Operational Challenges Faced by Distribution Utilities in the Era of Climate Change

Omar AlAhmad
Operation Planning and Studies Department
Al Ain Distribution Company
Al Ain, United Arab Emirates
Omar.Alahmad@aadc.ae

Maha AlDahmi
Operation Planning and Studies Department
Al Ain Distribution Company
Al Ain, United Arab Emirates
maha.aldahmi@aadc.ae

2024 6th International Conference on Smart Power & Internet Energy Systems (SPIES) | 979-8-3503-6886-4/24/$31.00 ©2024 IEEE | DOI: 10.1109/SPIES63782.2024.10983148

***Abstract*—This paper explores the operational challenges faced by electricity distribution utilities in the context of climate change. Due to climate change, distribution utilities encounter severe damages and interruptions to their infrastructure and services' reliability due to the increase in the frequency and intensity of extreme and adverse weather events, rising temperatures, and shifting rainfall patterns. Globally, key challenges include damage from storms and floods, increased strain on equipment during heatwaves, and the threat of wildfires. Additionally, the integration of intermittent and weather dependent renewable energy sources as well as the compliance with evolving regulatory requirements adds complexity to utility operations under adverse weather conditions. To address these issues, utilities must invest in resilient infrastructure, adopt advanced monitoring and control systems, and implement strategic planning and sustainability practices. By understanding and mitigating these challenges, distribution utilities can enhance their resilience and continue to provide reliable service in increasingly unpredictable climate events. The paper illustrates the challenges faced by AADC during the last adverse weather conditions that had the highest amount of rainfall in 75 years and the extremely hot temperatures reached in the last few summers.**

Keywords—AADC, climate change, distribution network, DMS, flood, security of supply

I. Introduction

Al Ain Distribution Company (AADC) is a public joint stock company located in the eastern region of emirate of Abu Dhabi, operating under Abu Dhabi National Energy Company (TAQA) group in the United Arab Emirates (UAE) [1]. Its main responsibility is the distribution of water and electricity in the Al Ain region of Abu Dhabi Emirate. AADC's power network handles medium and low voltage levels, ranging from 0.4 kV to 33 kV. The company places high importance on customer satisfaction as a core aspect of its business strategy, focusing on ensuring a secure and safe power supply for its clients [1].

The effects of climate change are becoming more evident with the rise in abnormal weather events. Its impact is so substantial that various countries are beginning to recognize the importance of addressing climate change and are taking action in response [2]. Climate change greatly impacts electricity distribution utilities, bringing challenges that require adaptation and innovation. Rising temperatures and more frequent extreme weather events like heatwaves and heavy rain can damage infrastructure and disrupt power supplies causing interruption to huge areas. Higher temperatures increase the demand for cooling, straining the grid and causing potential blackouts. Changing precipitation patterns and stronger storms can lead to flooding, damaging power substations and overhead lines. Therefore, utilities need to invest in stronger infrastructure, better grid management technologies, and sustainable energy sources to ensure reliable service despite unpredictable climate conditions.

The UAE has taken the lead as the first country to initiate a comprehensive reduction in emissions and to unveil a Net Zero by 2050 strategic plan, demonstrating its dedication to climate action. During COP28 in December 2023, TAQA along with 31 partners including 25 global utilities serving over 250 million customers, made a historic joint commitment to promote electrification, renewable-ready grids, and clean energy, aligning with the 2030 Breakthrough goals and aiming for a net zero future by 2050 [3].

In this paper, an overview of AADC distribution network is illustrated, followed by the effects of climate change on the electricity distribution network. The third section discusses the operational challenges due to climate change along with illustration of AADC mitigation actions. Lastly, the recommendations and conclusions are represented to overcome the challenges and have a roadmap to cope with the expected challenges.

