offer huge facades areas suitable for BIPV applications [5].

II. Test Setup

This prototype project is a BIPV experimental research setup in DEWA Solar R&D Centre in Dubai, United Arab Emirates. The DEWA BIPV Cube was installed in 2017. The building's facades face East, South, and West azimuth orientations at tilt angles of 90° (Vertically installed modules). In addition, top roof modules are horizontally installed. Each face contains six operating PV modules: Three C-Si and three CIGS modules. Figure 1 shows the photo of the BIPV Cube.

Individual microinverters measure the electrical parameters of each PV module [1]. A data logger recorded the electrical parameters and the temperatures measured by thermocouples PT100 attached to the backside of each PV module every 30 seconds.

Fig. 1 DEWA BIPV Cube: Northside with entrance and without PV modules.

All meteorological records were obtained by the weather station in the same outdoor testing field close to the BIPV Cube. The in-plane irradiance records were measured by four pyranometers installed at the same orientations and tilt angles as the BIPV Cube. Figure 2 shows a photo of the DEWA BIPV Cube showing the module layout.

1: C-Si Modules (1.20m x 1.00m)
2: CIGS Modules (1.20m x 0.60m)

Fig. 2: PV Module layout in DEWA BIPV cube.

DEWA BIPV Cube is an example of applying a passive cooling technique in BIPV. It features a double-skin façade that allows natural ventilation conditions for the back side of PV modules. This happens by the entry of ambient air through the gaps in between the PV modules and moves upwards by the

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Tracking the Sun: Performance Analysis of Single-Axis vs Dual-Axis Solar PV Systems in UAE Desert Climate

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***Abstract* — In this study, a comparative analysis was conducted for single-axis and dual-axis tracking photovoltaic (PV) systems installed in the Outdoor Test Facility (OTF) at DEWA R&D Center, Dubai UAE. Same type of crystalline modules were installed in both the tracking systems and performance of the two was evaluated based on the daily power output, energy yield, and solar irradiation received. The analysis was conducted using the field data collected for 2 equinox days (March 21, 2018, and September 23, 2018). The results show that the dual-axis tracking system provided higher energy yield by 10.8% for the selected day in March and 8.57% for the selected day in September, compared to the single-axis tracking system. The findings of this study can provide valuable insights for the selection, design and feasibility of the PV tracking systems in desert climates.**

***Keywords* — Sun tracking, Single-axis tracking, Dual-axis tracking, Energy yield, Desert climate**

I. Introduction

Sunlight, which can be converted into electrical energy by means of photovoltaic (PV) systems, is a clean, renewable, and abundant source of renewable energy available in most parts of the world. However, the continuous change in the relative position of the sun poses a challenge for the output power produced by solar PV systems, which is directly related to the amount of solar energy acquired by the system [1].

A sun tracking PV solar system is a type of solar power system that employs photovoltaic (PV) panels to convert solar energy into electricity. Its distinctive feature is the capability to track the sun's movement during the day, which distinguishes it from a conventional solar system, maximizing the amount of solar energy collected by the panels. By tracking the sun's path across the sky, these systems can minimize the angle of incidence losses, thus optimizing the amount of energy captured and ultimately increasing the system's overall efficiency [2].

Two such types of commercially available sun tracking systems exist based on their degree of freedom: single-axis and dual-axis. The former has a single degree of freedom and tracks the sun's east-to-west movement, while the latter has two degrees of freedom and can track both the sun's east-to-west movement and changing altitude angle. Although the sun-tracking systems can enhance electricity output compared to conventional fixed systems, their more intricate design often results in cost, reliability, and maintenance issues [3], [4].

To compare the performance of single-axis and dual-axis systems installed in the desert conditions of United Arab Emirates, we selected 2 equinox days, 21 March 2018 and 23 September 2018, when the sun crosses the Earth's equator. On the day of the equinox, the sun appears to rise due east and sets due west.

II. Test Setup

The experimenatal setup of both single-axis and dual-axis tracker systems is detailed as follows:

A. Single-Axis Tracker

A total of 36 modules in 6 strings connection were installed at the Outdoor Testing Facility (OTF) of Dubai Electricity and Water Authority (DEWA) R&D Center, which is located right next to the planned 5GW Mohammed bin Rashid (MBR) Solar Park in Dubai. Each string consists of 6 modules of the same type connected in series. The layout of these 6 strings on two parallel single-axis trackers is shown in Fig. 1.

B. Dual-Axis Tracker

The dual-axis tracking system was also installed in the OTF, close to the single-axis tracking systems. As shown in Fig. 2, the system has 8 PV modules (in the stand-alone configuration) of different types. Out of the 8 PV modules, 6 are same as installed on the single-axis structure.

Fig. 1 36 PV modules in 6 string series connections on two parallel single-axis tracking systems.

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Trends and variability in methane concentrations over the Southeastern Arabian Peninsula

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Methane (CH_4) is a potent greenhouse gas with an important contribution to global warming. While national and international efforts have been put in place to reduce methane emissions, little is known about its variability, especially in hotspot regions where natural and anthropogenic emissions are compounded. In this study, the current state of CH_4 concentrations and their trends over the United Arab Emirates (UAE) and surrounding region are investigated with satellite and reanalysis data. CH_4 concentrations have increased over the last 5 years, with a trend in the satellite-derived column values (XCH_4) of about 9 ppb/year. A clear annual cycle is detected in XCH_4, with an amplitude of up to 75 ppb and peak values in the warmer months. The largest concentrations are found in coastal sites, where sabkhas and landfills are present, and along the Al Hajar mountains, where agricultural activities and microhabitats that may host CH_4-producing microbes occur and where advection by the background flow is likely an important contributor. The reanalysis data shows a good agreement with the satellite-derived estimates in terms of the spatial pattern, but the magnitudes are smaller by up to 50 ppb, due to deficiencies in the data assimilated. Surface CH_4 concentrations in the reanalysis data account for more than 50% of the corresponding XCH_4 values, and exhibit a seasonal cycle with the opposite phase due to uncertainties in the emissions inventory. Our findings provide an overview of the state of CH_4 concentration in the UAE and surrounding region, and may aid local authorities to propose the appropriate emission reduction strategies in order to meet the proposed net-zero greenhouse gas emission target by 2050. This study highlights the need for the establishment in the Arabian Peninsula region of a ground-based observational network for greenhouse gas concentrations which is still lacking to date.

KEYWORDS

greenhouse gas, global warming, methane, TROPOMI, CAMs, Arabian Peninsula

Highlights

- ➢ Variability of methane concentration in the eastern Arabian Peninsula over 2018–2021 is analyzed with satellite-derived and reanalysis data.
- ➢ Satellite data shows a trend of 9 ppb/year, 50% larger than that estimated elsewhere, consistent with the region being a methane hotspot.
- ➢ Largest column methane concentrations in coastal sites, due to the presence of sabkhas and landfills, and at the Al Hajar mountains.

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REGULAR ARTICLE OPEN ACCESS

Mission profile concept for PV modules: use case – middle east deserts vs temperate European climate

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Abstract. The paper addresses the need to simplify the comparison between different climatic conditions. Therefore, the concept of Mission Profiles is introduced to PV. Mission Profiles are a set of climatic stresses compiled to allow direct comparisons such as temperature, humidity, and UV exposure. The use-case in this paper is a comparison of a temperate with a hot climate. The results show that temperature driven processes are highly accelerated for the hot climate, whereas processes that involve humidity may lead to a similar annual degradation. The impact of light, particularly UV, is even more complex. UV triggered reaction processes can be photon absorption triggered and accelerated by temperature. However, for most observed interactions and material changes UV light goes in conjunction with moisture (H_2O) for the chemical reaction and is accelerated by temperature. Calculating the impact of temperature and UV is possible. However, the impact of moisture is almost impossible as it requires the knowledge of the local microclimate. Only a "worst-case" scenario can be assumed while using ambient relative humidity for most events of the day, that, however, do typically not include condensation. With the introduction of Mission Profiles, it should be possible to assess stress more easily for particular sites in general. Differences in mounting such as open rack compared to e.g., BiPV can also better addressed, however, with some assumption to define the microclimate (e.g., exclude rear side cooling).

Keywords: Mission profile / climate data / degradation / forecast / simulation

1 Introduction

Within the last years the installed number of PV systems dramatically increased and will further grow in the future. In addition to that, the number of different cell architectures (TOPCon, HJT, IBC), electrical interconnection methods (lead free solder, ECA) combined with larger wafer sizes, multiple cut cells and new encapsulation systems [1] require a more in-depth understanding of the environmental loads the PV module experiences in the expected service life.

To keep up with the need to have reasonable prices as well as durable and reliable PV modules for extended service life of more than 20 years, the "one-size-fits all" approach is not appropriate, as the differences in environmental stress conditions are very diverse. They not only vary from location to location, but also vary from type of installation such as open-rack vs e.g., BiPV applications. To tackle this challenge stress profile specific PV module construction will be needed. Those stress profiles must contain the main stressors such as temperatures (ambient and component), temperature changes, number of freezing cycles, wind direction, wind speed, irradiance profiles including amounts of UV-light. Additionally, more seldom loads such as snow loads, high winds or hailstorms must be considered for mechanical stability and possible electrical safety hazards. As more installations are built in sandy and dusty climates this is an extra stress factor to address. Soiling, among other things, not only can cause a reduction in performance [2,3], but it can also add extra stressors by e.g., cleaning robots.

In the past, several classifications were proposed to assess the impact of the climate. Most often the Köppen-Geiger scheme [4,5] is used, developed in the 1930s and updated over the years (e.g., [6–9]). Alternatives are the USDA hardiness zones [10] and similarly, such zones were developed basically for all regions. However, the focus for classification is on plant growth, not on photovoltaic application. More recently the Köppen-Geiger scheme was updated also to include more the relevant information for PV-systems [11]. To better assess the climate induced stress factors such as high temperatures, temperature fluctuations, humid heat, wind stress, and UV exposure the current work goes into PV specific climate zone

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ORIGINAL ARTICLE OPEN ACCESS

Assessing the feasibility of nighttime water harvesting from solar photovoltaic panels in a desert region

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Abstract. Photovoltaics has emerged as a crucial and progressively significant contributor to renewable energy generation. Nevertheless, its effectiveness is limited to daylight hours when sunlight is available. This research paper presents an approach to promote dual usage of solar panels beyond daytime operations to facilitate water production. An AWGPV (Atmospheric water generation on PV modules) system is built and operated for nearly a year. During this period, several prototypes were built to produce up to 2.5 L/panel per day without optimizing the energy consumed during direct cooling. A techno-economic assessment was done for the prototype AWGPV system. The prototype system consisting of 3 AWGPV panels connected to the grid was able to produce water at 33 USD cents per liter in Dubai, UAE. If the electricity for direct cooling is reduced, the cost of water can be reduced further. The results point to new avenues to explore methods for reducing the electricity consumption for cooling for achieving further cost reduction. A parameter n-MHI (night Moisture harvesting index) is introduced to evaluate the feasibility and energy demands of harvesting atmospheric moisture through direct cooling. Through a climate-based analysis of various locations, the global potential of this process is explored. The collected water can be used for dust cleaning of solar panels, agrophotovoltaic systems, and other applications where water and electricity generation needs to be decentralized.

Keywords: Photovoltaic / atmospheric water generation / solar cooling / integrated energy-water system

1 Introduction

In 2022, the global installation of photovoltaic (PV) systems experienced significant growth, reaching a cumulative capacity of 1.2 TW [1]. The Middle East region, particularly the Gulf countries, has emerged as a hub for exceptionally low solar tariffs in recent years. Most projects have been awarded prices that steadily approach an impressive rate of 1 USD cent per kilowatt-hour (ct/kWh). These accomplishments are attributable to favorable solar conditions, the availability of cost-effective desert land, low labor costs, affordable project financing, supportive tax systems, economies of scale benefitting large-scale projects, and decreasing prices of PV system components.

Projections suggest that the countries in the Middle East region will deploy approximately 50 GW of solar PV by 2030 [2]. For instance, the second phase of the MBR solar park in the UAE [3], with a capacity of 200 MWdc, covers an area of 4.5 square kilometers and encompasses roughly 2.3 million solar panels. Based on this, a solar PV plant with a capacity of 1 MWdc occupies approximately 22,500 square meters. Consequently, by 2030, the collective utilization of the sunny desert lands by Middle East countries will occupy a substantial area of 1,125 square kilometers for solar PV plants.

The sub-tropical regions of the Middle East and Africa regions experience the highest average number of sunshine hours throughout the year. In the UAE, for example, the sunshine hours during winter and summer solstices amount to 12 and 14 h, respectively. Consequently, a significant portion of land remains unused during nighttime due to the presence of solar panels. This paper explores a potential solution that harnesses the utilization of the vast surface area occupied by solar panels during non-sunshine hours.

Numerous advancements [4–7] have been made in the field of water production, focusing on cost-effectiveness, accessibility, and environmental sustainability. The primary objective of these studies is to generate potable water. Globally, various approaches are employed to meet water

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Full length article

Outliers in Shannon's effective ionic radii table and the table extension by machine learning

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A R T I C L E I N F O

Dataset link: https://cmd-ml.github.io/, https://github.com/cmd-ml/cmd-ml.github.io/blob/master/ImprovedShannonTableML.xlsx

Keywords:
Ionic radii
Outliers
Data analytics
Material informatics
Machine learning

A B S T R A C T

In materials informatics and computational design, ionic radius is an essential physical feature needed to predict and model structures and other material properties. Currently, the most used reference for ionic radii is the renowned Shannon's table set in 1976, where each ionic configuration is composed of the element, oxidation state (OS), and coordination number (CN). The original table has 488 radii for 476 unique ionic configurations. The table was extended recently using machine learning (ML) to add 512 missed known configurations, which are not in the original table. Conceptually, the accuracy of ML prediction depends on the reliability of the original data. In this work, multiple techniques are used to detect outliers in Shannon's table to improve the prediction accuracy. It turned out that there are 24 outliers. The ionic radius testing root mean square error using Gaussian process regression is reduced from 3.99 pm using all Shannon's data (488 data points) to 2.71 pm (with 464 data points), with R^2 scores of 0.989 and 0.995, respectively. This is done by removing only 4.92 % of the data. The cleaned data are then used to estimate the ionic radii of the additional 512 OS/CN ionic configurations and the detected outliers. The consolidated table of 988 unique ionic configurations is provided in the Supplementary Information and is made available online.

1. Introduction

Nowadays, material informatics is considered among the essential pillars in materials science and engineering, and it has grown considerably in the past few years [1–7]. This could provide unconventional venues to accelerate materials discovery [8,9]. Actually, material informatics was eminent considering the fact that materials data has been expanded substantially in the past few decades by many computational materials initiatives [10–12]. Thus, data analytics and machine learning (ML) are certainly needed to mine and utilize the generated data [13].

In principle, the essence of proper physical modeling using ML lies in determining the relevant and necessary features [4,11,14], seeking authentic and reliable data [13,15,16], and using appropriate model vector spaces [17,18]. In material informatics, ionic radii are arguably among the essential physical features needed to predict crystal structure and material properties [19–22]. They have been utilized successfully for both inference and prediction in a wide range of materials related application [23–29]. As a consequence, having accurate ionic radius for a given element with an arbitrary configuration of oxidation state (OS) and coordination geometry is crucial for proper applications of machine learning in materials science.

Conceptually, the sum of ionic radii of two bonded ions is the distance between the nuclei of a cation and its adjacent anion in a crystal structure. The foundational studies of ionic radii can be traced back to Goldschmidt [30], Pauling [31], Zachariasen [32], and Wasastjerna [33]. Actually, Wasastjerna devised a technique for determining an ion's radius by utilizing the comparative ionic volume as estimated by spectrophotometer [33]. The field is still active and further improvements and refinements were introduced [22,34–36]. For example, Gebhardt and Rappe [37] estimated the effective ionic

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CHAPTER 3

Quantum efficiency as a tool for defect analysis in solar photovoltaic modules

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1. Introduction

Driven by the surge in global economic recovery postpandemic, global energy demand has increased by 6% in 2021, which was the largest annual increase ever recorded in absolute terms (over 1500 TWh) [1]. Global energy demand growth is expected to persist during 2022 given the continued economic recovery. In turn, this phenomenon has caused an increase in energy demand, which is causing a noticeable increase in renewable energy growth on a global scale. Solar energy in the form of photovoltaics (PV) has become a key player in that regard, leading to an increase in solar energy capacity worldwide. Global renewable energy capacity is expected to have an annual increase of 305 GW per year for the next 5 years [2]. Given the rapidly rising dependence on solar energy as a major energy source, the weaknesses and defects of solar panels become increasingly more vital to solar output, and in extension, worldwide electricity generation. Hence, this highlights the importance of understanding the degradation mechanisms that are prominent in PV modules and quantifying their effect on output. Once that is properly achieved, one can reliably avoid or mitigate losses in all of its forms, in turn improving the reliability and hence energy yields of solar PV at a utility scale. The focus of this chapter is specifically on the optical and/or electrical losses caused by the defects, quantified using the cell's spectral response in terms of quantum efficiency (QE), and a proposal for a subsequent measurement and analysis technique.

1.1 Optical losses in PV modules

Considering that PV modules are constantly outdoors, under sunlight, and exposed to harsh weather elements, it is only natural that a wide variety of

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PROPOSAL FOR HOT DESERT TEST CYCLE

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Motivation

More and more PV systems are being installed in deserts with hot-dry climates. Higher module temperatures, ultraviolet radiation, sandstorms and soiling with sand dust are the main challenges. In this work, the degradation effects of PV modules in deserts are analyzed based on modules in the Outdoor Test Facility (OTF) at the DEWA R&D Center which is located at the 5 GW MBR Solar Park in Dubai. A total of 120 PV modules are individually monitored since 2016. Due to the coastal site of Dubai the humidity is high.

A standard for the operation of PV modules under harsh conditions in hot deserts for benchmarking PV modules shall be developed. The goal of the Hot Desert Test Cycle sequences is to reproduce and to accelerate hot desert induced PV module failures.

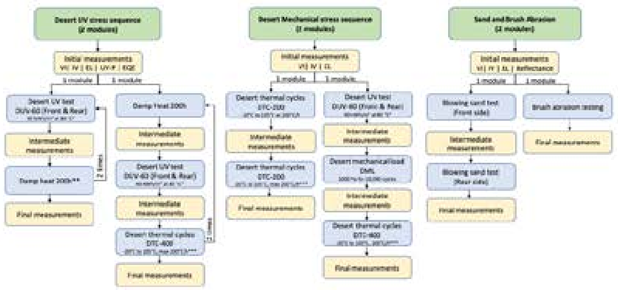
Two approaches have to be considered:

- Performing a complete standard test schedule as e.g. IEC 61215 with test parameters which are more severe (e.g., thermal cycle test from -40°C to 105°C instead of 85°C).
- Conducting additional Test Sequences which are developed and verified to reproduce failures which are found in the field.

The proposed approach targets large-scale utility scale solar power plants with monofacial or bifacial modules with bifacial cells, fixed or single-axis mounting configuration, regular cleaning using robotic systems. For a successful standard development more work is needed:

- Test durations and costs are discussed in a techno-economic analysis.
- Benchmark criteria have to be evaluated in further experiments.

HDTC Test Flow Chart



Outdoor Test Facility, since 2016

Row	R1	R2	R3	R4
Tilt angle	5	25	25	90
Cleaning Frequency	Monthly	Monthly	Weekly	Monthly

Summary HDTC

For the qualification and benchmarking of PV modules for hot desert operation, three test sequences, additional to IEC61215/61730 are proposed.

- **Desert UV Stress Sequence (2 modules)**
  - Inducing the browning (UV+DH) and backsheet defects (DH+UV and TC).
  - UV conducted at 60kWh/m^2 at an elevated temperature of 80 °C, for both front and rear side of the modules.

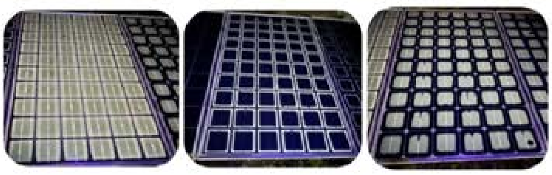
Test Leg 3 of IEC TS 63209-1 is a known test sequence of extended UV exposure testing. For desert applications, the humidity freeze cycles part are replaced by further thermal cycles. A test sequence with the execution of the 200 hours damp heat pre-conditioning after the first UV test sequence is proposed.

- **Desert Mechanical Stress Sequence (2 modules)**
  - simulates the impact of thermo-mechanical breakages (TC) and
  - cleaning robot induced stresses (UV+ static and cyclic ML + TC) I
  - modified temperature cycle between -20 °C and 105 °C..
  - For the cyclic mechanical load test, 10 000 cycles at 1000 Pa to reflect 25 years of daily cleaning.

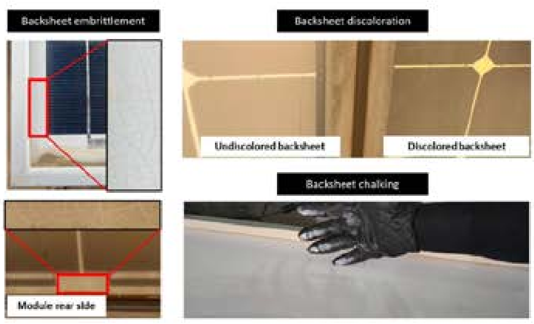
Additional mechanical loads for PV modules just arise in the last years at utility-scale PV power plants: 1-axis tracking with short purlins and the cleaning with robots. Furthermore, numerous PV modules, especially frameless modules, are permanently bended in hot desert PV power plants.

- **Sand and Brush Abrasion Sequence (2 modules)**
  - Blowing Sand Testing according to IEC 60068-2-68
  - Brush Abrasion Testing with a Cleaning Robot with Soft Nylon Bristles for 25 years daily cleaning.

Failures Found in the OTF: UV Degradation of Polymers



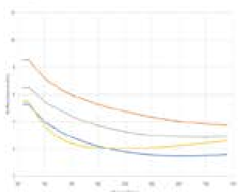
Different types of discoloration patterns observed in UV-F images from 7-year-old outdoor field modules in desert



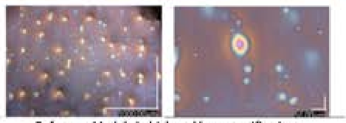
Backsheet defects including, embrittlement, discoloration and chalking observed in 7-year-old outdoor field modules in desert

Failures Found in the Field: Loss of the Anti-Reflective Coating

PV modules in the field are loosing the anti-reflective capabilities due to sandstorms, robotic cleaning or chemical dissolution.



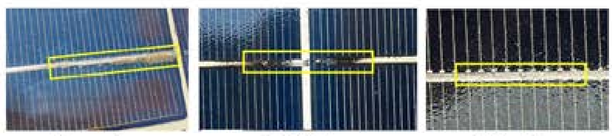
Hemispherical Reflectance (SCI) of 2 Fielded Modules and two Reference Modules with 2...4 % higher reflectance



Reference Module in high and low magnification under Coaxial microscope

Fielded Module in high and low magnification under Coaxial microscope

Failures Found in the OTF: Metallization Defects



Corrosion Oxidation Chipping

Metallization and Interconnect defects including, Corrosion, Oxidation and Chipping.

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PV Module Mission Profile from Middle East Deserts vs temperate European climate

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Identification and analysis of metallization defects in desert-operated photovoltaic modules

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***Abstract*—The day and night temperature differences in desert regions are relatively extreme compared to moderate conditions, causing thermo-mechanical fatigue within installed photovoltaic (PV) modules. This leads to breakages in cells and its metallization, which causes resistive losses. Herein, finger metallization are major current-carrying components, which are reported to fail under such conditions. There are various types of finger defects depending on the mode of degradation, source of breakage and degradation severity. This paper discusses and analyses different types of finger defects observed in 5-year desert-aged modules. The work also proposes methods to differentiate between aged finger defects from manufactured-based ones.**

***Keywords*—desert climate, crystalline PV modules, thermo-mechanical fatigue, finger defects**

I. Introduction

The Middle East and North Africa (MENA) region has been witnessing exponential growth in utility solar plants, with expected solar capacities reaching up to almost 35GW by 2024 [1]. However, PV modules in desert climate are exposed to environmental stressors such as elevated temperature and ultraviolet (UV) radiation, sand abrasion and large temperature cycles [2] [3] [4] [5], which can degrade different components of the module and eventually lead to defects such as encapsulant discoloration and delamination, cell cracks, hot spots, finger breakages, discoloration of metallization, solder-bond failure and glass abrasion and breakages [2] [3] [4] [5] [6]. These defects and degradations reduce the power output of the system, as well as the lifetime of PV modules, affecting system reliability.

Many studies conducted in hot and dry climates identified series resistance as a major mode of degradation [2] [7] [8]. Emitter resistance, fingers, busbars, solder, and interconnects are major contributors to series resistance. During operation, high-temperature variation between day and night in desert climates subject the PV module components to thermo-mechanical loads [2] due to the difference in their thermal expansion coefficients [9]. Finger-solder interfaces are more susceptible to such conditions in comparison to other components, owing to the small size of fingers and material properties of solder. Solder thermal fatigue failures results in finger breakages, which increases series resistance and reduce fill factor, causing power losses. In addition, finger and busbars can also corrode under chemical modes, which arises due to the ingression of moisture and gas to the PV cell through the encapsulant and back sheet, resulting in metallization corrosion and increased series resistance and power losses [10]. Thermo-mechanical-based finger defects are more commonly observed in the desert region due to the high-temperature variation between day and night [2]. Moreover, another mode of finger defect is manufacturer-induced due to insufficient silver pasting during the screen-printing process of metallization or non-optimal soldering conditions. In addition, fingers defect may be introduced as a result of accidental damages during transportation or installation [10]. This type of defect is referred to as finger interruption and can occur anywhere along the finger length [10]. Finger interruptions are often mistaken for finger breakages as they both look very similar in electroluminescence (EL) imaging; presented as dark elongated box-like features, which can lead to misanalyses of data in reliability studies.

Thus, current-carrying metallization is important in reliability studies and requires detailed studies on the identification, investigation and analysis of different finger defects commonly found in desert climates. This paper contains a study on different modes of finger defects and degradation modes observed in 5-year-old desert fielded PV modules installed in DEWA R&D center, Dubai, UAE. It utilizes non-destructive techniques such as electroluminescence (EL) imaging and microscopic visual inspection for structural defect detection, identification, analysis and differentiation between different types of finger defects. This would be instrumental in early detection of such defects and differentiation between them based on their respective reason of breakage which could be either induced during manufacturing process, during transportation/installation or field operation. Furthermore, this paper could assist in the mitigation of such defects in the design of desert-resistant PV modules, as well as contribute to the development of PV standards specific to desert conditions.

II. Methodology

The crystalline silicon PV modules were installed at Dubai Electricity and Water Authority (DEWA) R&D Center within the MBR Solar Park, Dubai, UAE for a period of 5 years. For this study, 20 crystalline silicon PV modules were investigated,

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IDENTIFICATION AND INVESTIGATION OF MATERIALS DEGRADATION IN PHOTOVOLTAIC MODULES FROM MIDDLE EAST HOT DESERT

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ABSTRACT: The desert climate is the best solar climatic zone on Earth for harvesting solar power because of its higher irradiance resources. The severity of material degradation depends upon the photovoltaic (PV) modules installed in which type of climate zones, weather conditions, and module tilt angles. The paper's main objective is to show the desert's harsh weather conditions and material degradation modes. The encapsulant discoloration and chalking in the backsheet were two dominant material degradation modes observed in desert-operated PV modules at different tilt angles. Majorly, short circuit current (Isc) and fill factor (FF) losses were observed almost in all outdoor teste facility (OTF) modules. Fill and frame discoloration patterns were observed in fluorescence images of OTF PV modules. Encapsulant type is detected with Raman spectroscopy. Ethylene vinyl acetate is identified as an encapsulant material used in c-Si PV modules. The annual Isc degradation rate is 0.28%/year and 0.41 %/year for frame and filled discoloration patterns. Backsheet chalking is analyzed with scanning electron microscopy (SEM) and Energy dispersive X-ray spectroscopy. Chalking is due to the titanium dioxide formation on the outer layer of the backsheet. This paper motivates the researcher and PV community to study the PV materials degradation behavior and defects impact on PV modules operated in desert climates.

