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MASTER'S THESIS:

INTEGRATION OF GROUND FAULT DETECTOR (GFD) EQUIPMENT IN THE UFD NETWORK

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I declare, under my own responsibility, that the Project submitted under the title **Integration of Ground Fault Detector (GFD) Equipment in the UFD Network** in the Higher Technical School of Engineering - ICAI of the Universidad Pontificia Comillas in the academic year of 2023/2024 is of my authorship, original, unpublished and has not been previously presented for other purposes.

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INTEGRATION OF GROUND FAULT DETECTOR (GFD) EQUIPMENT IN THE UFD NETWORK

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ABSTRACT

This master's thesis focuses on integrating Ground Fault Detectors (GFDs) into UFD's electrical distribution network, addressing technical challenges related to their implementation. The study aims to analyse GFD performance, automate device integration into management systems, and streamline data collection. Additionally, it consolidates relevant documentation to create a comprehensive resource. While the GFDs have enhanced network monitoring, the findings reveal disparities in effectiveness across different centres, highlighting the need for targeted strategies to optimize deployment. The successful automation of processes lays a strong foundation for UFD's ongoing digitalization efforts.

Keywords: Ground Fault Detectors, UFD, electrical distribution network, digitalization, real-time monitoring, automation, asset management, data integration, operational performance.

1. INTRODUCTION

This master's thesis investigates the integration and performance of Ground Fault Detectors (GFDs) within UFD's electrical distribution network. This project is a cornerstone of UFD's digitalization strategy, aimed at enhancing the safety, reliability, and efficiency of its network infrastructure, making possible to prevent the on-site visits to perform Regulatory Periodic Inspections (RPIs). The GFDs play a crucial role in monitoring the grounding systems across the grids, detecting faults early to prevent potential hazards, reduce outage times, and maintain the integrity of electrical systems. This study examines the technical and operational aspects of deploying GFDs, providing a comprehensive analysis that informs future strategies for UFD's network management.

2. PROJECT DEFINITION

The primary objectives of this master thesis were defined as follows:

- ***Documentation Consolidation and Organisation***

The first objective was to consolidation and organisation of diverse documents and information related to GFDs within UFD. Given the proprietary nature of how different companies implement these devices in their databases, this objective aimed to centralize and clarify information, creating a more coherent and structured understanding of GFD deployment within UFD.

- ***Analysing the Performance of GFD Devices***

A important part of the project was the evaluate the operational performance of GFD devices installed across UFD's network. This involved assessing the effectiveness of these devices in detecting ground faults, their reliability, and their overall contribution to network safety. The goal was to identify areas for improvement in the deployment and operation of GFDs.

- ***Automating Integration of New GFD Devices into Management Systems***

Another key objective was to automate the process of integrating new GFD devices into UFD's Asset Management Interface (GdA) and Intelligent Network System (eSIR). The aim was to streamline the integration process, reduce manual errors, and ensure that data from newly installed devices are accurately and efficiently reflected in the management systems.

- ***Automating Data Collection***

The thesis also aimed to implement automated processes for the collection and analysis of data generated by GFD devices. This automation was intended to enhance real-time monitoring capabilities, improve data consistency, and support more informed decision-making within UFD's operations.

3. METHODOLOGY

The first stage of this master's thesis consisted of a comprehensive analysis and documentation consolidation of information of the GFD technology. The project began with an in-depth review of the technical specifications of GFDs, focusing on their operational parameters and the standards governing their use. Next step focused on the review and organized the diverse range of information created by all different departments inside UFD.

The second stage included the automation of device integration into UFD's existing systems, which required the development of custom interface rules to ensure seamless data flow. Also, data collection was automated using advanced software tools used to capture and analyse data from GFDs in real-time.

The third and final stage of this master's thesis focused on analysing the performance of the GFD devices deployed across UFD's network. This phase involved a detailed evaluation of the operational effectiveness of the devices, comparing the number of devices budgeted, installed, and those that were operational. Additionally, this stage included the synthesis of all gathered data and insights into comprehensive conclusions, offering strategic recommendations for future improvements in the implementation and management of GFD technology within UFD.

4. RESULTS

The results of this project provide a detailed overview of the implementation and performance of Ground Fault Detectors (GFDs) within UFD's network.

- ***Analysis of GFD Performance***

This section focused on the deployment and operational performance of Ground Fault Detectors (GFDs) within UFD's network during the years 2023 and 2024. The initial two years of the project were dedicated to pilot testing, with significant deployment efforts and results emerging in 2023 and 2024.

In 2023, UFD had budgeted for the installation of 5,000 GFDs across various operational centres. By the end of the year, a total of 1,738 devices had been installed, reflecting an installation rate of 34.76%. Out of these installed devices, 788 were reported as operational (OK), resulting in an operational effectiveness rate of 15.76%. Below can be seen differences between installed and budgeted devices:

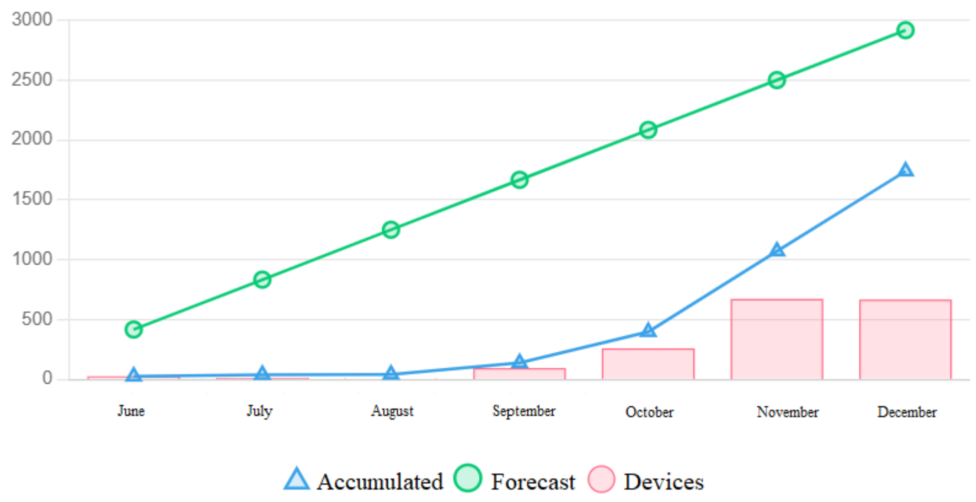

Figure 1. Yearly Overview of Budgeted, Installed, and Cumulative GFDs for 2023

The deployment plan for 2024 had allocated 3,854 GFDs for installation. By August 2024, 2,557 devices were successfully installed, achieving an installation rate of 66.33%. The number of devices that were operational by this time was 1,471, leading to an operational effectiveness rate of 43.49%. Below can be seen differences between installed and budgeted devices:

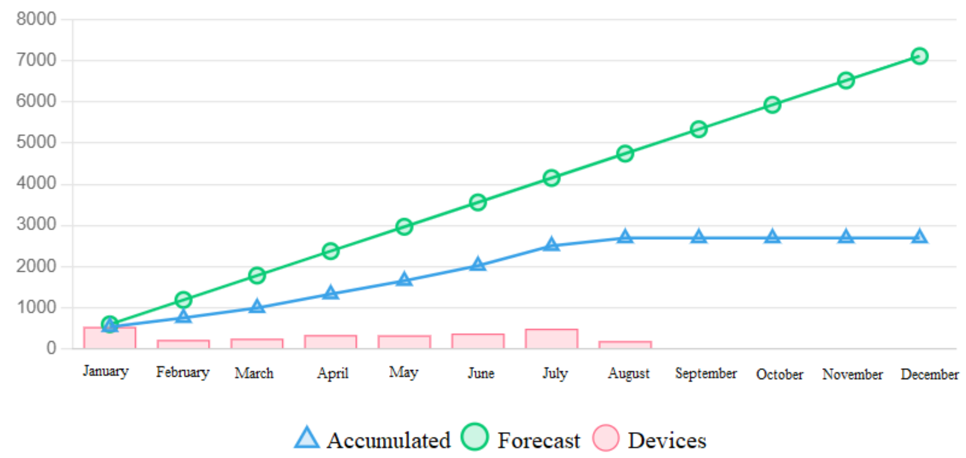

Figure 2.Yearly Overview of Budgeted, Installed, and Cumulative GFDs for 2024.

Over the entire period from 2021 to 2024, UFD had budgeted a total of 8,854 GFDs for installation across the network. Of these, 4,442 devices were installed, resulting in an overall installation rate of 50.17%. However, only 2,266 devices were reported as operational, leading to an overall operational effectiveness rate of 25.59%.

When analysing the performance by operational centres over the entire period:

- ***OP MAD MUNICIPIOS NORTE:*** This centre had an installation rate of 206.11% (270 devices installed out of 131 budgeted) with an operational effectiveness rate of 63.36% (83 operational devices out of 131 budgeted).
- ***OP C. REAL OESTE:*** Achieved an installation rate of 79.77% (205 devices installed out of 257 budgeted) and an operational effectiveness rate of 58.37% (150 OK devices out of 257 budgeted).
- ***OP MAD CAPITAL SUR:*** Recorded an installation rate of 21.43% (12 devices installed out of 56 budgeted) with no operational devices, leading to an operational effectiveness rate of 0%.
- ***OP MAD CAPITAL NORTE:*** Had an installation rate of 28.57% (6 devices installed out of 21 budgeted) and an operational effectiveness rate of 4.76% (1 operational device out of 21 budgeted).

- ***Automation of Device Integration***

The automation of integrating GFDs into UFD's systems was a major focus of this project. By the conclusion of the project, 4,335 GFDs were registered in the G-DFT application, which is the primary tool for managing these devices. However, in the broader network management system, eSIR, only 3,442 devices were successfully integrated. This represents about 79.45% of the devices recorded in G-DFT. Additionally, within eSIR, 36 devices were identified with duplicated serial numbers, and 6 devices were found without properly assigned BDI registration number.

This dissertation also addresses the various scenarios for data management and integration in GFD deployments within UFD's network. The focus was on ensuring that all new assets, requiring monitoring via GFDs, are seamlessly integrated into the company's systems. The accompanying flowchart illustrates the most common steps involved in integrating a new asset into UFD's network, showcasing the crucial process for registering and monitoring these assets across different platforms within the company, including *G-DFT*, *GdA*, *eSIR*, *ATOM/ARGOS*, and *IGEA*. This standard process ensures that every new installation is accurately documented and operationalized, facilitating consistent and reliable data collection and system management.

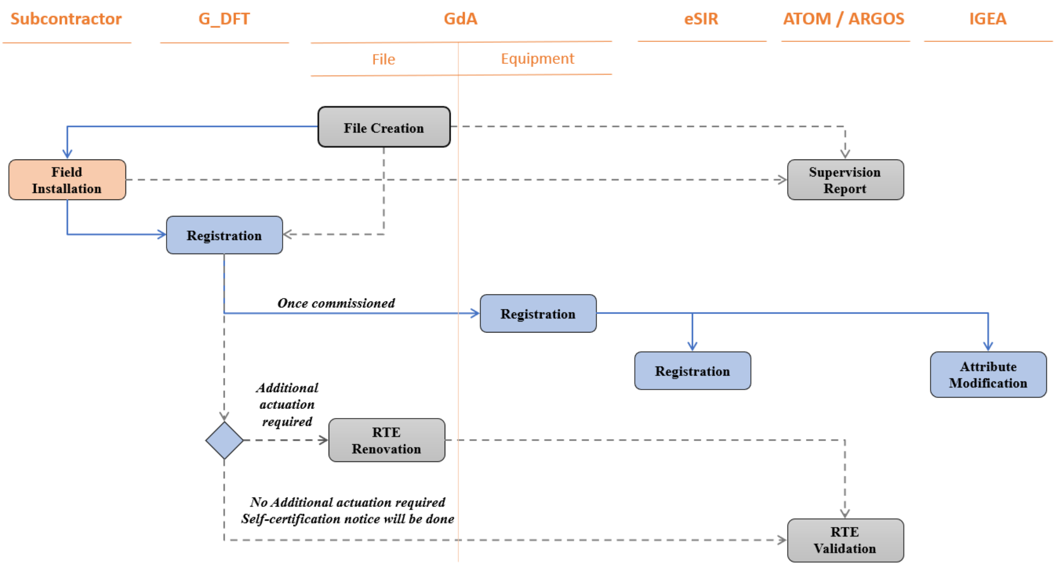

Figure 3. Flowchart of the integration of a new GFD.

- ***Data Collection and Analysis***

Automated processes were implemented to enable continuous collection and analysis of data generated by GFDs within the Intelligent Network System (eSIR). These processes aimed to significantly enhance UFD's real-time monitoring capabilities by ensuring timely and accurate fault detection across the network. As part of this implementation, existing templates were carefully filled out to define how eSIR should process the incoming data from the new assets. This step was crucial to ensure that the incidents reported by GFDs are correctly interpreted and managed by UFD's operational teams.

While the automation led to improvements in incident response times and enhanced data consistency in certain regions, challenges persisted. The quality and integration of data varied across different operational centres, underscoring the need for ongoing refinement of the data collection and integration processes. This experience highlights the importance of continuous improvement in the automation systems to achieve uniform data quality and reliable network monitoring across UFD's entire operational area.

- ***Documentation Consolidation***

This project involved an extensive effort to consolidate and organize the wide range of documentation related to Ground Fault Detectors (GFDs) within UFD. The documentation consolidation covered several critical aspects:

- ***Technical Characteristics of GFD Equipment:*** Detailed analysis of material, construction, functional, dimensional, and electrical characteristics of the GFDs. It included aspects such as auto-calibration protocols, digital signals, communication ports, and degree of protection.
- ***Monitored Assets with GFD Equipment:*** Documentation of various assets monitored by GFDs, including Secondary Substations (SS), Switching Centres (SC), and Frequented Supports. Each category was assessed for its specific requirements and configurations related to GFD integration.
- ***Applicable Regulations and Standards:*** A thorough review of the regulations and standards governing the deployment and operation of GFDs, ensuring compliance with both national and international guidelines.
- ***Conditions and Procedures for Installation:*** Comprehensive guidelines for the installation of GFDs, covering general conditions, grounding characteristics, and preliminary grounding system measurements. These procedures are vital for ensuring the correct and safe installation of GFD equipment.
- ***Communication of GFD Devices with the Manufacturer's Application (G-DFT):*** Analysis of the system and data architecture, communication protocols, and security measures in place for the effective operation and integration of GFD devices within UFD's digital ecosystem.