II. Overview of AADC Power Network

A. Roles and Functions of Distribution Utilities

Electricity distribution utilities play an essential role in the electric power industry, serving as intermediaries between high-voltage transmission systems and end-users, including commercial, industrial, and residential customers. Their main functions encompass several key areas. In electricity sector, distribution utilities are responsible for developing, constructing, maintaining, and upgrading the distribution network, which includes substations, transformers, overhead lines, cables, and meters. They ensure smooth power delivery from high-voltage transmission lines to low-voltage consumers. For operational reliability, they manage load balancing to maintain system stability, and efficiently handle outage management to minimize downtime. They provide customer services that involve accurate metering and billing, support for billing inquiries, service requests, outage notifications, and promoting energy efficiency programs to encourage energy-saving practices. Lastly, regulatory compliance requires adherence to safety standards to protect the public and utility workers, operation regulations, and following environmental regulations to minimize the ecological impact of operations [4].

B. Current AADC Operational Framework

The AADC network contains a variety of electrical equipment, ranging from voltage levels of 0.4 kV up to 33 kV. Fig. 1 below represents the single line diagram (SLD) that illustrates the vertical flow of power starting from the feeding source at grid stations (interface points with transmission) to the 11 kV medium voltage network.

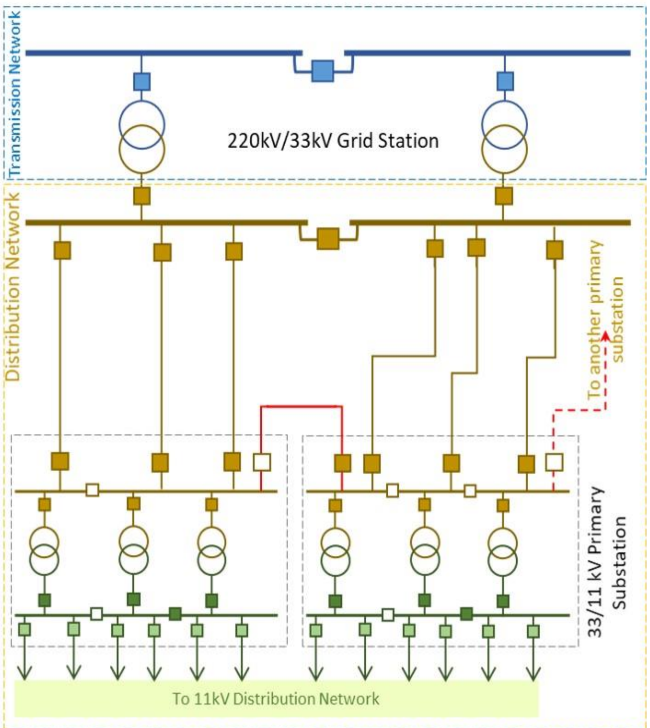

Fig. 1. SLD of AADC medium voltage network

The AADC network's diverse range of electrical equipment is designed to manage and distribute electricity efficiently across different voltage levels. The network starts at grid stations with high voltage levels of 220/33 kV. From these grid stations, the electricity is transmitted to primary substations, where it is stepped down to 33/11 kV. The primary substations then distribute power to the 11 kV rings, which ensure that the electricity reaches various end-users reliably. This hierarchical structure of voltage levels and substations is crucial for maintaining the stability and efficiency of the electrical distribution network [1].

III. Impact of Climate Change on AADC

Climate change presents a significant challenge for humanity, particularly the power sector. The Earth's temperature is increasing rapidly, leading to rising sea levels, more frequent droughts of extreme high temperatures, flash floods, and other extreme weather conditions that severely impact electricity grids. It may impact the grid infrastructure, service continuity, and the demand patterns. Global temperatures have already exceeded the pre-industrial average by 1.1°C. There is now more than a 50% likelihood that the 1.5°C threshold established by the Paris Agreement will be reached or surpassed within the next two decades [3]. Accordingly, AADC as a distribution utility is directly impacted by the climate change and takes it seriously especially after the clear signs of adverse weather conditions that occurred this year.

A. Droughts and Temperature Impact on Demand

As the world gets warmer due to climate change, more people are using air conditioning to stay cool leading to higher electrical demands [5]. In Al Ain area, the residential load is dominating and the behavior of the households across the area determines the load profile of the whole system.