Keywords— Desert climate, PV component defects, discoloration patterns, encapsulant, back sheet.

1 INTRODUCTION

Solar energy is becoming a promising candidate in the renewable energy technology world, especially in the Middle East (ME) hot desert, where there is an abundance of solar irradiation [1], [2]. Therefore, the ME regions are adopting PV modules power plants at both residential and utility-scale. In this view, Dubai has launched a Clean Energy Strategy that aims to produce 75 % of its energy requirements from clean energy sources by 2050 [3]. This includes initiatives such as Mohammed Bin Rashid Al Maktoum Solar Park (launched in 2012 in Dubai). According to J. Ascencio-Vásquez, et al. and J.-F. Leli`evre et al., a hot desert climate is the best solar climatic zone on Earth for harvesting solar power because of its higher irradiance resources [4], [5]. However, there is no indication for selecting packaging materials for PV modules for the desert climate application. A PV module is typically made of multiple components and together called the 'bill of materials (BOMs) [6] namely solar cells, encapsulant film, glass, backsheet film, connecting ribbons, protective frame, junction box, sealants, and external cable. Encapsulant discoloration/yellowing, delamination, corrosion, snail trails, chalking, hot spots, interconnects and finger breakages & discoloration, and cell cracks are the common defects observed in PV modules. When a PV module operates under different climatic conditions shows different degradation modes and defects [4,7–11]. The material degradation in each PV component is different. The severity of material degradation depends upon the PV modules installed in which type of climate zones, weather conditions, and module tilt angles. The formation of defects shows a significant impact on the performance of the PV modules. PV modules in the desert experience multiple stressors such as large temperature differences in day and night temperatures, high UV radiation, medium humidity, windspeed, and soiling[11]. It is necessary to understand the defect formation and their impact on PV modules especially in desert climates.

The IEC 61215 standard series is recognized for approval type and designed for moderate climates [12]. This standard is not sufficient to represent the desert conditions and desert-induced defects and degradation modes. The reliability and durability of PV modules are of great importance for the development of desert standards for all PV utility industry segments.

The paper's main objective is to show the PV component defects and their identification in PV modules exposed to ME hot desert regions. As is the case with the ME hot desert, which is characterized by harsh weather conditions, it can raise concerns about the PV modules' long-term performance. Collecting harsh weather conditions, and surveys of PV module defects motivate the researcher and PV community to focus on hot desert standard development for representing the desert-induced defects and degradation modes in the PV modules exposed in the ME region.

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MODULE EXTERNAL QUANTUM EFFICIENCY MEASUREMENTS AS A METHOD FOR DEFECTS ANALYSIS IN BIFACIAL PV MODULES.

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ABSTRACT: This paper aims to further expand on defects analysis of PV modules by introducing a module-level External Quantum Efficiency (m-EQE) measurement technique onto bifacial solar modules exposed to harsh desert conditions for 7 years. The technique is used to measure the EQE of a cell within the module with a spatial resolution of 5 cm x 2.5 cm, on degraded bifacial modules. Results show a clear difference in EQE between the rear and front surfaces, with the rear surfaces showing lower EQE in all four cases (two cells per module) at lower wavelengths, and higher EQE in the rear surface at higher wavelengths and the infrared range. Results are correlated with other testing methods, including current-voltage (IV), Electroluminescence (EL), and Ultraviolet Fluorescence (UV-F), which showed a current loss that was attributed to encapsulant degradation seen in UV-F patterns and EQE loss in lower wavelengths. Module-EQE is a non-destructive technique that provides critical insight into the spectral behavior of the modules. Adding module EQE as part of the intermediate testing technique for defect analysis test cycles is suggested, especially to progressively observe changes under a desert-based test cycle.
Keywords: Module-EQE, defects analysis, bifacial EQE, spectral response, encapsulant degradation.

1 INTRODUCTION

Solar energy, especially in the form of photovoltaics (PV), is slowly becoming a dominant source of energy production globally. This rise in solar energy production, combined with the continued decline in the cost of solar energy, makes PV an essential aspect of meeting global electricity demand. As such, it is crucial to thoroughly understand the nature of the various defects and degradation mechanisms that negatively impact solar module performance, especially in the harsh desert conditions where the solar resource is most abundant.

Of the various available means to analyze solar module performance and reliability, the measure of External Quantum Efficiency (EQE) is considered to be an excellent method for determining defects and performance optically and on a cell level, even being able to identify and locate such losses within the specific layers of the solar cells making up the module. Such defects include the likes of encapsulant discoloration, surface glass abrasions, and transmittance losses [1,2]. Hence, this method would prove especially useful when analyzing bifacial solar modules due to the differences between the front and back surfaces in material composition and layers. However, spectral response measurement, and in extension EQE, is typically performed on separate solar cells, and there isn't a very extensive amount of literature on module-level.

This paper aims to introduce a module-level EQE measurement technique and equipment where the EQE of any cell within the module is measured at a spatial resolution and area of 5 cm x 2.5 cm. These measurements were done on bifacial solar modules which have been exposed to 7 years of degradation in desert conditions and compared to conventional testing techniques in order to further understand how EQE testing can be implemented in PV defects analysis, especially for bifacial modules.

2 LITERATURE REVIEW

Despite the proven reliability of EQE measurements as an accurate and useful means for analysis in solar cells of all types, its use on a module level is not commonly used or entirely well-understood yet, which is especially true regarding bifacial modules and their unique design.

However, various authors have attempted to tackle this issue by designing and utilizing systems for module-level EQE [3,4]. Some of these designs are unique in implementation, including Perulli et al.'s utilization of a technique that combines photocurrent (PC) and photoluminescent (PL) mapping to calculate EQE, while using fluorescence maps to differentiate the data points based on different layers within each solar cell [5].

Moreover, a few examples exists where such techniques were used to test bifacial modules specifically. For instance, a test on PERC bifacial modules was carried out by Luo et al., where degradation due to PID was correlated to EQE loss at higher wavelengths (800-12000 nm) [6]. The authors conclude that this degradation occurred at the rear side, recommending the reinforcement of these areas in the module. Another study by Sulas-Kern et al. tests bifacial mini-modules, where the EQE loss was attributed to rear-side surface recombination in EVA modules, since POE modules did not exhibit such losses [7].

3 METHODOLOGY

3.1 Equipment Setup

The module-EQE measurements are carried out using a custom-made Bunkoukeiki device, shown in Fig. 1. The equipment is able to hold up a PV module on a test bench and expose it to a monochromatic light that can simulate a range of wavelengths. The device also provides bias light to each cell within the module to ensure homogeneity throughout the cells. The setup also consists of power sources for voltage injection and a data acquisition setup. The device then starts taking spectral response readings for the cell as it cycles through the wavelength range provided, creating a spectral response curve that is translated into an EQE curve.

This data is then compared to other various testing techniques commonly used for solar PV degradation analysis. This includes our use of current-voltage IV curves, Ultraviolet Fluorescence (UV-F) imaging, and Electroluminescence (EL) imaging.

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020228-001

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Defects and degradations in photovoltaic modules from hot Middle East deserts

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***Abstract*— The Middle East is witnessing rapid solar energy growth, exemplified by the Mohammed Bin Rashid (MBR) Solar Park in the UAE. With 1000 MW operational capacity, and plans to reach 5 GW by 2030, harsh desert conditions pose challenges. High solar irradiation, intense UV exposure, extreme temperatures, and sand-dust accumulation lead to premature defects and power loss in PV modules. Existing testing lacks desert-specific standards. This study establishes hot desert environmental guidelines by analyzing common defects and degradation in MBR Solar Park modules. An outdoor facility monitored 120 modules for 7 years, employing various indoor techniques. The research identifies degradation modes, conducts root cause analysis, and assesses long-term performance impact, instrumental in guiding solar installations in desert environments.**

Keywords—desert climate, crystalline PV modules, thermo-mechanical fatigue, finger defects

I. Introduction

The Middle Eastern region is seeing rapid growth in solar installations. The Mohammed Bin Rashid (MBR) Solar Park, located in a hot desert in United Arab Emirates (UAE), recently reached an operational solar PV capacity of about 1000 MW in April 2021, and plans to install 5 GW by 2030 [1]. However, such desert regions pose harsh climate conditions, owing to a very high solar resource. This leads to early defects leading to power degradations in the installed PV modules, causing long-term reliability and durability issues [2]. The major environmental contributors to such degradations are high solar irradiation with strong UV dose, high ambient temperature, large variations between day and night temperatures, and sand-dust accumulation, as shown in Fig. 1 (a). Among these, the dominant stressor is high solar irradiance and UV dosage, which is more than double that of a city in Germany.

The existing IEC testing protocols do not cater to any specific climate conditions, especially the harsh climate conditions of this region, and are not sufficient to replicate the observed degradation modes. The standard development project is working towards developing hot desert environmental standards for photovoltaic modules being installed in such harsh conditions [3]. As a precursor, it is important to identify and analyze different types of commonly observed defects and degradations from the field. For this purpose, an in-house outdoor testing facility (OTF-A) was set up within the desert environment, as shown in Fig. 1(b). It consists of a total of 120 modules (30 types) installed in 4 rows at 3 angles of installation (0°, 25°, and 90°) for a period of 7 years. Periodic investigations and analyses have been conducted on these modules using outdoor and indoor techniques [4]. The outdoor performance and weather data are also being constantly monitored and analyzed. The modules are also tested in the in-house testing facility for a more in-depth analysis of the observed defects and degradation. This paper is focused on findings from the indoor testing of these modules and presents the use of illuminated current-voltage (I-V) analysis, electroluminescence (EL) imaging, ultra-violet fluorescence (UV-f) imaging, module-external quantum efficiency (EQE) analysis, Raman spectroscopy, and colorimetry. The findings include the major degradation modes observed in the field, including their root cause analysis and assessment of their impact on long-term performance. The purpose of this backyard study is to provide feedback and benchmarking for developing hot desert standards based on the findings. The first draft of the hot desert standard has been presented in [3]. A study based on material analysis on modules from different manufacturers will also lead to selecting hot desert-appropriate PV module packaging materials.

II. Methodology

This study presents findings and learnings from 7-year-old exposed modules from a hot desert outdoor testing facility at DEWA R&D center, Dubai, UAE. The site presents harsh weather conditions. Such harsh weather conditions have led to defects and degradations within different components of the PV modules during the 7 years of exposure. Fig. 1 shows the visual defects observed in all modules, binned based on the defect severity.

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10. Robot Cleaning

CREATING STANDARDS FOR PV MODULE CLEANING

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ncreasingly, PV systems are installed in desert environments due to higher irradiation levels and more available space. Desert winds often carry sand and dust that is deposited on the PV modules, thereby significantly reducing energy yield. The soiling effect is greater at the lower tilt angle of the installed PV modules. Therefore, various waterless cleaning methods in desert regions are often used to avoid performance degradation. DEWA is installing a large PV test field to systematically assess the effectiveness and impacts of different automated cleaning systems in realistic and controlled conditions. This article introduces the system capabilities and objectives in the context of the challenges of cleaning modules in the desert.

At the end of 2022, the new DEWA test field for automated PV module cleaning systems was inaugurated at the DEWA Research and Development Center in the MBR Solar Park in Dubai. After the installation of 384 modules on fixed and single-axis tracking mounting structures, the installation of various cleaning systems will begin. In the first year of operation, continuous daily cleaning of PV modules is planned for all systems to validate the assessment methodology. In the second year, the scope will be expanded to include more specific testing in collaboration with manufacturers who can demonstrate their capabilities with standardised test sequences. The results will apply to the entire MENA region, especially to hot desert regions with quartz-containing dust.

Advantages of Floating Solar

Dry cleaning methods, preferred due to water scarcity in desert environments, use friction to dislodge dried dust layers, which is less effective than removing dust and salt with water. Also, dry cleaning can damage PV modules due to the friction required to overcome the adhesion of particles to the glass surface. Even if the brush materials are soft, the dust particles themselves can scratch the surface, causing permanent abrasion on the PV module surface. In addition, if the dust sticks on the glass surfaces and the cleaning frequency is not high enough, harder brushes may be needed to remove the stuck particles. The harder brush, in particular, requires testing and evaluation due to its anticipated increased abrasive effects on PV modules. Overall, the effectiveness and frequency of cleaning are inversely correlated, and an optimum frequency would be between one to eight days.

Most PV module manufacturers use PV module glass with an anti-reflective coating (ARC) to reduce reflection losses at the glass surface. ARC is more sensitive to abrasion than glass and may be removed or scratched by repeated cleaning. Such damage is not visible to the naked eye but may result in yield losses from abrasion that reduce the anti-reflective properties of the ARC.

When it comes to robotic cleaning devices, most use the module frame and glass surface as a rail and mechanical support for the cleaning system. In these cases, the ability of the PV modules to withstand the additional load without damage needs to be verified. The cleaning load or pressure applied directly to the front of the modules should not exceed the mechanical load capacity of the modules. Additionally, heavy or uneven loading in modules with crystalline silicon cells could cause microcracks in the cells, resulting in hot spots and power loss. Semi-automated systems pose a particular risk in this regard, as they must be manually placed on each table of PV modules. The weight of these systems ranges from 35 to 65 kg and could have a material impact if mishandled.

Finally, cleaning during the day must be avoided, as there is a risk of damaging the PV modules by forming hot spots because of partial shading. The reason is that the hot spot effect occurs when individual solar cells within the series connection in the PV module are covered and shaded. The hot spot effect can also be caused by uneven cleaning, especially at the bottom edge of modules where brush coverage may be limited, or tougher soiling may be prevalent.

PV Module Cleaning Test Field in Dubai

In order to optimise PV system operations, the long-term performance of PV modules and cleaning robots needs a detailed study. A standardised evaluation system is required to consider the harsh climatic conditions of deserts (sand and dust storms, high temperatures, UV light and often condensation during the night). The study will create criteria and metrics that evaluate the effectiveness and reliability of existing and new cleaning systems and anti-soiling coatings. As a result, the evaluation will provide important insights into the relative performance of different options and identify further improvement opportunities.

The Cleaning Test Field (CTF) has been established at the DEWA Research and Development Centre near the

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10. Robot Cleaning

MBR solar park. The CTF provides an opportunity to test different robotic cleaning systems on various modules that have been or may be installed in the different phases of the MBR solar park. The CTF will allow researchers and customers to test different cleaning equipment, PV modules with different coatings, and different test procedures with different parameters (cleaning time, brush rotation speed, and module tilt angle). The primary cleaning method is dry cleaning, but wet cleaning could also be evaluated.

The CTF is a grid-connected PV system with 384 modules. It consists of eight 16-module strings with fixed mounting at a 25° tilt angle, eight 16-module strings on one-panel single-axis trackers and eight 16-module strings on two-panel single-axis trackers (see Fig. 1). The CTF is used to test the performance (cleaning efficiency, power dissipation) and reliability of different types of cleaning systems under various conditions on 24 module strings using IV data from the inverter. The evaluation process consists of two aspects: operations and assessment. Through this process, different cleaning systems such as robotic cleaning, semi-automatic brush cleaning methods and others are selected and integrated to investigate their performance and reliability compared to no cleaning and manual cleaning. In addition to string evaluation, electronic loads and microinverters with data acquisition systems will be available to measure individual modules at the end of the strings or to measure additional modules from other manufacturers.

After a prescribed period, potential damage to the glass surface and ARC will be investigated with various methods, including spectral reflectance measurement, evaluation of abrasion using optical microscopy, roughness measurement, and electroluminescence. These methods are used to study potential invisible damage caused by the mechanical stress of the cleaning process. Each PV module installed has been individually tested in the laboratory before installation and will be assessed monthly in situ and again in the laboratory after one year.

In conclusion, further tests are planned to; measure cleaning efficiency after artificial soiling with a sand blower, test the climbing ability of robots using flexible bridges and study the effect of mechanical loading of robots on modules due to different attachment points and purlins. The results and learning experience from these tests will be used to develop a standardised testing method and standards for cleaning equipment. This addresses an unfulfilled need to adopt test specifications in the assessment of cleaning equipment by PV module manufacturers, PV module plant operators and cleaning companies.

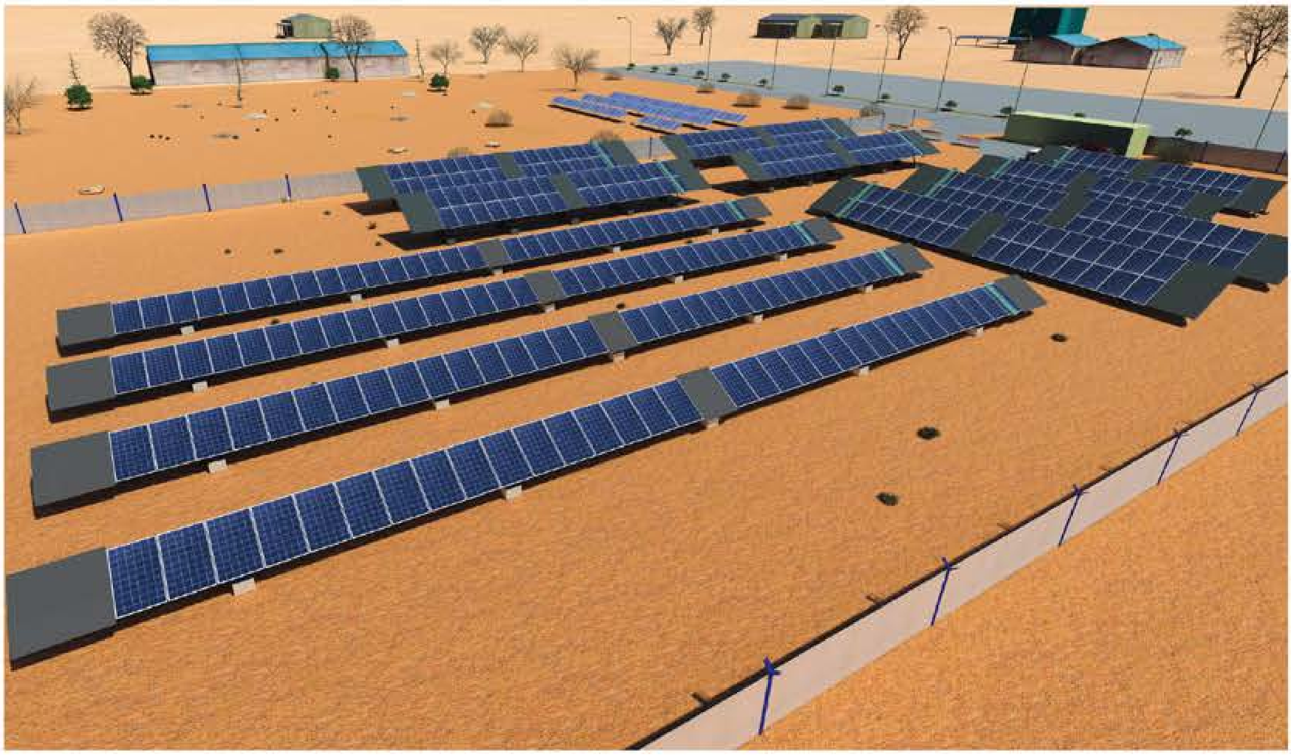

Figure 1: Sketch of the cleaning test field in the DEWA R&D centre with four fixed tables facing south and eight single-axis movable tables. Each table has four strings with 16 modules. Docking stations for the cleaning systems and the space between two strings are coloured grey.

12. Drones for PV Inspection

DRONES BOOST THE SOLAR INDUSTRY

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AI Program Lead
DEWA R&D

The solar power industry has advanced at an exponential rate during the last two decades covering thousands of square kilometres on the earth's surface and maintains a strong growth momentum with a massive need for further expansion. Considering the large surfaces inherently involved in solar power generation installations at urban and industrial levels, the facilitating role of drones that offer a bird's eye view becomes evident. Drones are Unmanned Aerial Vehicles (UAVs) with a wide variety of applications and classification types, depending on their wing type, automation capabilities, endurance, flying range and height, weight, special features, etc. Drones are already transforming selected activities in the solar industry, like topography studies, construction development and final commissioning surveying, as well as periodical inspections during operation. As a result, dozens of start-up companies work in this field, while all large and medium scale solar plant operators are looking to improve asset performance management (APM) in terms of efficiency, reliability, and preventive maintenance using drones. This article focuses on the intersection between drones and the solar power industry by providing a review of applications, benefits, technology drivers and the outlook for this domain.

Drones supported by the appropriate payloads and artificial intelligence (AI) can fly over solar PV panels and capture thermal and visual images for automated anomaly detection and performance monitoring. This application has evolved over the last decade to a competitive level of maturity by detecting cell hotspots, diode issues, bypassed substrings, module failures, cracks, soiling, potential induced degradation and electrical connection problems. Thermographic inspections are typically required on an annual basis, while combined thermal and visual inspections can be insightful on a quarterly and even monthly basis, depending on operating conditions and the level of automation in APM functionalities. Similar services have also been launched recently for concentrated solar power (CSP) plants, especially those using parabolic trough type collectors. An aerial inspection that combines state-of-the-art UAV technology with electro-luminescence (EL) image capture is an emerging technology to support quality control, predictive maintenance and performance evaluation of PV plants. Beyond inspection, drone solutions are currently being developed for PV module cleaning, mainly for remote or hard to access areas.

We highlight the potential benefits of these applications. At first, drones reduce PV plant maintenance costs and operation times. They can provide PV health assessments through thermal inspections at a speed of 10 minutes per MW, while a manual method like the standard I-V curve tracing would need 2-5 hours per MW, which is more than 10 times faster. Similarly, ground inspection technologies are an order of magnitude slower than airborne ones for solar generation plants. Drones achieve high professional standards in image acquisition that enable smooth post-processing and accurate analysis to conclude inspections by means of image processing and customised algorithms. The inspection reports can be automated, and the results can be sent to the technical crew for targeted and effective action using smart dispatching. Furthermore, rapid, comprehensive and automated historical archiving can be implemented by means of drone systems with elaborate sensors, Internet of Things (IoT) technology, complemented with AI and data transfer & storage functionalities. Thus, solar power producers and maintenance service providers can derive baselines of data for future inspections and performance comparisons. Similarly, automated inspections can effectively support contractual and warranty claims to reflect the appropriate standards, such as IEC TS 62446-3 for thermography. Improved accessibility is another great advantage of drone technology for the solar industry. Indeed, solar PV plants are often installed in remote locations, whereas rooftop and floating installations can be particularly challenging in terms of accessibility without a drone.

The technology drivers of drone applications to solar energy systems are summarised in Figure 1. The core driver is the field of drone technology, which has been evolving rapidly in the last two decades. We expect rapid advances in flying range, smooth and highly autonomous flight capabilities, and lift capacity. As shown by Ernst 1997, patent data can offer valuable insights into technological forecasting and thus, Figure 2 (a) depicts the patent count associated with drones by year over the last 10 years. Comparing the shape of this trend with the shape of a likely industrial field lifecycle, the current market status is observed to have surpassed the emerging phase and heading towards full commercialisation.

12. Drones for PV Inspection

The evolution of drone payloads, another important drone technology driver, is constantly adapting to the prevalent drone types and includes sensors (like infrared and visual cameras), actuators (like valves, spraying systems, and robotic arm manipulators) and IoT devices for communications and positioning functionalities.

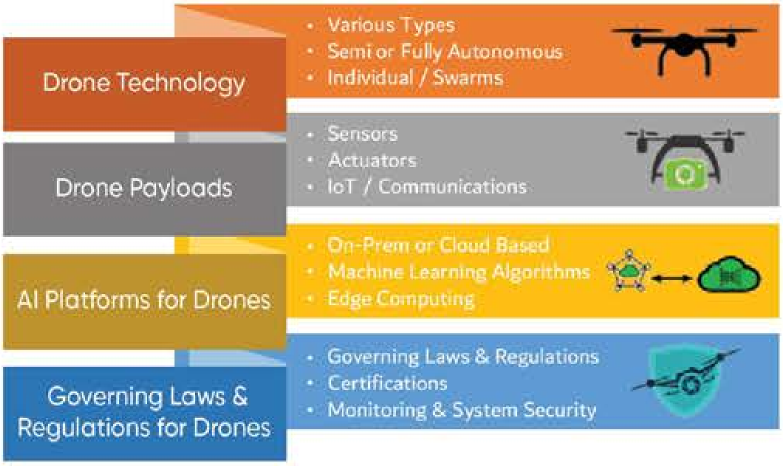
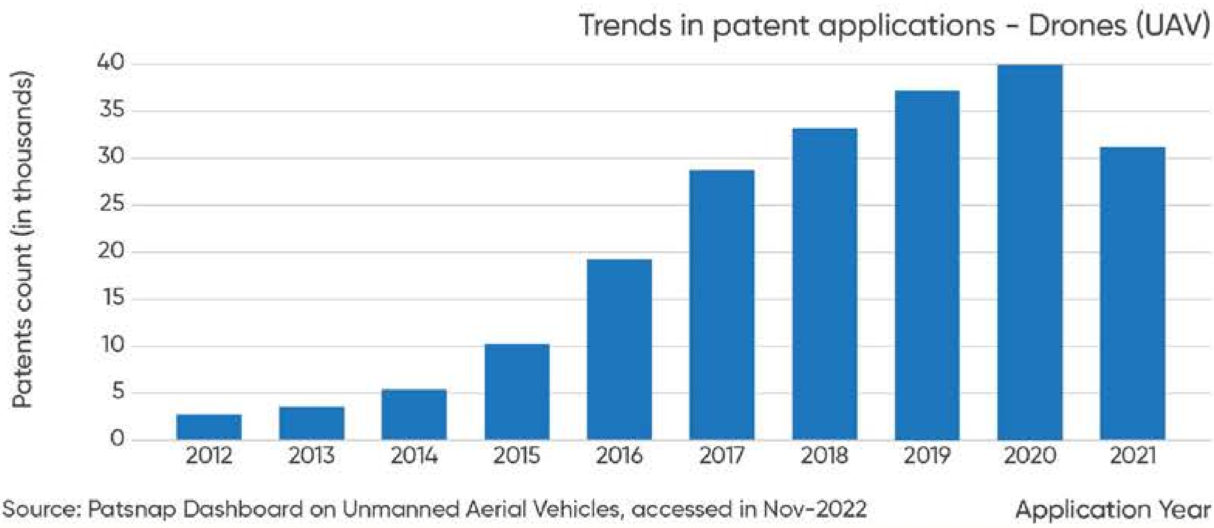


Figure 1. Technology Drivers Behind the Solar Industry Applications of Drones

The third in this stack of technology drivers corresponds to AI and IoT platforms for drones. This architectural solution is instrumental for efficiently managing drone operations and promoting scalability. Such platforms provide control, navigation, storage and extra computational power for drone operations in a user-friendly compact matter. Given the advancement in data transfer technology and the introduction of 5G, real time control is now more reliable, which gives room for most computationally extensive tasks to be transferred to an online server, reducing the computational load undertaken by drone payloads. By shifting computationally intensive tasks to the cloud, like computer vision for navigation, a drone's flight time can be effectively increased.

The last driver for drones refers to governing laws & regulations for drones and directly affects market challenges and opportunities. This entails the development of systems that ensure security in controlling drone flights, risk mitigation, reliable certification processes and the elimination of uncertified activities. Currently, the MENA region features a variety of regulatory frameworks for organisations flying drones that mostly involve strict registration and security clearance requirements.