By consolidating this information, the project provided UFD with a unified and organized repository of GFD documentation. This resource supports ongoing operations and offers a valuable reference for future projects, ensuring that UFD maintains high standards in network management and operational efficiency.

5. CONCLUSIONS

The implementation of Ground Fault Detectors (GFDs) within UFD's network has yielded mixed results, reflecting both the successes and challenges encountered throughout the project. The analysis of GFD performance across various operational centres revealed significant disparities in effectiveness, with some centres demonstrating commendable performance while others struggled to achieve operational success. The overall effectiveness rate of 25.59% highlights the challenges faced in ensuring consistent performance across all centres.

The automation of device integration into UFD's systems marked a significant advancement, improving operational efficiency and reducing manual errors. However, the discrepancy between the number of devices registered in the G-DFT application and those successfully integrated into eSIR indicates that further improvements are needed. This gap suggests that, while automation has made strides in optimizing network management, the process is not yet fully aligned, and additional refinements are required to achieve comprehensive integration.

The data collection and analysis processes implemented during the project demonstrated the potential for enhancing real-time monitoring and incident response. However, the variability in data quality and integration across different centres underscores the need for continued efforts to ensure consistent and reliable data flow throughout the network. These challenges indicate that the current automation processes, while beneficial, require further optimization to fully realize their potential.

The documentation consolidation effort provided a valuable outcome, creating a centralized and organized repository of information related to GFDs within UFD. This consolidation has improved the accessibility and coherence of critical information, supporting UFD’s ongoing and future operations. However, the project also highlighted the fragmented nature of the information prior to this the effort, emphasizing importance of maintaining an organized and up-to-date repository as the GFD deployment continues to evolve.

In summary, while the project has achieved significant progress in several areas, including device integration and documentation consolidation, the findings suggest that there are still some areas that require further attention. The lessons learned from this deployment will be beneficial in guiding future improvements, ensuring that UFD can optimize the effectiveness and efficiency of GFD deployment across its network. The project’s outcomes provide a strong foundation for continued innovation, but also highlight the need for ongoing refinement to meet the network’s operational and strategic objectives.

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1 INTRODUCTION

1.1 PROJECT MOTIVATION

The motivation behind this master's thesis stems from the need of *Union Fenosa Distribución* (UFD) to explore, understand, and effectively integrate new Ground Fault Detector (GFD) technology into its complex and extensive electrical distribution network. As UFD continually strives to enhance the safety, reliability, and efficiency of its operations, the introduction of GFDs presents a significant opportunity—but also a set of challenges that this project aims to address.

UFD is pioneering the use of GFDs within its network, a technology that is relatively new and not yet widely adopted in the industry. The company is venturing into largely uncharted territory, with limited publicly available information on how to best implement and integrate these devices. Unlike more established technologies, GFDs come with a steep learning curve, particularly in understanding their operational parameters, performance reliability, and the best practices for deployment.

A critical challenge lies in the integration of GFDs into UFD's existing systems, which are complex and involve multiple layers of data management and operational oversight. The systems, such as the Asset Management Interface (GdA) and the Intelligent Network System (eSIR), require meticulous configuration to accommodate the new devices. This integration is not straightforward; it involves numerous steps, from device registration and data communication to real-time monitoring and incident management. The lack of a standard, publicly available approach to this integration further complicates the process, necessitating custom solutions tailored specifically to UFD's infrastructure.

Moreover, the novelty of GFDs means that there is little to no public information available on how other companies have tackled similar challenges. This absence of a "state of the art" forces UFD to rely on its internal expertise and innovative approaches to address the technical and operational hurdles that arise during the deployment and integration of GFDs. The project therefore not only aims to implement this new technology but also to create a blueprint for future deployments, which will serve as a critical reference for UFD and potentially the broader industry.

In summary, the motivation for this thesis is driven by UFD's need to:

- Understand and evaluate the performance of a new, relatively untested technology.
- Overcome the challenges of integrating GFDs into an existing, complex system with multiple stakeholders and processes.
- Develop internal knowledge and documentation in the absence of external resources or industry guidelines.
- Lay the groundwork for future deployments and innovations within the company.

This project is, therefore, not just a technical exercise but a strategic initiative that aligns with UFD's broader goals of maintaining its leadership in innovation while ensuring the safety and efficiency of its operations.

1.2 OBJECTIVES

This dissertation aims to collaborate in the implementation of GFDs in UFD's distribution network to enhance remote management, safety and reduce costs of it. This study will analyse the technical implications of GFD integration within all the infrastructure including the data flow from the devices to the internal data bases of UFD. Below are the detailed objectives to be achieved in this dissertation as part of the high-level project:

1. Consolidation and Organisation of GFD Documentation

Another objective of this dissertation is to consolidate and organise the diverse range of documents and information related to GFDs within UFD. This involves gathering the most relevant aspects from various sources and providing a comprehensive overview of the GFD initiative. The analysis covers the technical characteristics of the devices, applicable standards and regulations, the data communication process, and the functionality of the manufacturer’s application that collects device data.

Given that the GFDs used in this project are proprietary devices developed by UFD, there is limited publicly available information regarding their implementation. Moreover, the way these devices are integrated into the company’s networks is highly customised and varies between organisations, leading to fragmented information. This dissertation aims to centralise and clarify UFD's internal information, creating a more coherent and structured understanding of GFD deployment within the organisation.

2. Analysing the Performance of GFD Devices:

The first goal is to conduct an analysis of the performance and functionality of the newly installed GFD devices. This includes evaluating the accuracy and reliability of the ground resistance measurements provided by these devices. Moreover, it involves identifying and documenting any fault patterns or anomalies detected by the GFDs that are currently installed, which will help in understanding the operational effectiveness and potential areas for improvement.

3. Automating Integration of new GFD devices into Management Systems:

One of the objectives of this dissertation is to develop solutions for an automated integration of new GFD devices into the Asset Management Interface (GdA) and the Intelligent Network System (eSIR). This involves configuring and assessing the interface rules to ensure that new GFD devices integrate seamlessly with existing and future systems.

4. Automating Data Collection:

This dissertation aims to design and implement processes for the automated collection of data generated by the GFD devices. This includes configuring the necessary tools for an automatic integration of the data generated by the fleet of devices deployed in the field. This automation will enhance the ability to monitor the network incidents that occur in this type of device.

Finally, is important to consider the fact that this dissertation will be done working directly with the Asset Operation Centre (COA) from UFD, but the project is done collaborating with other departments such as Asset Life Cycle (CVA), Innovation of Distribution Systems, and Specialized Technical Services (STE). Also, this project has been active since 2021 and is not clear the temporal horizon.

1.3 GROUND FAULT DETECTION TECHNOLOGY

1.3.1 DEVICE DESCRIPTION

The equipment consists of an integrated measurement and communication device. The measurement process is based on loop impedance measurement, which involves injecting a 1130 Hz signal and receiving an attenuated signal to determine the loop impedance formed by all the grounding interconnections within the secondary substations. Both the emitter and receiver are housed in external clamps connected by a cable, the optimal length of which is determined during installation.[1]

Calculating the specific grounding resistance of the secondary substation is only necessary if the loop impedance exceeds the maximum regulatory value. However, an iterative algorithm is available to calculate this resistance using both the loop impedances of the centre in question and the adjacent centres.

The device includes a signal storage and processing unit, and a communication unit that transmits data via an independent Nb-IoT channel to a Purdue level 3 system. To ensure communication during network failures, the device is equipped with a small battery that maintains operation and communication for several hours. This independent communication capability is crucial, as relying on the secondary substation's router would result in loss of functionality during power outages unless remote control is implemented. By not using the infrastructure of remotely controlled centres, we simplify communication schemes and reduce the variety of different device types in the network.[1]

The uploaded data is categorized into two types: operational data for network management and encrypted data for device maintenance. Operational data includes information formatted for application interpretation (such as electrical data and digital data on battery life, communication coverage, battery voltage, temperature, etc.). Maintenance data includes measurements and performance metrics of the device's internal components required by the manufacturer for warranty purposes and continuous product improvement.

The application is designed to interpret data not only from this manufacturer but also from other manufacturers that may emerge in the coming years. This requires the data to arrive in a specific format, and we may either have all manufacturers adapted to this model or use a middleware solution to translate the data from each manufacturer into the required format. The latter approach provides more flexibility in case the application needs to be changed in the future, as it would not bind all manufacturers to a specific data model. [1]

1.3.2 IMPEDANCE MEASUREMENT

Impedance measurement is the fundamental technique used by GFDs to monitor the resistance of grounding systems. This method is crucial for ensuring the safety and reliability of electrical networks by providing accurate and real-time data on the condition of grounding systems.

This systems in electrical networks consist of various interconnected components designed to ensure safety by dissipating fault currents into the earth. The primary components of a grounding system are explained below [2]:

- ***Ground Rods:*** These are metallic rods driven into the ground to provide a low-resistance path for fault currents. Typically made of copper or galvanized steel, ground rods are essential for effective grounding.
- ***Grounding Conductors:*** These conductors connect the electrical system to the ground rods. They are usually made of copper or aluminium due to their excellent conductivity and ability to carry fault currents without significant heating or damage.
- ***Connection Points:*** These include connections to the neutral point of transformers, the metallic parts of electrical equipment, and the structural grounding of buildings. Proper connections ensure that fault currents are effectively transferred to the ground rods.
- ***Measurement Points:*** In an impedance measurement system, specific points within the grounding system are selected for signal injection and reception. The signal is injected at a defined point, and the reception unit measures the signal at another point in the grounding network, helping to identify the impedance of the path between these points.

The technical functioning of impedance measurement in GFDs involves the following steps [1]:

1. ***Signal Injection:*** The emission unit injects a low-frequency signal, typically at 1130 Hz, into the grounding system. This frequency is chosen because it minimizes interference from other electrical noise and provides a stable measurement environment.
2. ***Signal Propagation:*** The injected signal travels through the grounding conductors and ground rods. As the signal propagates, it encounters various resistances and reactances, which attenuate the signal.
3. ***Signal Reception:*** The reception unit, placed at a strategically chosen point, measures the attenuated signal. The level of attenuation indicates the overall impedance of the grounding path between the emission and reception points.
4. ***Data Processing:*** The measured signal is then processed using algorithms. These algorithms calculate the impedance based on the observed attenuation. The results are displayed in real-time, providing continuous monitoring of the grounding system's condition.

1.4 RESPONSIBILITIES OF DEPARTMENTS IN THE GFD PROJECT

The successful implementation of Ground Fault Detectors (GFDs) within UFD's network has required the coordinated effort of several departments, each playing a critical role in the project's development, deployment, and operational management.

The ***Innovation of Distribution Systems*** department was responsible for initiating the project by proposing the case study that laid the foundation for the GFD initiative. This department identified the need for enhanced monitoring and safety measures within the network, which led to the conceptualisation of the GFD technology. Once the case study was approved, the project moved to the next phase.

The external company ***Aplicaciones Tecnológicas***, took charge of designing and developing the GFD devices. This stage involved extensive research and development to ensure that the devices met the specific requirements outlined in the case study and were capable of integrating seamlessly with UFD's existing infrastructure.

Upon the completion of the device development, the ***Specialized Technical Services (STE)*** department was tasked with the homologation process. This department conducted a thorough technical review of the GFDs to ensure they met the necessary standards and specifications. STE's approval was crucial for validating the technical viability of the devices before they could be deployed on a large scale.

The ***Asset Life Cycle (CVA)*** department played a pivotal role in deciding which assets within the network required monitoring. CVA was responsible for identifying the critical points in the network that would benefit most from GFD deployment, based on factors such as asset condition, strategic importance, and historical performance. Additionally, CVA developed the deployment plans, outlining the specific locations and timelines for installing the GFDs across UFD's network.

Once the GFDs were installed, the ***Asset Operation Centre (COA)*** department became responsible for resolving any incidents detected by the devices. COA's role was to ensure that any issues identified by the GFDs were addressed promptly, thereby maintaining the integrity and safety of the network.

Finally, the ***Network Operation Centre (COR)*** took on the responsibility of real-time incident resolution. COR monitors the real-time status of the monitored assets' grounding systems, enabling immediate action to be taken when faults or irregularities are detected. This department ensures that the network remains operational and safe by continuously overseeing the condition of the assets and responding to any anomalies reported by the GFDs.

Through the collaborative efforts of these departments, the GFD project has been successfully integrated into UFD's network, enhancing both the reliability and safety of the electrical distribution system.

2 RELEVANT DOCUMENTATION

2.1 TECHNICAL CHARACTERISTICS OF GFD EQUIPMENT

The GFD equipment is autonomous, using unattended measurement instruments for monitoring grounding systems. This monitoring involves measuring the earth resistance using the loop impedance method, as well as recording and analysing the electrical activity flowing through the earth conductor, including fault currents, leakage currents, and harmonics.

One of the primary functions of this equipment is to prevent the need for certain on-site visits to perform Regulatory Periodic Inspections (RPIs), thus it must include a self-calibration function to ensure measurement validity throughout its operational life.

The GFD equipment is equipped with an autonomous communication system operating through GSM 2G/NBIoT/LTE-M networks. This system is used to send data collected by the equipment, whether periodic or real-time events, and for remote configuration via configuration commands or through a remote update system that allows the devices to be reprogrammed remotely.

The equipment includes an internal battery with sufficient capacity tailored to each case, either as a backup for versions powered by 230V AC or 48V DC, or for uninterrupted supply in versions powered by solar panels. These devices are designed to have minimal power consumption in a permanent regime, ideally less than 2 W, which may increase during transient moments when the device takes measurements and communicates the data. To manage low battery levels, the devices have a low power mode, which reduces measurement frequency to one every 24 hours and disables communications until necessary or until the battery charge recovers.

