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Challenges for Resilient Power Distribution Network in AADC and Measures to Enhance its Performance

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ABSTRACT: This paper addresses the challenges and corresponding solutions related to modern power networks, with a focus on specific configurations in substation feeding arrangements and all distribution networks at different voltage levels. For example, a single 33kV source from a 220/33kV grid substation feeding multiple intermediate substations in a series loop creates vulnerabilities in network reliability and protection concepts. A similar feeding arrangement challenge is the 11kV switching stations that are feeding from express circuits from 33/11kV primary substations. Furthermore, the paper investigates system and protection constraints with OHL configurations, including tee-offs, cable loops within OHL circuits, high-tension (HT) fuses as protection devices for pole-mounted transformers (PMTs), auto-reclosers and sectionalizers, and coordination across these OHL protection units. On the other hand, 11kV loops are discussed, emphasizing their impact on network operating conditions and the protection scheme. Changes in standard network operating conditions, protection impact and safety, as well as the operational implications of back-to-back connections, are also considered. The phenomenon of sympathetic tripping of 33kV and 11kV feeders is explored, in view of fault-induced delayed voltage recovery (FIDVR) caused by highly concentrated inductive motors. Solutions to mitigate these issues at network and customer levels are discussed. By addressing these challenges and proposing innovative solutions, the paper aims to enhance the reliability and protection of the AADC power network, ensuring a stable and efficient power supply.

KEYWORDS: Back-to-back, Coordination, Distribution Networks Fault current, FIDVR, Protection, Reliability, Sympathetic Tripping

I.INTRODUCTION

Al Ain Distribution Company (AADC), a subsidiary of the TAQA Group, serves as the sole provider of electricity and water distribution in the Al Ain region of Abu Dhabi, United Arab Emirates (UAE). AADC is pivotal in ensuring an uninterrupted power supply, leveraging advanced control technologies and implementing smart grid strategies where AADC's control center is equipped with a Distribution Management System (DMS) that enhances operational excellence and maximizes customer delight. The company also employs state-of-the-art protection technologies to safeguard its personnel and assets. The company's power network starts at the 220kV interconnection with the TRANSCO-owned transmission network. AADC manages the high and medium voltage networks, from the 220/33kV grid stations to the low voltage network at 0.4kV of distribution substations, feeding from 11kV rings originating from 33/11kV primary substations [1].

The power distribution network of AADC faces unique challenges that require tailored solutions to enhance its resilience and performance [2]. This paper explores various aspects of these challenges, focusing on substation feeding arrangements, OHL configurations, and protection schemes. The goal is to identify vulnerabilities and propose measures to improve network reliability and efficiency.

1. Challenges in substation feeding arrangements.
One of the main challenges when a standard feeding configuration is violated. The standard one includes express feeders either cables or OHL circuits from the busbar at the feeding source to the busbar at the downstream substation. This applies for 33kV busbars at 33/11kV substations, and 11kV busbars of 11kV switching stations that are feeding from 33/11kV substations.

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1.1 Single 33kV Source Feeding Multiple Substations

A common configuration challenge in the AADC network is a single 33kV source from a 220/33kV grid substation feeding multiple intermediate substations in a series loop. This setup creates several issues and results in the following challenges:

1.1.1 Vulnerability to Single Point Failures:

A fault in the 33kV source can disrupt the entire loop, affecting multiple substations and customers [3]. This shall result in poor results of main KPIs such as SAIDI, SAIFI, and CML where it can also escalate a minor circuit fault into a series of tripping events at different substations [4].

1.1.2 Protection Coordination:

Ensuring proper coordination of protection devices across multiple substations becomes a very complex task and can lead to mis operations or delayed fault clearing [5].

1.1.3 Load Restoration:

Load restoration becomes more complex and takes longer time as the operator has to coordinate the restoration at several substations.

1.1.4 Violation to Regulation:

This design violates the Security of Supply recommendations of Electricity Distribution Code of Department of Energy for classes C and D [6].