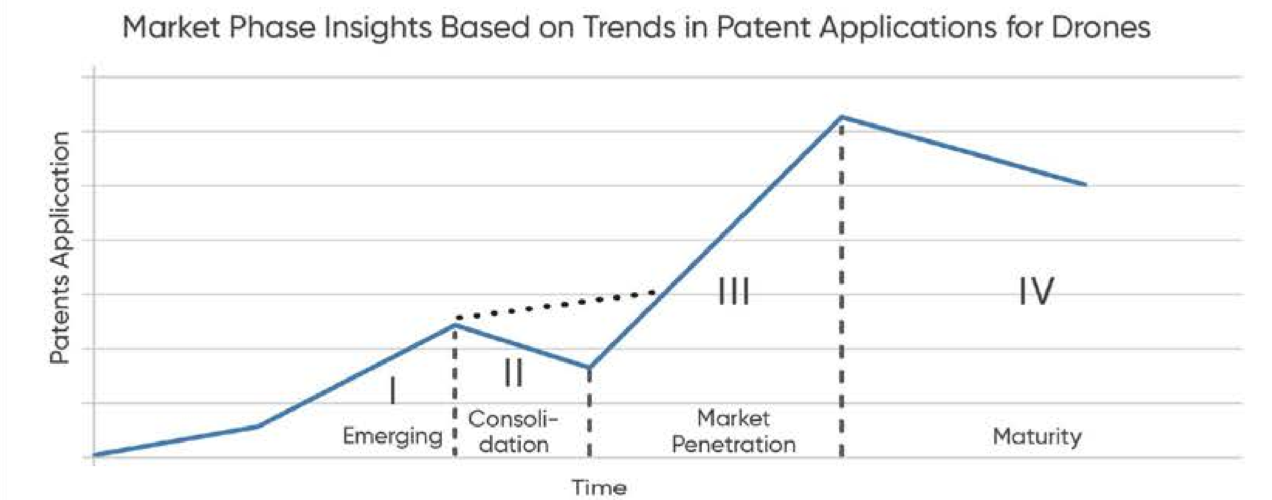


Source: Patsnap Dashboard on Unmanned Aerial Vehicles, accessed in Nov-2022

Figure 2 (a): Market Phase Insights for Drones

12. Drones for PV Inspection

DEWA R&D Centre, strategically located at the Mohammed bin Rashid (MBR) Al Maktoum Solar Park with an expected solar capacity of 5GW by 2030, is testing DRONIMOUS (Figure 3). This fully in-house developed drone-based solution uses thermal and visual images captured by drones with Real-Time Kinetic positioning systems and processed by deep learning to detect soiling, hotspots and other anomalies. Drone-based solar inspection service providers who are keeping abreast of the regulatory landscape and technology advancements have a great outlook, especially if they target economies of scale. Such economies of scale can be amplified either by combining services and clients in areas with a high density of solar generation capacity or by adding similar asset monitoring services like electrical distribution and transmission, agriculture, and more.



Source: Ernst H., "The use of patent data for technological forecasting: the diffusion of CNC-technology in the machine tool industry.", Small Bus. Econ. 1997

Figure 2 (b): Market Phase Insights for Drones

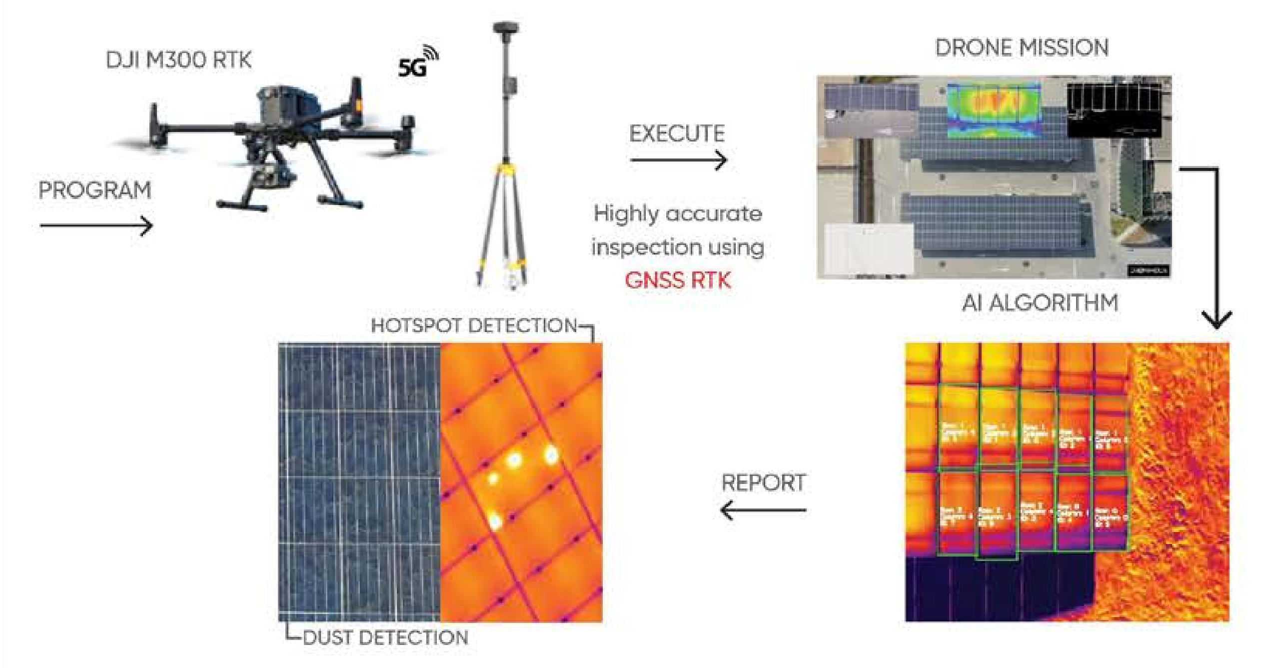


Figure 3. DEWA R&D DRONIMOUS System Overview

ENERGY EFFICIENCY

An Optimized Setpoint Framework for Energy Flexible Buildings in Hot Desert Climates

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Abstract. In Dubai, the rapid increase in electricity demand calls for investment in developing more efficient and enhanced future energy networks. There has been a yearly increase of 10% in both energy and power demand in 2021 compared to 2020. To accommodate the constant growth of energy demand and related carbon emissions, Dubai is implementing an ambitious plan to increase its share of renewables. The Dubai Clean Energy Strategy aims to provide 25% of power output from clean energy by 2030 and 100% by 2050. In addition, Dubai Electricity and Water Authority's initiatives, such as the Mohammed bin Rashid Al Maktoum (MBR) Solar Park and Shams Dubai distributed generation program, have significantly increased solar energy production. However, solar power is intrinsically variable and could affect the stability of the energy system, especially when it accounts for a high percentage of the total generation. In Dubai, buildings are major energy consumers accounting for 80% of the total electricity consumption, and their share is expected to grow due to accelerated urbanization. Energy Flexible Buildings can respond quickly to the grid's dynamic needs. Therefore, it is crucial to evaluate their implementation feasibility and capability to support the stability of the power grid. This article presents a study that utilized thermal models to determine the energy flexibility potential of a building in Dubai. The investigation was carried out using a grey-box resistance-capacitance model of the building. This model was validated against a detailed reference model developed in EnergyPlus. Then, it was used to study different energy flexibility strategies for the building. Two indicators including storage capacity and storage efficiency were utilized to quantify the energy flexibility for a typical day in each month of the year. However, it was observed that there is no significant difference in energy flexibility values between different months of the year. The model was then used to perform a predictive control study of different grid signals for the marginal cost of electricity. It was found that implementing the model predictive control strategies could result in 11% cost savings.

Keywords: Energy Flexibility, Grey-Box RC Model, Smart Buildings, Demand Response.

1 Introduction

The building sector uses about 40% of primary energy worldwide and emits about 39% of carbon emissions [1]. Decarbonizing the building sector is essential for

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Impacts of Photovoltaic Modules on Residential Buildings in Dubai

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***Abstract*—Climate change and fossil fuel depletion have increased the dependency on renewable energy sources. And solar photovoltaic (PV) technology has evolved to step in to fill the gaps. Dubai, the region with abundant sunlight, has emerged as a significant player in the field of solar energy. This work aims to present the impact of PV modules in sample residential buildings of Dubai, exploring how imported energy is affected by the distributed energy in the region. The study uses empirical data from smart meters to provide valuable insights into the role of PV modules in achieving a sustainable energy future for Dubai.**

***Index Terms*—Solar modules, net-zero buildings, smart meters, energy import/export.**

I. INTRODUCTION

Dubai's remarkable growth over the past few decades has led to a substantial increase in energy consumption. The government of UAE has invested heavily in solar power infrastructure not only to meet the energy demands but also to mitigate the environmental impact of conventional energy sources [1]. Apart from having solar plants, the initiatives to have solar modules in the residential building rooftops have opened the door towards net-zero Energy concepts. Thus, this work analyzes how photovoltaic (PV) modules in different residential building types affect the required energy consumption from the grid.

Dubai's commitment to sustainability and green initiatives has been evident in its various projects and policies. The government has encouraged the construction of environmentfriendly buildings through its Green Building regulations and specifications [2], which provide standards for energy and water efficiency, waste management, and sustainable materials. And Dubai has made significant strides towards achieving its goal of having net-zero energy buildings in the city [3], [4]. Shams Dubai [5] is Dubai's Demand-Side Management (DSM) smart initiative program to connect solar energy to buildings in Dubai. As a part of Distributed Renewable Resources Generation (DRRG) program launched by the Dubai Electricity and Water Authority (DEWA) [6], Shams Dubai allows the installation of PVs in residential, commercial, and industrial buildings to generate electricity and to connect them to DEWA's grid [7]. The DRRG regulates building energy generation in Dubai and consists of a process that ensures compliance based on the connection guidelines and technical requirements, including rules for maximum solar module array voltages and power quality such as phase unbalance, harmonics and flicker, and electromagnetic compatibility. Currently, only rooftop PVs are permitted, meaning no ground-mounted PVs are allowed, as there is no regulation for Building Integrated Photovoltaics (BIPVs) [8].

Solar modules can significantly impact energy imports from the grid depending upon various factors, such as the size of the solar modules, their orientation angle, and the amount of sunlight received by modules. Since even a small solar module can impact energy imports, it helps improve the overall energy efficiency of a residential building and relieve stress on the grid. Thus, the main contribution of this paper is to compare the residential units of similar types with and without PVs and analyze these residential units with PVs to determine whether they comply with net-zero energy buildings' criteria. The paper also touches upon the benefits of PVs on Dubai's residential buildings.

The rest of this paper describes the methods and data used in this study in Section II; Section III discusses the results, and Section IV summarizes the overall work presented.

II. METHODS AND DATA USED

The overview of the approach used in this study can be seen in Figure 1.

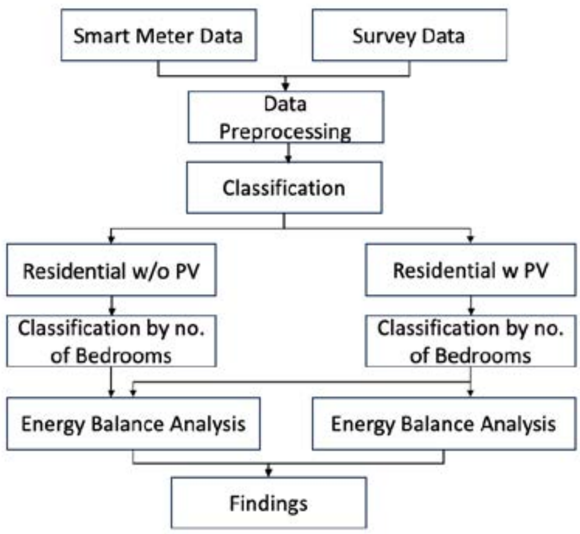

Fig. 1. The Overview of the Approach Use

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Wind Speed effect on the performance of Free-Standing PV Modules in Hot Desert Climate

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***Abstract* — The economic and environment impacts of photovoltaic (PV) modules have made them a suitable clean energy alternative to boost energy transition initiatives. To leverage PV modules at full extent, it is desirable that it has high efficiency. However, increased module temperature is one of the main factors that cause lower module efficiency. Studies have shown that wind has a positive impact on decreasing module temperatures and thus increasing its efficiency. This paper analyzes the effect of wind speed and its direction on south-facing PV module efficiency. One year data was considered for this study which was collected at the outdoor test facility of Dubai Electricity and Water Authority R&D Center. Visual inspection of the sampled data collected in summer and winter as well as transient analysis showed high wind speeds ranging from 6 to 13 m/s coming from south direction can reduce module temperature by more than 8°C. The transient model analysis proved the relation is inversely proportional and nonlinear.**

I. Introduction

With the recent energy transition efforts, the solar photovoltaic (PV) generation increased by 270TWh in 2022, reaching a total generation of almost 1300 TWh [1]. It now holds the larger share of the global energy portfolio that matches with the level envisioned from 2023 to 2030. Maintaining this continuous growth would require massive development in supply chain, increased policy support, and improved electricity outputs from PVs [2]. Site selection is one of the most critical tasks for developing a large, utility-scale, ground-mounted solar PV power plant. Mounting technologies as well as a wide range of environmental, geographical, and climatic factors need to be considered for developing solar PV plants with high average annual power generation and low operational costs [3]. Among these factors, climatic conditions such as solar irradiance, ambient temperature, sun hours, and wind have significant impact on PV module efficiency.

Literature has shown that the efficiency of PV modules decreases with the increased module temperature, accumulation of dust, and partial shading conditions [4]. A study conducted by Deb Mondol et al. [5] noticed a 10% decrease in PV module efficiency due to increased module temperature in summer months. A field study on 5.28kW PV system indicated that an increase in PV module temperature from 35˚C to 60˚C caused 35% reduction in PV performance ratio [6]. Park et al. [7] found that PV panel output power decreases by 0.52% with one degree (1˚C) rise in module temperature. Similar studies conducted in [8], [9] indicated 0.3-0.65% decrease in the efficiency of crystalline silicon modules with (1˚C) rise in module temperature.

To reduce the operating temperatures of the PV system and improve the efficiency and performance of modules, several cooling techniques were experimented with and reviewed in literature. Liquid-based, air-based, radiative and thermo-electric cooling are some of the means explored for lowering the PV system's Temperature[10]. An experimental setup in Alexandria university investigated forced convection as a method to cool of their modules. Using small motor fans directed to the back of the modules resulted in a 2.1% increase in PV panel efficiency [11]. The cooling potential of ventilation air as well as exhaust air from a building were utilized as a cooling fluid in a PVT setup in south of Iran [12]. Results from that experimental setup proved the positive effect of air cooling for enhancing the efficiency of the panels. Water cooling of Polycrystalline Silicon modules through porous gravel was also able to reduce the module temperature by 10°C [13].

Accordingly, any change helping with the cooling of PV modules cause the efficiency of solar PV plants to increase [14], [15]. Natural wind has shown to be an effective way of cooling the PV modules [16]; thus, aiding in increase of PV efficiency. Damon and Alona [2] showed that southern winds increase the electricity generated by PV modules. These studies effectively proved the importance of wind speed and wind direction on improving the PV module output. However, it is not clear how these factors vary for free-standing PV modules in the hot desert climate of the GCC region. Therefore, in this paper, the effect of wind speed and wind direction for free-standing PV technologies are analyzed. Additionally, the variability of these parameters during summer and winter seasons are also discussed. This study would help to answer whether wind speed and its direction needs to be included in climate parameters that are considered during building applications, solar park site selection or design. This study would also help improve PV electricity output predictions by incorporating wind speeds and direction as input features for the models.

The paper is structured as follows. Section II presents materials and methods, where study area, data sources, preprocessing and modeling is discussed. Section III discusses the results obtained through the visual inspection, and transient modeling analysis of natural wind on PV modules efficiency.

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Crystalline Silicon Solar PV Integration in Residential Buildings: Case Studies from Solar Decathlon Middle East

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***Abstract* — The integration of crystalline silicon solar PV modules in the built environment holds immense potential for sustainable development in the Middle East. Optimizing PV performance, however, in the hot and harsh climate presents several challenges. Through the Solar Decathlon Middle East competitions, international university teams demonstrated innovative approaches to enhance the performance of building-integrated c-Si PV systems in the region. This paper investigates the PV systems and unique strategies adopted by the teams to boost energy performance, considering approaches like passive and active cooling, bifacial PV integration, and tracking systems. Besides their key role, implementing these advances can lead to additional benefits such as energy and cost savings.**

I. Introduction

Crystalline silicon (c-Si) Solar Photovoltaic (PV) is a highly reliable technology suitable for a wide range of applications. It currently dominates the global market with approximately 90% penetration and is expected to maintain its dominance in the upcoming years [1]. C-Si PV modules offer numerous advantages, including their long service life, competitive pricing in utility-scale PV mass markets, widespread availability, and continuous technological advancements [2]. Also, despite its low resistance to heat-related performance losses compared to thin film technologies, c-Si PV's high energy efficiency allows it to surpass thin films in terms of overall performance [3]. In addition to conventional rooftop installations, c-Si cells can be integrated into buildings in various ways, such as opaque cladding, glass-glass translucent elements, and laminated roof tiles [4]. These applications are known as Building Integrated Photovoltaics (BIPV).

Globally, BIPV technology is considered one of the most promising contributors to Net Zero Energy Buildings (NZEB) [5]. Due to their flexibility, BIPV elements can be installed in new as well as existing buildings. Besides increasing the surface area for solar collection, their multifunctionality can enhance buildings' aesthetics while reducing the energy loads required for air conditioning and lighting [6]–[8]. Hence, the technology has a high potential in countries like the United Arab Emirates (UAE), with high solar radiation, many medium and high-rise buildings, and elevated energy consumption associated with the cooling systems. Nevertheless, the thermal control of the PV modules and their effect on buildings is crucial to tackle the influence of the harsh hot temperatures in the region [9], [10].

In regions with high solar angles like in the Middle East, the most preferable location for PV integration is the roof [9]. However, due to the limitations of roof space, integrating PV elements into surfaces like walls, balconies, and shading components is an appealing alternative. Moreover, in the northern hemisphere, PV modules' preferred integration orientation is the south. However, recent research conducted in the UAE has shown that, besides increasing energy production, installing PV modules facing east and west can help meet buildings' typical load profile [3].

Solar Decathlon is an international competition created by the US Department of Energy (DOE) for university teams to design, build, and operate grid-connected sustainable solar-powered houses. At the final stage of the competition, the teams assemble their houses in an expo area and open them to the public while undergoing ten different contests in two weeks (Architecture, Engineering and Construction, Energy Management, Energy Efficiency, Comfort Conditions, House Functioning, Mobility, Sustainability, Communication, Innovation). In collaboration with the US DOE, the Dubai Supreme Council of Energy and Dubai Electricity and Water Authority (DEWA) have organized two editions of Solar Decathlon Middle East (SDME) in Dubai in 2018 and 2021. Both competitions hosted remarkable solutions and designs driven by the adaptability to the climate in the Middle East. With solar energy being the primary source of electricity in these houses, all participants in both editions utilized crystalline silicon modules, at least in the main solar PV system of the house. The teams considered different strategies and state-of-the-art solutions to ensure the optimum performance of their PV systems.

In this paper, we are reviewing the advanced crystalline silicon technologies and modules' performance enhancement features adopted by selected teams from both editions of SDME. These houses represent ideal energy-efficient homes for the Middle East.

II. Performance Enhancement of PV in Buildings

The key strategies to achieve optimal performance and output from solar PV modules include maximizing solar radiation intake, choosing appropriate PV technology, and effectively regulating operational temperatures [11]. PV modules' energy production capabilities can decrease drastically in hot temperatures, especially when integrated into buildings [12], [13]. Methods that can regulate their temperatures and enhance their energy efficiency include passive cooling, active cooling,

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Assessment of PV Performance-Enhancing Technologies in Desert Climate Conditions of Dubai

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***Abstract* — Dubai receives 2,200 KW/m2 of global horizontal irradiance (GHI) annually, and its desert areas have an albedo of 0.4, making it an excellent location to generate electricity through photovoltaics (PV). However, it also has extremely hot temperatures in the summer and constant dust. Therefore, this study investigated and compared several performance-enhancing technologies, installation parameters, and site conditions to produce relevant information for improving the behavior of PV plants in Dubai's urban and desert conditions. The results of simulations carried out in the System Advisor Model (SAM). For monofacial modules the energy production is increased using: ideal thermal management by 12% (fixed horizontal); single-axis east-west trackers by 34.2%; and their combination by 52.8%. Fixed-mounted bifacial modules produce 19% more than the base case of horizontally tilted monofacial modules without thermal management, and this type of module in a single-axis tracker achieved more than 54% improvement. Monofacial module mounted over dual axis tracker with thermal management showed the best increment in energy yield of all cases.**

I. Introduction

Global CO2 emissions from energy are approximately 31.5 Gt, adding considerably to the highest-ever average annual CO2 concentration, 412.5 ppm in 2020 [1]. Solar Photovoltaic (PV) technology is critical to countries' decarbonization efforts, and it remains the third most important green energy source after water and wind. Indeed, PV technology is becoming more cost-effective [2] and rapidly growing renewable energy sources. In 2021, its power production increased by 22% over 2020, hitting a record 179 TWh [2].

Dubai experiences year-round (3448 sun-hours) and high solar irradiation (2137 kWh/m^2). Furthermore, there is continued interest and significant investment in developing solar facilities to reach the sustainable development objective of producing 75% of electricity from clean and green sources by 2050 [3]. To meet this target, the Government of Dubai has invested in multiple initiatives, such as the Muhammad bin Rashid Al Maktoum Solar Park, the world's largest single-site solar park with a production capacity of 5000 MW by 2030. By the end of 2022, the solar park's clean energy capacity will have reached 2,027MW, raising Dubai's clean energy production capacity to around 14% of the total electrical energy production capacity. Additionally, Dubai's Shams Dubai program encourages building owners to install PV modules with bidirectional metering [4], resulting in 459GWh excess generation in 2021. These numbers show how Dubai effectively utilizes its solar resources and plans to increase its solar share in the emirate's energy mix.

Investigating the most effective PV performance-enhancing solutions suitable for local climatic conditions will help optimize investment in the solar sector. Kazem [5] conducted a performance evaluation-based experiment on a water-based PV/T system in Oman, showing that the average PV/T electrical power was 6% more than a conventional PV module. Similarly, Li et al. reported a 13-19% improvement in electricity generation from PV/T compared to conventional PV setup in outdoor field tests in Saudi Arabia [7]. Furthermore, Safieh et al. [6] evaluated fixed tilt and single-axis tracking in Dubai with multiple monofacial photovoltaic technologies. The results showed that east-west tracking monocrystalline and thin film, on average, generated 16% and 24% more than fixed-tilt PV modules, respectively. In the desert climate of Saudi Arabia, Castro et al. [8] observed a 15.1% bifacial energy increase in Saudi Arabia. Similarly, Baloch et al. presented a 16.3% gain from conventional bifacial PV setup in Qatar [9]. Unfortunately, the literature lacks generic and consistent studies to evaluate different performance enhancement technologies that provide the most effective technology for Dubai. Therefore, this study aims to analyze and compare different performance enhancement strategies separately and in combination to find the optimal PV configuration and installation parameters for Dubai's climatic conditions.

II. Methods

To investigate and carry out the comparison of the energy benefit using different performance enhancement technologies to increase the performance of photovoltaic modules in Dubai, the authors followed these steps:

1. Study Dubai weather and albedo data.
2. Select the enhancing performance-enhancing technologies and installation parameters.
3. Define the cases combining technologies and installation parameters.
4. Setup the models and run the simulations
5. Analyze the results and contrast them with experimental results.
6. Carry out daily, monthly, and annual comparisons between the cases and analyze the impact of the solutions and parameters on the study.

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Identification of Micro-Defects in Solar Cells using Electroluminescence Images via Hybrid Approach

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***Abstract*—Renewable energy resources can play an important role in significantly offsetting the power demand in most of the world. Being the lowest-cost renewable resource, investment in photovoltaic solar can be prioritized if the reliability of continuous generation is guaranteed. Micro defects in PV cells can reduce the electrical output and if not detected can lead to large-scale power distributions. Therefore, electroluminescence (EL) image is commonly used these days to detect these micro defects and classify the various types of these defects. Hence, a hybrid approach consisting of Alibi detection algorithm is proposed, which makes use of a deep learning-based approach to detect abnormal solar cells. And decision tree is employed for the previously obtained outlier instance score to further classify it into the different kinds of defects present in the EL image of the solar cells. The proposed model is tested on the ELPV image dataset consisting of mono conventional crystalline silicon cells with above 97% accuracy.**

***Index Terms*—Electroluminescence, Alibi-Detect, Outliers, Classification, Decision Tree, Solar Cells.**

I. Introduction

Electricity generation via photovoltaic has shown the second-largest growth of all other renewable energy generation resources, with a record increase of 179 TWh (up 22%) in 2021. Solar PV is currently standing at 1000 TWh generation capacity, and in the right environmental conditions, it can manifest as the lowest-cost electricity generation option [1]. High irradiance plays a key role in having high generation from solar PV but is often accompanied by harsh ambient conditions such as extremely high or low ambient temperature, dust or hail storms, high daily temperature swings, and soiling or snowing issues. The fragile crystalline structure of solar cells can be damaged while operating under these harsh operating conditions. The microcrack developed during the production or installation of PV modules can further aggravate due to these extreme environmental conditions [2].

To assess the performance degradation due to this defect mechanism, a general approach is to take electroluminescence (EL) images of the modules [3], [4], [5]. When a current is applied to the solar cells module, it causes the silicon layer to emit light in the near-infrared spectrum. This light is then captured by specialized cameras. Multiple attempts have been made to automate this process and several techniques are being used to increase the accuracy of the detection. Utilizing machine learning, Demirci et al. [6] successfully detected these defects but the accuracy of the model suffered considerably if the EL images have complex backgrounds. It showed good results in processing EL images with simple backgrounds; however, the accuracy decreased greatly in complex backgrounds. A study performed by Akram et al. [7] utilised optical convolutional neural network (CNN) architecture to achieve 93.02% EL image classification using little computational effort. Tang et al. [8] developed a model that can detect unlabelled defects using an evolutionary algorithm that combines multiple data science tools such as deep learning, deep clustering, and image processing. The proposed model can detect these new defects with greater than 92% accuracy. Acharya et al. [9] performed pre-processing to remove the distortions and noise and used Deep Siamese CNN to provide improved accuracy of classification 74.75% on average. Wang et al. [10] performed a comparative benchmarking, using multiple CNN architectures. They reached the binary classification task of identifying the presence up to 96.17% and performed multiclassification with an accuracy of 92.13% to identify various types of defects. Another study concludes that ResNet18 and YOLO are superior architectures with resulting macro F1 scores of 0.83 (ResNet18) and 0.78 (YOLO). They also claimed that the proposed model can process images with complex backgrounds such as vegetation and other installed PV modules [11].

To summarize applied deep learning tools have satisfactory defect detection and classification. However, this performance is achievable with the availability of a large training dataset. prediction results, however, public solar module datasets are not easily available [12]. Also, the selection of the architecture and algorithm greatly depends on the application and hence this leads to computationally demanding and data-sensitivity models. To address these problems, in this work, researchers have proposed an outlier-based detection model that relies on a newly introduced Opensource algorithm called Alibi-Detect [13]. This algorithm facilities a largely unsupervised wide range of outlier detectors, flexible enough to be customizable for specific application needs.

The following are the main contributions of this study. The hybrid approach is used consisting of CNN architecture of the Alibi-Detect algorithm to detect abnormal solar cells based on the outlier's instance score. Further, the decision tree is employed in this instance outlier score to classify it into different types of defects with significant improvement in accuracy. The images that are categorized as normal are used for training the Alibi-Detect model. Then the test set consisting of different defect types along with normal ones is used for evaluation.