For measurement acquisition, a frequency range of 1 kHz to 2 kHz is used when the loop is not closed with the Low Voltage (LV) neutral earth. In such cases, a capacitor is used to electrically isolate both earths at service frequency, allowing only currents at frequencies above 8 kHz to pass.

Therefore, the equipment consists of four main functional units:

- *Power supply unit.*
- *Communications unit.*
- *Measurement unit.*
- *Expansion unit.*

The information from this section has been done following the information included in documents [2], [3].

1.1.1 MATERIAL CHARACTERISTICS

The use of PVC is strictly prohibited in both main components and accessories of the equipment. The enclosure material for indoor versions is ABS-PC plastic, which must be thermally rated to 105ºC (formerly class A) according to UNE-EN 60085 and self-extinguishing at 960ºC as per UNE-EN 60695-2-10. For outdoor versions, the enclosure material is EMI aluminium or stainless steel. All insulating materials (polyester, fibreglass, polycarbonate, etc.) used for the mounting base plate, covers, or veils must be thermally rated to 105ºC and self-extinguishing at 960ºC.

Ventilation devices, plugs, cable glands, and their locknuts must be made of insulating plastic material with a thermal rating of 90ºC (formerly class Y) as per UNE-EN 60085 and comply with UNE-EN 61439-1. All fittings used in outdoor versions must comply with UNE-EN 10056-1 and UNE 36522 standards and be made of stainless steel or, if not, general construction steel with appropriate corrosion protection indicated by the manufacturer. All auxiliary screws must be stainless steel or, if not, protected against corrosion by galvanisation according to UNE-EN ISO 10648. Screws must comply with UNE-EN ISO 4018, be quality 5.6 according to UNE-EN ISO 898-1, and nuts and washers must comply with UNE-EN ISO 4034 and UNE-EN ISO 7091.

GSM 2G/NBIoT/LTE-M communication antennas must be passive and meet gain requirements between 2 and 5 dBi. Extension jumpers may be used for connections in cases of low coverage at the equipment location, provided they do not significantly attenuate the gain and comply with criteria for other cables installed in the equipment.

Generally, the assembly of supplied equipment involves first fixing the main console, then the sensor or measurement cables, followed by the communication antenna if it is not integrated, and finally connecting the power supply. The power supply can be from a photovoltaic panel (code 869925), directly from the LV network at 230V AC connecting to the Low Voltage Switchboard (LVS) auxiliary circuit (code 869923), or from a secure 48V DC battery supply (code 870385). All assembly and wiring will be carried out considering the characteristics and prescriptions described in the following sections.

2.1.1.1 CABLE LAYING ELEMENTS

All control, measurement, or power cables entering or exiting the equipment must be protected during installation, either under corrugated polyamide tubing with appropriate cable glands or another solution that ensures mechanical resistance and sealing at both ends. The supply of these tubes is outside the scope of the GFD equipment manufacturer.

All fittings, plugs, and their locknuts used in cable laying must be plastic (preferably polyamide 6) with a 1.5 thread pitch. Power cabling connections to the equipment can be made at the factory or during installation. Equipment powered by 230 V AC will connect to the LVS auxiliary power circuit. For photovoltaic panel or 48V DC secure power supply, the connection is direct, either from the photovoltaic panel or the 48V DC terminal strip. The power connection hose will be 2.5 meters long, with other lengths available upon request.

Similarly, the connection cable from the measurement equipment to the sensor in the earth circuit will be factory-fitted. This cable can be pre-connected at both ends, eliminating the need for field connections between these elements, or disconnected to facilitate installation. The standard length is 1 meter.

2.1.1.2 CABLES

The cables used must comply with UNE 211002 or UNE-EN 21123-4 standards. LV electrical network connection cables will be single-core, flexible, Class 5 with 450/750 V insulation, composed of annealed electrolytic copper or aluminium with thermoplastic insulation type TI 7 according to UNE 211002 and UNE-EN 60228 standards. All cables used in the installation, whether internal to the equipment or for interconnections, must meet fire reaction requirements according to UNE-EN 50575, with a minimum classification of Cca-s1b-d1-a1.

Internal wiring in the modular case for indoor installations will have 450/750 V insulation per UNE 211002. For other cables, 0.6/1 kV insulation according to UNE-EN 21123-4 will be used. Measurement cables should be at least category 6A network cables and shielded to avoid electromagnetic interference from both external and internal sources. Shielding must be applied to both the entire cable set and each pair of cables individually.

The minimum cross-sectional areas to be considered are as follows:

Circuit Type	*Minimum Cross-Section (mm²)*
Instrumentation cabling: shielded pair cables for low-value signals (mA/mV)	2x2x0.6
Control, signalling, regulation, measurement circuits	1.5
Circuits powered by transformer secondary windings	2.5
Protection earth circuits for installed devices	4

Table 1. Minimum cross-sectional areas for cables.

2.1.2 CONSTRUCTION CHARACTERISTICS

In the subsequent sections, the essential construction features of each version of the GFD equipment are detailed.

2.1.2.1 ENCLOSURE OF THE EQUIPMENT

The indoor versions (codes 869923 and 870385) feature an injection-moulded ABS-PC plastic enclosure, designed for wall mounting or preferably DIN rail mounting. The outdoor versions (codes 869924 and 869925) have a metallic enclosure made of EMI aluminium or stainless steel, with various mounting accessories to ensure proper attachment to different types of supports (lattice, concrete, mast type, etc.).

Each enclosure type is equipped with appropriate IP and IK protection ratings suited to the installation type. In all cases, cable entry elements (connectors, wall bushings, cable glands, etc.) provided for both the measurement equipment enclosure and the sensor, are designed to ensure the assembly's sealing and resistance to mechanical impacts. Fixing methods that compromise the enclosure's integrity are not permitted.

The hardware supply includes a sealed plastic bag containing all screws, nuts, coupling nuts, plugs, and other fixing elements required for the specific type of mounting. Cable entry into the enclosure, for both the power and the measurement cables, is done through cable entries located in specific holes made in the enclosure wall.

The equipment enclosure will have an outlet for the communications antenna and another for the power supply, as well as for sensor and measurement cables. There will be a designated terminal for grounding the assembly, clearly marked on the exterior of the enclosure with a weather-resistant and UV-resistant label incorporating the earth symbol according to IEC 60417 (5019), like the one shown below:

Figure 4. Grounding symbol next to the terminal.

2.1.2.2 MOUNTING SUPPORT

For indoor versions, the enclosure should be mounted on a DIN rail within the LV panel, provided there is available space. If the existing LV panel cabinet lacks sufficient space, the GFD equipment will be mounted directly on the SS wall using an appropriately sized DIN rail. In indoor applications, the sensor will be supported by the selected earth conductor.

Outdoor versions of the GFD equipment come with plates or lugs featuring the appropriate number and metric of holes to enable a preferred fixing system using stainless steel straps with screw tensioning. Alternatively, the manufacturer may propose the use of the following anchor plates for mechanical clamping to the metallic profile:

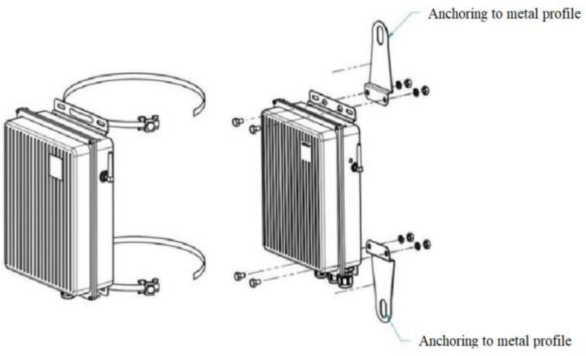

Figure 5. Anchor plates for mechanical clamping to the metallic profile.[2]

Regardless of the type of fixing system provided, both the strap and the anchor plates must be included in the supplier's scope of supply. Drilling of the profiles forming the support structure is strictly prohibited for lattice installations. If an anchor plate fixing system is supplied, an additional frame constructed from four metal profiles and four M10 threaded rods, along with the necessary screws, will be required to secure the support without drilling. This frame and all necessary elements for fixing to the support will not be included in the GFD equipment supply and will be provided separately during field installation by the responsible collaborating company.

The fixing frame will have two horizontal profiles at the top intended for support fixing and GFD cabinet mounting, and two at the bottom. The complete assembly is illustrated below:

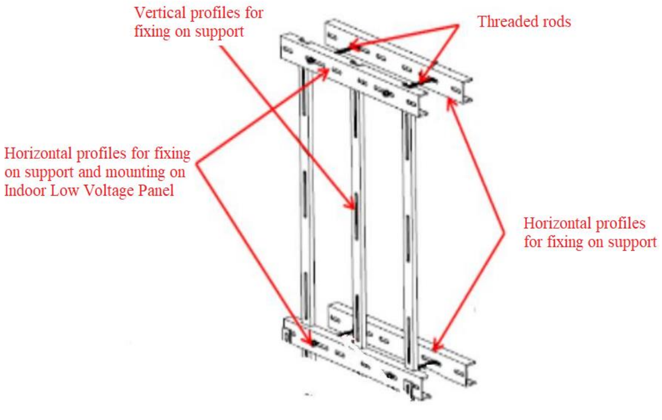

Figure 6.Support for fixing on support.[2]

All horizontal profiles will be identical, and the two auxiliary profiles for support fixing will be pre-fitted to the upper and lower profiles of the fixing frame using four 250 mm long threaded rods and the necessary screws. If longer threaded rods are required in the field, they will be supplied by the installer.

To ensure stability once placed on the support, the fixing frame will have a completely flat surface facing the support. Necessary recesses in the two horizontal profiles will accommodate the three vertical profiles, which must be welded. All profiles and plates used in constructing the support will have any lamination burrs or those produced by drilling or cutting removed. Welded joints must be sealed, free from porosity and slag, with weld seams closing the entire overlap surface perimeter, complying with the UNE-EN 3452 standard.

2.1.3 FUNCTIONAL CHARACTERISTICS

The power supply unit manages the energy provision for various operating scenarios and different power supply options:

- *Power supply from LV at 230 Vac.*
- *Direct from 48V DC secure power supply batteries.*
- *20 W - 1A photovoltaic panel.*

The power supply unit includes the voltage regulation system for the operation of the various electronic components of the equipment, as well as charging the backup battery (3Ah) or the supply battery (10Ah) for autonomous power supply with a solar panel. The power supply unit will have two modes of operation:

- ***Normal operation:*** The case where there is a continuous power supply.
- ***Low Power mode:*** This mode activates in the event of power supply interruption and when the equipment battery reaches a 30% depth of discharge. In this mode, the equipment will shut down some internal modules and reduce the measurement frequency to once a day and extend the availability time for event measurements.

The GFD equipment with a backup battery (3Ah) must be able to operate without a mains supply. With a fully charged battery, no additional sensors, and a measurement frequency of one hour, the expected operating time is approximately two days. This duration may decrease over the equipment's life due to temperatures outside the usage range, increased communication flow, natural battery degradation over time, surges or overloads affecting the charging and battery control process.

The model with a supply battery (10Ah) must be able to operate without solar panel input (night, cloudy days, snow, etc.). With a fully charged battery, no additional sensors, and a measurement frequency of one hour, the expected operating time is approximately ten days. This duration may decrease over the equipment's life due to similar factors affecting the backup battery.

For models powered by a photovoltaic panel, the panel must comply with applicable standards and certifications regarding design, construction, testing, and trials. The panel will also have CE marking. The GFD equipment supplier is responsible for providing this component and the associated documentation (technical data sheet, dimensional and operational characteristics, manuals, test protocols, etc.), as well as all elements necessary for its installation and connection. Generally, the photovoltaic panel will have at least 20 W maximum power and a minimum current at maximum power of 1 A. The manufacturer should indicate additional characteristic values for the panel:

The communications unit enables communication via 4G technologies, such as LTE-M or NBIoT, with at least one alternative technology to use if the primary 4G network is unavailable. The communications unit must manage technology changes and even operator changes in multi-operator SIM scenarios.

The measurement and management unit handles earth resistance measurements according to programmed periodicity parameters. It also manages the measurement of electrical activity in the earth conductor and other special functions, such as the *Hub&Spoke* function, where one device injects current into an interconnected earth network while other connected devices determine the signal reaching their respective nodes. Another function managed by this unit is auto-calibration (explained in the next section). This unit also manages periodic measurements and events, interprets remote commands, coordinates remote firmware updates, controls relays for local actions, determines alert states and self-management actions, and handles storage and synchronization.

The expansion unit manages communications via the equipment's expansion port to add new functionalities that the equipment can centralize, as well as reading expansion ports intended for sensor expansion if available.

2.1.4 AUTO-CALIBRATION PROTOCOL

The auto-calibration protocol is a fundamental procedure carried out on Ground Fault Detection (GFD) devices periodically. The frequency of this procedure is configurable, with the default setting being once a month. This protocol is crucial for ensuring the accuracy and reliability of the resistance measurements recorded by the devices.

The auto-calibration protocol is configured by default to occur once a month but can be changed. The protocol is triggered if the measurement recorded by the device exceeds 1 ohm. This protocol ensures that the device operates within safe parameters and that the measurements taken are accurate and reliable.

The auto-calibration procedure consists of the two following parts:

1. Local Adjustment on the Device:

In the first phase, the adjustment is carried out directly on the GFD device. The device performs a measurement on an internal loop with a known resistance value, formed by precision resistors. After completing this measurement, the device automatically adjusts its internal coefficients so that the recorded value matches that of the internal precision resistor. This process ensures that the device is calibrated to provide accurate measurements.

2. Generation of the Calibration Report on the Server:

In the second phase, the server processes the information sent by the device after the adjustment. A calibration report is generated based on the data obtained during the adjustment process. This report includes the quantification of the uncertainty of the internal precision resistor, the temperature recorded during the adjustment, and a set of at least 10 measurements taken simultaneously on the internal loop. This report is essential for evaluating and documenting the accuracy of the device's measurements.