Fig. 1 illustrates an example of a single 33kV line (labelled A) feeds a 33/11kV Package Unit then continues to feed a 33kV busbar of 33/11kV Primary Substation in parallel to another express feeder (labelled B).

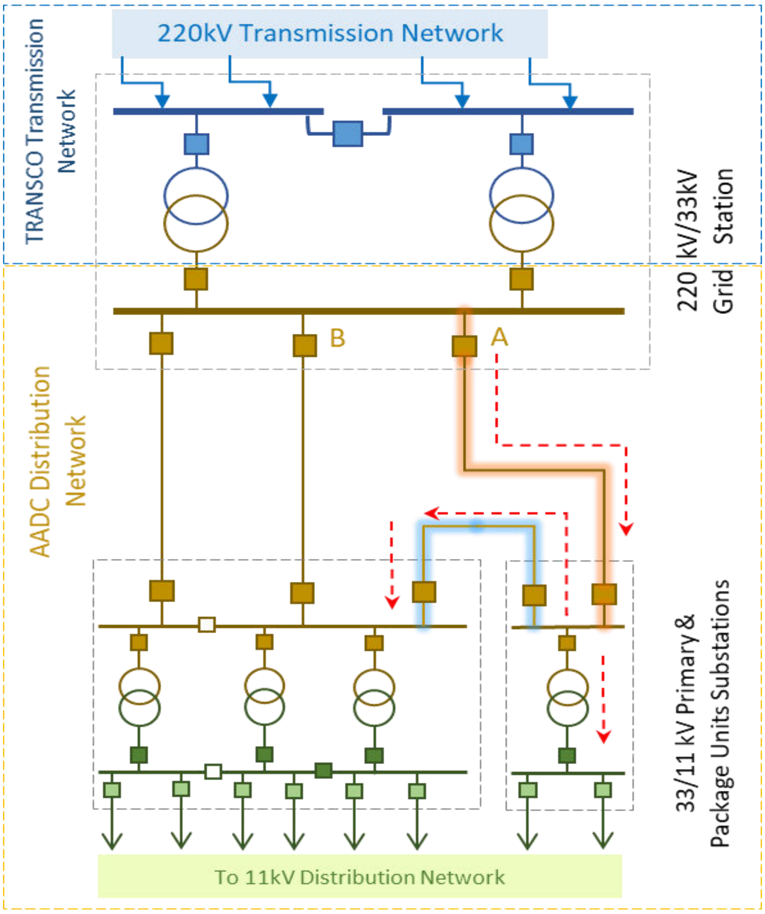

Fig. 1 Single 33kV Source Feeding Multiple Substations.

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The line A ideally shall be only feeding the Package Unit while another additional line similar to line B shall be dedicated to the Primary substation. One reason that forces utilities to follow this unpreferred setup is the limitation in spare panels in 220/33kV grid stations when installing additional Package Unit as extension in a location before the old primary substation.

2.1 11kV Switching Stations (SWS) from Express Circuits

The 11kV SWS fed from express circuits from 33/11kV primary substations also pose several challenges like:

2.1.1 High Fault Currents:

The express circuits can result in high fault currents, stressing the protection devices and reducing their effectiveness [7]. Accordingly, distribution utilities shall consider this while designing and commissioning such setups by implementing robust protection scheme.

2.2.2 Limited Backup:

In case of a fault, limited backup options can prolong outages and reduce network reliability as the SWS usually depends on one or two main express feeders [8]. Accordingly, AADC usually installs backup diesel generators to secure the load as usually SWS's are part of VIP 11kV networks like hospitals.

TABLE 1. COMPARISON OF SWITCHING AND RING CIRCUITS

Parameter	SWS Circuits	Ring Circuits [a]
Selective Coordination	Demanding and discrimination challenges are high	Easier
Backup Availability	Limited, requires redundant circuits and backup generators	High, for open ring system only restoring load from other side.
Protection Device Stress	High	Moderate
Cable Size	Higher, to meet the higher demand	Normal, standard conductor size.
Operation Complexity	High	Low

A simple ring circuit consists of distribution substations fed by two feeder heads with NOP

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The following Fig. 2 illustrates an 11 kV switching station featuring express incoming feeders, outgoing rings, and backup generators. Additionally, the diagram also represents another 11 kV ring as a standard distribution circuit.