The rest of this paper describes the methods used in this

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Assessment of Photovoltaics Shading Devices (PVSD) Impact on the Energy Generation, Cooling Load, and Daylighting in an Office Building in Dubai

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***Abstract* — This study presents an assessment of the Photovoltaic Systems Shading Devices (PVSD) installed in a Dubai commercial building, in terms of energy generation, and its affects on the daylight and thermal energy performance of the building. The assessment is based on the yearly PVSD energy generation and building energy demand and the daylight performance of different facades during different times of the day and seasons of the year. The results show that in terms of generation, the south façade provides 43.5 MWh of energy. In terms of daylight, PVSD on the south façade reduces the average illuminance in the building to almost half of its value during the summer solstice and march equinox. In terms of thermal energy performance when put on the south facade of this model of a medium office building, offset 68.51% of the cooling load of the south perimeter zone. As predicted the PVSD in the south façade has the most impact in reducing cooling load and amount of daylight within the building, whereas the impact of PVSD on the northern and western facades is negligible, and this study quantifies these impacts.**

I. Introduction

According to the International Energy Analysis Organization (IEA), the production of electricity and thermal energy for buildings accounts for 19% of global energy generation emissions [1]. In Dubai, the residential and commercial sectors account for up to 79.44% of the total electricity generation [2]. It is essential to reduce the higher energy consumption of buildings to counter ever so increasing CO_2 emissions that reached to 31.5Gt in 2021[3].

Dubai, which experiences year-round and high solar irradiation, has launched Shams Dubai, a program that encourages building owners to install PV modules with bidirectional metering, resulting in 459 GWh more generation in 2021 [4]. These figures show how efficiently Dubai manages its solar power resources and how it intends to raise the proportion of solar energy in the emirate's energy mix.

In terms of a building's performance, a well-designed façade that considers local conditions can lead to improved inside comfort and a decrease in energy demand. [5] Investigating the effective Photovoltaic Systems Shading Devices (PVSD) configuration suitable for the local climatic conditions will help optimise investment in the PVSD sector.

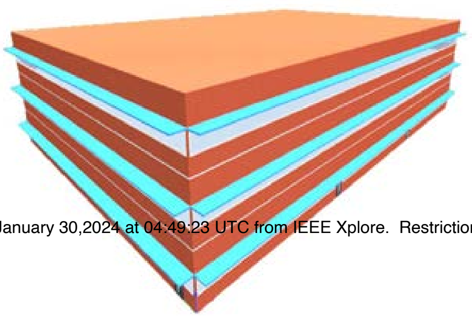
Peres et al. [6] studied the effect of shading devices on the internal thermal load of a building facade in Rio de Janeiro. The results revealed a 14%–19% reduction in cooling loads. Similarly, Baghoolizadeh et al. [7] studied five European cities with various climates and had their energy simulations run using the EnergyPlus software. The findings suggest that choosing the right solar shade can save a building's electricity use by 17% to 34%. Jafari et al. [8] presented a study to evaluate how well photovoltaic shading systems functioned to maximise energy utilisation in Iran. The results demonstrated that the Photovoltaic Shading systems, created with four louvres, a slope angle of 45 degrees, and zero degrees azimuth (facing south), have the maximum efficiency compared to other situations. Literature lacks case studies to evaluate PVSD performance in Dubai and this study aims to provide an initial assessment of a PVSD under the Dubai's climatic conditions.

II. Methodology

The proposed methodology for this study consists of four steps:

1. Select the building case study to test the Photovoltaic Systems Shading Devices (PVSD), as well as the PVSD module itself.
2. Model, simulate, and optimize:
   - *A. The Energy Generation* of the PV modules;
   - *B. The Daylight Performance* of the building;
   - *C. The Thermal Energy Performance* of the building after applying the shading.
3. Analyse the simulation results.
4. Discuss the findings and draw conclusions.

As a case study to apply test the PVSD is chosen the Building Energy Model (BEM) of a medium-sized office building, illustrated in Figure 1, developed by the United States Department of Energy (DOE) [9], part of their developed and calibrated EnergyPlus [10] commercial prototype building models. The building has three floors, and as illustrated in Figure 2, it is modeled applying two types of thermal zones, the core (zone 5) and the perimeter, where the perimeter is divided into four sub-zones, one for each façade. The main dimensions of the office building are summarized in Table I.



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Thermal or photovoltaic rear sides? A parametric comparison between photovoltaic thermal and bifacial technology

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Bifacial
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ABSTRACT

The photovoltaic generation has experienced high growth in recent years. However, more effort is needed to get on track with the net-zero scenario. The use of the photovoltaic modules' rear part can increase their electricity generation by controlling their temperature (hybrid photovoltaic/thermal solutions) or by adding conversion capability to the backside (bifacial modules). However, which solution is more effective in increasing energy yield, and under what conditions? To answer these questions, the authors conducted a worldwide comparative parametric study considering a wide range of site conditions and photovoltaic module specifications. Two relevant results came from the study. The first is a global technical competitive analysis to determine favorable site and module specifications for each rear-side utilization alternative. The second is the mathematical expression of a new parameter named "critical bifaciality," which expresses the minimum bifaciality rate required to obtain a performance superior to similar monofacial photovoltaic-thermal modules. This parameter serves as a design rule for the selection specification of the bifacial system, which depends on both the location's climate and site conditions. It also permits determining the feasible locations for adopting either technology based on electricity production. The study concludes that using bifacial modules is the most effective way to increase electricity generation. For typical site conditions (albedo = 0.3), module specifications (cell efficiency = 20%, and Temperature coefficient (-0.3%/°C), the energy benefit can range from 1 to 5% near the equator and more than 25% near the poles.

1. Introduction

Global CO_2 emissions related to energy are about 31.5 Gt, significantly contributing to the highest-ever average yearly CO_2 concentration in the atmosphere, 412.5 ppm in 2020 [1]. Solar Photovoltaic (PV) technology plays a crucial role in the countries' decarbonization, and it is still the third most significant green energy source after water and wind. Indeed, it is becoming the lowest-cost option for new energy production in most part of the world [2] and is one of the fastest-growing renewable energy sources [3]. In 2021, its power production grew 22% over 2020, reaching a record 179 TWh [2]. However, more effort is needed to get on track with the 2030 net-zero scenario. According to the International Energy Agency (IEA), the annual PV capacity must be more than threefold by 2030 [2].

Increasing the annual capacity of photovoltaics requires the collaboration of all stakeholders, including policymakers, regulators, financing agents, researchers, manufacturers, developers, and investors. The PV capacity shall be increased by adding more PV installation and selecting the more appropriate systems. Researchers around the world have developed several ways to increase the efficiency of PV modules at cell, module, and system levels. In the literature, various techno-economic studies have been carried out to encourage the adoption of efficient PV solutions, such as bifacial technology [4], thermal management [5], advanced device architectures [6], and multi-junction solar cells [7].

Adding a thermal management system to the PV modules' rear side effectively increases their efficiency. Typically, PV systems convert 6–25% of the solar radiation, depending on the semiconductor material and device architecture [8]. Large share of the unexploited solar energy is converted into heat, raising the cells' temperature and lowering their efficiency [9]. This thermal energy can increase the module temperature

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Data-driven key performance indicators and datasets for building energy flexibility: A review and perspectives

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HIGHLIGHTS

- Studies on data-driven methods for building energy flexibility quantification have been reviewed.
- Existing data-driven energy flexibility KPIs have been systematically categorized.
- Various aspects of the KPIs, including application, stakeholder, complexity, data requirements, and popularity, have been analyzed.
- Public datasets for energy flexibility studies have been reviewed and summarized in a standardized data collection process.
- Research trends, open questions, and future opportunities are identified.

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Keywords:
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Demand response
Demand-side management
Building-to-grid service
Key performance indicator
Demand response datasets

ABSTRACT

Energy flexibility, through short-term demand-side management (DSM) and energy storage technologies, is now seen as a major key to balancing the fluctuating supply in different energy grids with the energy demand of buildings. This is especially important when considering the intermittent nature of ever-growing renewable energy production, as well as the increasing dynamics of electricity demand in buildings. This paper provides a holistic review of (1) data-driven energy flexibility key performance indicators (KPIs) for buildings in the operational phase and (2) open datasets that can be used for testing energy flexibility KPIs. The review identifies a total of 48 data-driven energy flexibility KPIs from 87 recent and relevant publications. These KPIs were categorized and analyzed according to their type, complexity, scope, key stakeholders, data requirement, baseline requirement, resolution, and popularity. Moreover, 330 building datasets were collected and evaluated. Of those, 16 were deemed adequate to feature building performing demand response or building-to-grid (B2G) services. The DSM strategy, building scope, grid type, control strategy, needed data features, and usability of these selected 16 datasets were analyzed. This review reveals future opportunities to address limitations in the existing literature: (1) developing new data-driven methodologies to specifically evaluate different energy flexibility strategies and B2G services of existing buildings; (2) developing baseline-free KPIs that could be

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Review article

Current status, challenges, and prospects of data-driven urban energy modeling: A review of machine learning methods

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A B S T R A C T

Urban energy modeling is essential in planning electricity generation and efficiently managing electric power systems. Various urban energy models were developed for several energy-driven applications, including emission reduction, retrofit analysis, and forecasting. Electricity load forecasts help to estimate the load demand and effectively aid in power system operation and balancing. The accuracy of load forecasts at high temporal and spatial resolution can impact system planning and operation. Therefore, it is essential to know the factors that affect the accuracy of these forecasts and how they can be improved regarding the current state of the art. This article reviews the recent literature on data-driven electricity load forecasts in three steps. First, different phases of the review process are explained to select and analyze recent literature on machine learning-based short-term load forecasts. Then various aspects of load forecasting techniques have been reviewed, addressing their advantages, disadvantages, temporal resolution, and performance. Finally, the review covers the current challenges in load forecasting and describes the reasons for performance degradation and lower accuracy. Based on the reviewed literature, it was found that temperature, user load profiles, and proper management of input data highly affect load forecast accuracy. In addition, shortcomings of existing performance evaluation metrics make the applicability of those techniques questionable. Finally, we conclude the review by highlighting the necessary actions to improve load forecast accuracy that are relatively unexplored and can be used as a reference for future research on accurate load forecasts.

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Quantitative assessment of the HVAC system of zero-energy houses of the Solar Decathlon Middle East 2021

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Abstract

HVAC systems consume up to 50% of the total energy demanded by buildings. This paper aims to provide quantitative assessment of the HVAC solutions used on the highly efficient houses competing in the Solar Decathlon Middle East 2021. This international competition challenges university students to design, build, and operate sustainable zero-energy houses. The analysis includes the system selection, capacity, and coefficient of performance (COP), as well as the monitored indoor temperature, relative humidity, and CO_2 levels. The university teams' selection capacity (systems availability) and budget were affected by the COVID-19 pandemic. However, they designed their houses to respond appropriately to arid climates and reduce HVAC consumption. The study evaluates the HVAC solutions of all eight projects, providing more information about the four top-ranked teams. Most homes use air-to-air, decentralized, and multizone air-conditioners. The teams made the best effort to select systems that significantly exceed the COP required by the local regulations. Some also exceed the local energy codes regarding refrigerants' global warming potential. The average COP (at T1 i.e., Moderate Climate Conditions) of air-to-air systems was 3.71 kW/kW, and the air-to-water system was 3.42 kW/kW. The lower installed cooling capacity per area of air-to-water HVAC systems was 57 W/m^2 and 122 W/m2 in the air-to-air ones. In several cases, the HVAC systems' consumption was affected by the short assembly period (15 days), nonprofessional student construction, and the lack of a testing period before starting the competition. Nevertheless, these houses exhibited excellent performance, and their analysis brought relevant lessons for buildings in arid climates.

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Power Engineering, ICPE, 2022.

Keywords: Zero-energy; HVAC; Solar decathlon; Arid climate

1. Introduction

The energy impact of Heating, Ventilation, and Air Conditioning (HVAC) systems is significant in the overall consumption of buildings around the world, accounting for up to 50% of their total energy use [1–3]. This percentage

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sustainability

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Article

Sustainable Off-Site Construction in Desert Environments: Zero-Energy Houses as Case Studies

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Abstract: The construction industry is one of the largest consumers of natural resources, and the building sector accounts for around 40% of energy consumption and CO_2 emissions. To contribute to the need for more sustainable solutions, this research analyzed and highlighted the benefits of off-site construction, utilizing eleven zero-energy prefabricated houses from the Solar Decathlon Middle East competition as case studies. The study used construction data documented by the competition organizers, such as drawings, manuals, photos, and in-person observations during the assembly process. The comparative analysis focused on the construction categories, types of solutions, structural materials, façade types, and building materials. The case studies featured both heavy and lightweight construction and three types of off-site construction: panelized, volumetric, and hybrid. The hybrid construction was the most utilized since it combines the advantages of less intensive on-site work of the volumetric solutions with the transportation benefits of 2D elements. The designers justified their selection of timber as a structural material based on its low environmental impact. In addition, they enhanced the environmental benefits of off-site construction by selecting eco-friendly materials and solutions that increase the efficiency of the houses.

Keywords: modular construction; prefabricated houses; off-site construction; sustainable construction; zero energy; solar decathlon

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1. Introduction

The building construction industry has a high environmental footprint due to its high energy consumption, high rates of GHG emissions, waste, elevated health and safety risks, and high cost [1,2]. In 2020, this industry was responsible for 6% of global final energy usage and 10% of energy-related CO_2 emissions [3]. On the other hand, as Figure 1 shows, buildings accounted for 30% of global final energy usage and 27% of energy-related CO_2 emissions. Therefore, the construction and building sectors have become priorities for addressing climate change [4]. In addition, the need for new buildings is increasing due to rapid urbanization and population growth. This means that unless there is a change in the construction industry, their energy demand and associated GHG emissions will also increase [3]. This fact is noticeable, especially in the Middle East, which has had one of the fastest-growing urban populations in the world in the last few decades [5].

Developing more restrictive building codes, requiring nearly zero-energy buildings (on the path towards zero-energy ones), is crucial for maintaining a country's competitiveness, securing energy supplies, and reducing the built environment's carbon emissions. There are several definitions of nearly and zero-energy buildings and two of them are most widely recognized. The European Parliament and Council of the European Union published one, and the United States Department of Energy created the other [6,7].

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energies

Article

Understanding Energy Behavioral Changes Due to COVID-19 in the Residents of Dubai Using Electricity Consumption Data and Their Impacts

Prajowal Manandhar, Hasan Rafiq, Edwin Rodriguez-Ubinas *, Juan David Barbosa, Omer Ahmed Qureshi, Mahmoud Tarek and Sgouris Sgouridis

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Abstract: The building sector consumes as much as 80% of generated electricity in the UAE; during the COVID-19 pandemic, the energy consumption of two sub-sectors, i.e., commercial (50%) and residential (30%), was significantly impacted. The residential sector was impacted the most due to an increase in the average occupancy during the lockdown period. This increment continued even after the lockdown due to the fear of infection. The COVID-19 pandemic and its lockdown measures can be considered experimental setups, allowing for a better understanding of how users shift their consumption under new conditions. The emergency health measures and new social dynamics shaped the residential sector's energy behavior and its increase in electricity consumption. This article presents and analyzes the identified issues concerning residential electricity consumers and how their behaviors change based on the electricity consumption data during the COVID-19 period. The Dubai Electricity and Water Authority conducted a voluntary survey to define the profiles of its residential customers. A sample of 439 consumers participated in this survey and four years of smart meter records. The analysis focused on understanding behavioral changes in consumers during the COVID-19 period. At this time, the dwellings were occupied for longer than usual, increasing their domestic energy consumption and altering the daily peak hours for the comparable period before, during, and after the lockdown. This work addressed COVID-19 and the lockdown as an atypical case. The authors used a machine learning model and the consumption data for 2018 to predict the consumption for each year afterward, observing the COVID-19 years (2020 and 2021), and compared them with the so-called typical 2019 predictions. Four years of fifteen-minute resolution data and the detailed profiles of the customers led to a better understanding of the impacts of COVID-19 on residential energy use, irrespective of changes caused by seasonal variations. The findings include the reasons for the changes in consumption and the effects of the pandemic. There was a 12% increase in the annual consumption for the sample residents considered in 2020 (the COVID-19-affected year) as compared to 2019, and the total consumption remained similar with only a 0.2% decrease in 2021. The article also reports that machine learning models created in only one year, 2018, performed better by 10% in prediction compared with the deep learning models due to the limited training data available. The article implies the need for exploring approaches/features that could model the previously unseen COVID-19-like scenarios to improve the performance in case of such an event in the future.

Keywords: COVID-19; lockdown; electricity consumption; behavioral analysis; machine learning

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1. Introduction

COVID-19 has challenged the traditional ways of living and interacting worldwide since the World Health Organization (WHO) declared a COVID-19 pandemic on 11 March 2020. COVID-19 has become a global health concern and has changed how people live and work, affecting their lifestyles. The 21st-century pandemic condition has introduced

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BUILDING STRUCTURES AND MATERIALS

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Thermal performance of 3D concrete printed walls: calculated and in-situ measured U-values

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ABSTRACT

Buildings with excellent thermal performance offer numerous benefits, including reduced energy consumption for climatization, minimized environmental impact, and enhanced comfort for occupants. In regions with extreme temperatures, like the United Arab Emirates (UAE), the importance of thermal efficiency is even more pronounced. Therefore, this study evaluates the thermal performance of two 3D printed structures in the UAE by employing experimental and theoretical analyses of their U-values following ISO 9869:1 and a thermal bridge analysis in accordance with ISO 6781. The investigated 3D printed structures utilized different insulation approaches, which led to valuable conclusions. Uninsulated large cavities in 3D printed walls adversely affect their thermal performance. Filling these cavities with insulating materials could reduce the U-value by up to 60%. Similarly, adding a continuous exterior insulative layer improves the U-value while minimizing thermal bridge risk. Thermal bridges were most problematic at the joints between 3D printed sections, embedded structural elements, and around doors or windows. These insights underscore the significance of thermal optimization and advocate for the adoption of 3D printing in construction to achieve energy conservation and environmental responsibility. Implementing the study's conclusions can potentially drive the development of more energy-efficient 3D printed buildings.

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Thermal transmittance; 3DCP; thermal bridges; 3D printed building; concrete

1. Introduction

The rapid growth of urbanization and population worldwide has led to an increased demand for buildings. However, this surge in construction also raises concerns about the extensive energy consumption and environmental impacts associated with the industry. Construction materials alone account for up to 10% of global energy consumption and approximately 40% of solid waste and greenhouse gas emissions (Al-Haidary 2018)– (Wong and Zhou 2015). In hot climate countries like the United Arab Emirates (UAE), energy consumption is further intensified due to factors like material manufacturing, solid waste, emissions, and the extensive use of cooling systems, which consume about 70% of electricity in commercial, residential, and governmental buildings (Afshari, Nikolopoulou, and Martin 2014; Al-Haidary 2018). Energy conservation codes have become a priority for governments to address these challenges. It has also been helpful to implement international green building rating systems like LEED and BREEAM and local ones such as Estidama and Al Safat in the UAE. While energy conservation is frequently focused on active factors like HVAC and lighting systems, passive solutions such as optimized buildings' envelopes, shading, and natural ventilation play a significant role in reducing buildings' energy consumption.

In recent years, 3D concrete printing (3DCP) technology has garnered significant interest. This technology offers notable environmental benefits, cost and waste reductions, and the ability to precisely create unique and complex geometric structures (Mohammad, Masad, and Al-Ghamdi 2020). By using the process of contour crafting, 3DCP builds concrete structures layer by layer through a digitally controlled nozzle, allowing for the use of different consistencies of concrete. Studies have demonstrated impressive reductions in cost, CO2 emissions, and energy consumption achieved through 3DCP (Mohammad, Masad, and Al-Ghamdi 2020). However, despite its promising advantages, the 3DCP industry still lacks standardized guidelines. It also requires further research to optimize its thermal characteristics, especially under extremely hot weather conditions, such as those prevalent in the UAE (Alchaar and Al-Tamimi 2021).

Thermal insulation is a crucial aspect of reducing energy consumption in buildings, and it is determined by thermal resistance (R-value) and thermal

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Analysis of residential electricity consumption patterns utilizing smart-meter data: Dubai as a case study

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ABSTRACT

Analyzing residential load profiles and usage patterns is critical to making better decisions for demand-side management initiatives and designing strategies to get more people interested in energy savings. Therefore, analyzing load profiles, it is crucial to know how hourly consumption varies during summers, winters, weekdays, and weekends. In addition, determining the influence of occupancy, dwelling size, and building topologies on consumption is equally important to build predictive models. Therefore, this paper presents detailed research on the electricity consumption and profiles of the residential sector in Dubai based on the dwellings' characteristics and 15-minute resolution smart meter data. The data utilized includes the cooling systems, the number of occupants, and the physical characteristics of a dwelling, such as its typology, sizes, and number of bedrooms. First, using the K-Means clustering method, the authors grouped the households based on their consumption profiles. Second, the consumption patterns of each group of households were identified and organized based on similar consumption profiles over 24 h. Third, the authors applied several classification algorithms to assess the potential of using dwellings and occupants' characteristics to predict the patterns with which each household is associated. The analysis of consumption patterns showed that 43% of households with cooling included in their bills had the global peak demand at midnight during weekdays and weekends in summer. However, the global peak demand for cooling-excluded households occurs from 7:00 to 10:00 pm on weekdays and, in some specific cases, on the weekends, as early as 10:00 am. Finally, the methods used for classification were able to identify key characteristics driving the patterns of electricity demand and were well suited to this predictive modeling context.

1. Introduction

The global residential electricity sector consumed over 13,000 terawatt-hours (TWh) at the start of the 21st century and steadily grew by approximately 3,000TWh every five years [1]. Similarly, the United Arab Emirates (UAE) consumed 38 TWh in 2000 and had similar growth characteristics with increments of 15 TWh in the first five years, doubling this figure over the next five years to reach a total consumption of 124 TWh in 2020 [1]. However, the UAE energy infrastructure has been stressed due to rapid economic and population growth over the last decade [2]. Therefore, planning for this expansion and implementing sustainable energy strategies that reduce the stress on the grid is vital for the country's future development [3]. Furthermore, apart from sustainable strategies, analyzing energy consumption patterns of households and identifying consumers with similar needs and behaviors is critical for shaping demand-side policies [5].

Energy consumption in residential buildings represents a significant share of total energy consumption, about 27.4% in the European Union [6] and about 30.4% in Dubai [7]. Traditionally, utility companies collected, processed, and stored consumption data solely for billing purposes. Therefore, such data was summarized on a monthly resolution which masked daily, hourly, or even higher frequency trends [8]. Technological advancements and dynamic market policies have enabled consumption data collection at a higher resolution, such as hourly or even finer minute level [9]. Dubai Electricity and Water Authority (DEWA) supported Dubai's 'smart City' initiatives of 2015 [10] by installing smart meters that enabled collecting data via a Radio Frequency-mesh (RF-mesh) communication system and providing a complete history of consumption. Analyzing high-resolution smart meter data helps define energy-saving plans and policies at the authority level, the demand-side response at the distribution level [12], and identifying energy efficiency strategies at the consumer level [13].

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PERFORMANCE LIMITATION OF UTILITY SCALE BATTERY STORAGE SYSTEM: CASE STUDY

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***Abstract*—The deployment of utility-scale battery storage systems is rapidly expanding to facilitate the seamless integration of renewable energy sources into the electrical grid. However, these systems encounter a range of performance constraints, influenced by factors such as temperature, size, and technological limitations, which can have an impact on their operational efficiency and capacity. To ensure optimal performance of BESS, it is essential to establish a comprehensive understanding of the capabilities and constraints of BESS technology, particularly in areas with environmental conditions resembling to those in Dubai. This paper showcases the complete deployment of a Sodium-Sulfur battery storage system seamlessly integrated into the grid, providing essential support to the Photovoltaic (PV) plant generation in Dubai. The study is focused on evaluating the system's performance by testing a range of operational conditions and detecting any potential limitations. The findings from these tests have been thoroughly examined and are detailed within this paper.**

***Index Terms*—Battery storage, operation mode, PV system, energy shifting, energy and power derating, NAS battery storage.**

I. Introduction

Renewable energy sources like wind and solar power are becoming increasingly popular as a way to lower greenhouse gas emissions and combat climate change. However, these sources can be sporadic and difficult to predict, which poses a challenge for the grid operators, who must balance energy supply and demand in real-time [1]. Utility-scale battery storage systems have emerged as a promising solution, allowing excess energy to be stored during periods when electricity usage is low, and the subsequent discharge of stored energy during high-demand times. As of the conclusion of 2021, the total capacity of grid-scale battery storage systems had reached nearly 16 GW, with the majority of newly installed capacity coming from lithium-ion battery storage [2]. Although battery storage systems hold promise for facilitating a more sustainable and resilient electricity grid, utility companies have been hesitant to adopt these systems due to various considerations that have caused delays. These include concerns about cost, battery degradation over time, and potential environmental impacts [3]–[5]. In order to implement utility-scale battery storage systems effectively, it's essential to have a grasp of the strengths and weaknesses of various battery storage technologies. The cost associated with utility-scale battery storage systems has posed a significant obstacle for their widespread adoption, despite their potential to improve the reliability, resiliency, and efficiency of the power grid. Several studies have examined this issue and proposed various solutions to address the cost challenge. According to study conducted by authors in [6], it was found that the cost of lithium-ion batteries, the most commonly used battery technology for utility-scale storage will keep declining in upcoming years. Authors in [7] suggested that further cost reductions can be achieved through continued research and development, scaling up production, and improving manufacturing processes.

Another performance limitation is the degradation of battery cells over time. All battery storage systems have a limited lifespan, and their ability to store and discharge energy decreases as they age. This can lead to a decrease in the overall system capacity, energy storage capacity, and power capability [8]. Battery degradation over time is a well-known issue in energy storage systems, and several studies have been conducted to investigate this issue on operational aspects and market implications. Authors in [9] examined how battery degradation impacts the real-time operation, financial aspects, and overall performance of BESS in the energy sector. The study's findings suggest that battery degradation can significantly diminish BESS's role in the energy market. However, the participation of BESS in reserve and regulation markets

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Improved NaS Battery State of Charge Estimation by Means of Temporal Fusion Transformer

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***Abstract*—The stability of the grid is being challenged by the increasing penetration of renewable energy resources for green and diversified power generation, as well as for the reduction of CO2 emissions. The installation of battery energy storage systems (BESS) to support intermittent and variable renewable energy generation is a promising solution and Sodium sulfur (NaS) batteries have shown an outstanding performance for energy-intensive and high utilization BESS solutions due to their low cost and long lifecycles. The ability to accurately estimate the battery's state of charge (SOC) at all potential utilization scenarios is a critical element of the effective BESS operation. Despite the considerable number of studies available on the SOC estimation of lithium-ion BESS for improved battery management systems (BMS), there is scarcely any literature about the challenges and methods for the SOC estimation of NaS batteries. This work highlights the challenge of reliable SOC assessment in NaS BESS by means of a pulse charge/discharge test, introduces a methodology to refine the SOC values collected from an associated BMS / SCADA system and proposes a data-driven approach for the corresponding SOC estimation using a Temporal Fusion Transformer model. After the application of hyper-parameter tuning, this state-of-the-art deep learning (DL) model demonstrates an R-square (R2) value of 0.997, which is superior to the R2 of 0.987 achieved by a recurrent neural network / long short-term memory (RNN/LSTM) DL architecture.**

***Index Terms*—Deep learning, deep neural network (DNN), state-of-charge (SOC) estimation, sodium sulfur (NaS) battery.**

I. Introduction

Battery energy storage systems (BESS) are gaining momentum as important components in power distribution grids due to their ability to provide a variety of grid services and accommodate the variable and intermittent behavior of renewable generation resources [1], [2]. However, performance and capacity degradation due to aging and unfavorable operating modes are inevitable in stationary electrochemical BESS [3], [4]. Therefore, the state of charge (SOC) is a crucial parameter that indicates the battery remaining capacity and needs to be continuously and accurately tracked by battery management systems (BMS) for optimizing the battery's performance and extend its lifetime [5]. Even for mature BESS technologies like lithium-ion, the accurate and reliable SOC estimation across a wide range of operating conditions is challenging and can only rely on indirect methods, as presented in the literature [6].