2.1.5 DIGITAL SIGNALS AND OPERATIONAL INDICATORS (LEDS)

The equipment provides a set of digital signals to represent specific information on the device, either on a TFT screen or through a set of LED indicators showing various operational states. If equipped with LED indicators, the device will have four indicators labelled *OK*, *COMM*, *TRIGGER*, and *SENSOR*, characterized by the following behaviour:

Led	*State*	*Meaning*
ON	250ms ON / 250ms OFF	Equipment pending calibration. Notify the manufacturer.
	3000ms ON / 100ms OFF	Normal operation
COMM	Permanent ON	Modem OK, in configuration process
	1000ms ON / 1000ms OFF	Modem configure, network available
	100ms ON / 100ms OFF	Modem establishing communication
	Permanent OFF	Modem error detected. Notify the manufacturer.
TRIGGER	1000ms ON / 1000ms OFF	Device armed correctly
	100ms ON / 100ms OFF	Device recording a new event
	Permanent OFF	Not armed for event measurement
OPEN COIL	500ms ON / 500ms OFF	Anomalous activity detected in the sensor. Possible causes: - Sensor not closed correctly - High current level in the earth conductor - Loop resistance below 0.5 Ohms
	100ms ON / 100ms OFF	Equipment pending calibration. Notify the manufacturer.
	Permanent OFF	Device OK

Table 2. LED States and Meanings

2.1.1 COMMUNICATION PORTS

For device versions that include this feature, there will be a single external RJ45 physical port. This port will be disabled in versions that do not communicate via LAN. If activation of this function is required, it will be necessary to insert the corresponding communication module and enable it. This activation will be carried out through a remote command.

2.1.1 EQUIPMENT AND CIRCUIT DIAGRAMS

The following section presents the different versions of GFD equipment with their corresponding input/output elements:

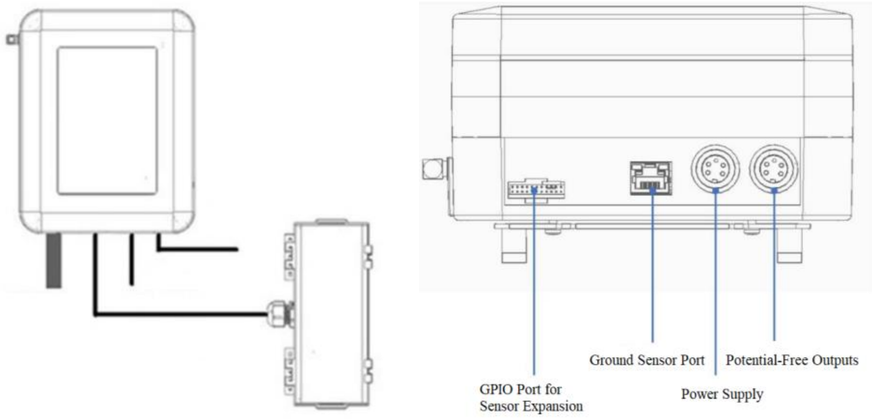

Figure 7. GFD cabinet at 230 VCA (869923).[3]

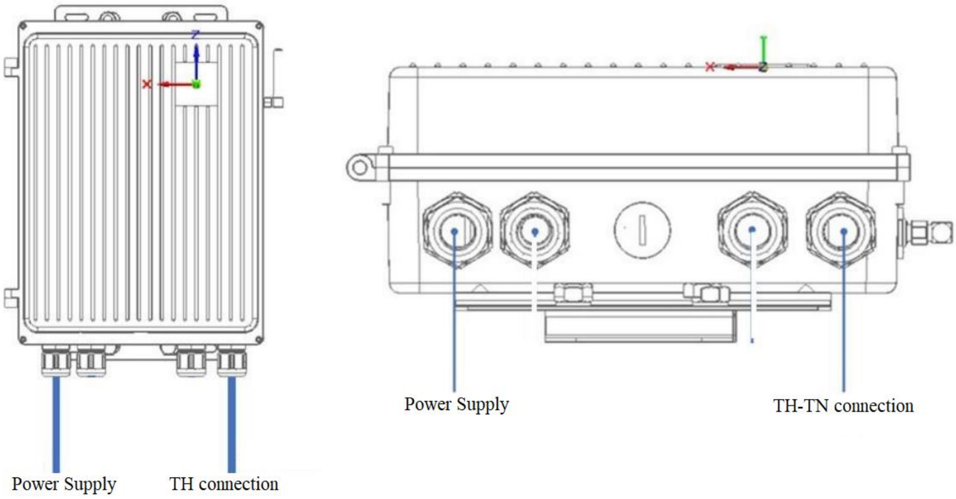

Figure 8. GFD outdoor at 230 VCA (869924).[2]

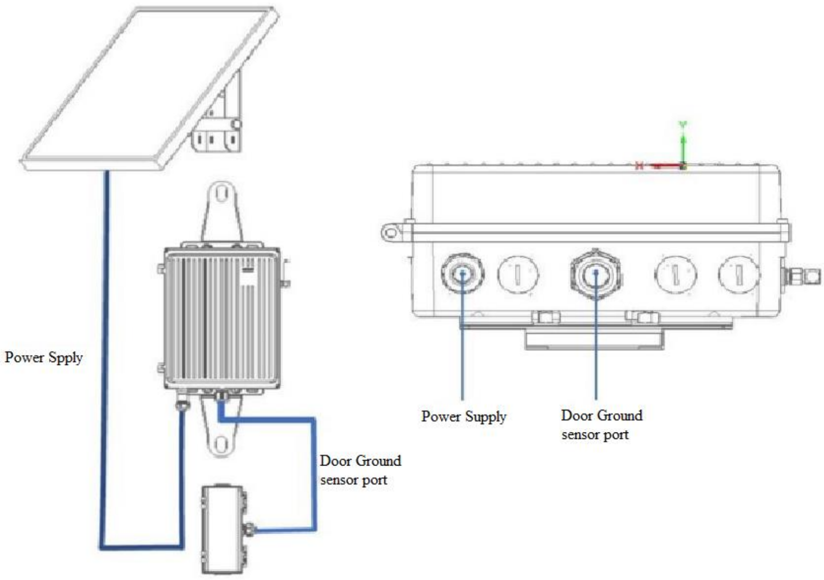

Figure 9. GFD freestanding with PV panel (869925). [2]

2.1.2 DIMENSIONAL CHARACTERISTICS

This section details the approximate dimensions of the various enclosures and components of the GFD equipment for both indoor and outdoor versions. Understanding these dimensions is necessary for proper installation and integration into different environments. The figures provided illustrate the key measurements for each version, including the measurement equipment enclosures, the ground sensor, and the photovoltaic panel.

The enclosure of the measurement equipment in the indoor versions has approximate dimensions of 165x211x88 mm (Width x Height x Depth). The main dimensions are shown in the following figure:

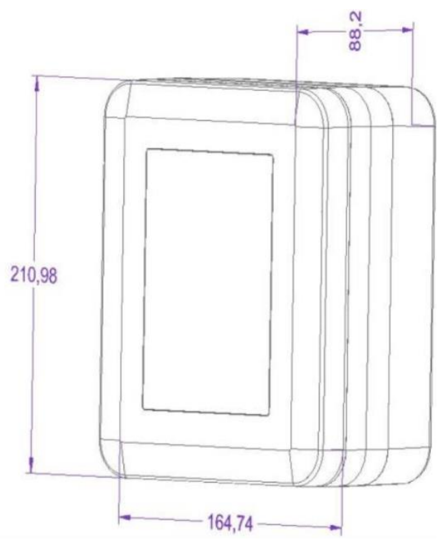

Figure 10. Dimensions of the indoor version enclosure.[2]

The enclosure of the outdoor versions has approximate dimensions of 240x280x91 mm. The main dimensions are shown in the following figure:

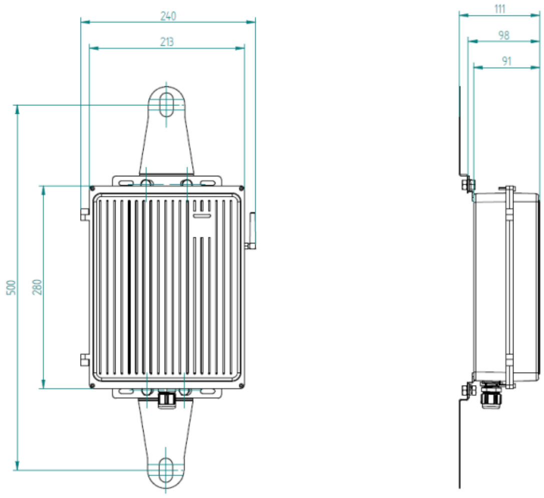

Figure 11. Dimensions of the outdoor version enclosure.[2]

The ground sensor has approximate dimensions of 79x179x68 mm. The main dimensions are shown in the following figure:

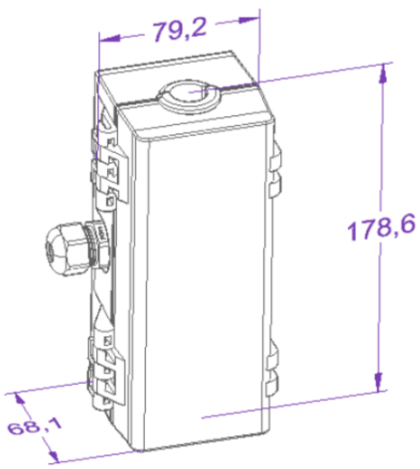

Figure 12. Dimensions of the ground sensor.[2]

Versions with a photovoltaic panel will incorporate a panel with approximate dimensions of 356x435x40 mm. The main dimensions are shown in the following figure:

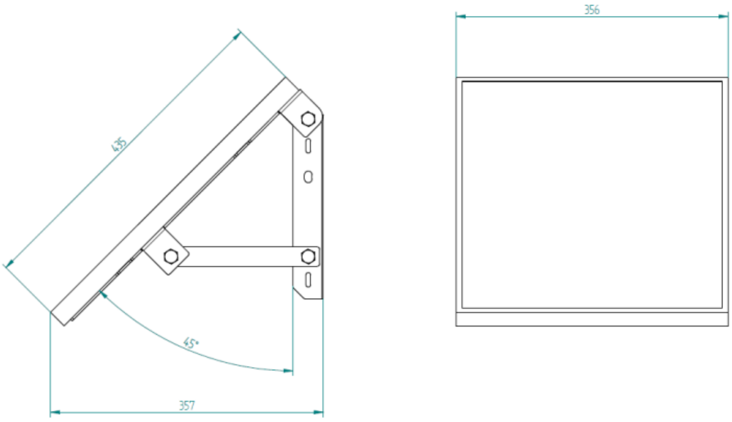

Figure 13. Dimensions of the photovoltaic panel for autonomous power versions.[2]

2.1.3 ELECTRICAL CHARACTERISTICS

The GFD equipment have the electrical characteristics specified in the following sections:

2.1.3.1 GENERAL CHARACTERISTICS

The general electrical characteristics of the different versions of the GFD equipment are indicated in the following table:

TYPOLOGY OF INSTALLATION	GFD cabinet at 230 VCA	GFD cabinet at 48 VDC	GFD outdoor at 230 VCA	GFD freestanding with PV panel
MATERIAL CODE	869923	870385	869924	869925
TECHNICAL CHARACTERISTICS				
Loop impedance range	0.400 Ohms	0.400 Ohms	0.400 Ohms	0.400 Ohms
Current measurement range	10mA..30A	10mA..30A	10mA..30A	10mA..30A
Temperature range	-20..60ºC	-20..60ºC	-20..60ºC	-20..60ºC
Injection frequency	1132 Hz	1132 Hz	10000 Hz	1132 Hz
No. of analogical-digital ports	5	5	5	5
No. of digital ports	5	5	x	x
No. of expansion ports	1	1	1	1
PHYSICAL CHARACTERISTICS				
Dimensions	165x211x88mm	200x130x45mm	290x210x100mm	290x210x100mm
Weight	1kg	1kg	3kg	3kg
Operating temperature range	-20..60ºC	-20..60ºC	-20..60ºC	-20..60ºC
IP rating	20	20	65	65
Enclosure material	PVC-PC	PVC-PC	EMI Alloy	EMI Alloy
POWER SUPPLY				
Supply voltage	220Vac	48Vdc	220Vac	Solar
Power voltage	10.30Vdc	30.60Vdc	10.30Vdc	10.30Vdc
Average consumption	300mA	300mA	300mA	300mA
Internal battery	5Ah	x	5Ah	10Ah
COMMUNICATIONS				
Communication type	GSM LTE-M, NBIoT, 2G	GSM LTE-M, NBIoT, 2G	GSM LTE-M, NBIoT, 2G	GSM LTE-M, NBIoT, 2G
Communication protocol	MQTT	MQTT	MQTT	MQTT

	STORAGE			
Storage type	SD	SD	SD	SD
Capacity	8GB	8GB	8GB	8GB

Figure 14. Electrical characteristics of the different versions of the GFD equipment.

2.1.3.1 ELECTROMAGNETIC COMPATIBILITY

All GFD equipment will have CE marking, complying with the Electromagnetic Compatibility Directive 2004/108/EC. Additionally, they will comply with all requirements specified in the IEC 61000-6-2:2016 and IEC 61000-6-4:2018 standards, along with IEC 61000-3-2:2018+AMD1:2020 and IEC 61000-3-3:2013+AMD1:2017+AMD2:2021 standards.

2.1.4 DEGREE OF PROTECTION

With the door closed, the GFD will provide a minimum protection rating of IP-65 against contact with live parts and penetration of foreign objects for outdoor installations according to UNE-EN 60529, and an IK-09 protection rating against mechanical impacts according to UNE-EN 62262.

For indoor or enclosure installations, the minimum protection ratings to consider are IP-43 and IK-07, respectively.