Temperature has a significant impact on electrical load growth. As temperatures rise, especially during the summer months, the demand for electricity tends to increase substantially. This phenomenon can be attributed to several factors. Firstly, higher temperatures lead to increased use of air conditioning systems, which are among the most energy-intensive appliances in many households and commercial buildings [5]. Additionally, elevated temperatures can reduce the efficiency of electrical equipment, such as transformers and motors, requiring more energy to achieve the same level of output [6]. Thus, temperature fluctuations play a pivotal role in shaping electrical load patterns, making it imperative for power network operators and operation planning & studies engineers in the distribution utilities to anticipate and manage these variations effectively to ensure a stable and reliable power supply.

In 2023, the temperatures recorded in the three days leading up to the peak day were significantly higher than those in 2022. Similarly, even higher temperatures have been recorded in 2024. The comparison chart in Fig. 2 illustrates the increase in aggregated temperatures and demonstrates how this has significantly contributed to the growth of AADC peak load by 5.8% in 2023 and 2.8% in 2024.

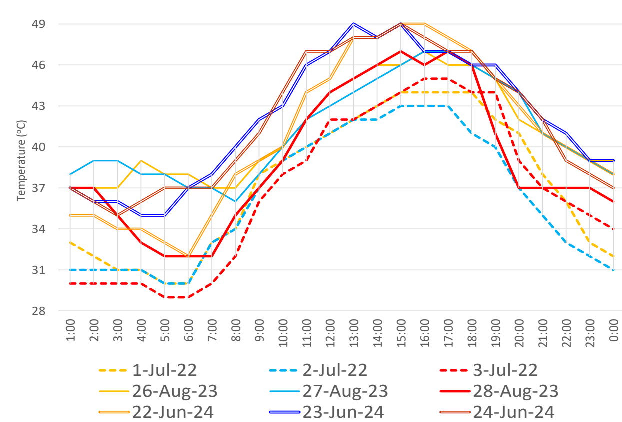

Fig. 2. 3-days Temprature leading to Peak Load in 2022, 2023, and 2024.

Though, having a higher temperature and more droughty weather results in higher demands and significantly increase the stress on the power network during peak season. Table 1 illustrates the significant increase in average daily temperatures for the peak day and 2 days prior to recording the maximum demand for years 2022, 2023, and 2024.

TABLE I. AVERAGE TEMPERATURES OF PEAK DAYS 2022–2024

Peak Days	Temperatures[a] (°C)		
	Average Daily	*3- Days Average*	*Increment from Previous Year*
1-Jul-22	37	37	-
2-Jul-22	36		
3-Jul-22	37		
26-Aug-23	41	40	3
27-Aug-23	41		
28-Aug-23	39		
22-Jun-24	41	42	2
23-Jun-24	42		
24-Jun-24	42		

[a.] Measurements are collected from the weather station at AADC control Center.

This explains how climate change is driving the weather to be hotter and how this impacts the total demand of AADC. Thus, more network expansion is required to accommodate the increase in cumulative temperature resulting from climate change.

Recently, renewable Distributed Energy Resources (DER)s are progressively integrated in AADC's distribution network as PVs [7]. Accordingly, PVs are the only DERs available in our power network in the current time. Overall, PVs are impacted by high temperatures where the estimated output power of installed PV arrays is reduced when having higher ambient temperature (higher than 25 °C) as illustrated in (1) [8]:

$$P_{PV} = \eta\% \times A \times I_r \times [1 - 0.005 \times (T_o - 25)] \qquad (1)$$

where η is the efficiency of PV module, A is the PV arrays area (m^2), I_r is the solar irradiance (kW/m^2), and T_o is the outdoor ambient temperature (℃).

This adds more complexity to the analysis where the demand by the conventional generation of the grid shall be increased due to lower performance of PVs because of droughts.

B. High Rainfalls and Flash Floods

On February 12, 2024, and April 16, 2024, Al Ain Area suffered from flash floods due to extremely high rainfall that was the highest amount of rainfall in 75 years [9]. This led to high water levels at some of the power substations of different voltage levels leading to widescale outages at those substations.

Floodwaters inundated major electrical assets at some nearby substations to the valley, including 33kV switchgear, protection panels, DC systems, and auxiliary supply system. The water reached a height of 1.2 meters, causing immediate isolation of these substations from service as precautionary actions. The accumulation of water in the breakers led to severe failures, flashovers, and significant damage to numerous panels in the affected substations. The main power supply was disrupted, necessitating the use of alternative power sources to restore the service.