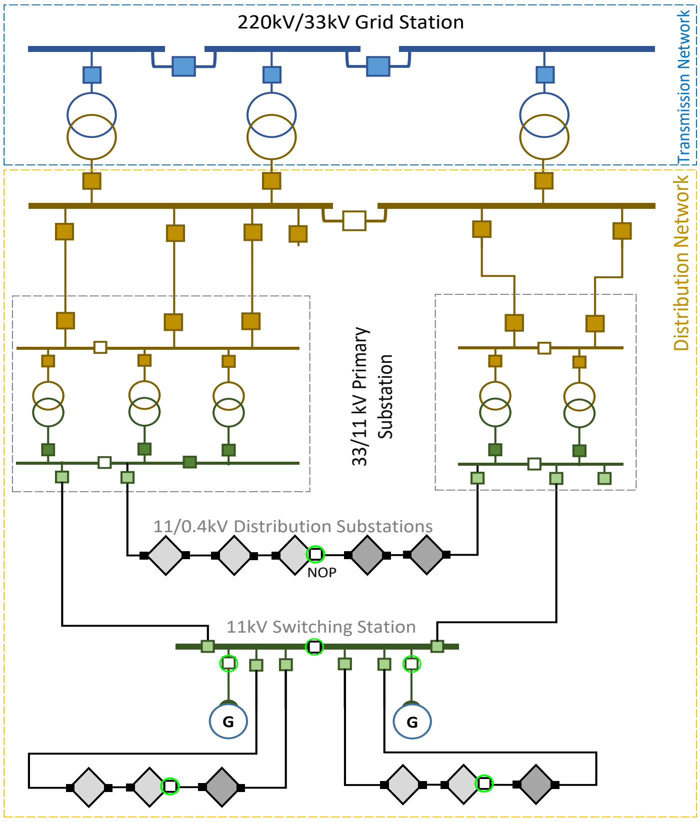

Fig. 2. 11kV standard circuit vs. 11kV switching station circuits.

II. PROTECTION CONSTRAINTS IN OHL CONFIGURATIONS

In OHL networks, ensuring proper coordination of protection devices is essential to maintain system reliability and minimize outage durations. Protection devices like auto-reclosers and sectionalizes must work in harmony to isolate faults effectively without causing unnecessary disruptions to the healthy portions of the line. In addition, High-Tension (HT) fuses used for protecting pole-mounted transformers (PMTs) can sometimes be unreliable resulting in prolonged outages and potential equipment damage. This is particularly valid under specific fault conditions when the fuse is incorrectly oversized.

OHL configurations with tee-offs and cable loops introduce unique constraints. Auto-Reclosers are devices that automatically close after opening due to a transient fault, attempting to restore power quickly and reduce outage times. They are typically set to attempt reclosing multiple times before locking out and remain open. Sectionalizes operate in conjunction with auto-reclosers in the sub-lines' portions. They count the number of fault current operations and open to isolate the faulted section when the auto-recloser opens, preventing the recloser from continuously reclosing into a persistent fault. The primary challenge lies in setting the correct timing and current settings so that the auto-reclosers and sectionalizes do not miss-operate. Incorrect settings can result in large sections of the network being unnecessarily disconnected. It's important to ensure that these devices discriminate correctly between transient and permanent faults. This requires precise engineering and understanding of the network's characteristics [8].