2.1.5 MARKING

In addition to the CE marking, the GFD will have a nameplate with the following information indelibly and legibly marked:

- *Manufacturer*
- *Model Reference*
- *Serial Number*
- *Manufacturing Date (year)*

The equipment must have a digital labelling system with a QR code. This digital labelling system will include the electrical data of the equipment and shipment information, consisting of the following fields:

1. A digital label with a QR code engraved on a corrosion-resistant plate on the equipment, preferably on or next to the nameplate.
2. An adhesive digital label with a QR code on the equipment packaging with the same data as the engraved label.
3. An adhesive label with a QR code on the packaging exterior with shipment details.

Each box label will indicate the UFD material code, manufacturer's brand, storage instructions (maximum stacking height, avoiding contact with sharp objects, etc.), and manufacturing date. Also, the installation and maintenance instructions will be included inside the box.

2.2 MONITORED ASSETS WITH GFD EQUIPMENT

In this section, we will delve into the specifics of where GFDs are installed within the UFD network. Understanding the installation locations and conditions are crucial for appreciating these devices' practical application and integration into the different existing infrastructures.

By the end of this section, readers will have a comprehensive understanding of the diverse installation environments for GFDs, the technical requirements and configurations involved, and the specific adaptations necessary for effective deployment. This foundational knowledge is essential for appreciating the broader integration and operational considerations discussed in subsequent sections.

2.2.1 SECONDARY SUBSTATIONS (SS)

The integration of GFDs in secondary substations allows for continuous monitoring of the impedance of the grounding systems and detection of anomalies that may indicate potential faults. This continuous data collection enhances the ability to detect issues earlier compared to actual Regulatory Periodic Inspections (RPIs) taken every three years. Specific issues that GFDs can detect include hazardous step and touch voltages, anomalies in the grounding system's impedance. These capabilities reduce the risk of electrical hazards and improve overall network safety by allowing for proactive maintenance and timely intervention. These GFDs are strategically positioned to monitor the grounding system effectively. Typically, they are installed near the grounding points of the transformers [3].

2.2.2 SWITCHING CENTRES (SC)

Switching Centres (SC) are facilities that primarily handle the routing and switching of electrical power within the network. These centres manage the flow of electricity by opening and closing circuit breakers and isolating faulted sections of the network to maintain service continuity and minimise outage impacts. Incorporating GFDs in SC provides real-time monitoring of grounding systems enhancing the security of the Medium Voltage (MV) network [1], [4].

These GFDs are placed in SCs to effectively monitor the grounding systems associated with circuit breakers and switching devices. Like SSs the data collected by these devices is used for detecting anomalies in grounding impedance and reducing hazardous risks as step and touch voltages, enhancing the safety of the network. The GFD devices allow the detection of any deviations from normal impedance levels which might indicate some fault. The real-time monitoring helps in promptly identifying and mitigating hazardous [1], [5].

2.2.3 FREQUENTED SUPPORTS

Frequented Supports within the MV network are individual structural elements such as poles, towers, or supports that hold electrical equipment and conductors. These supports are regularly accessed for maintenance and inspections and are crucial for the physical support and accessibility of electrical infrastructure components, so ensuring safety in these assets is a priority.

Given the increased accessibility and the potential risks they pose, frequented supports necessitate specific configurations and considerations for the installation of GFDs. The configuration on frequented supports is done in order to meet the specific grounding and structural requirements, which again is vital for operational safety standards [1], [3].

2.3 *APPLICABLE REGULATIONS AND STANDARDS*

The GFD devices adhere to a comprehensive set of regulations and standards that ensure their safe and efficient operation. It is important to note that the standards and regulations referenced are updated to the latest editions as of the date of this document's drafting. This ensures that all guidelines, safety measures, and technical requirements are in alignment with the most current industry practices and legal requirements.

The GFD devices comply with the following regulations and standards:

IEC Standards

- ***IEC 61000-6-2:2016:*** Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments. This standard specifies the EMC immunity requirements for electrical and electronic equipment intended for use in industrial environments, ensuring that the equipment can operate without harmful interference.
- ***IEC 61000-6-4:2018:*** Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments. This standard covers EMC emission requirements for electrical and electronic equipment in industrial environments, ensuring that the equipment does not emit electromagnetic interference that could affect other devices.
- ***IEC 61000-3-2:2018+AMD1:2020:*** Electromagnetic compatibility (EMC) - Part 3-2: Limits for harmonic current emissions (equipment input current $\leq$16 A per phase). This standard defines limits for harmonic current emissions produced by electrical and electronic equipment with an input current $\leq$ 16 A per phase, crucial for reducing harmonic distortion in electrical systems.
- ***IEC 61000-3-3:2013+AMD1:2017+AMD2:2021:*** Electromagnetic compatibility (EMC) - Part 3-3: Limitation of voltage changes, voltage fluctuations, and flicker in public low-voltage supply systems. This standard establishes limits for voltage changes, voltage fluctuations, and flicker in public low-voltage supply systems, ensuring network stability and minimizing the impact on other connected equipment.

Spanish Royal Decrees

- ***Royal Decree 337/2014:*** Approving the technical conditions and safety guarantees for high-voltage electrical installations and their complementary technical instructions.
- ***Royal Decree 842/2002:*** Approving the low voltage electrotechnical regulations and their complementary technical instructions.
- ***Royal Decree 223/2008:*** Approving the technical conditions and safety guarantees for high-voltage power lines and their complementary technical instructions.

UFD Specifications

- ***ES.06256***: General conditions for the approval and quality assurance of material supplies.
- ***ES.04665:*** General specification for the acquisition of works and services.

Other Specific Standards

- ***UNE-EN 60529:*** Degrees of protection provided by enclosures (IP Code).
- ***UNE-EN 62262:*** Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK Code).
- ***UNE-EN 61010-1:*** Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements.
- ***UNE-EN 61000-3-2:*** Electromagnetic compatibility (EMC). Part 3-2: Limits. Limits for harmonic current emissions (equipment input current ≤16 A per phase).
- ***UNE-EN 61000-4-2:*** Electromagnetic compatibility (EMC). Part 4-2: Testing and measurement techniques. Electrostatic discharge immunity test.
- ***UNE-EN 61000-4-3:*** Electromagnetic compatibility (EMC). Part 4-3: Testing and measurement techniques. Radiated, radiofrequency, electromagnetic field immunity test.
- ***UNE-EN 61000-4-4:*** Electromagnetic compatibility (EMC). Part 4-4: Testing and measurement techniques. Electrical fast transient/burst immunity test.
- ***UNE-EN 61000-4-5:*** Electromagnetic compatibility (EMC). Part 4-5: Testing and measurement techniques. Surge immunity test.
- ***UNE-EN 61000-4-6:*** Electromagnetic compatibility (EMC). Part 4-6: Testing and measurement techniques. Immunity to conducted disturbances, induced by radio-frequency fields.
- ***UNE-EN 61000-4-8:*** Electromagnetic compatibility (EMC). Part 4-8: Testing and measurement techniques. Power frequency magnetic field immunity test.
- ***UNE-EN 61000-4-11:*** Electromagnetic compatibility (EMC). Part 4-11: Testing and measurement techniques. Voltage dips, short interruptions, and voltage variations immunity tests for equipment with input current up to and including 16 A per phase.
- ***UNE-EN 50575***: Power, control, and communication cables - Cables for general applications in construction works subject to reaction to fire requirements.
- ***UNE 211002***: Low voltage electrical cables - Cables with assigned voltage ≤ 450/750 V (Uo/U).
- ***UNE 21123-4:*** Industrial use electrical cables with assigned voltage 0.6/1 kV - Part 4: Cables with cross-linked polyethylene insulation and polyolefin sheath.
- ***UNE-EN 60754-1:*** Tests on gases evolved during the combustion of materials from cables - Part 1: Determination of halogen acid gas content.

- ***UNE-EN 60754-2:*** *Tests on gases evolved during the combustion of materials from cables - Part 2: Determination of acidity (by pH measurement) and conductivity.*
- ***UNE-EN 60228:*** Conductors of insulated cables.
- ***UNE-EN 60085:*** Electrical insulation - Thermal evaluation and designation.

This detailed list ensures that the GFD devices meet all necessary safety and performance criteria, reflecting the latest industry standards and regulatory requirements. This approach guarantees the reliability and compliance of the equipment within the operational framework of UFD and its broader regulatory environment.

2.4 CONDITIONS AND PROCEDURES FOR INSTALLATION

Proper installation of GFD equipment in MV networks requires careful consideration of various factors and prerequisites. The following sections detail the essential aspects to be reviewed to ensure a successful installation.

The instructions in this section apply to the installation and connection of GFD equipment in existing and operational UFD network installations. These guidelines ensure that the integration of GFD units does not disrupt current operations and that the equipment performs its monitoring functions accurately. The addition of GFD equipment may necessitate improvements, such as enhancing the grounding systems to ensure accurate measurements. This might involve installing new grounding rods or upgrading the current grounding setup. Additionally, connection boxes might be required if it is not feasible to connect the GFD equipment within the existing infrastructure. These connection boxes should be designed to withstand environmental conditions and provide secure connections.

For new constructions, the installation of GFD equipment should be predefined in the corresponding material specifications and construction project. This pre-definition helps in planning and executing the installation seamlessly, ensuring compatibility and compliance with the designed infrastructure.

Also, to protect the GFD equipment and maintain the integrity of the measurements, anti-climbing devices may be installed. These devices prevent unauthorized access to the equipment, ensuring that the monitoring data remains accurate, and the equipment is safeguarded against tampering or damage.

When planning the installation, it is crucial to conduct a thorough site assessment. This assessment should identify potential obstacles, environmental conditions, and specific installation requirements unique to each site. Ensuring all necessary tools, materials, and personnel are prepared in advance will facilitate a smoother installation process.

By adhering to these guidelines and considering the outlined factors, the installation of GFD equipment can be carried out efficiently and effectively, providing reliable monitoring and protection for the MV networks.

2.4.1 GENERAL CONDITIONS

The typical connection method for the different elements configuring the SS, Outdoor Secondary Substation (OSS), Sectioning Centre (SC), and Reflection Centre (RC) in the UFD MV network is derived from an interior grounding ring as shown in the following figure:

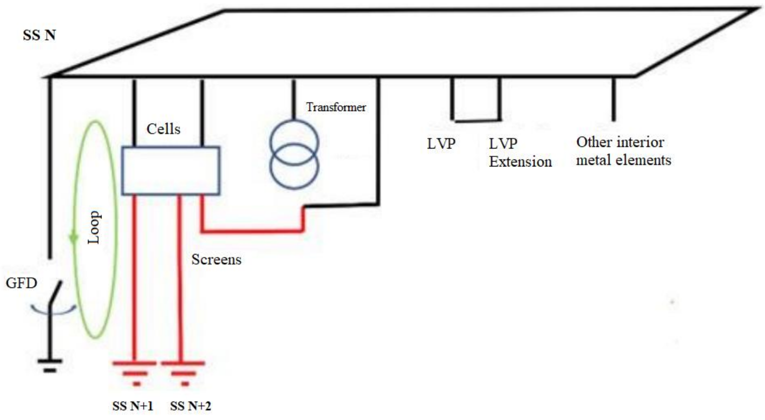

Figure 15. General connection diagram for GFD installation.

The GFD is a device that measures the loop impedance between the ground of a SS and the rest of the security network formed by the interconnected ground mesh of the insulated cables entering and exiting the centre. In the case of OSSs, the loop return for impedance measurement is carried out through the neutral or service ground. When it is not possible to join the structural and neutral grounds in an OSS, an auxiliary ground is used.

For freestanding supports, the loop can be closed with the structure itself if it is metallic, or by installing a second control ground to close the loop. This second control ground does not need to meet minimum values and is only measured to subtract from the loop measurement.

The aim of installing the GFD is to perform continuous ground system monitoring and detect any disconnected elements. To achieve this, modifications to the existing ground scheme may be necessary to include all elements that form part of the active system.

This reconnection of grounds complies with regulatory requirements and allows for remote monitoring of the correct connection.

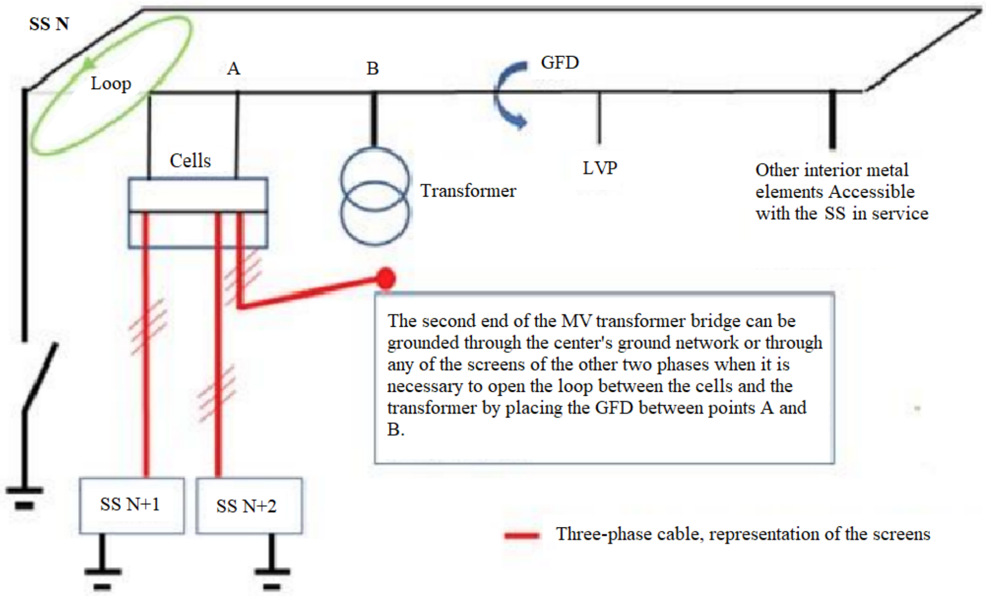

Figure 16.Modified ground system scheme for GFD installation.

2.4.1.1 PHYSICAL CONFIGURATION AND INSTALLATION

The physical configuration of the GFD consists of a console designed to withstand various environmental conditions. As mentioned in previous sections, th console can be installed on a support structure, mounted directly on a wall, or attached to a DIN rail within an appropriate cabinet, providing flexibility in installation options to suit different setups.