The unexpected and unusual rainfalls, along with cloudy weather, have negatively impacted the efficiency of photovoltaic (PV) systems. Since the output power of PVs is intermittent and dependent on weather conditions and direct sunlight, the installed PV farm in the powerhouse area has also been affected by climate change [8]. Recently, flash floods have severely damaged many PV arrays, worsening the situation.

Integrating more Energy Storage Systems (ESS), particularly Battery Energy Storage (BES), at the distribution level as ancillary services (network support) can effectively mitigate the limitations posed by short-term weather variations on PV systems [7].

IV. OPERATIONAL CHALLENGES AND MITIGATION ACTIONS

As a result of the previously highlighted challenges exaggerated by climate change, more operational risks have been evolved. Accordingly, AADC operation planning and studies team continuously evaluates and assess the network capabilities to withstand such adverse conditions. Actually, AADC's power network has a very strong structure at both 33kV and 11kV levels beyond the N-1 criterion in different locations, especially at 33kV network. The 33kV interconnectors between the different primary substations that are feeding from different sources (different 220/33kV grid stations) provides more flexibility and superior capability for maneuvering during outages. So, AADC could manage the load due to flash floods and high temperatures by taking either precautionary actions or immediate response (usually within 3 minutes) after the related trippings.

In addition, AADC has pre-prepared emergency plans for the extreme emergencies where restoration can be completed in a very short time that satisfy AADC main KPIs of SAIDI and achieve customer delight. Furthermore, AADC management assigned a dedicated experts committee from different department to propose and implement urgent emergency network reinforcements that would enhance the security of supply under major incidents that might result due to climate change and weather adverse conditions.

As a lesson learnt from the last flood, using mechanical power cable sealing for power cables' ducts and trenches openings to the substation's basements as illustrated in Fig. 3 are proposed. Also, water stoppers around the old low-level substations near valley routes shall be installed to stop floods water as much as possible from entering the substations since higher rainfall levels could occur in the next years.

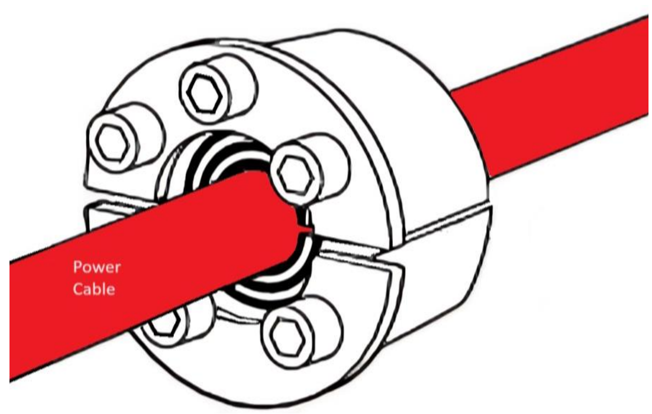

Fig. 3. Mechanical Power Cable Sealing.

For temperatures, AADC and TAQA specifications have already considered Maximum ambient outdoor air temperature of 50 ºC. However, this value has to be reviewed to ensure it withstands the future temperature increase due to climate change.

Finally, it's important to highlight that AADC has a main and backup control centers that uses a state-of-the-art monitoring and control system known as advanced Distribution Management System (DMS). The DMS provides the operators the capability to monitor the network in real-time context and take necessary prompt actions to avoid overloading. It helps in fast restoration of the interrupted supply under emergency cases. The system is equipped with Expert System (XPS) server that supports Advanced Network Operation (ANOP), Intelligent Alarm Processing (IAP) functions that both helps the operator to analyze events and get help in the decision-making process from this system that uses AI technologies [10]. Accordingly, the DMS plays a vital role in supporting the control center operators to have immediate response to unexpected weather conditions and provides the operational planning and studies team with the required information to analyze and prepare operational plans to face climate change impact.