SOC estimation methods vary depending on the battery type [7] and can be classified into three categories: non-model-based or direct measurement [8], [9], model-based methods [10], and data-driven methods [11]. The direct measurement class involves a variety of measurement methods, such as the open circuit voltage (OCV) [12], the ampere-hour (Ah) integral [13], and the internal resistance [14]. Under certain circumstances, the OCV method can provide decent accuracy, although it faces serious challenges in non-equilibrium states [12]. As the electrolyte inside the battery is distributed uniformly, the battery takes a long time to reach the point of balance which makes it difficult to measure OCV in real time [15]. Another way to measure SOC is by using the Ah integral, or Coulomb counting method, which integrates battery current over time. However, this method also lacks accuracy due to errors in the determination of initial parameter values, open-loop nature, charge/discharge hysteresis effects, and sensitivity to noise and drift of current sensors [16].

The group of model-based methods includes state observer and filter-based methods, depending on the underlying control principle [10]. State observer methods are suitable for high model uncertainty, although their development is rather complex. On the other hand, filter-based methods first apply filters to eliminate noise and then estimate the state of the system. By combining battery models with a closed-loop SOC estimation iteration process, filter-based methods are considered reasonably accurate and practical for real-time implementations.

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Integration of Distributed Energy Resources into a Virtual Power Plant–A Pilot Project in Dubai

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***Abstract*—The high penetration of Distributed Energy Resources (DERs) brings new challenges in the operation of the power grid such as generation-demand imbalance, voltage violations, reverse power flow, etc. To address the aforementioned challenges, Virtual Power Plant (VPP) can be used, which would be best deployed as a cloud-based system due to its ease of implementation, scalability, and ease of service and support. VPP can effectively integrate, aggregate, optimize, control, and dispatch various Behind-The-Meter (BTM) DERs to support grid operations. Therefore, this work discusses the integration and control of DERs such as rooftop solar PV, electric vehicle charging stations, flexible loads, and battery energy storage systems (BESS) through a VPP platform that has been implemented on a pilot scale in Dubai. The connectivity of the VPP with DERs has been established using an Internet of Things (IoT) gateway as well as cloud-to-cloud communication via REST application programming interface (API). The test results are presented to show the response of various DERs based on the instructions through the VPP platform. The current work forms the basis for future work to scale up the VPP connectivity with DERs on a larger network and evaluate the best-suited VPP use cases for the Dubai power network.**

***Index Terms*—Virtual Power Plant, DERs monitoring and control, distributed energy resources, electric vehicles, battery energy storage system, flexible load, PV system, IoT Gateway**

I. Introduction

Electricity generation from Distributed Energy Resources (DERs) such as wind, and solar has seen significant growth in the last decade. This growth is due to the cost reduction of the technology used for the manufacturing of these resources [1]. However, the intermittent nature of DERs and the lack of their visibility to the network operator make them challenging to integrate into the grid. A number of challenges may be introduced to the grid if not controlled such as generation-demand imbalance, voltage variations, reverse power flow, etc. [2]. The continuous increase of DERs calls for new solutions to facilitate their integration into the network. Not only that, but solutions to make use of these DERs as additional resources to provide services in the distribution network for improved network operations [3]. A digital solution based on the concept of a Virtual Power Plant (VPP) is one of the solutions that is used by utilities and aggregators to provide such services. VPP enables the management of the distribution network as active instead of passive in the framework of Active Network Management (ANM) [4]. A VPP consists of a digital platform that manages multiple DERs, such as rooftop solar panels, battery energy storage systems, electric vehicles, controllable loads, etc. to be aggregated and managed as one single source or a plant operating as a single entity [5]. As far as the network operators are concerned, they will only know the aggregated amount of available resources and they will only request the total required load/generation reduction or increase in order to bring the network into its operational constraints. In case of network violations, VPP would receive the instruction signals from the system operators and would dispatch the set points to the assets to meet the requirements of the system with an optimized schedule or instructions [6]. With the advancements in control, measurement, and communication technologies, VPP can communicate to a variety of DER assets using different communication protocols such as Modbus TCP/IP, Modbus RTU, DNP3, XML, BACnet, etc. The connection and communication to assets can be done locally at the edge using IoT gateways or can be connected using the digital platform of the VPP where it communicates and fetches the data using Rest-API to another digital platform through cloud-to-cloud configuration [7]. VPP has been studied in the literature, where most of the research has focused on determining the best operational strategies for a VPP when participating in grid support services. Authors in [8] proposed a method to provide voltage regulation support along a distribution line by using the VPP paradigm. A scheduling method for the optimization of EVs has been summarized in [9] to address the constraints associated with EVs integrated into VPP. A thorough analysis of VPP structure and functionality is discussed in [10] which covers a detailed overview of the VPP framework and its application in the energy industry. Authors in [11] discussed a mechanism for a VPP, which consists of PV and BESS to take part in the ancillary service market. Similarly, authors in [12] have discussed the information and concepts that can aid in comprehending the function of VPPs in power systems and their interaction with the power market. Despite the considerable number of studies available on the role of VPP in the deregulated energy markets where retailers and aggregators can take part in providing grid ancillary services, there is scarcely any literature which lays emphasis on the challenges linked with the integration and communication of DERs with VPP platform in a vertically integrated environment. This paper focuses on the integration methodologies of DERs integrating real assets that are owned by customers (behind the meter). We have tested the response of these assets using a VPP platform such as active power control, demand response, and smart charging. The testing of these assets has been done in Dubai for a vertically integrated utility. The assets

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Real-time Condition Monitoring and Diagnostic Solution for Utility-scale Inverters and Distribution Transformers

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***Abstract*—Due to the need to decarbonize the power industry, distributed energy resources (DER) integration and penetration are increasing annually at unprecedented levels. This decarbonization will be enabled by the connection of inverter-based DER (IBD) technologies as well as the required distribution transformers(DT) to connect the inverters to the grid. Failure of these critical equipment, namely the inverters and DT, may lead to the partial or complete loss of the DER as a source or enabler of renewable generation. This paper tests and validates a real-time condition monitoring and diagnostic solution that can be used for utility-scale inverters and DTs. The solution is based on IoT edge processing technology and cloud-based data analytics, offering ease of integration, implementation, and scalability. The data analytics estimate in real-time the severity level of the asset condition using a mathematical model of the asset combined with the extended park vector approach (EPVA). This is a generic approach that could be applied to assets owned by utilities or assets owned by developers like PV generators and battery energy storage developers. In this paper, we tested this approach on two critical assets associated with the NaS battery energy storage system (BESS): DT and inverters. NaS BESS installed at the 13 MW PV plant in Dubai. This approach is a real-time monitoring and diagnostic solution for condition-based monitoring of critical assets. This is part of the utility strategy to study the effectiveness and move towards a data-driven and predictive maintenance approach.**

***Index Terms*—Real-time monitoring, condition monitoring, diagnostics, utility-scale IBD, inverter, distribution transformer**

I. Introduction

Power system reliability is of the greatest priority in the evolving electric power sector because of the heavy stress placed on transmission and distribution assets, which gave rise to asset management [1]. With proper asset management, Equipment failure risk is decreased, equipment life is increased, and the occurrence of unplanned outages is decreased. It is the systematic process of upgrading, operating, and maintaining assets with minimum investment. Asset management describes each asset's intended maintenance, asset replacement, and contingency plans, as well as the expenditure associated with each of these plans. Ageing assets, uncertainty in load demand profiles, renewable energy resources, and demand management make optimal grid maintenance and operation challenging [2]. The asset maintenance strategy is generally classified into scheduled and reactive maintenance. The proactively planned actions that ensure the health of the asset is called scheduled maintenance. While reactive maintenance is the repair action caused by asset failure. Scheduled maintenance provides support towards achieving the reliability targets and also offers significant maintenance cost reductions that may happen due to sudden faults. Reactive maintenance causes costly outages and huge repair costs for utilities[3]. This is the worst maintenance strategy could be adopted by any utility. Scheduled maintenance is a time-based maintenance strategy that allows the detection of defects between examinations. Due to the gap in time between the inspections faults may be triggered if not detected during the inspection time. For this reason, utilities are switching their maintenance strategy from scheduled to Condition-Based Maintenance (CBM). This is carried out by utilizing sensors, communication technology such as IoT, and data analytics solutions. CBM aims to prevent significant asset damage by continuously monitoring and analysing signals from assets leading to the detection of early signs of failure. The data analysis could be used to provide insights into the conditions of the asset to decide on the repair action and the time of this action to be executed by the asset management team. Moreover, CBM would also provide a cost-effective solution to the utility in prioritizing the assets to be inspected. This would complement their current scheduled maintenance strategy offering an optimized utilization of the available resources.

Numerous studies exist on online health and condition monitoring of various power network assets. Examples of these online and offline analyses are Dissolved Gas Analysis(DGA), Partial Discharge (PD) test, thermal monitoring, etc. DGA involves testing the gases present in the oil to detect any potential faults within the transformer. However, its application is limited by factors such as manual handling of fault data, lack of severity information about the failure, etc [4]. A partial discharge test is done to find any defects or weaknesses in the insulation of oi-immersed transformers, which helps prevent downtime and ensures reliable operation[5]. However, this would require specialized equipment and trained personnel to perform the tests accurately and interpret the results correctly. Moreover, thermal monitoring of transformers involves measuring and analyzing temperature data at various points at the transformer to detect any abnormal temperature rise that could indicate a potential fault[6]. This however cannot provide

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Utility Scale Battery Energy Storage Modes of Operation implemented in Dubai

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***Abstract*—The integration of renewable energy sources into the power system is greatly facilitated by the use of Energy Storage Systems (ESS). In addition to providing direct support for the integration of variable renewable energy sources, ESS can offer a wide range of ancillary services to support grid operations and increase flexibility for grid operators. However, it is important to understand the capabilities and limitations of different battery storage technologies, particularly in regions with high temperatures such as Dubai. This study presents a full-scale implementation of a Sodium-Sulfur battery storage system that is directly connected to the grid and supports a Photovoltaic (PV) plant generation in Dubai. Various operation modes are tested and evaluated to demonstrate the capabilities and limitations of the system. The potential for combining different operation modes to enhance grid operations and the effect of temperature on the performance of the inverter are also examined. The results indicate that the battery storage system is effective in supporting the grid through various operation modes and ancillary services, helping to ensure normal operations and maintain grid stability while mitigating the effects of PV system intermittency.**

Keywords*—Battery storage, operation mode, PV system, ramp-rate control, ancillary services, NAS battery

I. Introduction

The power systems worldwide are changing by incorporating intermittent distributed generation rather than depending only on centrally dispatched large-scale synchronous generation. The continuous development of PV technologies and their economics has placed solar energy generation as the leading renewable energy in the energy mix around the world. In the UAE, the PV system has a high potential compared to other renewable sources due to its geographic location. It receives an average of 10 hours of sunlight daily and approximately 350 days of sun yearly. Therefore, the high penetration of inverter-based generation in Dubai power system will increase rapidly in the coming years as the Dubai national energy Plan targets to have a 100% of total power output from clean resources by 2050 [1]. The high penetration of these energy sources triggers many challenges to the power system operators due to their variable nature that can affect the power system stability [2]. ESS is one of the key enablers of the high penetration of renewables to the grid, which can enhance the performance of large-scale PV plants by mitigating its power variability [3], [4]. Similar to renewables, the continuous development of ESS technologies and their economics has placed the storage industry as a competitive entity in the energy market, and further reductions in their price are expected [5]. Several ESS technologies are suitable for utility applications (energy and/or power applications) [6]–[8]. Electrochemical batteries (i.e., lithium, flow batteries, sodium-sulfur) are excellent candidates due to their fast dynamics, reasonable life cycles, and current lower prices; they can be used for energy and/or power applications. Mechanical storage systems are mainly flywheels for power applications with high-speed dynamics and low energy capacity, Compressed Air Energy Storage (CAES), and Pumper Hydro for energy applications with lower dynamics and large energy capacity. Thermal Storage systems are mainly solar thermal plants with molten salts for energy applications with lower dynamics and large energy capacity. Finally, Hydrogen (chemical energy storage) can be considered for energy applications due to low dynamics during the re-electrification process and tank capacity. These ESS can be used for energy applications, where the purpose is to inject power into the grid for several hours. In power applications, the objective is to provide power peaks requested from the grid for a few minutes. In addition, the ESS can provide ancillary grid services (i.e., frequency regulation, voltage support, ramp-rate control, reactive power compensation, etc.) [9]. This provides more flexibility to the grid operators to react to unexpected changes in either demand or generation and help to restore system equilibrium [10].

Researchers have carried out extensive research in recent studies related to BESS supporting renewable generation systems operation and providing ancillary services to the grid. Authors in [11] proposed a real-time control framework for battery energy storage systems (BESS) to provide ancillary grid services to the power grid. The proposed control strategy improves the efficiency of the BESS operations in providing frequency control and voltage support services to the grid. The operation principle of high-power energy storage devices such as lithium-ion batteries and super-capacitors flywheels is discussed in [12]. The study also discusses the role of storage devices in supporting critical and pulse loads and their added value to the power grid. Market assessment studies of BESS is carried out in [13] to facilitate higher renewable energy penetration in power system. The analysis is based on the surplus energy reserve model of BESS during the time of low demand, which can support reducing ramp rates and expensive peak load running in the system. The life-cycle planning model of BESS is developed in [14] to provide multiple functional services to the grid, such as frequency regulation and load shifting. Authors develop an optimization

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An Open-source Automated Distribution Network Analysis (O-ADNA) tool for Modeling and Visualization

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***Abstract*—Distribution network analysis is a crucial application for network operators, especially with the widespread deployment of distributed energy resources. Over the years, many platforms for analysis have been developed and automated through different programs. Some platforms are open-source, like OpenDSS, GridLAB-D, etc., while tools like Matlab/Simulink and ETAP are commercial software that requires a license, which limits their adoption. This paper presents a python-based Open-source Automated Distribution Network Analysis (O-ADNA) development that provides a fully automated modeling and visualization tool The developed analysis framework uses OpenDSS to model and analyze the distribution networks, whereas Grafana is used for visualizing the results. The modeling relies on OpenDSS, which imports the network information from a CSV file containing information about the network, like bus connection, line parameters, and the load information connected to each bus. The developed tool can perform analysis in both snap-shot and time-series modes. In snap-shot analysis, the network is solved using the rated values for the loads. The time-series analysis requires a load profile to solve the system at each time stamp. The results are processed using Python, sent to a database, and visualized in Grafana. The features of O-ADNA are demonstrated for a utility distribution network in Dubai using both the snap-shot and time-series simulations.**

***Index Terms*—Distribution, OpenDSS, Grafana, Open-source, Snapshot, Time series, Automated**

I. Introduction

The distribution network is the fastest-evolving part of the power system network. Previously distribution was primarily a passive network and needed limited analytics, but now, with distribution networks becoming more active, the importance of the power distribution network analysis has increased tremendously. Thus it is essential to make distribution network analysis more manageable and more accessible for the network operators to ensure the performance of the system as designed and ensure the compatibility of the power system components and the suitability of the device ratings [1].

In the past years, there has been a massive interest in open-source software and tools from developers and companies around the world [2]. The motivation behind focusing on open-source tools is to increase their adoption in the industry and facilitate research by increasing accessibility [3]. The main advantage of open-source programs is that, along with being free, they adapt faster to the needs of the users than licensed programs because of their free source codes. Table I lists some of the common open-source and licensed programs used for transmission and distribution analysis among the power system programs. MATPOWER is an open-source transmission analysis program that performs steady-state analysis like power flow (PF), continuation power flow (CPF), etc., using Matlab-language [4]. POWERWORLD is a Licensed transmission analysis program that is capable of solving the PF, optimal power flow (OPF), etc., up to 250,000 buses and uses drag-and-drop user interface (DD-UI) to design [5]. PSSE is a licensed transmission analysis program that performs steady-state and dynamic analysis and uses DD-UI or internal sheet to model the network [6]. OpenDSS is an open-source distribution steady-state analysis program that is used to solve the PF in snapshot or time-series mode [7], [8]. Gridlab-D is an open-source distribution analysis program that solves the power system in a steady state. It is useful to solve the distribution network that has distributed energy resources (DERs) and uses DD-UI [9]. ETAP is a licensed distribution design and analysis program that is used to perform analysis for electrical power system transients, dynamics, and protection. It uses DD-UI to model the network [10]. PSSsincal is a distribution analysis software developed by the same developers of PSSE [11]. PowerFactory is a licensed transmission and distribution software that is used for the design and analysis of the power system and uses DD-UI for design [12]. Matlab/Simulink is a licensed software that is used to design the power system and the control on the same diagram. It uses DD-UI to design and supports creating new blocks to use in the design, analysis for the system in steady-state and dynamic, etc. [13]. The user can chose open-source or licensed program based on the needs of the analyzed system i-e transmission or distribution network. The difficulty with open-source programs is their requirement for specific programming skills. In this regard, this work aims to develop an easy-to-use open-source distribution analysis tool which can make the data integration with the proposed tool simpler for the utility operators.

This work presents O-ADNA tool based on OpenDSS, python, and Grafana to make OpenDSS more accessible for the utility operators by improving data integration and visualization. OpenDSS is a fully open-source software developed by Electric Power Research Institute (EPRI). It is a power distribution system simulator(DSS) designed to model and perform steady-state analysis. It can solve the network in two modes: snapshot and time-series, it supports DERs and

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Adaptive Optimization to Enhance Operational benefits of Utility-scale BESS and PV for MV Dubai Distribution Network

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***Abstract*—Distribution networks are undergoing a massive transition due to the continuously increasing penetration of renewable energy resources. The presence of renewables, like Photovoltaic systems (PVs) and Battery Energy Storage Systems (BESS), in the conventional passive distribution networks provides opportunities to utilize these for improving the distribution network operation. For example, BESS can reduce the intermittency in PV output, peak shaving, congestion management, and improvement in voltage profile. This paper investigates the operational benefits of BESS and PV for additional voltage support to legacy voltage control (On-load Tap-changers) in a real MV distribution network considering local and centralized voltage control approaches. The analyzed network is part of Dubai distribution network and consists of 80 nodes at 33 kV and 11 kV voltage levels. In the local voltage control approach, the impact of BESS and PV inverters are analyzed when operated in constant power factor mode. Since the local voltage control approaches can often lead to sub-optimal utilization of Distributed Energy Resources (DERs) for voltage control, this work also considers centralized adaptive voltage control to maximize the DER support. Detailed simulation-based analysis and comparison of the performance of voltage control schemes is performed using MATLAB and OpenDSS simulations with actual measurement data.**

Keywords: Adaptive Control, Battery Energy Storage System (BESS), Solar photovoltaic (PV), Voltage Support, Smart Inverters

I. Introduction

The distribution networks are mostly radial in nature, with high R/X ratios. The physics of the distribution networks makes it prone to voltage issues in times of peak loading [1], [2]. These issues are usually tackled by operating legacy devices like on-load tap changers and switched capacitor banks. In recent times utilities have also increasingly deployed FACTS devices like STATCOM, which are much faster and capable of providing dynamic voltage support [3]. Although the FACTS devices possess the ability to provide fast voltage support, their cost limits the wide-scale deployment. This encourages the utility operators to look at distributed inverter-based resources as a potential source for dynamic voltage support [4], [5].

Distribution networks are rapidly transitioning from passive to active due to the increasing deployment of inverter-based resources (IBR) [6]. These resources, such as PVs, wind turbines, and battery energy storage systems, are being installed at a fast pace, as many utilities worldwide are aggressively pursuing net-zero carbon emissions from power generation to reduce their carbon footprint [7]. One example is the Dubai Electricity and Water Authority, which has deployed numerous utility-scale PV farms and implemented a program called Shams Dubai to integrate PV from residential customers. With these resources in place, it is possible to explore their use for voltage support in distribution networks [8], [9]. In particular, the dynamic voltage support provided by inverter-based resources can help resolve voltage issues in the network and facilitate the integration of renewable generation [10].

Traditionally the PVs and BESS are operated at or near the unity power factor and are primarily not used for voltage support. [11] The main drawback with PVs is that the generation is not available at night, and hence the inverter capacity is underutilized [12]. The value of PV and BESS systems for the grid operator can be increased much more if these resources can provide voltage support during the evening peak hours. The voltage violations during evening time are expected to rise even more with the increasing penetration of EVs [13], which will increase the loading at night. It is thus becoming increasingly important to utilize PV and BESS for voltage support by utilizing modern smart inverters equipped with the required controllers.

Smart inverters are advanced power electronic devices that IBRs use to convert direct current (DC) into alternating current (AC) power that can be fed into the electrical grid or used by a building. The smartness of these inverters lies in their ability to communicate with the grid and other devices in real time, allowing them to respond to changes in grid conditions and adjust their output accordingly. The idea of smart inverters was introduced by EPRI in 2012 [14]. The smartness of the inverter is defined by the ability to provide ancillary services like dynamic reactive power support, real power support, frequency support, and low voltage ride-through in addition to traditional power generation [14], [15]. Smart inverters are a vital cog of the future smart grid and can potentially enhance the stability and security of the changing grid due to the

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Optimal Feeder Reconfiguration of Power Distribution Network using PSO with Population Adaptation

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***Abstract*—This paper presents the distribution network optimal feeder reconfiguration problem, which is formulated using multi-objective functions such as voltage profile optimization, active power loss reduction, and load balancing. The formulated problem is solved using a technique incorporating Population Adaptation with Particle Swarm Optimization (PAPSO). In the proposed PAPSO technique, the concept of diversity is used to determine stagnation in the population. Thereafter, an enhancement step of population adaptation is employed to induce randomness in the particle population that reinitializes the population for further search. The outcomes are depicted on a modified IEEE 33-bus network at distribution voltage level, showing the most optimum feeder configuration obtained using the proposed algorithm. Furthermore, a quantitative comparison has been made between the PAPSO and standard Particle Swarm Optimization (PSO) results. The results and discussion depict that the suggested technique is relatively effective in providing the best solution in accordance with the set objectives.**

Keywords— Load Flow, Multi-Objective Functions, Normalization, Particle Swarm Optimization, Population Adaptation, Power Distribution Network, Reconfiguration.

I. Introduction

The reconfiguring of a distribution network addresses issues such as load balancing among main feeders, optimizing the voltage profile, minimizing power losses, and preserving operational constraints and limit violations. This process is carried out by operating the two types of switches available in a distribution network, i.e., Normally open and Normally closed switches. The normally open switches/points, known as ring-offs, are utilized to operate the network as a radial network. The distribution network operator (DNO) may change the status of a normal open point while opening a normally closed switch to transfer the loads from one feeder to another. This operation of changing the status of switches to improve system efficiency while meeting the operational constraints is called Optimal Feeder Reconfiguration (OFR) [1].

Generally, the problem of OFR is formulated as an objective function for loss minimization. Article [2] classifies the solution technique for OFR into two categories, i.e., classical and heuristics/meta-heuristics techniques. Articles [3]-[6] provide examples of classical techniques based on a mathematical approach. In contrast, research articles [7]-[12] describe the numerous heuristics techniques inspired by knowledge or natural phenomena such as Genetic Algorithm [7], Tabu Search [8], Bacterial Foraging Optimization (BFO) [10], PSO [11] , Teaching-Learning Based Optimization (TLBO) [12], etc. Meta-heuristic approaches are relatively easy to develop and have considerable exploration efficiency. However, most of these techniques suffer from the challenge of discovering non-global optimal solution, especially in the context of power distribution networks with a vast number of nodes and an enormous search space.

Mathematically, the OFR is an optimization problem to find the best combination of branches to be selected as normal open points, one point from each loop, such that the optimal solution is selected according to multi-objective functions. In this paper, the OFR is formulated as an optimization problem using a multi-objective approach considering load balancing, loss reduction, and voltage profile improvement. The formulated problem is solved by an improved variant of PSO that computes diversity to determine population stagnation and uses population adaptation step to improve the functionality of PSO. The suggested technique has been employed to a modified IEEE-33 bus network at the medium voltage distribution level to obtain optimal reconfiguration. Furthermore, a comparative analysis between the improved PSO and traditional PSO has been made to show the effectiveness of the proposed approach in solving the OFR problem.

The structure of the further paper is as follows: Section II explains the multi-objective function methodology for OFR. Section III presents an outline of PSO and explains the PAPSO technique. Further in Section IV, the results have been presented, and the findings are discussed. Lastly, Section V concludes the paper.

II. Problem Formulation

A. Objective Function

For OFR in a power distribution network, multiple objectives, such as load balancing, voltage profile, and power losses, may need to be optimized simultaneously. The objective functions are defined as

1) Load Balancing Objective Function (f_{LB})

The objective function of balancing the load currents can be obtained as a standard deviation value for all feeder head currents in a ring.

$$f_{LB} = \sqrt{\frac{\sum (I_i - \bar{I})^2}{N_F}} \tag{1}$$

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A Study on Various Conditions Impacting the Harmonics at Point of Common Coupling in On-Grid Solar Photovoltaic Systems

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Abstract: Renewable penetration, particularly the increasing deployment of PV by residential customers, organizations, and utilities, is leading to the rapid evolution of the power grid. However, the power system's architectural changes affect the quality of supply and give rise to power quality issues such as harmonics, fluctuations, disturbances, etc., at the point of common coupling (PCC). Therefore, in this work, a power network was modeled to study the impact of PV systems on PCC. At first, a detailed review is presented for on-grid PV systems with different inverter topologies, control techniques, sources of harmonic generation, and their mitigation strategies. After that, several use cases considering various sources of harmonics in a network with on-grid PV are modeled and simulated using MATLAB/Simulink. In-depth research was performed in this work to examine the many variables that affect harmonics, such as solar radiation levels, controller tuning, and load changes. Results with a real-time simulation platform (OPAL-RT) are presented in this paper for several use cases. Lastly, comprehensive discussions are presented from the acquired offline and real-time simulation results.

Keywords: on-grid PV systems; power quality; PV inverter; harmonics; non-linear loads; mitigation methods

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1. Introduction

Solar photovoltaic (PV) demand is growing, as it has become the most cost-effective alternative for energy production in many areas, such as residential and commercial applications, utility-scale projects, etc. According to the Renewables global status report, all continents contributed substantially to the worldwide growth in the total capacity of renewables. Figure 1 depicts the global solar PV capacity and annual addition from 2010 to 2023 [1], which shows a 350 GW addition is projected in the year 2023 globally [2].

The fundamental goals of a power system are to create high-quality energy, transfer it efficiently, and provide it to customers for a reasonable price. The utility system must deliver energy to all consumers at the rated voltage magnitude and frequency [3]. Simultaneously protecting the environment from the danger of gas emissions and decreasing the risk of global warming, the adoption of renewable energy technology has grown rapidly [4]. Also, it is essential for utilities to accomplish their primary objective, which is to transfer electricity as efficiently as possible from the generation plant to the end users [5]. To achieve the above requirements, PV technology has shown the highest potential for environmental friendliness, security, and effectiveness [6]. As a result, a high increase in PV penetration into the grid has been observed over the years [7]. PV systems with a suitable topology and filter configuration are generally connected to the grid using an inverter (DC/AC) at the point of common coupling (PCC). Because of the increased penetration of PV on the grid,

Impedance Modeling With Stability Boundaries for Constant Power Load During Line Failure

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***Abstract*—Harbor cranes particularly use induction motors (IM) as the main prime mover, which are powered by the grid through the machine side converter (MSC) followed by a grid side converter (GSC). To supply power to multiple cranes in parallel, double-circuit lines are utilized. Failure of a single feeder causes voltage instability in the load bus. To analyze the voltage stability on the load bus, this article proposes a comprehensive model of the GSC while simplifying the MSC as constant power loads (CPL). When used to describe the CPL behavior of the connected IM load, the proposed modeling shows how input admittance behaves as a negative incremental, growing voltage instability on the load bus. This study uses Nyquist-based stability analyzes to address the voltage stability issue caused by a double-circuit line failure and a negative incremental input admittance. The feasibility of creating a phase-locked loop (PLL) for such grid disturbances is investigated. The possibility of installing a static VAR compensator (SVC) with a battery energy storage system (BESS) on the load bus is explored if there is no equilibrium point in the P_e - δ curves during line failure.**

***Index Terms*—Constant power load, energy storage system, grid side converter, phase locked loop, static VAR compensator, voltage stability.**

I. Introduction

THE fundamental interface for grid-integrated variable speed drives is a voltage source converter (VSC), also known as a grid side converter (GSC) or a machine side converter (MSC) (VSDs) [1]. Interactions between converters and the grid can result in two types of instability: interharmonic and subsynchronous oscillations [2]. However, because of their negative incremental input impedance and regulated output voltage, VSCs exhibit constant power load (CPL) behavior. An electrical system may collapse if there are too many critical power loads (CPL), such as induction motor (IM) loads [3]. The most common causes of this problem are overvoltage and oscillations. Because it is time-dependent, the impedance mismatch between the source and load has an effect on the small signal stability of both the DC and AC systems. The results of the small signal stability analysis have a significant impact on the design of three-phase power conversion systems for such IM loads. These practical considerations require the advancement of VSC-based system control methods. The impedance-based method [4] gained its popularity and can be calculated theoretically or measured using a variety of state-of-the-art techniques. The voltage stability of the GSC, as well as that of any other connected system with source-load equivalency [5], can be examined using the Nyquist Criterion (NC) [5]. The harmonic linearization method is used to generate the sequence impedance in the phase domain, whereas traditional linearization methods are used to obtain an approximate impedance in the *dq* domain. In this case, the impedance is represented as symmetric 2 × 2 matrices with nonzero off-diagonal elements. Examining the eigenvalues of such matrices is a common technique for assessing the dependability/stability of power systems [6]. Both physical components and control parameters can be fully dynamically specified using this method. There is a substantial amount of research on load modeling and how voltage phenomena are affected by load dynamics [7]. However, there are few resources available to model the dynamic loads of interconnected VSCs.