HT fuses are designed to clear high fault currents. Their operation is based on the melting of a fuse element when a specific current threshold is exceeded. Under certain fault conditions, such as low fault currents or high impedance faults, HT fuses may not blow, leading to prolonged fault conditions and potential damage to transformers and other equipment. HT fuses pose a main challenge as they can be slow to respond to certain types of faults, especially those with low current levels that do not generate sufficient heat to melt the fuse element quickly. Also, they must be

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coordinated with other protection devices in the system. Miscoordination can lead to scenarios where fuses fail to operate correctly, causing extended outages and increased risk of equipment damage [3].
Similar to the complexity that arises from longer power paths of SWS configuration in 11kV systems highlighted earlier in this paper, large OHL circuits with many branches off the main line can result in selective coordination issues. It will be difficult to achieve discrimination in the protection scheme while maintaining effective protection at all levels.

III. NETWORK OPERATING CONDITIONS CHALLENGES

In this section, two main operation challenges impacting the protection scheme are 11kV closed loops and back-to-back connections at either 33kV or 11kV feeders. Fig. 3 illustrates examples for these connections.

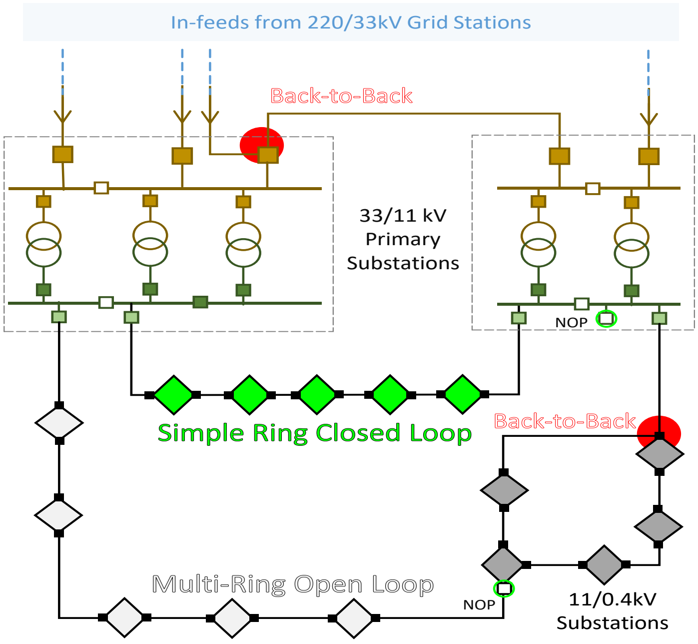

Fig. 3. 11kV closed loops and back-to-back connections at 11kV and 33kV.

3.1 11kV Closed Loops

11kV rings are the standard configuration of AADC distribution network and have significant benefits:

- Redundancy and availability of alternative supply.
- Load management and possibility for load maneuvering under normal operation and planned/unplanned outages.

Similarly, another standard configuration known as multi-ring, is consisting of several simple rings with multiple NOPs as illustrated in Fig. 3. However, this configuration is similar to the simple ring from the protection point of view.
Furthermore, there are some benefits that arise of applying 11kV loops (closed NOPs) arrangement like reducing operation cost for planned outages, minimizing interruption time for unplanned outages, and enhancing network performance indices of SAIDI and SAIFI accordingly. While 11kV loops provide more operational flexibility, there are implications of applying 11kV loops [9]:

- Protection schemes complications and fault isolation.
- Load flow issues that might result in high currents and overcurrent tripping.

3.2 Back-to-Back Connections

Back-to-back connections in electrical power systems refer to configurations where two power systems or components are directly interconnected without intermediate elements such as transformers or large sections of 33kV or 11kV lines. This configuration lead to severe health and safety issues. In addition, it results in complex fault dynamics and require advanced protection strategies as follow [3]:

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3.2.1 High Fault Currents:
When two power sources are connected back-to-back, the potential fault current can be very high due to the low impedance path between the sources. This high fault current can cause significant damage to equipment if not properly managed.

3.2.2 Propagation of Faults:
Faults in one part of the system can propagate quickly to the other part due to the direct connection. This rapid propagation can make it challenging to isolate the fault before it affects both interconnected systems.