V. Conclusions

This paper explores the challenges faced by distribution utilities due to climate change, using AADC as a real case study. As extreme weather events become more frequent, there is a pressing need to upgrade aging infrastructure and revise specifications and regulations to address these changes. For instance, increasing the maximum ambient temperature rating of power equipment to above 50°C is necessary to cope with the rise in average 3-day system peak temperatures, which jumped from 37°C in 2022 to 42°C in 2024. To address these issues, utilities must adopt advanced technologies such as DMS with XPS tools and functions, enhancing the monitoring and decision-making capabilities of network operators. Additionally, upgrading infrastructure and integrating new renewable energy sources and storage systems will better prepare utilities for the impacts of climate change although it adds more complexity to the operational concepts and load studies. Finally, this paper highlights several lessons learned in efforts to maintain the security of supply within the network, such as the importance of pre-prepared emergency plans. Furthermore, installing mechanical cable seals for power cables' ducts can help prevent water ingress into substation basements during flash floods and protect the power equipment. As climate change continues to affect the energy sector, it is crucial for utilities to innovate and adapt to ensure the continuous provision of electricity to all customers under adverse weather conditions and high temperatures.

Acknowledgment

Authors express their sincere appreciation and gratitude to AADC's higher management for their support to prepare this paper and participate in IEEE related conferences to adopt innovation in this field.

References

[1] O. Al-Ahmad, M. Aldahmi, and A. M. Rayees, "Parallel Operation for 11 kV Ring System with Normally Open Point at Distribution Networks in AADC," Journal of Physics: Conference Series, vol. 2689, no. 1, p. 012007, Jan. 2024, doi: 10.1088/1742-6596/2689/1/012007.

[2] M. U. Nakmali, "Climate Change Effects on Grid Infrastructure and a Focused Review of Oregon Response Opportunities," *2024 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*, Anaheim, CA, USA, 2024, pp. 1-5, doi: 10.1109/TD47997.2024.10556181.

[3] United Arab Emirates, "The United Arab Emirates First Long-Term Strategy (LTS): Demonstrating Commitment to Net Zero by 2050," Jan. 08, 2024. https://unfccc.int/documents/636722 (accessed Jun. 22, 2024).

[4] P. M. Jansson and V. E. Udo, "The role of the electric power industry in global sustainable development," *SMC'03 Conference Proceedings. 2003 IEEE International Conference on Systems, Man and Cybernetics. Conference Theme - System Security and Assurance (Cat. No.03CH37483)*, Washington, DC, USA, 2003, pp. 1729-1736 vol.2, doi: 10.1109/ICSMC.2003.1244662.

[5] R. Obringer, R. Nateghi, D. Maia-Silva, S. Mukherjee, V. CR, D. B. McRoberts, and R. Kumar, "Implications of increasing household air conditioning use across the United States under a warming climate," Earth's Future, vol. 10, p. e2021EF002434, 2022. doi: 10.1029/2021EF002434.

[6] IEEE Standard Test Procedure for Polyphase Induction Motors and Generators, IEEE Standard 112-2017, Feb. 2018. doi: 10.1109/IEEESTD.2018.8291810.

[7] O. AlAhmad and M. AlDahmi, "Enhancing Security of Supply Using Battery Energy Storage Systems in Distribution Networks in UAE," 2021 11th International Conference on Power and Energy Systems (ICPES), Shanghai, China, 2021, pp. 168-171, doi: 10.1109/ICPES53652.2021.9683958.

[8] O. AlAhmad and T. K. Abdel-Galil, "Risk Assessment for 11kV Unsecured Rings in Distribution Utilities in UAE Based on Probabilistic Approach," 2021 6th International Conference on Renewable Energy: Generation and Applications (ICREGA), Al Ain, United Arab Emirates, 2021, pp. 112-118, doi: 10.1109/ICREGA50506.2021.9388299.

[9] "Adverse weather condition witnessed by UAE caused by climate change: Environmental Expert," Emirates News Agency - WAM, Apr. 21, 2024. [Online]. Available: https://wam.ae/a/b2roasi. [Accessed: Jun. 22, 2024].

[10] O. AlAhmad and M. AlDahmi, "A Review of Operation Planning and Distribution Network Optimization of AADC Network," 2021 IEEE International Conference in Power Engineering Application (ICPEA), Malaysia, 2021, pp. 216-220, doi: 10.1109/ICPEA51500.2021.9417765.