When there is a large number of CPLs, power grids experience harmonic stability and loss of synchronization (LOS) [8]. Due to the control dynamics of the GSCs, the phase-locked loop (PLL) experiences LOS, posing a serious risk to the stability of the power grid. Second-order adaptive PLLs are introduced in [9], although they still pose a risk of LOS when operating in the presence of large disturbances in the grid. Several control techniques were used in [10] to avoid LOS with PLL-synchronized GSCs. According to a study by the North American Electric Reliability Corporation (NERC), freezing the PLL at a certain bandwidth is the fastest way to restore a grid fault [11]. However, the use of zero current injection, adaptive current injection based on the X/R ratio of the grid impedance, and adaptive injection

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Lower Inclination Orbit Concept for Direct-Communication-To-Satellite Internet-Of-Things Using Lean Satellite Standard in Near-Equatorial Regions

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Abstract: This research proposes a low-inclined orbit concept and design for the Internet-of-Things (IoT) using lean satellite standards in near-equatorial regions. The study aims to evaluate the coverage of various inclination angles at various latitudes and inclination angles in order to determine the most suitable satellite design for providing IoT coverage in these regions. The main methods applied in the study included analyzing the coverage performance of different inclination angles, the link budget analysis using simulations and the definition of the mission criteria. The results of the study show that the overall coverage performance decreases with an increase in the inclination angle. Satellites with lower inclination angles have ground tracks that are more closely aligned with the equator, while satellites with higher inclination angles have ground tracks that are inclined further toward the poles. In addition, the results show that the fraction of orbits with coverage (expressed as a percentage) declines with increasing latitude. Based on these findings, a low-inclined orbit of 24° provides the best coverage for IoT in near-equatorial regions within ±20 and 26° latitude, with a peak coverage of 27% at 24° latitude and a minimum coverage of 10% in the region spanning from 0° to ±27° latitude. This design offers more coverage time and a shorter revisit time to the selected regions for communication missions.

Keywords: LEO; lower inclination orbit; IoT-LoRa; CSS modulation; link budget; coverage

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1. Introduction

Low Earth orbit (LEO) satellites are considered a huge qualitative leap in the field of communication. With the rapid advancement of technology, nanosatellites have become a very powerful tool for communication across the world [1]. IoT communication satellites are the new revolution in the space industry. Due to their crucial advantages, and since LEO satellites provide an attractive platform, the demand for IoT communication satellites increased significantly [2]. In locations, such as the oceans, deserts, wilderness or earth poles that are not serviced by cellular or phone networks, LEO satellites will enable wireless communication. There are many different communication protocols and methodologies used in the IoT, depending on the specific requirements of the devices and applications being developed. Some of the most commonly used protocols include Bluetooth [3], Zigbee [4] and Z-Wave [5], which are all designed for low-power, low-bandwidth devices. More recently, the development of 5G networks has paved the way for the use of cellular networks for IoT communication, allowing for higher speeds and greater capabilities.

One promising technology for IoT communications on LEO satellites is LoRa (long range) technology, which is well suited to the constraints of satellite operations. LoRa [6] is a wireless communication technology that is designed for long-range, low-power communications. Nowadays, LoRa is used in a wide range of applications, from smart cities and agriculture to industrial IoT and asset tracking. LoRa is often used in combination

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Mission Concept, Analysis, and In-orbit testing of DEWASAT-1

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Abstract

Satellite-based Internet of Things (IoT) system is rapidly gaining popularity, permitting high connectivity to create an effective and reliable network of smart devices to operate, interact, connect, and share data. DEWASAT-1 is the first utility nanosatellite developed by Dubai Electricity and Water Authority (DEWA). The primary mission of DEWASAT-1 is to provide connectivity using IoT as a primary or backup system for electricity and water network devices and increase the flexibility in monitoring the network. Also, IoT connectivity is expected to enhance operational efficiency and effectiveness. DEWASAT-1 implements a novel method using a direct IoT-LoRa communication system to eliminate the necessity to include LoRa gateways. The satellite receives the LoRa signal through the onboard IoT-LoRa receiver, where the message approaches the nanosatellite directly. The link budget of the S-band transceiver closes at 5 degrees with a data rate of 3 Mbps. The UHF transceiver link budget closes at 0 degrees with a data rate of 2.4 kbps. The data budget illustrates that up to 256 MB of data can be generated and collected per day, where the data downlinked occurs in two passes. The data is then shared with the end-users to be employed for electricity and water utilities.
Keywords: DEWASAT-1, IoT, LoRa, CSS, Link Budget.

Abbreviations

Attitude Determination Control System (ADCS), Bit Error Rate (BER), Binary Phase-Shift Keying (BPSK), Communication System (COM), Chirp Spread Spectrum (CSS), Dubai Electricity and Water Authority (DEWA), Direct Communication To Satellite (DCTS), Electrical Power Subsystem (EPS), Engineering Model (EM), Flight Model (FM), Free Space Path Loss (FSPL), Internet-of-Things (IoT), Low Earth Orbit (LEO), Long Rang (LoRa), On Board Computer (OBC), Quadrature Amplitude Modulation (QAM), Research and Development (R&D), Receiver (RX), Radio Frequency (RF), Spreading Factor (SF), Transmitter (TX), Ultra-High Frequency (UHF), Wide Area Network (WAN).

1. Introduction

Small Satellites have gained popularity over the last few years for their low cost and capability to perform different missions for different payloads [1]. CubeSats are type of nanosatellites that comes in several sizes, which are based on the standard 1-U (Unit) CubeSat. A 1-U CubeSat is a 10 cm cube with a mass of up to 1 kg [2]. Typically, CubeSats consist of the bus and the payload. The bus consists of different subsystems required to operate the spacecraft, such as the COM, EPS, ADCS, and OBC [3]. Furthermore, the payload is determined based on the mission objective. Each mission begins with the mission requirements and identification. By adopting fewer restrictions and incorporating commercial technology, a rapidly expanding nanosatellite sector has made it possible for space missions to become more capable and affordable during the past few decades [4].

Nowadays, utility companies are exploring new energy management technologies that increase their capabilities. Space-D is an initiative of DEWA's R&D center. The project aims to build, design, and implement a series of nanosatellites to form a constellation in LEO. The nanosatellites are equipped with state-of-the-art technologies of remote sensing and communication devices utilized for utilities monitoring. The first nanosatellite, DEWASAT-1, was launched in January 2022, by Falcon-9 SpaceX, while the remaining are under development. DEWASAT-1 is a pilot project to build and implement an IoT-satellite-based network for electricity and water utilities.

IoT devices are growing at a rapid rate. The forecasted growth of IoT looks at having 75 billion devices connected by 2025 [5]. IoT is still the newest trend in the IT industry and is continuing to develop. The IoT is the concept of a worldwide infrastructure of networked physical things that allows for any time, everywhere connection for anything and not just for any one person [6]. IoT and Satellites have made a major leap in enabling DCTS. In fact, DCTS is a method where the Internet of Things device is outfitted with a potent Radio Frequency (RF) transceiver capable of broadcasting the LoRa frames at distances of up to 550 km, which is the altitude at which the

WATER

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Environmental performance of a photovoltaic brackish water reverse osmosis for a cleaner desalination process: A case study

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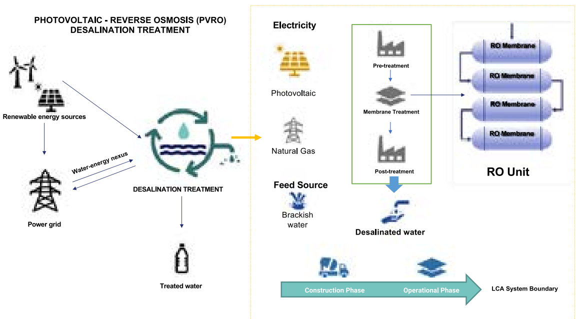
HIGHLIGHTS

- LCA was conducted on the RO desalination system using photovoltaic electricity.
- NaOCl consumption was a treatment hotspot impacting TETP at 4.13 kg 1,4-DCB/m^3.
- Operational phase contributed 52 % towards GWP compared to construction phase.
- Sensitivity and uncertainty analyses were included to support the findings.

GRAPHICAL ABSTRACT



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ABSTRACT

Reverse osmosis (RO) membrane-based desalination system with various configurations has emerged as a critical option for reclaiming brackish water. This study aims to evaluate the environmental performance of the combination of photovoltaic-reverse osmosis (PVRO) membrane treatment system via life cycle assessment (LCA). The LCA was calculated using SimaPro v9 software with ReCiPe 2016 methodology and EcoInvent 3.8 database following the ISO 14040/44 series. The findings identified the chemical and electricity consumption at both the midpoint and endpoint level across all impact categories with terrestrial ecotoxicity (27.59 kg 1,4-DCB), human non-carcinogenic toxicity potential (8.06 kg 1,4-DCB) and GWP (4.33 kg CO_2 eq) as the highest impacts for the PVRO treatment. As for the endpoint level, the desalination system affected human health, ecosystems and resources at 1.39×10^{-5} DALY, 1.49×10^{-7} species·year and 0.25 USD2013 respectively. The construction phase for the overall PVRO treatment plant was also assessed and impacted less significantly compared to the operational phase. Three different scenarios (i.e. S1: Grid input (Baseline); S2: Photovoltaic (PV)/Battery; S3: PV/Grid) based on different sources of electricity used were also compared as electricity consumption is one of the significant impacts in the operational phase. The study found that S2 had the lowest environmental impact, while S1 contributed the highest when both midpoint and endpoint approaches are considered.

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Optical coherence tomography and digital image processing for scaling and Co-precipitation investigation on reverse osmosis membrane

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ARTICLE INFO

Keywords:
Optical coherence tomography (OCT)
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Reverse osmosis membrane filtration (RO)
Digital image processing

ABSTRACT

Scaling known as the precipitation of inorganic salts is a main concern in the reverse osmosis (RO) process due to its effects on the process performance and life-time of membranes. Although single salt precipitation has been continuously studied, the co-precipitation of salts is rarely investigated due to its complexity, especially under process hydrodynamic conditions. Recently, optical coherence tomography (OCT) has been adopted as an *in situ* and rapid technique for monitoring the fouling in membrane processes. This study aims to develop an approach using OCT and digital image processing for qualitative and quantitative analysis of single salt precipitation and co-precipitation on RO membrane under hydrodynamic conditions. The effects of supersaturation, sodium chloride (NaCl), flow rate, and applied pressure are investigated. The developed approach enables the detection of crystal growth under the OCT. The morphology of precipitated salt, i.e $CaSO_4$, including crystal shape and size obtained from OCT acquisition, agrees with the images from a scanning electron microscope (SEM). The growth of each crystal in co-precipitation of $CaSO_4$ and $CaCO_3$ is well detected in appearance time and growth pattern. This is beneficial to differentiate crystal morphology in the co-precipitation system. The quantitative surface coverage proportion and total volume are in well correlated the changes of RO performance parameters of permeate flux, conductivity (feed, concentrate, and permeate), and Ca^{2+} concentrate profile by time, which allows the scaling progress to be directly evaluated over time. This study reveals the high potential of combining OCT acquisition and digital image processing for direct observations and studying single salt and co-precipitation under RO hydrodynamic conditions, which can be extended for another type of composite fouling.

1. Introduction

The increase in water consumption and the impacts of climate changes result in the reduction of freshwater availability [1]. Desalination technology appeared as an economical solution to provide sufficient freshwater from unconventional water resources such as brackish water, groundwater, and seawater by removing salts and other minerals and collecting the effluent as freshwater [1]. Among various methods in desalination technology, RO membrane filtration has been one of the most promising in the water industry, mainly when applied to sea and brackish water [2]. Although highly preferred, RO technology is still facing two significant issues, energy consumption, and fouling, that have been continuously addressed for years. Fouling is defined as the deposits of unwanted matter on the membrane surface which directly affects the performance and efficiency of the membrane process. Membrane fouling leads to more energy consumption and to decrease in produced water quality and quantity. Consequently, more frequent cleaning and treatments or even replacements are necessary to maintain the filtration process efficiency, which increases the cost and shortens life-time of the membrane [3]. Fouling is primarily classified as particulate fouling, scaling, biofouling, and organic fouling. Scaling or salts precipitation consists of the deposition of inorganic salts at the membrane surface once the concentrations of the salts exceed their solubility limits [1]. Detailed insights into scale development as well as changes in

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Modeling of temperature profile in semi-permeable membrane channel at non-isothermal conditions

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ABSTRACT

We present a model for thermo- and pressure-driven membrane processes accompanied by transmembrane water and heat fluxes combined in a single unit. High-pressure channel (high-pressure control volume) is characterized by low operating temperature and vice versa. A symmetric plate-and-frame membrane channel was considered in this study. An elementary parallelepiped was selected as a control volume. Balance equations were written over the control volume. A membrane element was represented as a set of conjugate semipermeable volumes. The model is based on the following assumptions: (1) incompressible fluid under steady-state conditions; (2) *trans*-membrane water flux is opposed to transmembrane heat flux. Transverse velocity profile is approximated by Berman distribution; (3) the mechanisms of transverse transport include: convection resulting from pressure differences and conduction resulting from temperature gradients; (4) the thickness of thermal layer is equal to half height of the channel ($\delta_t = H$). The temperature polarization (TP) module reveals high sensitivity to thermo-physical properties and hydrodynamics such as to the coefficient of thermal diffusivity $a = \lambda / c\rho$ and to the transverse velocity, $V(z)$. We find that (a) variation of the coefficient of thermal diffusivity in liquid phase from $a = 2.0\ 10^{-7}\ m^2/s$ to $a = 1.0\ 10^{-7}\ m^2/s$ will reduce TP module from 0.96 to 0.91; (b) variation of transverse velocity at the membrane surface from $5.5\ 10^{-5}$ to $1.5\ 10^{-5}$ m/s can decrease of TP module from 0.95 to 0.79. The developed solution can be used as a sub-model for quantitative estimation of TP phenomena in thermo-driven membrane operations. It can be applied for analysis of pressure-driven processes at non-isothermal conditions and be used as a mathematical algorithm for process analysis and optimization.

1. Introduction and formulation of the problem

Membrane processes, being of low energy consuming and environmentally friendly, have become a competitive alternative for different applications. In recent years we see the growth of interest to different groups of them such as pressure- and thermo-driven processes. Successful application of those processes is often hampered by the existing level of modeling and analysis. Some physical phenomena underlying the process require more comprehensive level of modeling and analysis.

These processes are unavoidably accompanied by polarization phenomena such as temperature- and concentration polarization. Those phenomena are caused by unbalanced transport between bulk and membrane surface and quantified by the degree of polarization and polarization module. Temperature polarization is a complex phenomenon that requires a more detailed understanding of the thermal profile in the liquid phase of the semipermeable membrane channel. The phenomena of temperature polarization (TP) in particular are quantified by TP degree or TP module. Those phenomena impose physical limitations to the boundaries of driving forces and transmembrane fluxes, necessitating their quantification in design and analysis of the processes.

There are different approaches to the modeling and analysis. In Direct Contact Membrane Distillation (DCMD), several methods have been proposed to evaluate the impact of thermal conditions and hydrodynamic on heat- and mass-transport. Ali et al. [1] used a specially designed cell and pure water as the feed solution to assess these effects. Martinez-Diez and Vázquez-González [2] proposed a method to estimate temperature and concentration polarization based on criterion equations. Termpiyakul et al. [3] developed a method to calculate heat- and mass-transfer using linear vapor pressure difference across the membrane for mass flux and convective and conductive heat transfer through the membrane for heat flux. There are published studies focused on modeling concentration polarization [4–6]. Yaeli S. Oren et al. [4] focused specifically on the effect of electromigration in the boundary layer on trace-ions concentration polarization and derived new sim-

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Improvement of Direct Communication to Satellite Using LoRa-FHSS Compared to LoRa-CSS (DEWASAT-1 Case of Study)

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***Abstract*—This research paper presents a comprehensive study on the utilization of Long Range (LoRa) communication for IoT (Internet of Things) applications via satellite links. The focus of the study is to evaluate the performance of LoRa communication when employing different modulation techniques, specifically Chirp Spread Spectrum (CSS) and Frequency Hopping Spread Spectrum (FHSS), in a satellite based IoT network. Real-time results obtained from satellite-based experiments are presented and interpreted to assess the effectiveness of these modulation techniques. The paper begins by providing an overview of LoRa technology and its suitability for IoT applications, emphasizing its advantages such as long-range communication, low power consumption, and robustness against interference. The research methodology involves implementing a satellite based LoRa communication system with CSS and FHSS modulation schemes. A comprehensive set of experiments is conducted, simulating real-world scenarios to evaluate the system's performance in terms of signal range, reliability, and power consumption. Multiple metrics are measured, including airtime, bit rate, and link margin, to assess the effectiveness of CSS and FHSS modulation techniques in satellite based IoT communication. The paper concludes by providing insights into the suitability of CSS and FHSS modulation techniques for satellite based IoT communication, based on the interpreted real-time results. Recommendations are given to optimize the performance of LoRa communication in satellite based IoT networks, considering factors such as system design, modulation scheme selection, and network configuration.**

Keywords—LoRa communication, Modulation techniques, IoT, DEWASAT-1

I. INTRODUCTION

The Internet of Things (IoT) refers to the interconnected network of physical devices, vehicles, buildings, and other items embedded with sensors, software, and network connectivity that enable these objects to collect and exchange data[1]. The IoT industry is expected to grow at 19% by 2025[2]. With the growing understanding of IoT, various protocols have been developed for short-range communications and low-power transmissions. New transceiver technologies for Low Power Wide Area Networks (LPWAN) have emerged to support these needs, such as Long Range (LoRa), Sigfox, and Narrowband IoT (NB-IoT)[3]. These technologies are designed to provide long-range connectivity while minimizing power consumption, making them well-suited for IoT applications[4].

Satellite based IoT offers significant advantage in addressing the growing demand and stress on existing terrestrial networks[5]. Satellite provides Ubiquitous coverage enabling seamless connectivity for remote sensing devices where cellular connections are limited[6]. Nanosatellites, such as CubeSats, operating in Low Earth Orbit (LEO), present a cost-effective solution to connect a myriad of smart devices worldwide through the IoT[7]. Satellites play a crucial role when smart devices are in remote areas making them inaccessible through conventional means. Combination of terrestrial and satellite network introduce and integrated solution for achieving global IoT coverage[8].The IoT based satellites will see an exponential growth in the upcoming years.

LoRa (Long Range) is a wireless communication technology that provides long-range connectivity for low-power IoT devices[9]. The LoRa protocol operates in the unlicensed spectrum and can be used for both terrestrial and satellite communications. It uses spread-spectrum technology to achieve long-range communication with low power consumption, making it an ideal solution for IoT applications requiring long-range connectivity[10].LoRa uses two different modulation techniques such as LoRa CSS and LoRa FHSS to achieve long range and robust communication in low-power devices. LoRa CSS (Chirp Spread Spectrum) is a spread spectrum technology used in the LoRa communication protocol to achieve long-range and secure wireless communication. It is a variation of the LoRa modulation that adds a spreading mechanism called “chirping”. This allows for more efficient use of the available spectrum, resulting in improved signal quality, increased range, and reduced interference with other devices in the same frequency band. LoRa CSS also provides stronger security features, making it ideal for IoT applications that require secure data transmission[11].

An extension of the LoRa physical layer has been introduced by Semtech, known as LR-FHSS, which expands the capabilities of LoRa with Long Range-Frequency Hopping Spread Spectrum technology[12].The introduction of LR-FHSS as an extension of the LoRa physical layer stems from the growing demand for larger and denser network deployments, including LoRaWAN networks on a satellite scale[13]. This extension aims to enhance network capacity and resilience by incorporating the fundamental principles of

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Enhancing CO_2 separation from N_2 mixtures using hydrophobic porous supports immobilized with tributyl-tetradecyl-phosphonium chloride $[P_{44414}][Cl]$

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A R T I C L E I N F O

Keywords:
Supported ionic liquid membrane
Phosphonium-based Ionic liquid
Post-combustion CO_2 capture
CO_2 permeability
CO_2/N_2 selectivity.

A B S T R A C T

The main obstacles in adopting solvent-based CO_2 capture technology from power plant flue gases at the industrial scale are the energy requirements for solvent regeneration and their toxicity. These challenges can be overcome using new green and more stable ionic liquids (ILs) as solvents for post-combustion CO_2 capture. In the current study, tributyl-tetradecyl-phosphonium chloride $[P_{44414}][Cl]$ as an IL, was immobilized on hydrophobic porous supports of polypropylene (PP), polyvinylidene fluoride (PVDF), and polytetrafluoroethylene (PTFE) at 298 ± 3 K and pressures up to 2 bar. The surface morphology indicated homogenous immobilization of the IL on the membrane support. Supported ionic liquid membranes (SILMs) were tested for CO_2 permeability and CO_2/N_2 selectivity. None of the SILMs exhibited IL leaching up to 2 bar. The PTFE-based SILM performed better than other supports with minimum loss in water contact angle (WCA) and achieved good antiwetting with a maximum CO_2 permeability and selectivity over N_2 of 2300 ± 139 Barrer and 31.60 ± 2.4, respectively. This work achieves CO_2 permeability about two-fold more than other works having CO_2/N_2 selectivity range of 25–35 in similar SILMs. The diffusivity of CO_2 and N_2 in $[P_{44414}][Cl]$ was measured as 3.64 ± 0.18 and 2.01 ± 0.09 $[10^{-8}\ cm^2\ s^{-1}]$ and CO_2 and N_2 solubility values were 9.79 ± 0.47 and 0.19 ± 0.001 $[10^{-2}\ cm^3(STP)\ cm^{-3}\ cmHg^{-1}]$, respectively. The high values of Young's modulus and tensile strength of the PTFE support-based SILM (234 ± 12 MPa and 6.07 ± 0.31 MPa, respectively) indicated the long-term application of SILM in flue gas separation. The results indicated phosphonium chloride-based ILs could be better solvent candidates for CO_2 removal from large volumes of flue gases than amine-based ILs.

1. Introduction

Carbon dioxide (CO_2) emissions in the atmosphere are key contributors to global warming (Shaikh et al., 2023). According to the International Energy Agency (IEA), an annual 6% increase in CO_2 emissions is mainly related to fossil fuel usage as a significant source of energy (Global, 2019). The rapid growth of global industrialization and urbanization led to increased fossil fuel usage. Thus, prompt actions to curtail the CO_2 emissions and advance the carbon capture technology

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Design and Implementation of a Locomotion Suspension System for a Desert Terrain UGV

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***Abstract*— Unmanned ground vehicles (UGVs) are currently used to collect data and deliver payloads across industries. Most wheeled UGV implementations for uneven terrain are based on a combination of rocker and bogie. This paper proposes a variation of a suspension system for locomotion suitable for desert terrain. This variation is the transformation of the traditional inclined bogies parallel to the ground surface as the front of the rover, along with an additional transversal bogie as the rear of the robot. The design parameters, material selection, and fabrication process were performed to achieve the highest possible performance of the UGV in navigation on desert terrain. To test stability and obstacle climbing ability, experiments were carried out in desert terrain and concrete surfaces.**

***Index Terms*—Locomotion systems, suspension systems, all-terrain robots, mobile robotics.**

I. Introduction

Unmanned ground vehicles (UGVs) are currently used to collect data and deliver payloads in various industries and have been deployed for several years. Therefore, their design becomes a significant factor for varying applications. The best- known UGV examples were developed for the DARPA grand challenge in the United States. These UGVs generally came from modified passenger vehicles, such as General Motors and Volkswagen. The purpose of UGVs has always been to automate tasks and operations that humans perform currently in civilian or military activities [1]. UGV design revolves around its applications and environments. The mechanical architecture of the locomotion system is considerably more complicated when traversing uneven or soft terrain and over- coming obstacles. For these terrains, three different locomotion systems are used: wheeled, legged, and tracked robots and their respective combinations [2]. Wheeled UGV suspension systems can be active or passive. Most implementations for uneven terrain are based on passive suspension systems, such as the combination of a rocker and a bogie [3]. Active suspension systems, although not common, exist in cases where a human payload is on board the vehicle [4]. Active suspension systems also require complex control systems that are susceptible to failure [3].

In recent years, many UGVs have been designed with a passive suspension mechanism to help maneuverability in unstructured terrain. In one study, a researcher created a prototype vehicle to be able to travel across the surface of ocean world bodies after studying the surface environmental conditions. According to the kinematic optimization and dynamic simulation analysis requirements, a six-wheel drive vehicle prototype was constructed, each side of the rover chassis having a rocker joint, a bogie joint, and three steer-drive wheels [5]. In another study, a six-wheel rocker-bogie was designed and fabricated so that it could progressively climb over most obstacles rather than impact and climb over them. The UGV was also equipped with a sun tracking solar panel to give it a more modern and less sophisticated design [6]. Researchers have done more work in the field of rocker bogie, where they developed a better formulation for rover optimization utilizing smooth functions, which permits the use of powerful gradient-based nonlinear programming (NLP) solvers for finding solutions, to increase the performance of rocker bogie suspension. Their approach to ascending a step with a height twice the radius of the wheel is 13% more effective than the nominal rover [7]. Another researcher developed the ideal design of a mobile robot capable of climbing stairs. To maintain all wheels on the ground while climbing stairs, the Taguchi method was used as an optimization tool. The optimization process is carried out against different sizes of stairs, greatly improving the resilience and adaptability to structured terrains that are typically found in indoor applications [8]. An approach to modeling the kinematics of a six- wheel rocker-bogie mobile robot was given in another paper. With the help of the ground contact angle of the wheel and the calculation of the Jacobian matrices of the wheel, the forward kinematics of the mobile robot was determined [9]. Another researcher designed a six-wheel drive UGV with a rocker-bogie mechanism to efficiently spray pesticides on a farm. The rocker-bogie mechanism helps spray pesticides evenly without problems in motion on unstructured terrain [10].

Passive suspension systems where a rocker and/or a bogie are used tend to have several configurations. These implementations are Mars Exploration Rover (MER), SOLERO, CRAB, RCL-E, RCL-C, CRAB-S, CRAB-8, and DoubleSpring [3]. In [11], CRAB and RCL-E were evaluated based on specific performance criteria related to contact forces and motor torque requirements, where CRAB outperformed RCL-E.