The installation of these devices should include securely mounting the sensor in the measurement loop of the active network ground to ensure accurate readings. If no loop exists, one should be created by integrating the sensor with the neutral network in OSSs or establishing a secondary auxiliary ground in freestanding supports. This ensures that the GFD can perform its monitoring functions effectively.

For OTCs, when joining grounds with bridging connections, it is crucial to place the sensor inside the same box that houses the device. This positioning ensures that the sensor does not obstruct any ground cable entrances, allowing for a seamless integration into the existing infrastructure. Proper placement and connection are essential for the optimal performance and accuracy of the GFD system.

There are three different installation scenarios depending on the GFD model installed:

- ***In SS cabinet type:*** Connected to the 230 Vac auxiliary circuit of the low voltage panel (LVP), either directly or mounted on a DIN rail.
- ***In SC and RC cabinet:*** From a 48 Vdc battery with appropriate protection.
- ***In OSS and freestanding supports:*** Through a photovoltaic panel, ensuring continuous power for reconnection points and remote-control switches.

The equipment must operate within the following environmental conditions to avoid loss or degradation of its characteristics in the long term:

- ***Operating Temperature:*** -10ºC to +55ºC
- ***Storage Temperature:*** -5ºC to +40ºC
- ***Annual average:*** ≥75% (non-condensing)
- ***30 days per year:*** ≥95% (non-condensing)
- ***Pollution Degree:*** 3 (presence of conductive pollution)
- ***Altitude:*** ≤1500 m

2.4.2 GROUNDING CHARACTERISTICS IN MV INSTALLATIONS

Before installing the GFD equipment in any asset of the UFD MV network, it is essential to determine whether the grounding system in the targeted installations needs to be adjusted.

For Secondary Substations, Outdoor Secondary Substation, Sectioning Centres, and Reflection Centres, the design of the grounding electrode system generally adheres to the ITC-RAT-13 application. For freestanding supports, the ITC-LAT 07 prescriptions have been considered. Both cases account for personal safety regarding potential rise, dangerous overvoltage for the installation, and the fault current value that triggers protections ensuring fault elimination. Selecting the appropriate type of grounding system to be monitored is crucial. The following cases are distinguished:

- ***Complex Grounds:*** These involve multiple locations (more than two) connected by the grounding screens of insulated cables or guard wires. This scenario applies to SSs, SCs, and reflexive centres (RCs).
- ***Isolated Grounds:*** These installations have a grounding system isolated from the rest of the network, requiring a forced path to close the ground loop. This scenario generally applies to freestanding supports and OTCs. Although for OTCs, the ground measurement loop can be closed through the neutral ground if the fault voltage values are within appropriate limits.
- ***Paired Grounds:*** This involves monitoring two installations connected by the same grounding system.

2.4.3 GROUNDING SYSTEM PRELIMINARY MEASUREMENTS

Once the type of grounding system has been selected, as indicated previously, the first step is to measure the primary ground (R_{ppal}) or structural ground of the installation using an earth tester. When measuring the structural ground, it is necessary to ensure that it is isolated from the neutral ground.

For installations with isolated or paired grounds, it is also necessary to identify and measure the secondary ground (R_{aux}), which will allow the loop to be closed. The measurements obtained for R_{ppal} and R_{aux} will provide the reference values for the grounding of each element separately.

Next, it is necessary to measure the loop resistance (R_{loop}) where the GFD equipment will be connected. To do this, a temporary bridge will be set up, and the measurement will be carried out using a manual clamp or an earth tester, depending on the number of poles. This measurement aims to verify that the grounds are indeed isolated from each other, as the value of R_{loop} will be lower than either of the individual measurements (R_{ppal} and R_{aux}) if they are not isolated.

Additionally, this measurement will serve as a verification of the actual measurement obtained once the GFD equipment is installed. The measured value should be close to the manual measurement, with an acceptable 20% tolerance. This tolerance is allowed due to the differences in timing and frequency between the manual and automatic measurements with the GFD and will only be applicable when the loop resistance value exceeds 20 ohms.

2.4.3.1 COMPLEX GROUND SYSTEMS

Complex ground systems involve interconnected grounding systems spanning three or more locations, requiring individual equipment installation for each location. These interconnected ground systems are found in SSs, SCs, RC in the MV network, and Overhead-Underground Transition (OUT) supports, as well as supports with guard wires or those interconnected by optical fiber tensioners.

In these cases, the R_{loop} value must be measured at the ground exit of the relevant installation, as well as the structural ground measured with an earth tester isolated from the rest of the installation. If isolation has not been achieved, this must be indicated to calculate appropriate values based on the obtained data. The measurement is taken on the perimeter ring (loop) surrounding the centre's structures, to which the masses of the different components are connected.

If the R_{loop} value indicates that the loop is closed, it may be because the loop is either closed on itself or closed on the installation's neutral ground. In this case, it is necessary to locate the point where the loop closure occurs within the installation and undo or eliminate this closure. This requires creating an insulation point where the grounds contact (loop closure), using insulating tape or sleeves on a section of the conductors that close the loop.

Next, the existing ground ring will be opened, typically by cutting it with shears, as shown in ***Figure 16***. Once the ring is opened, it is checked with a manual clamp that any point along the loop closure path has the same resistance value as previously measured at the installation's exit.

Finally, the location for installing the measurement equipment is selected. Generally, this will be where the equipment is most accessible, where there is the best communication network coverage, where access to the LVP is easiest since the measurement equipment needs electrical power from the LVP, and as close as possible to the MV cells to detect potential faults in the MV system with minimal noise.

2.4.3.2 ISOLATED GROUND SYSTEMS

Case of OSS:

For the case of OSSs, the structural ground (R_{ppal}) and the auxiliary ground (R_{aux}) should be measured separately using an earth tester without separating the structural ground rod, the neutral ground, and the auxiliary ground. This setup will close the loop between both grounds to monitor them simultaneously, ensuring it meets the following condition:

$$Parallel\,(R_{ppal} - R_{aux})\,x\,(I_{Def} + 50\%) < 1000V$$

Equation 1

With the available data, the integrated calculation system in the GFD application will verify that this condition is met. If not, the value of R_{ppal} should be reduced until the required value is achieved. If the target value is difficult to reach, an auxiliary ground should be installed to close the loop, as described for freestanding supports. The same conditions regarding the maximum permitted value (400 Ω) will then apply.

Another relationship to be checked to ensure the sensitivity of loop measurements is the relationship between R_{ppal} and R_{loop}:

$$S = \frac{R_{ppat}}{Z_{loop,ppal}} \leq 2\ and\ S = \frac{R_{ppal}}{Z_{loop,loop}} \geq 0{,}2$$

Equation 2

Under these circumstances, monitoring the neutral ground together with the main ground is waived, and a loop is generated with the auxiliary ground as if it were an isolated support, noting that the GFD equipment used will not draw power from a photovoltaic panel (material code 869925) but from the LVP of the Outdoor Low Voltage Panel (OLVP) (material code 869924).

If the above conditions are not met, appropriate actions on the grounds must be taken to ensure compliance with the indicated relationships.

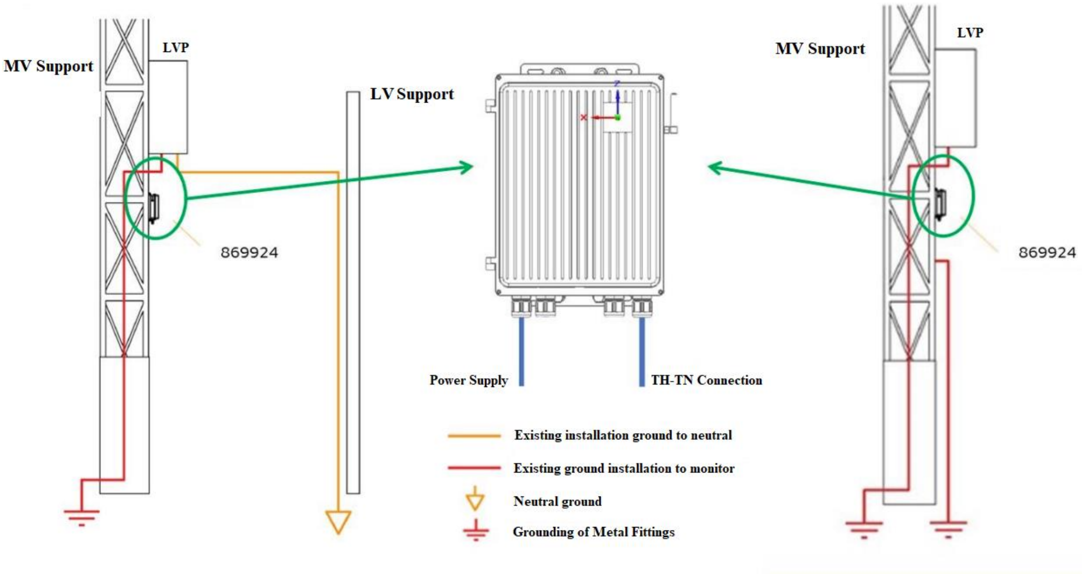

Figure 17. Schematic of isolated ground system setup.

Case of Frequented Supports:

The auxiliary ground to close the loop can be the structure itself embedded in the ground; although not optimal, it is sufficient if it meets the following condition:

$$R_{ppal} + R_{aux} < 400\ \Omega$$

Equation 3

To measure the loop correctly, the primary ground must be extended with an insulated cable to create a loop between both grounds, long enough to introduce a loop impedance measurement clamp and take the R_{loop} measurement. This cable must comply with the required sections according to regulations for ground circuits depending on its material and verify the following condition:

$$R_{loop} > (R_{ppal} + R_{aux})\ x\ 0{,}7$$

Equation 4

If both grounds are independent, the extension for the measurement must be fixed to a prepared point on the support above the anti-climb barrier. The sensor clamp should be attached to this added cable, ensuring that the photovoltaic panel is mounted at a height above 3.5 meters on the south side of the support, with the solar panel anchorage positioned at approximately 45° to facilitate the equipment's power supply.

If the solar panel is shaded by trees or buildings, the installation of the equipment should be abandoned, as there will not be enough solar energy to power the equipment.

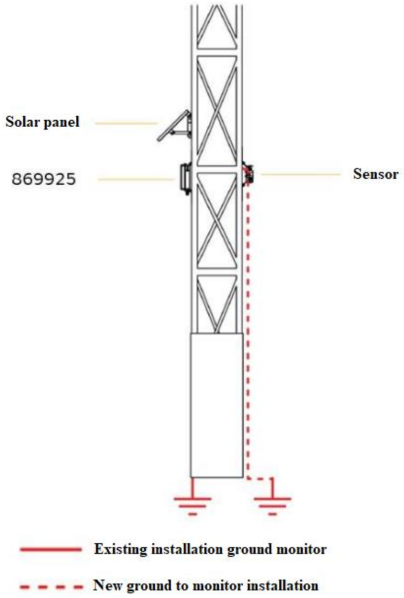

Figure 18. Setup for auxiliary ground using the embedded structure.

If both grounds are not independent, a new auxiliary ground must be installed, separated by 2.5 times the width of the primary ground (approximately 3.5 meters from the support), using insulated cable with a minimum cross-section of 6 mm². This ground is sufficient with a single rod, provided it meets the previous conditions both in absolute value, in its sum with the primary, and in its loop to certify isolation.

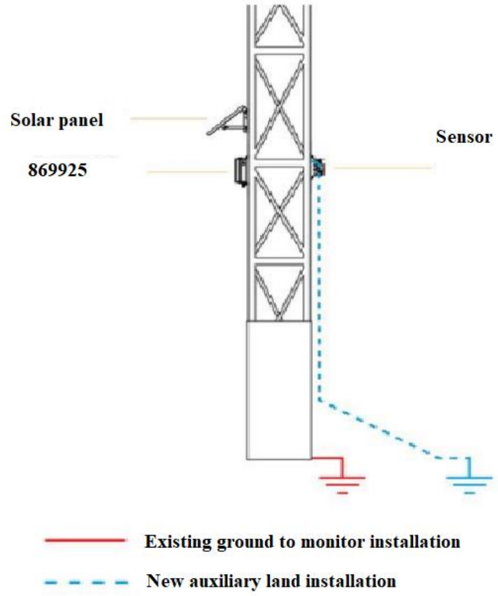

Figure 19. Setup for new auxiliary ground installation.

If the sum of the resistances cannot be reduced below 400 Ω or if the grounds cannot be isolated, this device is not suitable for remote ground monitoring at that location. For frequented concrete supports, the configurations for the auxiliary ground depend on whether there is an internal or external ground conductor.

The following figure shows the auxiliary ground system configuration for each of these two cases:

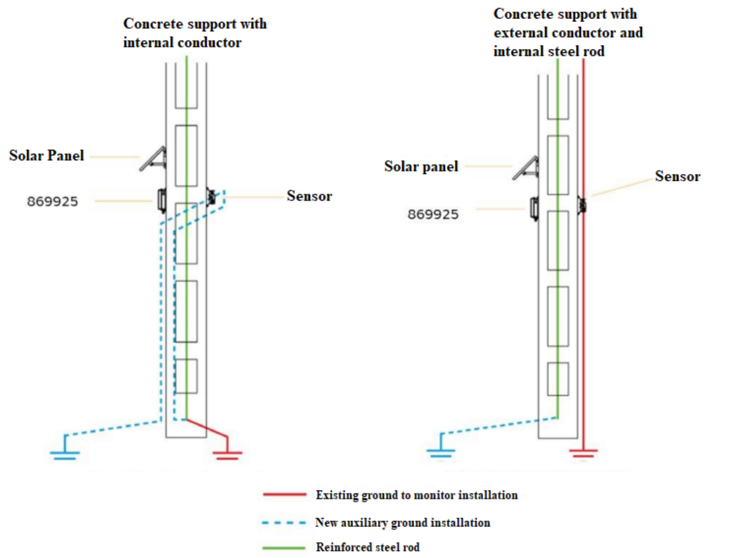

Figure 20. Auxiliary ground system configuration for concrete supports.