3.3 Sympathetic Tripping and Fault-Induced Delayed Voltage Recovery (FIDVR)
The phenomena of sympathetic tripping and FIDVR, caused by highly concentrated inductive motors, present unique challenges of both voltage stability and protection scheme adaptation. FIDVR can destabilize voltage levels, significantly impacting sensitive equipment and disrupting customer services. This voltage instability arises from the delayed voltage recovery after faults, which can cause sustained low-voltage conditions detrimental to the performance and longevity of electrical devices [10]. To mitigate these issues, protection schemes need to be adapted to account for the delayed voltage recovery associated with FIDVR. This adaptation involves enhancing the sensitivity and selectivity of protection systems to prevent widespread outages, ensuring that protective relays and other devices can accurately distinguish between normal transient conditions and genuine fault scenarios, thereby maintaining system reliability and continuity [7].

IV. RECOMMENDATIONS TO ENHANCE NETWORK RELIABILITY AND PROTECTION

4.1 Advanced Protection Coordination
Implementing advanced protection coordination strategies can mitigate many of the identified challenges. One effective approach is the use of adaptive protection schemes, which can adjust settings based on real-time network conditions. This dynamic adjustment improves fault isolation and reduces outages, as the protection system can respond more precisely to the current state of the network [8]. Additionally, integrating high-speed communication links of fiber optics between protection devices significantly enhances coordination and fault response times. This allows for rapid information exchange, enabling the system to quickly isolate faults and maintain service continuity.

4.2 Robust Backup Systems
Enhancing backup systems provides additional resilience to the power grid. One key strategy is the implementation of redundant feeds for critical substations, which reduces the impact of single point failures. By having multiple feeds, the system can maintain operation even if one feed is compromised, thus ensuring a more reliable power supply [3]. Another important measure is incorporating distributed generation sources, which can provide localized backup and support during faults. Distributed generation helps to decentralize the power supply, enhancing the overall robustness of the grid [10].

4.3 Enhanced Fault Detection and Isolation
Improving fault detection and isolation capabilities is crucial for maintaining grid reliability. Deploying advanced sensing technologies, such as phasor measurement units (PMUs), enhances fault detection accuracy and response times. These technologies offer precise monitoring and can quickly identify faults, allowing for faster and more effective responses [7]. Furthermore, the use of automated isolation devices ensures rapid fault isolation, minimizing outage durations. Automated devices can quickly disconnect faulty sections of the grid, preventing the spread of disturbances and maintaining service for unaffected areas. Accordingly, AADC utilizes the advanced related functions and tools equipped with the Advanced DMS system at the control center like: Fault Isolation Service Restoration (FISR) to enhance the fault isolation processes.

4.4 Addressing FIDVR and Sympathetic Tripping
Mitigating the effects of Fault-Induced Delayed Voltage Recovery (FIDVR) and sympathetic tripping requires targeted solutions. Implementing dynamic voltage support devices, such as static var compensators (SVCs), is crucial for maintaining voltage stability during faults. These devices can dynamically adjust reactive power to stabilize voltage levels, thus preventing voltage dips that lead to FIDVR [10]. Additionally, implementing load management strategies to control inductive motor operations during fault conditions reduces the risk of sympathetic tripping. By managing the load effectively, the system can prevent the chain reaction of tripping that can occur when motors react to faults [3].

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V. CONCLUSIONS

This paper discussed the operational challenges that affects the protection scheme at AADC's power network at medium voltage of 11kV and 33kV. The authors addressed the identified challenges and suggested implementing proposed solutions. Mainly, the paper suggested implementing advanced protection coordination utilizing high speed communication networks, robust redundant feeding sources, enhanced fault detection and isolation strategies, and applying FIDVR and sympathetic tripping mitigation measures for resilient power network. Therefore, AADC power distribution network can achieve enhanced reliability and protection especially when utilizing advanced DMS tool of FISR and other related intelligent functions. These measures ensure a stable and efficient power supply, supporting the growing energy demands of Al Ain region.

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