This paper proposes a variation of a passive suspension system suitable for desert terrain, our implementation follows the RCL-E architecture, due to its mechanical simplicity (no differential). Passive suspension serves the purpose of overcoming the uneven and soft terrain that is faced in the desert. In addition, we explore the impact of force on a robot

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DEWA R&D Data Lake: Big Data Platform for Advanced Energy Data Analytics

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***Abstract*—The digital transformation of the utility sector has resulted in a flood of data incoming from diverse and dispersed data sources, which requires huge integration, storage, processing, and management efforts. In this work, we present a Big Data advanced analytics platform for utility data, that allows for easier data retrieval, processing, and visualization, with enhanced data security. The successful implementation of Data Lake at DEWA (Dubai Electricity and Water Authority) R&D Center increases valuable insight extraction from raw and processed data, that can be employed in informed decision-making and cross-utilization of data between different sectors in the utility company.**

Keywords—utility data, big data platform, internet of things, digital transformation, advanced data analytics

I. Introduction

In our modern digital reality, Digital Transformation is penetrating every industry as an indispensable process for business growth and persistence through ongoing rapid technological advancements [1]. The growing digital transformation trend has resulted in an abundance of data [2] which requires management, storage, and processing to be transformed from its unusable raw form into a valuable asset that can be utilized in generating actionable insights and driving informed decision-making processes.

In the utility sector, data flows from numerous sources, such as smart meters, grids, consumer consumption, traffic, and EV charging stations, and they are increasing by the second with the vast implementation of sensing devices.

The utility sector can be considered as the lifeline of other industries; it provides other industries with their required energy resources. To manage the huge amount of data generated and drive actionable insights from it, Big Data analytics platforms become critical [3].

For data source integration and management, Big Data analytics platforms must tackle several challenges. For instance, energy data sources are scattered and geographically widespread between hundreds, or in some cases, thousands of IT/OT devices. Moreover, the generated data is heterogeneous [4] and can be structured, semi-structured, or unstructured, with disparate veracities, velocities, and volumes. All of which call for the implementation of systematic data integration and preprocessing layers' prior in achieving informative analytics in the platform.

The data analytics platform must also have real-time processing capabilities. Real-time processing is paramount for time-sensitive decision-making and forecasting applications [5]. For example, real-time processing of power consumption data in the utility industry allows the utility company to detect irregular electrical consumption, which can indicate an appliance defect. It can, then, notify the consumer about it instantly, which allows the user to monitor their energy consumption constantly and make informed decisions to increase their energy usage efficiency [2]. Such a service is sure to elevate user-experience quality and customer satisfaction, as well as increase utility business profit.

In this work, we designed and implemented an advanced Big Data analytics platform for DEWA R&D Center [6] (Dubai Electricity and Water Authority), named DEWA R&D Data Lake. The situation of DEWA R&D Center's diverse and widely dispersed data sources made this project paramount for increasing the efficiency and productivity of research in the center. The presented Data Lake platform supports seamless data integration for all energy data sources with developed connectors for utility. Data ingestion, validation, storage, processing, and consumption in a secure way. Our presented solution supports high data availability, easier data retrieval, enhanced security, and provides preprocessing and data visualization capabilities, leading to better information extraction and cross-utilization of data between different research areas.

II. Big Utility Data Characteristics

The term "Big" can be misleading; it mostly indicates largeness in size. However, Big Data Analytics are not associated with large quantities but are rather linked to the variation in features between different data sources, such as variation in velocity, variety, veracity, value, and volume, which are often referred to as the "5V" characteristics [7].

Fig. 1. Big Data characteristics

As depicted in Fig. 1, the "5V" characteristics of energy data in are reflected in the following aspects:

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IoT-based Test facility for a Water Transmission Line with Leak Simulation

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***Abstract*—Leakage detection in water transmission lines is a main concern of utility companies, as the early detection of water leakage in pipelines reduces the risk of major maintenance and financial losses. This work presents an integrated solution for accurate and efficient monitoring of leakage in water pipelines with the implementation of a Test Facility that mimics real-world water transmission lines. The Test Facility is implanted with sensors and valves that operate using IoT technologies. Moreover, the Test Facility is simulated in LabVIEW, where the software is used for real-time monitoring and control of the test pipeline. The proposed solution provides potential for enhancing current water leakage detection processes, by allowing utility companies to discover new indicators of leakage using sensors and advanced data analytics.**

Keywords*—*internet of things, water leakage detection, sensors, test facility, monitoring and control, utility company.

I. Introduction

The network of physical items, or "things," that is implanted with sensors, software, and other technologies to communicate and exchange data with other devices and systems through the internet is referred to as the Internet of Things (IoT) [1]. In the current year of 2022, there are more than 14.4 billion connected IoT devices, and according to analysts, the number is growing at a rate of 18% and is expected to reach 27 billion connected devices by 2025 [2]. Industries are investing more in incorporating IoT solutions into their existing infrastructure to collect data and generate insights by applying Artificial Intelligence and Machine learning algorithms [3]–[5].

Non-revenue water loss reduction is one of the main areas of concern for utility companies [6]. The water transportation system from the source to the reservoir in distribution units near cities involves a large pipeline carrying high volumes of water. Leakage and damages caused to the system pose major environmental hazards and financial losses for utility companies [7]. Preventing leakages is critical; detecting leaks and localizing the damage in the pipeline earlier reduces the risk of major maintenance and financial losses [8]. Industrial IoT solutions aim to track the real-time monitoring and control of water transmission systems [9].

This paper proposes an integrated solution for reducing leakages in the water transmission system using IoT technologies. A real-world implementation of the IoT solution will require a pipeline covering a long distance of more than thousands of kilometers. Testing such a solution is very hard and involves high costs. Thus, to test and develop an effective solution, we built a Test Facility that effectively mimics the existing transmission system. The IoT solution on the Test Facility consists of three main layers: equipment sensing layer, data acquisition and transmission layer, and test sequence generation with control layer.

The built system is also simulated in LabVIEW software, which integrates the communication between different sensors and enables real-time monitoring and control of the Test Facility.

In this paper, we explain the design of the real-time Test Facility of the water transmission line along with the development and implementation of the IoT system. The system can simulate any real-world problems occurring in the water transmission line. The system collects real-time data, which can be analyzed and processed for future improvements.

The paper is organized as follows; Section 2 discusses previous related work. Section 3 describes the construction and commissioning of the Test Facility with the standards followed by the utility company requirement. It also explains the hardware and software setup involved in the system, IoT system architecture sensors, communication protocols, and data acquisition system. Section 4 presents a case where a real-time test sequence is generated with a controlled flow of leaks using the IoT dashboard, and experimental results are analyzed. Section 5 describes the facility's system capability and future use cases and conclusions.

II. Related Work

IoT solutions are becoming more prominent in the pipeline health monitoring area due to their ability to provide accurate and early detection of water leakages. A work done in 2020 [10] focused on capturing acoustic signals using aluminum nitride-based micro-machined infrasonic hydrophone sensors as part of an IoT system to accurately locate leaks. Another work [11] done in the same year proposed an IoT network to monitor water consumption levels in an urban housing complex and detects leaks using a machine learning algorithm that takes its input from ultrasonic sensors.

IoT networks provide more valuable insights by allowing researchers to explore the connection and relation between different parameters. For instance, researchers from Yokohama Research Laboratory presented a new

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Hardware doppler shift emulation and compensation for LoRa LEO satellite communication

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***Abstract*— LoRa is the de facto wireless platform of the Internet of Things (IoT). It is a smart and globally accepted low power ultra-long range, low-data rate communication protocol widely used for low frequent sensor telemetry and actuation. The simplicity, license-free spectrum, and long range enable the end user to transmit data even to Low Earth Orbit (LEO) satellites. The relative velocity of the LEO satellite from a stationary transmitter on the earth's surface is very high and time-varying, because of its short orbital period and high velocity, due to which the doppler shift and doppler rate are more prominent. LEO satellite signal reception is highest at the mid-pass duration, but unfortunately, the doppler rate is also highest during the same duration. In LoRa communication protocol, a higher spreading factor (SF12) results in better signal reception and communication range. But the LoRa communication at a higher spreading factor (SF12) results in packet error mainly due to the doppler rate, due to which a transmitter is forced to choose a lower spreading factor (SF9). This paper looks at precisely emulating the doppler shift and doppler rate for the entire pass duration of a LEO satellite using dynamic external hardware clock manipulation on an SX1262 LoRa chipset. A low-cost transmitter-side hardware doppler compensation technique is also explored, which encourages the transmitter to use a higher spreading factor (SF12) for better-guaranteed packet reception by the satellite.**

Keywords—Internet-of-Things (IoT), LoRa, LEO satellite, Doppler effect, Doppler emulation, Doppler compensation

I. Introduction

LoRa is the de facto technology for Internet-of-Things (IoT) based on its widespread adoption and is responsible for connecting the next billion IoT devices [1], [2]. LoRa is flexible for rural or indoor use cases in smart agriculture, smart cities, Industrial IoT (IIoT), smart environment, smart homes and buildings, smart utilities and metering, smart supply chains, and logistics [3]. It is one of the most successful long-range, low-power but low-data rate communication protocol widely adopted for IoT [4]. LoRa is based on the Chirp Spread Spectrum Technology (CSS), where a single Radio Frequency (RF) tone sweeps linearly but discontinuously over time [5]. It is widely used for low-frequency sensor telemetry and actuation in industrial applications and comes under the Low Power Wide Area Network (LPWAN) with an unlicensed spectrum.

Due to LoRa's high immunity to noise and higher communication range with limited transmit power, it can send data from low-power LoRa-based IoT terminals [6], [7], to a Low Earth Orbit (LEO) satellite with the LoRa receiver as payload [8]. The spreading factor (SF) ranging from 7 to 12 is one of the important parameters in LoRa protocol. As the spreading factor increases, the range of communication increases with a penalty of increased 'on-air' time, low packet rate, and higher power consumption [9]. But in scenarios where the range is a real concern, increasing SF is one of the ways to get around it. With limited Transmission (Tx) power, low antenna gain or directivity, higher channel noise, and a long distance from the ground station IoT terminal transmitter to the satellite (~ 600 km), it is recommended to increase the spreading factor to prevent packet loss. LoRa receiver sensitivity at 125 kHz bandwidth for SF12 is -137 dBm and for SF7 is -123 dBm which means a higher spreading factor provides a better communication range.

For GEO Stationary Satellites, the relative velocity with a fixed point on the ground is zero, but for a LEO satellite, due to its lower orbital radius and higher velocity, it revolves around the earth around 16 times a day. Thus, the relative velocity of a LEO satellite with a transmitter on the earth's surface is very high and time-varying, which introduces a doppler shift and doppler rate to the frequency received by satellites [10],[11].

Cao et. al. [10] demonstrated simulation of doppler effect on LEO satellite. In this paper, we demonstrated the effect of static doppler shift and doppler rates on the 868MHz LoRa protocol by precisely emulating a moving satellite receiver in hardware. The paper also suggests a few hardware workarounds on the transmitter to compensate for the doppler shift.

II. Methodology

The Doppler effect or shift is the change in frequency of a wave relative to an observer moving relative to the wave source. The frequency received by a receiver moving towards a transmitter will receive a slightly higher frequency than the transmitted frequency, which depends on the transmitted frequency, speed of the wave, and velocity of the object towards (+) or away (-) from the transmitter.

$$f_r = \frac{c+v}{c} . f_t \tag{1}$$

$$f_d = f_c . v/c \tag{2}$$

Equation 1 is a simplified doppler shift equation for frequency received by a moving RF receiver from a stationary transmitter where 'c' is the speed of light, 'v' is the velocity of it towards the transmitter, f_t is the transmitted frequency, and f_r is the received frequency. Assuming a circular orbit, the relative velocity v is dynamic with a static transmitter on the earth's surface and cannot be considered as orbital velocity for the entire pass duration. A better equation for v for a circular orbit can be approximated below as a function of time where time zero is considered the mid-pass time.[10]

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Machine Learning Schemes for Leak Detection in IoT-enabled Water Transmission System

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***Abstract*— Reducing Non-Revenue Water (NRW) losses in water transmission and distribution networks is a critical challenge for water utility companies. The combination of unobtrusive Internet of Things (IoT) monitoring devices and Artificial Intelligence (AI) technology is one of the most promising directions in water leak detection techniques for industrial scale infrastructure and smart cities. Currently, the complicated network topology and underground nature of transmission and distribution water pipelines pose serious limitations for the effective elimination of associated water leaks. In this paper, a realistically dimensioned IoT-enabled water transmission system provides the basis for a series of simulated leak experiments and the subsequent application of three different anomaly detection schemes. Having full control over the mechanical valve behind the simulated leaks, this test rig addresses the issue of accurate labelling in leak data and serves as testbed for the evaluation of each anomaly detection method and the comparison between them. The first anomaly detection method is the unsupervised multi-variate classification known as Isolation Forest (iForest). Second, the Support Vector Classification (SVC) approach is implemented representing supervised classification methods in the Support Vector Machine (SVM) family. Finally, a deep learning RNN-LSTM (Recurrent Neural Networks–Long Short-Term Memory) model is used in conjunction with a single threshold to signify anomalies due to high deviations between actual and forecasted values of key infield sensors. These models can detect water leaks and the results provide insights regarding both the effective applicability of sensors and Machine Learning (ML) algorithms in this context.**

Keywords*— Anomaly detection, IoT enabled infrastructure, Machine learning, Smart water leak Test Rig, water supply network, Deep Learning.

I. Introduction

Pipeline monitoring plays a significant role in maintaining a safe and healthy infrastructure for utility, waste water and oil and gas companies [1]. Pipeline leaks constitute a major and critical concern for utility companies worldwide due to the major non-revenue water losses they are causing. Transmission pipelines that hold large volumes of water from the source are the most critical due to the high pressure in the pipeline, making them more inclined to leakage and bursts. Utility companies mostly depend on manual inspection of pipelines using acoustic devices, noise correlators and hydrophones after a leakage has been reported by the SCADA alarm system [2]. However, in transmission pipelines, SCADA mostly detect bursts and major leakage that causes significant changes in the values of pressure and flow, meaning that a reported leak would have been unnoticed for months until its size became big enough for SCADA to recognize and report [3][4]. The use of Machine Learning (ML) approaches has been widely used and integrated to develop a smart system capable of making accurate predictions and decisions in utility monitoring systems [5][6]. There has been active literature in utilizing large data sets from live and experimental distribution networks and ingesting them into different ML models that serve different applications (data processing, cyber security, data theft, leakage detection etc.) [7]. In [8], an algorithm based on neural networks' multi-layer protection (MLP) and Kpohonen has been tested on a hydraulic model for detecting and locating hidden leakage in several municipal water supply networks. The utilization of RNN-LSTM model for leakage detection in water distribution networks has been proposed [9]. The model extracts the flow rate pattern shape, predicts leakage using RNN-LSTM and sets threshold modules. The performance of the model was evaluated by a confusion matrix which proved 90% accuracy. In [4], a pressure point analysis (PPA) leak detection method is proposed for enhanced continuous pressure monitoring and to decrease triggering of false alarms. The proposed method uses Optimal-pruned extreme learning machine (OPELM) to achieve preliminary results. In another paper [10], two Gated Recurrent Neural Network architectures were experimented for leak detection. The pressure and flow data was extracted from LeakDB framework and then deployed into a leak detection system which was used to simulate real scenario. In another study, authors proposed a new machine learning framework for leakage detection and localization in WDN using a developed clustering-then-localization semi-supervised learning (CtL-SSL) model. The framework achieved 95% accuracy in leakage detection and 83% leakage localization which are considered promising results [11]. However, the use of simulated data from softwares don't always provide realistic hydraulic modeling.

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Design, Development, and Implementation of Internet of Things Enabled Laboratory

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***Abstract*—The Internet of Things (IoT) refers to the interconnected network of physical devices, vehicles, buildings, and other objects that are embedded with sensors, software, and network connectivity, enabling them to collect and exchange data. As the number of connected devices and applications has increased significantly in recent years, the IoT has become a key feature of the modern technological ecosystem. One major challenge facing society today is the issue of energy scarcity, and there has been a growing focus on finding ways to increase energy efficiency. One approach to addressing this challenge is to use the IoT to monitor and optimize energy usage in various settings. This paper presents the design and implementation of an IoT-enabled laboratory that aims to increase energy efficiency over the long term through the use of IoT monitoring and artificial intelligence (AI). The paper describes a practical approach and provides results from the sensors employed in the IoT lab. This research contributes to the growing body of knowledge on how the IoT can be used to improve energy efficiency and address the issue of energy scarcity.**

Keywords—Internet-of-Things (IoT), Energy Efficiency, Optimization, Wireless Sensor Network (WSN), MQTT

I. Introduction

With the energy scarcity in the modern world, raising awareness about energy usage is considered key in developing sustainable energy behaviors. Energy efficiency is generally the largest, least expensive, and most quickly deployable way to provide energy services [1]. The potential for energy efficiency is increasing rapidly with the emergence and adaptation of innovative design strategies and technologies. This paper presents a purpose-built IoT-enabled laboratory facility that can demonstrate the energy efficient by IoT and facilitate rapid prototyping & testing of new solutions.

The United Arab Emirates' (UAE) energy per capita is one of the highest in the world [2]. The UAEs diverse economic portfolio led to an increase in economic growth. This growth has led to massive demand for electricity [3], with the UAE's growth rate of 9%, three times greater than global average [2].

Internet of Things (IoT) has seen an expeditious increase in the number of sensors and physical objects connected. IoT is envisaged at both the individual and professional level playing a pivotal role in enhancing living standards [4]. Developments in Wireless Sensor Networks (WSNs) allowed the evolution of the pervasive intelligence concept [5],[6], where the future world can be envisioned as an Internet of Everything (IoE) environment [7] with interconnected devices at the individual level working with the Industrial IoT devices at a professional level improving business-to-business (B2B) services [8].

Previous work of Poongothai et. al. [9] looked at the development of a smart IoT lab in their campus. The focus was on implementing a remote energy monitoring and control system to reduce manual human intervention. 30% of total energy on their campus was saved through the IoT monitoring system.

Another paper by C. Adjih et. al. [10] explored a different aspect of implementing an IoT lab via the creation of a free-of-charge access to thousands of IoT devices where users can manipulate remotely. These characteristics make the IoT-lab a useful platform for benchmarking, validation, and testing software on IoT hardware [10].

Lastly, the paper by B. Ramprasad et. al. [11] discusses the challenges of conducting research and testing on large-scale Internet of Things (IoT) systems due to the high costs of acquiring specialized equipment and infrastructure. To address this issue, the paper proposes the development of a virtual lab called EMU-IoT, which utilizes virtualization and container technologies to enable researchers to conduct large-scale experiments and test various aspects of IoT systems with minimal requirements for devices and equipment. The paper discusses the benefits of using EMU-IoT, including the ability to run experiments and perform scalability tests, the ability to evaluate the entire IoT system (including both devices and applications), and the ability to monitor and automatically adjust the system to achieve performance goals.

The paper is divided into the four main sections starting with the Introduction. The second section looks at the proposed IoT lab architecture and devices used in the IoT Lab. The third section highlights the key results and analysis and lastly, the fourth section concludes the paper and identifies potential ideas for future work.

II. Proposed IoT Lab Architecture

This section looks at the design of the Smart IoT Lab and is divided into 2 main subsections. The first subsection presents the floorplan of the IoT Lab with the planned devices and the overall system architecture of the sensors. The second section focuses on the communication protocols and configurations designed for a seamless connection to the chosen IoT Platform.

A. System Architecture

The IoT Lab at the DEWA R&D Center is a 20m by 9.5m building with a total area of 190m^2. Figure 1 below provides an initial insight to the lab layout and where the main components of the lab are situated.

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PV module classification based on spatial distribution of soiling using Deep Learning model

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***Abstract*—Soiling is the most common phenomenon, especially in desert regions, resulting in power losses and reduced reliability for PV modules. The spatial distribution of dust particles can be uniform or non-uniform, both negatively affecting the performance. However, the latter has more pronounced effects as it leads to partial shading, leading to current mismatching with reduced performance and the formation of hot spots. Hence, it is necessary to perform timely inspection of solar PV farms to detect and identify the distribution of dust. We propose a deep learning model for detecting dust levels on a PV module based on uniformity to achieve this objective. The workflow involves first segmenting the modules from the farm, followed by its individual localization, classification based on dust or no dust, and finally, classification based on uniformity of the dust deposition. The data is gathered using a drone equipped with a camera autonomously navigated using real-time kinetics (RTK). The overall accuracy of the classification model is more than 90%. This enables a faster inspection process, which, combined with our algorithm, improves the overall efficiency and accuracy of the maintenance procedure.**

***Index Terms*—soiling, non-uniform, spatial, deep learning, classification**

I. Introduction

According to the International Energy Association, worldwide energy production by renewable sources is expected to increase by 2.4 TW over the next five years. The solar industry's contribution towards this increase is expected to be the highest, 1.5TW [1]. This tremendous increase is facilitated by the increased installation of photovoltaic (PV) modules worldwide and the development of new technologies to improve module efficiency, to name a few. Once installed, the PV modules are exposed to several environmental factors that negatively affect their performance [2] [3]. Soiling is one such example. It refers to forming an additional foreign layer over the module surface and mimics the behavior of an insulator. This hinders efficient light transfer and heat dissipation from the PV modules, resulting in increased operating temperature, decreased efficiency, and increased degradation. In desert regions, soiling is a major cause of PV performance degradation [4] [5] [6]. It mostly occurs in the form of dust and dirt particles. Studies have shown a significant loss in PV performance due to soiling. Research has shown a 50% drop in power output after prolonged exposure of the modules to environmental condition [7] [8] [9]. In one study, it was concluded that soiling may result in an average loss of 1% per day [10], while in another study, average daily energy loss was found to be up to 4.4% [11]. The spatial distribution of soiling varies based on the uniformity of dust deposition. Both uniform and non-uniform soiling cause a significant reduction in the power output. However, the latter is more dangerous due to the added effect of partial shading, which eventually leads to kinks in IV curves due to current mismatching and formation of hot spots [12] [13]. Due to the module tilt, non-uniform soiling most commonly occurs with the majority of the dirt accumulating on the module edges and results in varying degrees of power losses [14] [15] [16].

To avoid high power losses due to environmental conditions, timely and efficient visual inspection procedures for soiling on the installed modules are vital. Also, it is necessary to analyze further the extent of soiling occurring over the PV modules. In recent times, inspection using drones has become widespread, along with several image processing techniques to inspect the data for defects [17] [18] [19]. Researchers could quantify the dust on the modules using traditional image processing techniques [20] . However, this approach is highly dependent on the lighting conditions and would not work well on large-scale farms. In another study by Ramos etal, researchers detected dust based on the spectral wavelength of reflected light by analyzing color images [21]. This does not account for the module's location and is dependent on lighting conditions. Researchers used a deep learning model YOLOv5 for soiling detection on PV modules [22] . Their approach involves only classifying the type of soiling, not quantifying it. This causes a drawback in terms of assessing the urgency of the soiling. In another study [23], researchers used a feature extraction technique to classify modules as dirty or clean. Only 50 images were used in the dataset, and their approach does not account for the spatial distribution of the soiling.

In this paper, we introduce a novel concept of the classification of PV modules based on the spatial distribution of dust deposition using Deep Learning. The data is gathered using drones and is post-processed. The first step of the processing involves segmenting and uniquely identifying each PV module using Mask-RCNN. Followed by classification based on dust and clean modules using another deep learning model MobileDetectNet2. Finally, further evaluating the module for soiling distribution as uniform and non-uniform using the same model. This approach makes the inspection process faster, more reliable, and more efficient. It aids power-plant operators to conduct timely and appropriate mitigation procedures.

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An Ongoing Futuristic Career of Metal–Organic Frameworks and Ionic Liquids, A Magical Gateway to Capture CO_2; A Critical Review

Syed Awais Ali,* Asmat Ullah Khan,* Waqad Ul Mulk, Haris Khan, Syed Nasir Shah, Afrah Zahid, Khairul Habib, Mansoor Ul Hassan Shah, Mohd Hafiz Dzarfan Othman, and Saidur Rahman

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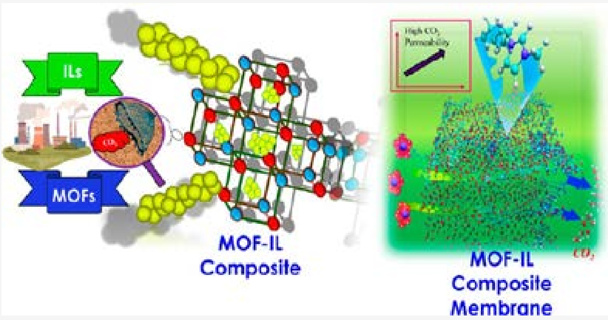
ABSTRACT: Carbon capture and storage (CCS) technologies are the "knight in shining armor" that can save humanity from burnout in the longer term, minimizing damage from CO_2 emissions by keeping them out of the atmosphere. Metal–organic frameworks (MOFs) have received a promising career for CO_2 capture due to their high porosity, surface area, excellent metal-to-ligand interaction, and good affinity to capture CO_2 molecules. On the other hand, Ionic liquids (ILs) as emerging solvents have reported a significant influence on CO_2 solubility due to their wide range of tunability in the selection of a variety of cations and anions along with the advantage of nonvolatility, high thermal stability, and nonflammability. The current Review highlights the recent progress and ongoing careers of employing MOFs and ILs in carbon capture technologies before their commercialization on a large scale. A brief overview of CO_2 capturing using MOFs and ILs is given under the influence of their possible functionalization to enhance their CO_2 separation. Information on the possible integration of MOFs-ILs as a composite system or membrane-based gas separation is also presented in detail. The integration has a high potential to capture CO_2 while minimizing the unit operation costs for a stable, efficient, and smooth industrial gas separation operation. Present work attempts to link the chemistry of MOF and IL and their successful hybridization (MOF-IL composite) to process the economics for CO_2 capture.



1. INTRODUCTION

The high consumption of fossil fuels with the rapid growth in industrialization and urbanization produces a significant amount of carbon dioxide (CO_2) in the surroundings.[1] The "CO_2 emissions" word has become a buzzword in recent years due to its anthropogenic role in increasing the global earth's temperature. Moreover, CO_2 has made the natural disaster worse.[2] According to the recent global monitoring report, the average CO_2 atmospheric concentration of 417.06 ppm (ppm) was recorded in the year 2022, with a high global growth rate of 2.13 ppm reported between the years 2021–2022.[3] The excessive release of CO_2 produces several environmental problems such as rising sea levels, global warming, ecosystem disorder, relocation of wildlife inhabitants, and adverse effects on human lives.[4] This has raised the alarm for all the countries to devise a methodology for CO_2 capture. Most of the efforts on CO_2 capturing are focused on sequestering CO_2 from large-point sources like power plants and the process industries. The technologies used to produce heat and electricity from fossil fuels determine the requirements for CO_2 capture.[5,6]

To capture CO_2, numerous technologies are widely used in this field, including postcombustion, precombustion, and oxyfuel combustion, as shown in Figure S1. The postcombustion conditions require complete fuel burning in a single step. This results in the release of excessive heat to generate steam at high pressure, which can then be used to drive a steam turbine for electricity generation.[7] The flue gas exposed to about 10–16% CO_2 after processing is released into the environment without involving a proper carbon-capturing system.[8] The precombustion mechanism involves gasifying fuel (coal, oil, etc.), including pure oxygen, and steam to form syngas.[9] During the water–gas shift (WGS) reaction process, the syngas, which are made up of hydrogen (H_2) and carbon monoxide (CO), go through purification before they go into the reactor.[10] The WGS reactor converts CO into H_2 and CO_2 by reacting with steam, producing both the steam and CO, which undergo desulfurization before going to the WGS reactor as per their requirements.[11] This stage of the process involves the gas mainly composed of H_2 and CO_2 which results in the capture of CO_2 and combustion of H_2 in a gas turbine utilized to generate heat and electricity.[12] The oxyfuel

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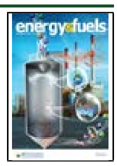

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Delayed and Partial Mixing Method of Operating Multi-Tank Redox Flow Battery Systems

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To reap the benefits of conventional single and multi-tank redox flow battery (RFB) fluid systems, we investigate a delayed and partial mixing methodology for operating RFB tank systems to maximise electrolyte utilisation and storage capacity. The method modulates an optimised mixing timeframe and mixed amounts of momentarily (un)circulated electrolytes in two vertically separated tank sections. The gravity-assisted mixing between the tank sections achieved by siphon or automatic valve ensures continuous uninterrupted flow occurs in a single direction within the cell while lowering additional auxiliary components/energy and system complexity/cost. We applied a detailed Multiphysics simulation of a test vanadium RFB cell to demonstrate the methodology and its capabilities - especially for larger tank volumes. Significant concentration overpotential reduction with the delayed and partial mixing leads to an increment in discharge capacity and energy efficiency up to 6.5% and 2%, respectively, compared to the conventional single tank system. The practical applicability of the investigated system was also discussed as promising for commercial RFB deployments.
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Supplementary material for this article is available online

The general operation of a typical RFB is dependent on its fluid system, which consists of; electrolytes, pumps, tanks, piping, valves, and sensors, for each half cell. During (dis)charging operation of the RFB, the fluid system works to deliver positive and negative electrolytes to and from tanks and the cell/stack. In the conventional fluid system, there is one tank each for the negative and positive electrolytes. In this configuration (See Fig. S1a in supporting information—SI), initially uncirculated electrolyte is pumped from the respective tanks, goes through the cell(s) to undergo the (dis)charging operation, and then returns to the same tanks to mix with other uncirculated electrolyte left. This described conventional fluid system—with workflow also summarised in SI Fig. S1b; we refer to it as a *full mixing* system herein. With an ideal membrane, the RFB is without crossover of reactants or electrolytes from one side (positive or negative) to the other.