2.4.3.3 PAIRED GROUND SYSTEM

This section applies to a wide range of installations within the UFD network that consist of two locations connected by the grounding system, where both need to be monitored. Generally, these are complex ground systems with several interconnected locations, but only two locations are involved. It can also apply to isolated systems where the two grounds that close the loop already exist, and no artificial ground is needed to close the measurement loop.

In these cases, a single GFD device can monitor both locations since the ground loop is the sum of the grounding systems of both locations. The most evident example is the retracing of an overhead to underground section between two OUT supports. The screens of the isolated dry cables close the loop of the grounds of both supports. Thus, if two GFD devices were installed, both would measure the same from both ends. The preliminary step required in these cases is to measure the characteristics of the ground systems separately before connecting them through the loop. This example can be seen in the following figure:

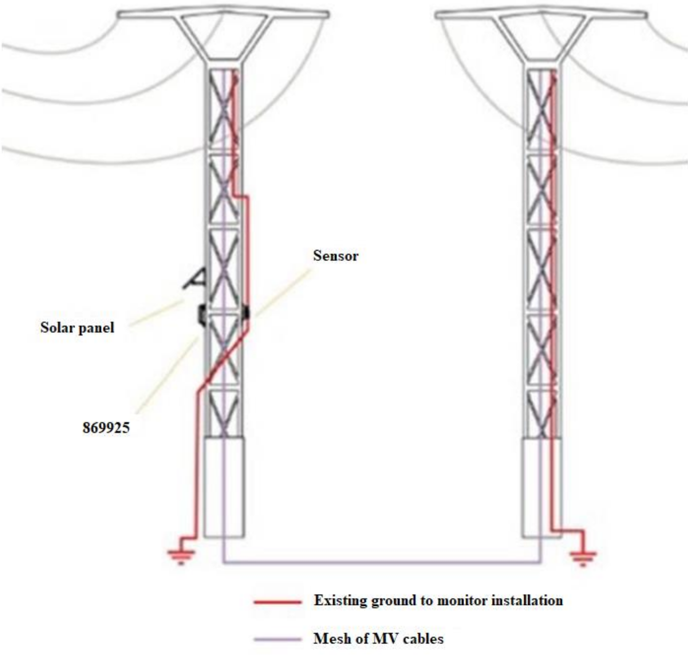

Figure 21. Measurement setup for paired ground systems.

Another example of a paired system is a final underground section that supplies a single secondary substation. The loop is formed between the support and the secondary substation, and if the network does not expand, a single device can monitor both locations. Again, it is necessary to take separate readings for both locations and then connect them through the loop. In this case, the optimal solution would be to place the indoor device in the secondary substation.

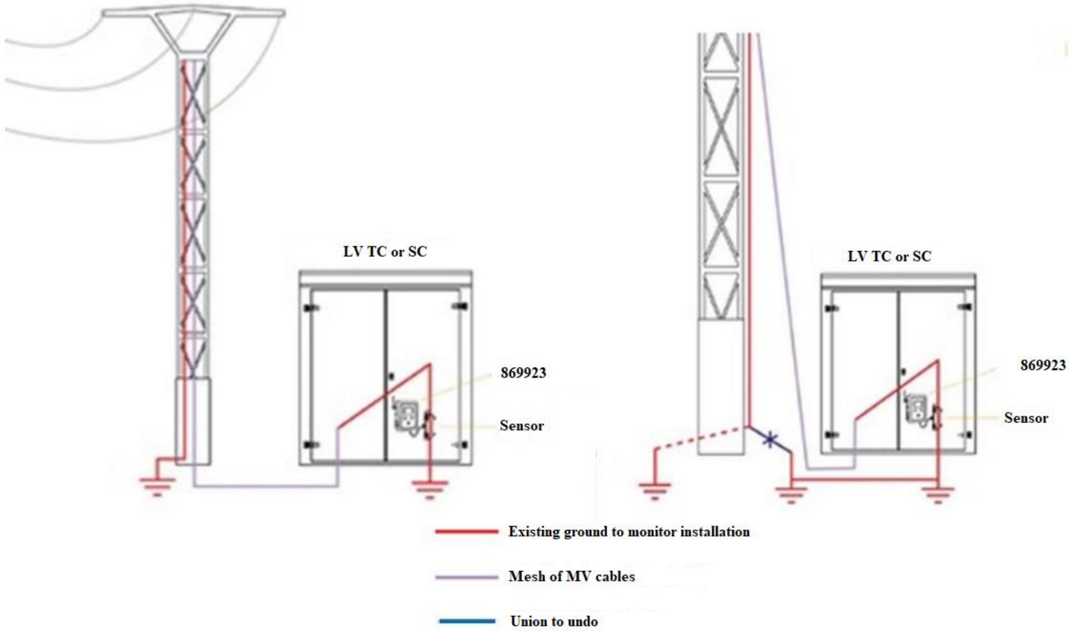

Figure 22. Schematic for monitoring a secondary substation with a paired ground system.

When dealing with a final underground section supplying a switching centre without LV (neither 230 Vac nor 48 Vdc), the optimal solution is to install the GFD device on the OUT support. If it is a double OUT feeding a switching centre, the situation does not differ from a single section, the only difference being that both locations are connected by six screens instead of three.

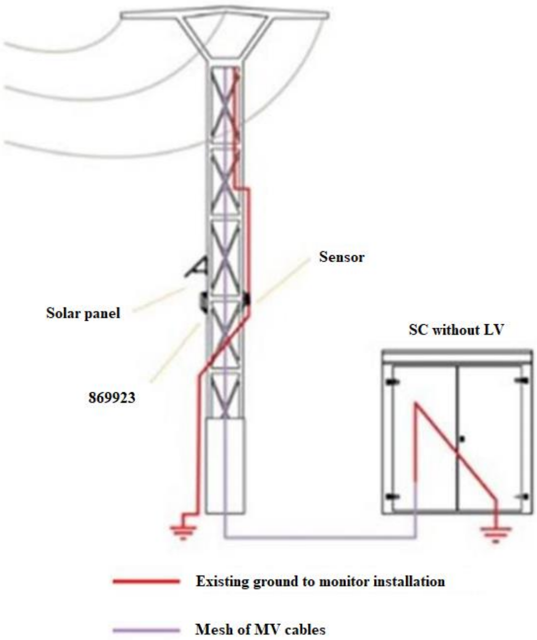

Figure 23. Configuration for monitoring a switching centre with a paired ground system.

2.5 COMMUNICATION OF GFD DEVICES WITH THE MANUFACTURER'S APPLICATION (G-DFT)

This section delves into the sophisticated communication infrastructure within the SIMCET+ system, highlighting the pivotal roles of GFD devices in interaction with the manufacturer's application *G-DFT*. The setup is engineered to manage and facilitate the flow of operational data and execute command directives robustly, ensuring comprehensive system integrity and enhancing real-time fault detection and response capabilities. The information treated in this section has been consulted from document [5]

2.5.1 SYSTEM ARCHITECTURE OVERVIEW

The SIMCET+ system architecture is designed with multiple integrated layers that span Operational Technology (OT) and Information Technology (IT) components across diverse network levels. It incorporates robust data acquisition methods, secure transmission protocols, and efficient data processing mechanisms. The key components include:

- ***GFD Devices:*** Installed at strategic network points, being crucial for monitoring ground system conditions and transmitting data using advanced wireless technologies (LTE-M, NBIoT, 2G) within a dedicated MPLS network.
- ***MQ Brokers at Levels 3 and 3.5:*** Serve as data conduits, ensuring seamless data forwarding from the GFD devices through the firewall at level 2.5 to the upper areas of the network.
- ***AAT-L3 and AAT-L4 Applications:*** Positioned at levels 3 and 4+, respectively, these applications are integral to processing incoming data for storage, subsequent analysis, and operational response facilitation.

The SIMCET+ system comprises a set of GFD devices and modules deployed across levels 2, 3, 3.5, and 4+ of the UFD infrastructure. Additionally, mobile applications and services are connected to the AAT-L4 at level 4+, aiming to fulfil intelligent monitoring functions for ground systems in the electrical network assets. The solution offers flexibility for integration, either within the IoT/Edge Hub or as an external system. The following figures illustrate the two proposed architectures providing a visual representation of the system’s structure, ensuring flexibility and adaptability in different deployment scenarios.

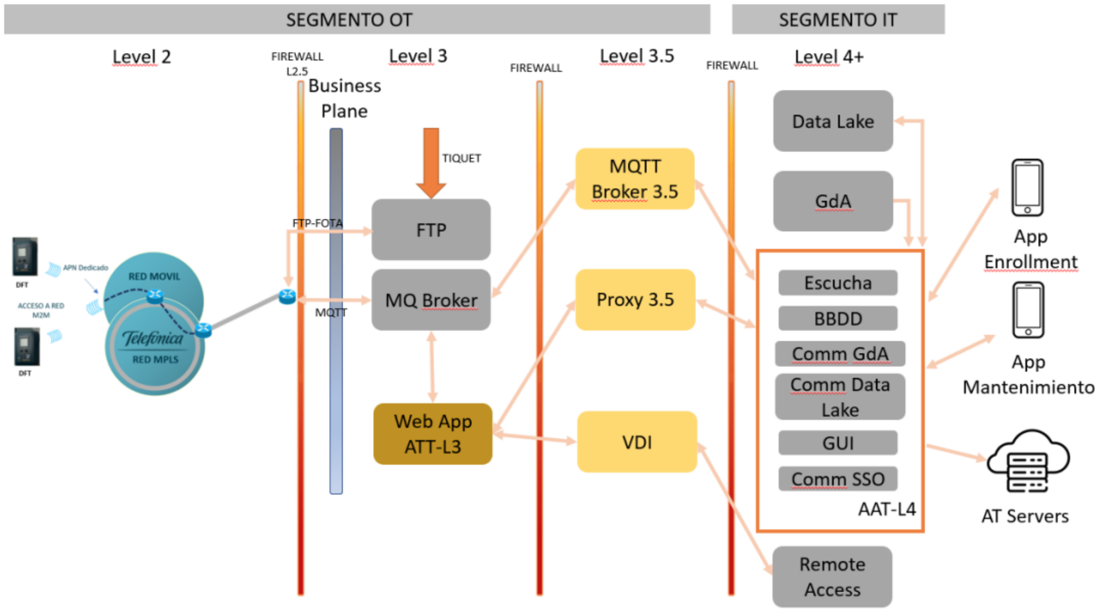

Figure 24. Architecture without integration into the IoT/Edge Hub. (Option 1) [5]

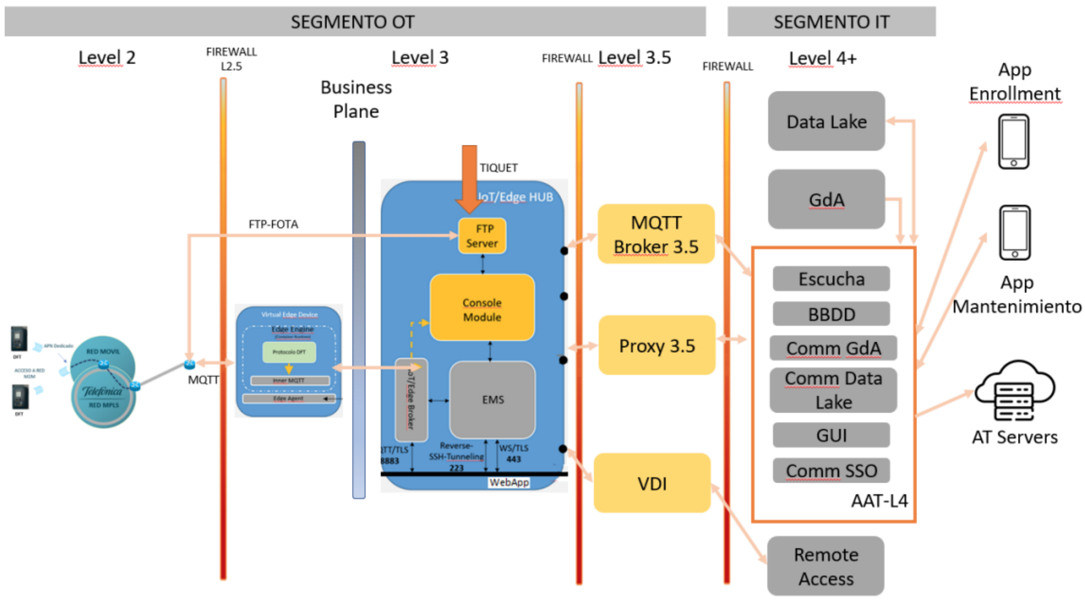

Figure 25. Architecture with integration into the IoT/Edge Hub. (Option 2) [5]

2.5.2 DATA ARCHITECTURE

The data architecture of the SIMCET+ system is a comprehensive framework designed to support the monitoring and management of ground fault conditions across various network levels. The system integrates several components that work together to ensure accurate data acquisition, secure transmission, and effective data processing and storage.

2.5.2.1 GROUND FAULT DETECTOR DEVICES

The system's foundation lies in the GFD devices installed on the assets to be monitored. These devices perform the following measurements:

- *Ground resistance.*
- *Continuity of the previous loop.*
- *Temperature.*
- *GPIO port reading.*
- *Coverage level.*
- *Equipment status.*
- *Battery voltage.*
- *Input voltage.*

2.5.2.2 AAT-L3 APPLICATION

The AAT-L3 application, used in the absence of an IoT/Edge Hub (Option 1), is installed at level 3 of the OT segment within the UFD infrastructure. This application has the following key components:

1. ***Database (BBDD):*** Utilizes MySQL for storing tables related to asset registrations, including serial numbers of GFD devices among other data.
2. ***Listening Service:*** Receives bindings between asset registrations and GFD identifiers sent from AAT-L4.
3. ***Command Service:*** Sends functional and maintenance commands to GFDs via the MQ broker.
4. ***User Management:*** Manages access controls, permissions, roles, and password requirements.
5. ***Activity Logging:*** Maintains logs of activities generated within the application.