Early RFB designs[1,2] utilized the full mixing system, as it offers the advantage of simplicity and lower system capital costs. However, mixing circulated and uncirculated electrolytes (at different states of charge) in the tanks leads to poor electrolyte utilisation by the RFB and, consequently, reduced charge storage/recovery. There is typically some crossover of active species and bulk electrolytes from one side (positive or negative) to the other. Therefore, crossover in a full mixing system is also detrimental to the energy efficiency of the RFB.

In response to these drawbacks of the full mixing system, a *no-mixing* system has been previously proposed.[3] In the no-mixing system, additional tanks are introduced to separate circulated and uncirculated electrolytes during a (dis)charging operation. The no-mixing system operation schematic is depicted in Fig. S1c of the SI. Multi-tank or multi-compartment tank RFB systems have also been proposed,[4–6] albeit for other aims. Other schools of thought in response to the described set-back of a full mixing system include; having multi-compartment cells/stacks for circulated electrolytes at different states of charge,[7] or multiple differently sized tanks.[8] Liu et al.[3] studied the advantages of a no-mixing VRFB system. They claimed a significant increment of >10% and 2% in capacity and voltage efficiency, respectively, compared to a full mixing system.

The no-mixing system operates by reversing the direction of electrolyte flow between two separate tanks during (dis)charging. Initially uncirculated electrolyte flows from tank A—through the pump to the cell(s) for (dis)charging. The now circulated electrolyte exiting the cells is collected in tank B until tank A is emptied. This transition can be regarded as a single pass. Multiple passes are needed because a single pass is typically insufficient to fully charge or discharge the electrolytes. The electrolyte is then continuously pumped forward and reversed using the two pumps (on each side) between the two tanks, A & B (see the workflow of Fig. S1d). The introduction of additional tanks requires additional pumps, sensors, etc, which translates to increased system capital costs.

The cost increase is a drawback when comparing the schematic of the no-mixing system to the full mixing system. Additional disadvantages with the demonstrated no-mixing approach and other previous responses to the full mixing system include:

- Power-consuming fluid system components (like pumps) are parasitic power consumption (or auxiliary energy) to the RFB. Adding more such components reduced overall system power output.
- The interrupted electrolyte flow after each pass (in the no-mixing system) due to different pump and other component activation times could lead to unstable (dis)charging, even if for milliseconds. Within the duration of flow interruption caused by different multiple component activation, current or potential may spike, which momentarily gives an erroneous state of charge indication (full (dis)charge) to the charge controller.
- The increased complexity of stabilisation, synchronisation, and control of both pumps on each side to achieve a stable flow rate in the no-mixing system.
- RFB cell(s) performance is slightly influenced by flow direction (along or against gravity). Depending on the electrode, one flow direction is typically more favourable for redox reaction—resulting in an improved capacity.[9] The no-mixing approach includes traversing flow in both favourable and less favourable directions. More complicated flow fields/manifolds/frames will be needed to address this compromise.
- Centrifugal pumps—most used for RFB, usually have a designated inlet/outlet and must continuously be wetted. Reversing the flow operation could lead to pressure loss and subsequent higher pumping power requirements or the application of more expensive pumps.
- The most common flow meters are not designed to operate in a bidirectional flow and can be damaged by reversed flow direction. Choosing other bidirectional pumps or complex flow meters with reverse flow capability increases cost.

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Evaluation of the infill design on the tensile properties of metal parts produced by fused filament fabrication

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A R T I C L E I N F O

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A B S T R A C T

Additive Manufacturing (AM) applications have expanded significantly from rapid prototyping to high-end products such as complex spare parts. AM has enabled advantages of reduced material usage, geometric freedom, and production automation, shaping the future of the manufacturing industries. With the rapid expansion of AM applications, feedstock materials have developed noticeably, from polymers and ceramics to metals and composites. The progress in metal feedstock material discoveries has empowered the exploration of implementing new AM technologies. Fused Filament Fabrication (FFF) is one of the most common and cost-effective material extrusion AM technologies. This study explores the effect of the infill pattern on the tensile mechanical properties of metal parts produced via FFF, using two feedstock materials, 17-PH stainless steel and copper. Two approaches are designed to investigate the results: experimental tensile test, and Finite Element Analysis (FEA) with digital twin reconstruction method. Results show that 17-4 PH Stainless Steel samples with a triangular infill exhibited a 42% drop in ultimate tensile strength compared to solid infill. However, it also revealed a 34% reduction in mass, cost saving of 36%, and a faster fabrication with a 25% reduction in lead time. At the same time, copper samples with triangular infill exhibited a 22% drop in ultimate tensile strength and a 12% mass reduction. However, it revealed a similar lead time with only a 3% reduction. A Scanning Electron Microscope (SEM) was used to investigate the parts' internal structure and average pore size, to understand the failure mode of the test specimens.

1. Introduction

Additive Manufacturing (AM) technologies have evolved significantly over the past decades; applications of AM have extended from rapid prototyping and spare parts manufacturing to a bigger scale, such as bridges and buildings. The first 3D-printed laboratory in the world was built within Dubai Electricity and Water Authority (DEWA) Research and Development Center at Mohammed Bin Rashid Solar Park in Dubai [1]. AM has various advantages, such as reduced material waste, geometric freedom, and automation compatibility, shaping the future of manufacturing and industry 4.0 technologies. AM set the basics of the transformation from design for production to design for function [2,3].

AM technologies are classified into seven main categories: Material Extrusion, Binder Jetting, Material Jetting, Powder Bed Fusion, Vat Photopolymerization, Directed Energy Deposition, and Sheet Lamination [4]. Each of the above groups can be classified further into sub-categories depending on the raw material used and the application. Feedstock materials used in AM technologies vary from polymers and ceramics to metal powders and advanced composites.

Powder Bed Fusion (PBF) and Direct Energy Deposition (DED) are leading AM technologies that successfully incorporate metallic feedstock material. The difference lies in the physical form of the feedstock material, powder, or wire forms, respectively. They also differ in the energy source: PBF with a laser beam, while DED with an electron beam or electric arc [3].

In 2017, Markforged™ launched Metal X, a metal 3D printer that uses a relatively new technology to the existing metal 3D printers, identified as Bound Powder Extrusion (BPE). BPE is similar to Fused Filament Fabrication (FFF) in extracting material feedstock from a filament through a nozzle. FFF technology is classified under material extrusion technologies of AM. FFF advantages include low cost and high

Abbreviations: FFF, Fused Filament Fabrication; SEM, Scanning Electron Microscopy; AM, Additive Manufacturing; BPE, Bound Powder Extrusion.

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Organized macro-scale membrane size reduction in vanadium redox flow batteries: Part 1. General concept

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A R T I C L E I N F O

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A B S T R A C T

The high costs of the currently used membranes in vanadium redox flow batteries (VRFBs) contribute to the price of the vanadium redox flow battery systems and therefore limit the market share of the VRFBs. Here we report a detailed simulation and experimental studies on the effect of membrane reduction of single-cell VRFB. Different simulated designs demonstrate that a proposed centred and double-strip membrane coverage showed a promising performance. Experimental charge-discharge profile of different membrane size reduction, which showed good agreement with simulated data, suggests that the membrane size can comfortably be reduced by up to 20% without severe efficiency or discharge capacity loss. Long-term cycling of 80% centred membrane coverage showed improved capacity retention during the latter cycles with almost 1% difference in capacity and only 2% in energy efficiency when compared to the fully covered-membrane cell. The results hold great promise for the development of cheap RFB stacks and facilitate the way to develop new cell designs with non-overlapping electrodes geometry. Therefore, giving more flexibility to improve the overall performance of the system.

1. Introduction

Redox flow batteries (RFBs) are seen as an attractive future energy storage system. The decoupled energy storage and power generation, scalability, safe operation, environmentally friendly and long cycle life promote these systems for large scale applications [1–5]. However, low energy density and overall efficiencies require additional space and infrastructure which increases the overall cost of RFB and complicates the market competition with other batteries [6,7]. The main three components affecting the performance of such batteries are (i) electrolyte solution which can suffer from ions precipitation or thermal instability, (ii) electrodes which can negatively affect the power rating by undesirable polarization, and (iii) membrane which cause ions crossover and imbalanced electrolyte [8,9].

Cost reduction measures and new stack designs can make RFBs more economically viable for standalone and grid-connected applications. A logical approach to reducing cost is to minimize the use of expensive components of the RFB stack without sacrificing performance – in terms of efficiency or storage capacity of the system. From the above-mentioned components of the RFB, membrane is considered as main cost contributor in the system [10], specifically ion exchange membranes. Commercial polymeric ion exchange membranes are most widely used in RFB, still the low ions selectivity and undesirable ion crossover restrain the technology [11,12].

Various approaches are demonstrated in the literature to improve the performance of these membranes. Some approaches are based on introducing hydrophilic inorganic-based nanoparticles or charged groups [13–16], while other structural modifications have also been investigated to reduce crossover, lower water uptake or swelling ratio, and increase thermal stability [1,17–21]. Unfortunately, these membrane modifications are often linked with increased membrane resistance or decreased chemical stability [22,23], consequently compromising charge-storage performance. Another reported membrane type used for flow batteries is nano-porous membranes/separators. Despite their high ion selectivity (when applied in the right battery chemistry) and stability, these nano-porous membranes/separators still suffer a trade-off between ion selectivity and conductivity [24].

Membraneless redox flow battery solutions have also been reported in recent years, trying to overcome the associated problems with membranes and their high cost [25,26]. Despite the considerable continuous improvement in power density of such systems [27–29], there are still issues of scalability in addition to

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Evaluation of Asymmetric Flow Rates for Better Performance Vanadium Redox Flow Battery

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Abstract

Electrolyte imbalance caused by water and ion crossover is one of the main factors affecting the capacity of vanadium redox flow battery system over cycling. Ion crossover and the associated water transfer towards the positive half-cell is mainly caused by the transfer of the vanadium ions, its bounded water and the water driven by osmosis. The different viscosity of the vanadium (III) ions in the negative half-cell builds inconsistent pressure profiles at both half-cells during charge-discharge cycling and therefore magnifies ions and water transfer tendency. To mitigate the effect of electrolyte imbalance, herein we report an experimental study on the effect of using asymmetric flow rates in the negative and positive half-cells. Over different current densities of 50 mA cm^{-2} 100 mA cm^{-2} and 150 mA cm^{-2}, the use of one magnitude flow factor lower in the negative half-cell and one magnitude flow factor higher in the positive half-cell is superior to the symmetric flow rates on reducing electrolyte imbalance and subsequently, improving the capacity retention. At 100 mA cm^{-2}, a gain of 5% in discharge capacity coupled with energy efficiency improvement of around 3% is achieved using a cell with asymmetric flow rates compared to a cell with the symmetric flow rates after 50 cycles. Low magnitude of flow rate asymmetry can sufficiently compensate for the half-cells pressures imbalance, higher increment in flow rate asymmetry showed that positive-to-negative crossover become more favourable.

Keywords: Asymmetric flow rates, Pumping losses, Pressure drop, Electrolyte viscosity, Vanadium redox Flow Batteries.

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Capturing water vapors from humid air using microporous activated carbon derived from sunflower seed shells

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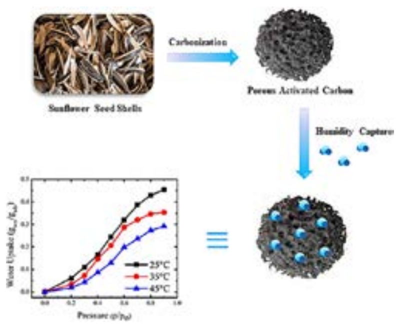
HIGHLIGHTS

- Sunflower seed shells were used to synthesize microporous activated carbon.
- The microporous activated carbon was characterized using TGA, XRD, FTIR, and SEM.
- Pore studies showed high pore density in the microporous range.
- The highest water adsorption capacity was 0.454 g_{wat}/g_{ads} at 90% RH and 25 °C.
- Adsorption capacity was higher than most activated carbon-based desiccants.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Microporous activated carbon
Sunflower seed shells
Solid desiccants
Water vapor adsorption

ABSTRACT

Water extraction from the atmosphere using solid desiccants is becoming an increasingly viable option for human consumption. Using sustainable raw materials is imperative to reduce the carbon footprint in the mass production of such desiccants. In this paper, we synthesized microporous activated carbon from sunflower seed shells (SSS-AC) to capture water vapors from humid or moist air. Sunflower seed shells (SSS) are an agricultural waste product that makes the final product a sustainable and environment-friendly alternative to traditional solid desiccants. Chemical activation was carried out using KOH as the activating agent, and the ratio of activating agent to carbon was 2:1. Different structural and morphological properties of synthesized microporous activated carbon (SSS-AC) were studied using FTIR, XRD, SEM, EDAX, and TGA characterization techniques. The surface area and pore distribution were characterized using N_2 adsorption/desorption studies, where a steep initial uptake with a wide capillary condensation step was observed for SSS-AC. The pore distribution of SSS-AC showed high pore volume in the microporous range. The pH_{pzc} value for the SSS-AC was measured to be 10.24 while the HI value was found to be 6.26, indicating an alkaline and hydrophobic surface. Water adsorption studies were carried out at 25, 35, and 45 °C, and the material was found to exhibit type-V isotherm, which is common for microporous activated carbons and indicates the likely occurrence of pore condensation. The SSS-AC reported a maximum adsorption capacity of 0.454 g_{wat}/g_{ads} at 90% relative humidity and 25 °C, which is higher than some

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Latest progress in utilizing gum hydrogels and their composites as high-efficiency adsorbents for removing pollutants from wastewater

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ARTICLE INFO

Keywords:
Polysaccharide hydrogels
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ABSTRACT

Water has great significance for human life, plants as well as animals. In modern times, the problem of contamination of different water bodies with increasing anthropogenic pollutants, including agricultural, industrial, and everyday domestic waste, has increased tremendously. Different organic/inorganic pollutants in water are a potential risk for water resources that has destructive health impacts on humans and other living organisms. Hence, it is crucial to prioritize the cost-efficient removal of organic and inorganic pollutants through environmentally friendly methods. Among the researched approaches, adsorption-based wastewater treatment stands out for its efficiency and practical economic benefits. The success of any adsorption process relies heavily on the characteristics of the adsorbent used. There has been interest in polysaccharide-based hydrogels and their nanocomposites incorporating metal oxide nanoparticles, clay minerals, zeolites, and carbonaceous materials for various water purification techniques like adsorption and photocatalysis. Hydrogel nanocomposites (HNCs) have gained attention as adsorbents for water treatment due to their eco-friendly adsorption capacity, low cost, non-toxic nature, and ease of synthesis. This article provides a review of the developments in utilizing polysaccharide hydrogels and their composites as effective adsorbents in removing different types of organic and inorganic impurities from wastewater. Specifically, it covers methods of hydrogel synthesis techniques to incorporate fillers into the polymer matrix as well as highlights the key advantages they offer when applied in wastewater treatment applications.

1. Introduction

Water is essential for the existence of human life as well as other living organisms on the earth. However, water covers almost 70% of the earth, and only 3% can be used as soft water for drinking [1]. Therefore, accessibility to pure and safe drinking water is a global concern, and the situation is even worsening with the rapidly growing population. Most industries, including paper, batteries, textiles, and lather, produce large quantities of waste with different organic/inorganic impurities. Discharge of hazardous pollutants containing effluents produced by these industries into water bodies without proper treatment contaminates underground water bodies. It reduces drinking water quality, a potential risk to human health and other living organisms. Synthetic dyes are chemically resistant to degradation because they are organic compounds with complex structures; therefore, most synthetic dyes remain in the environment over long periods. Dyes contaminated water is very harmful and poses a potential risk to human health as it can cause severe impairments to the kidney and liver functions, the human reproductive system, and the central nervous system [2]. Synthetic dyes also affect aquatic life by reducing sunlight availability for photosynthesis [3]. Different heavy metal ions are carcinogenic and potentially threaten human health. Most heavy metal ions are non-biodegradable. Therefore, they can stay for a long time in their bodies. Therefore, these pollutants should be completely removed from industrial effluents before their discharge into water bodies.

Commonly used methods for industrially polluted wastewater are coagulation-flocculation [4], photocatalysis [5,6], chemical precipitation [7], adsorption [8,9], membrane separation [10], and ion exchange [11]. Amongst different methods for water purification, adsorption is considered the most well-known technique due to various economic and practical advantages, including low cost, environment-friendly nature, and absence of secondary contaminants [12,13]. The overall performance of the adsorption process depends upon the properties of a material selected as the adsorbent. Any ideal adsorbent material for

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Recent developments in the adsorption of uranium ions from wastewater/seawater using carbon-based adsorbents

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ABSTRACT

The presence of uranium ions with extended half-life or heat emissions can lead to enduring environmental damage. Moreover, they can potentially enter the food chain posing risks to health due to their toxicity and radioactivity. Therefore, it is crucial to develop techniques and materials to effectively remove these ions, especially uranium ions from contaminated water sources. In recent times various carbon-based materials have gained attention as adsorbents for removing different organic/inorganic impurities from wastewater. These materials possess superior surface properties that can be easily modified to have a specific surface area with different structural variations. In this review article, we discussed the recent advancement in using different carbon-based adsorbents for the removal/recovery of uranium ions from wastewater. Further, different methods to prepare carbon-based adsorbents and their composites with other materials are discussed in detail. The key mechanisms involved in the adsorption of uranium ions using different carbon-based adsorbents are discussed in detail. The main objective of this article is to provide helpful information on how uranium ions can be effectively removed using carbon-based adsorbents. In conclusion, our discussion includes addressing the existing constraints and proposing directions for future investigation to promote substantial advancements in the domains of using carbon-based adsorbents for uranium-contaminated wastewater remediation applications.

1. Introduction

In the last few decades, with a rapidly growing population, high living standards, and industrial development, energy demand has increased many times around the globe. Traditional energy production methods cannot fulfill this high energy demand. Therefore, almost all the countries in the world are facing an energy crisis. The conventional methods of energy production, especially fossil fuels, cannot meet the energy requirements further. They are associated with other drawbacks, such as environmental pollution [1,2]. Therefore, considering high energy demand, sustainable development, and ecological concerns, there is a need for the development and sustainable growth of other clean energy generation methods capable of fulfilling the energy demand. Nuclear energy has been considered the most viable alternative to traditional energy sources, which can generate a high amount of sustainable energy without the emission of greenhouse gases [3]. Despite its efficient electricity production, nuclear power is still associated with concerns regarding radioactive or nuclear waste management and the possibility of reactor accidents [4]. In the nuclear industry, uranium is used as the primary nuclear element for energy production. Presently, uranium is obtained via mineral exploitation. With increasing energy demand, uranium mining has increased many folds, but the terrestrial uranium ores are limited [5]. Therefore, terrestrial uranium ores are estimated to be exhausted this century [3].

Further, during the extraction of uranium from terrestrial ores, a large quantity of uranium waste is discharged into different water bodies, contaminating groundwater with uranium ions [6]. Therefore, efficiently treating waste generated while mining uranium is very important. Further, the amount of uranium present in seawater is much higher than that in terrestrial ores, which can be used to supply uranium for nuclear energy generation for at least 1000 years [7–9]. However, uranium extraction from seawater is quite difficult because of the high salinity of uranium metal ions, low uranium concentration, and complex species presence [10,11]. Therefore, the extraction of uranium from

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Breaking boundaries in CO_2 capture: Ionic liquid-based membrane separation for post-combustion applications

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ABSTRACT

As a part of global warming reduction strategies, CO_2 capture and storage (CCS) is considered a promising and effective method, which can be classified as absorption and adsorption, chemical looping combustion and cryogenic distillation, hydrate-based separation, and membrane separation. But, the high energy requirement, solvent loss and degradation, corrosive nature, and toxicity of solvents can limit the applications. Developing novel techniques and materials are attracting high attention to achieve superior capacities. The supported ionic liquid membranes (SILMs) as a part of ionic liquids (ILs) have shown great potential for efficient and cost-effective separation of CO_2 from the gaseous flow. The present review demonstrates the mechanisms, advantages, difficulties, and disadvantages of CO_2 capture by SILMs and compares them with various conventional methods. A major part of this review covers the tunability of SILMs, experimental data of solubility, diffusivity, permeability, and selectivity of CO_2 in various combinations of ILs, membrane supports, and additives. Lastly, the stability of SILMs, reusability of ILs, membrane wetting, challenges, and future recommendations are presented.

1. Introduction

The rapid growth in industrialization is one of the major contributors to emissions of greenhouse gases which in turn causes an increase in average global temperature on earth. Carbon dioxide (CO_2) is a prime driver of climate change, accounting for almost 80% of all greenhouse gas emissions [1,2]. A recent IPCC report states that 62 million people have been directly affected by extreme weather anomalies due to climate change, attributed to the increased CO_2 level in the air [3]. To overcome this problem, the united nation framework convention on climate change (UNFCCC) Conference of Parties (COP-26) has set an undertaking for all nations to keep the goal of limiting global warming to 1.5 °C in its meeting, which was held at London in April 2021 [4]. To meet this objective and overcome the problem of global warming, CO_2 capture and storage (CCS) technologies are the need of the hour, as it allows the huge adsorption of CO_2 from different point sources for its smooth transportation and storage to prevent its emission into the atmosphere [5].

Various CCS technologies, including post/pre-combustion and oxy-fuel combustion, are being investigated and are in place to combat global warming. The post-combustion CO_2 capture method is mostly

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SrO-MnO/Ceramic: A Novel Bifunctional Catalyst for Biodiesel production via Simultaneous Transesterification-Esterification of Waste Frying Oil

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The strontium-manganese supported over ceramic was synthesized through wet impregnation method and investigated as a solid catalyst for its catalytic performance in transesterifying-esterifying low-grade waste frying oil with methanol in a batch reactor; parameters for synthesis of catalyst and transesterification reaction were also optimized. The maximum biodiesel yield of 93.66% was attained by SrO-MnO/Ceramic catalyst under normal process conditions. The synthesized catalyst reusability potential was also evaluated for 12 runs with regeneration carried out after the 7th run only and it revealed that the catalyst showed great stability for the initial five cycles offering yield of over 90%. The fresh and used SrO-MnO/Ceramic catalysts were characterized to address the mechanism of catalytic behavior and deactivation using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), benzoic acid and n-butylamine titration method, and Hammett indicators. The alteration in surface morphology; Mn solubility in glycerol and methanol; occupation of energetic centers by organics might be the reasons for diminished activity or deactivation of solid catalyst after repeated reuse.

Introduction

The quest for sustainable green energy supply, dwindling crude oil sources, and rise in energy prices are factors that urge scientists to develop alternative fuels. The characteristics of biodiesel chemically termed methyl esters of long-chain fatty acids have facilitated the hunt for biodiesel production alluring and an optimistic replacement for conventional renewable fuels.[1–3] Until now, biodiesel has been primarily prepared through the economically suitable transesterification/esterification method, which requires a triglyceride/free fatty acid of oil and alcohol customarily methanol (MeOH) or ethanol via appropriate catalyst presence to create methyl esters and glycerol as a by-product. Unlike homogenous, solid catalysts require no product purification steps and they are easy to separate owing to the solid-liquid phase in the reaction medium and offer a longer lifespan with reuse of several cycles.[4–6] The implementation of second-generation feedstock, such as waste frying oil (WFO) also described as acidic oil is preferred for transesterification since it can reduce production costs. However, one downside of WFO is that it contains more free fatty acids (FFA) in comparison to virgin oils.[7] Customarily, acidic oils are mostly catalyzed by acidic catalysts via esterification, and basic catalysts are often employed to catalyze vegetable oils through transesterification, respectively.[8] As needs be, the implementation of bifunctional heterogeneous catalysts is profoundly desirable due to their significant advantage to transform oil's triglycerides and FFA into methyl ester through simultaneous transesterification and esterification in one-step reaction because of the existence of both basic and acidic sites. These catalysts can increase methyl ester productivity and they are especially competent for low-grade oils.[4] For production of methyl ester from low-grade oils various bifunctional catalysts have been implemented, as presented in Table 1. However, for optimal yield, the temperatures employed were quite high due to the inhibition of transesterification reaction by FFA.[9] Hence, the goal of this current study is to develop an economical bifunctional solid catalyst capable of attaining a high yield of methyl ester from WFO under moderate operating conditions.

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Article

Understanding Characteristic Electrochemical Impedance Spectra of Redox Flow Batteries with Multiphysics Modelling

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Abstract

Electrochemical impedance spectroscopy (EIS) is a non-destructive technique for analyzing electrochemical systems (such as redox flow batteries – RFBs). Battery researchers widely adopt equivalent circuit models (ECMs) to analyze EIS spectra of RFBs and attempt to use the circuit to deduce prevalent transport and kinetic properties [1]. Straightforward adoption of these ECMs suffers from some setbacks which need rectifying. There is a major issue of poor or inconsistent physical interpretation of the different circuit elements. ECMs of batteries are commonly used in real-time applications due to their simplicity and importance for determining properties like state-of-charge. However, prediction performance in low state-of-charge areas has to be improved [2], which reinforces the need to relate recorded spectra to the physical properties of cell components. Using an experimentally validated full Multiphysics model of single-cell vanadium RFB analyzed in the frequency domain, we approach understanding the EIS spectra characteristics based on the influence of cell features and operating parameters. To achieve our analyses, we investigate the effects of different cell properties and operating parameters on the Multiphysics model produced EIS spectra and the resulting ECM circuit element parameters that fit the spectra. Five different values for each cell property or operating parameter are considered for the following components: Electrode: Electrical conductivity, porosity vis a vie specific surface area and hydraulic permeability, reaction rate constants for the positive and negative sides. Membrane: Ionic conductivity, fixed charge concentration, porosity, and hydraulic permeability. Electrolyte: State-of-charge, Composition vis a vie bulk diffusion coefficients of species, density, and viscosity. References [1] A.K. Tripathi, D. Choudhury, M.E. Joy, M.J.J.o.T.E.S. Neergat, Electrochemical Impedance Spectroscopic Investigation of Vanadium Redox Flow Battery, 169 (2022) 050513. [2] Y.A. Gandomi, D. Aaron, T. Zawodzinski, M.J.J.o.T.E.S. Mench, In situ potential distribution measurement and validated model for all-vanadium redox flow battery, 163 (2015) A5188.

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