To function correctly, AAT-L3 requires the installation of specific elements at level 3 of the OT segment. These include an FTP server, which hosts firmware update files for GFD devices, and an MQ broker, which centralizes data from GFD measurements and facilitates the transmission of commands to GFDs from the WebApp.

When integrating with the IoT/Edge Hub (Option 2), this application is embedded within the IoT/Edge Hub system, streamlining operations, and improving data management efficiency.

2.5.2.3 AAT-L4 APPLICATION

Installed at level 4+ of the IT segment within the UFD infrastructure, the AAT-L4 application includes:

1. ***Listening Service:*** Receives data from GFDs via the MQ broker at level 3.5.
2. ***Data Storage:*** Utilizes MySQL databases to store information received by the listening services.
3. ***GdA Communication***: Manages the registration of new GFD assets.
4. ***Data Lake Communication:*** Retrieves essential data such as asset registrations, GIS information, hierarchies, and other necessary data for system functionality.
5. ***User Interface:*** Provides visualization and exploitation of data from GFD devices.
6. ***User Management:*** Interfaces with the SSO module for user authentication.
7. ***Gateway to AT Servers:*** Sends encrypted information to AT servers for secure handling and storage.

2.5.2.4 EQUIPMENT REGISTRATION APPLICATION

This application is installed on the mobile devices of installation brigades, allowing for the linking of the GFD device identifier with the asset registration where it is installed. It also enables the entry of an initial measurement of ground resistance values.

2.5.2.5 MAINTENANCE APPLICATION

The maintenance application provides continuous monitoring of the status of AAT-L4 services, ensuring operational integrity and immediate issue resolution.

In conclusion, the data architecture of SIMCET+ is designed to support the seamless flow of data across various network levels. It ensures secure, efficient, and reliable data handling from the point of acquisition by GFD devices to the central processing locations. This architecture enhances the system's scalability, and real-time operational capabilities, making it a robust solution for fault detection and management.

2.5.3 COMMUNICATION PROTOCOLS

Telecommunication protocols play a crucial role in this project, ensuring efficient, secure, and reliable communication between the GFDs and the different data platforms of UFD. The main protocols used, their purposes, and specific use cases are detailed below.

2.5.3.1 MQTT PROTOCOL

The Message Queuing Telemetry Transport (MQTT) protocol is fundamental in the communication architecture of the SIMCET+ system. Designed for lightweight, publish-subscribe messaging, MQTT is ideal for IoT applications due to its efficiency in bandwidth and energy usage. In this system, MQTT is used extensively for the transmission of various data types and commands from the devices.

The SIMCET+ system utilises the MQTT protocol to manage the transmission of both periodic and event data. Normally it will be 24 hourly measurements sent daily or immediate fault detection events. This data is transmitted through a dedicated APN within the MPLS network.

For enhanced security, both periodic and event data are encrypted during transmission. Following the same pathway—through the dedicated APN, firewall at level 2.5, and MQTT brokers—the encrypted data reach the AT listening services at level 4+. From there, the data are forwarded securely to external AT servers via the Internet, ensuring safe data handling and storage.

This streamlined communication process ensures efficient, reliable, and secure transmission of data within the SIMCET+ system, enabling rapid and effective responses to detected incidents and comprehensive data management.

This protocol is also employed to send maintenance and functional commands to the GFDs from the WebApp ATT-L3 through the MQTT Broker, transmitted over the MPLS network. This ensures reliable and controlled communication, allowing for efficient remote management of the GFDs. While MQTT is used to send the command to initiate the firmware update, the actual file transfer for the firmware update is handled by FTP.

Additionally, the devices can receive various functional commands via the MQTT protocol to enhance their operational capabilities. These commands include initiating an immediate measurement and transmission of ground resistance, sending any pending files, and providing the measured level of electrical noise (in mA) in the surrounding environment. The GFDs also support the *Hub&Spoke* function, where the device listens for 30 seconds unless its IP is identified in the command to perform a current injection. This range of commands enables comprehensive and responsive remote management, ensuring the assets are always accurately monitored and maintained.

2.5.3.2 FTP PROTOCOL

The File Transfer Protocol (FTP) is used in the SIMCET+ system specifically to manage firmware updates for the devices. This protocol ensures that GFDs remain updated with the latest functionalities and security patches, which is crucial for system reliability and security.

The firmware update process involves several steps to ensure secure and efficient updates:

- ***Initiation and File Upload:*** Firmware updates begin with the opening of a ticket to the operations team, who then upload the encrypted firmware files to the FTP server located at level 3.
- ***Command Emission via MQTT*:** From the WebApp, a maintenance command is sent to the GFDs using MQTT, instructing them to update their firmware and specifying the file to download from the FTP server.
- ***FTP Session and File Download:*** The GFDs that receive this command initiate an FTP session to download the specified firmware file from the level 3 FTP server. This process uses the dedicated APN within the MPLS network, ensuring secure and isolated data transmission.

- ***Verification and Installation:*** After downloading, the GFDs decrypt the firmware file, verify its integrity, and proceed with installation if the file is validated. This controlled process includes encryption (FTPS) to protect the confidentiality and integrity of the firmware files during transmission.
- ***Rollback Mechanism:*** Additionally, the system includes a rollback mechanism that allows reverting to the previous firmware version if any issues are encountered during the new installation, ensuring the operational continuity of the devices.

In conclusion, MQTT is used for sending commands, including those initiating firmware updates, while FTP is used for the actual transfer of firmware files. This combined use of MQTT for command transmission and FTP for secure firmware updates ensures that the SIMCET+ system operates efficiently, securely, and reliably across its various layers.

2.5.4 ACCESS ARCHITECTURE

The SIMCET+ system's access architecture is designed to ensure secure and efficient access management for users interacting with the system's operational and informational segments. Utilizing a robust Virtual Desktop Infrastructure (VDI), the system enforces strict authentication and authorization protocols to secure sensitive operations and data access across different system configurations.

2.5.4.1 USER ROLES AND PERMISSIONS

The system categorizes users into specific roles, each one have tailored permissions to perform certain functions within the system:

- ***Administrator:*** Full control over system settings, user management, and critical operational functions within the AAT-L3 application.
- ***Functional User:*** Authorized to execute operational commands that affect the configuration and testing of the GFD devices.
- ***Maintenance User:*** Has the authority to initiate firmware updates and maintenance checks, ensuring the devices are up to date and functioning optimally.

2.5.4.2 AUTHENTICATION MECHANISM

In the SIMCET+ system, remote users gain access through a VDI provided by UFD. This VDI environment uses authentication protocols to verify user identities, ensuring that only authorized personnel can access system resources. User credentials are managed centrally by UFD, providing a secure and controlled entry point into the system.

- ***Option 1:*** Architecture without integration into the IoT/Edge Hub:

In this configuration, remote users access the AAT-L3 application directly through the VDI. The login process requires users to authenticate with specific usernames and passwords, which ensures that each user's access is restricted to functionalities pertinent to their role and permissions.

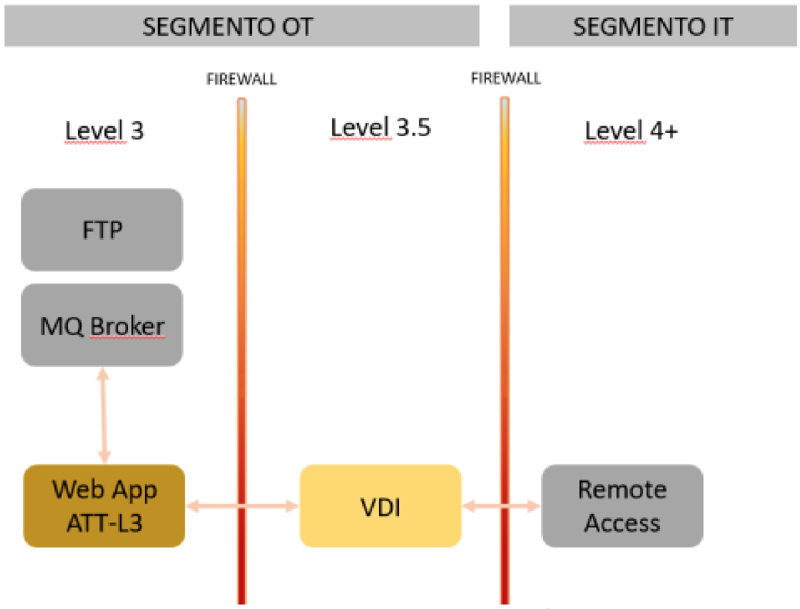

Figure 26. Access to ATT-L3 in Option 1. [5]

- ***Option 2:*** Architecture with integration into the IoT/Edge Hub:

When integrated with the IoT/EDGE Hub, the VDI facilitates access to the Web App hosted on the Hub. The IoT/EDGE Hub handles authentication, leveraging modern security frameworks to streamline access controls and integrate with the overall system's security strategies.

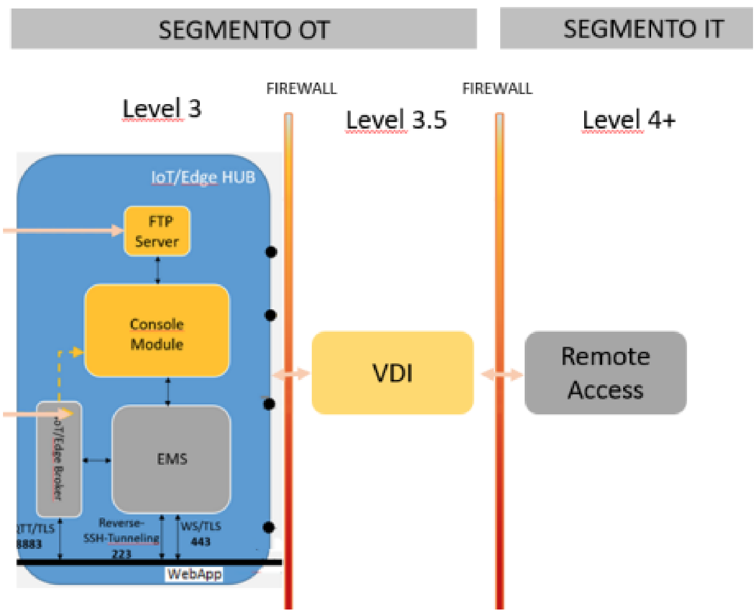

Figure 27. Access to ATT-L3 in Option 2.[5]

2.5.4.3 ACCESS CONTROL AND SECURITY POLICIES

Access to critical applications, either AAT-L3 or the Web App on the IoT/EDGE Hub, requires prior authentication through the UFD's corporate VDI. This layer of security is enhanced by Nartugy's authentication mechanisms, which verify user credentials before granting access.

The system supports a limited number of concurrent users (maximum of three) and allows up to five authorized users to maintain optimal performance and security.

By implementing strict access controls, detailed user role management, and robust authentication protocols, the SIMCET+ system's access architecture ensures that the system is secure against unauthorized access while facilitating efficient user interactions. This approach not only protects sensitive operational data but also aligns with best practices for critical infrastructure security.

2.5.5 COMMUNICATION ARCHITECTURE

The data reception of the SIMCET+ system is confined within the OT segment of UFD, completely separated from the IT segment. In the OT segment (Level 3, IEC-62443), communication with the GFDs occurs either through AAT-L3 (Option 1) or via the IoT/EDGE Hub (Option 2) using the established network infrastructure designed for this purpose. Elements housed at Level 3 are separated from those at Level 3.5 (IEC-62443) OT by firewalls. The existing OT-IT boundary equipment in UFD separates Levels 3.5 and 4.

Maintenance operations on modules at Level 3 (both Option 1 and Option 2) are conducted through established channels, which must be accessible to users via VDI. This structured separation and secure communication framework ensure robust data integrity and security across the SIMCET+ system architecture.

2.5.5.1 ASSET CONFIGURATION

The process carried out for the configuration of the devices is the same for the two proposed configuration options of the SIMCET+ system. In both cases, initially a command will be sent from Remote Access to the devices and secondly the devices will access the FTP to update the firmware. The specific diagrams for both options can be seen below:

- ***Option 1:*** Architecture without integration into the IoT/Edge Hub:

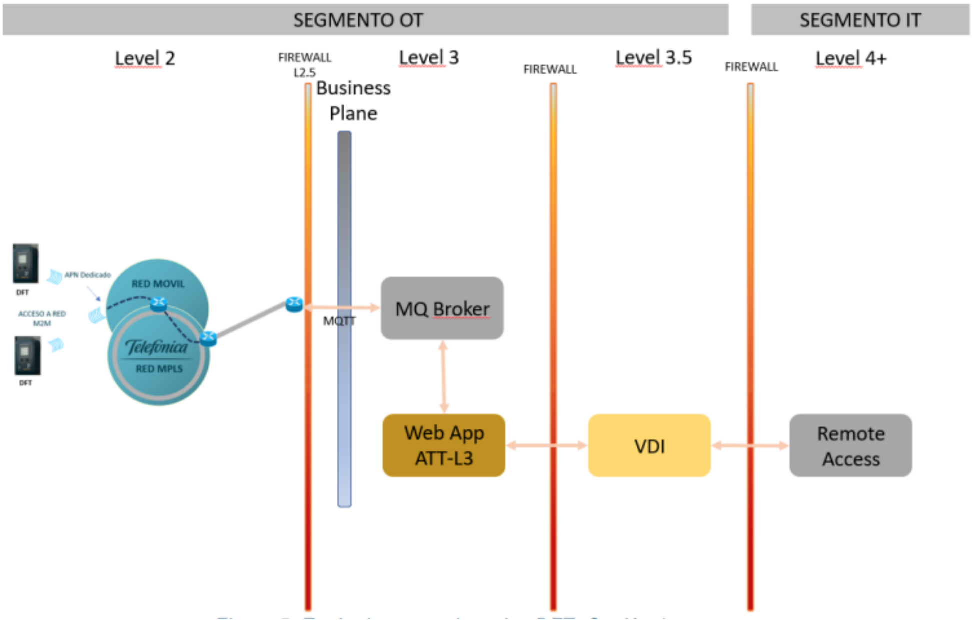

Figure 28. Sending commands to the GFDs devices from the remote access. (Option 1) [5]

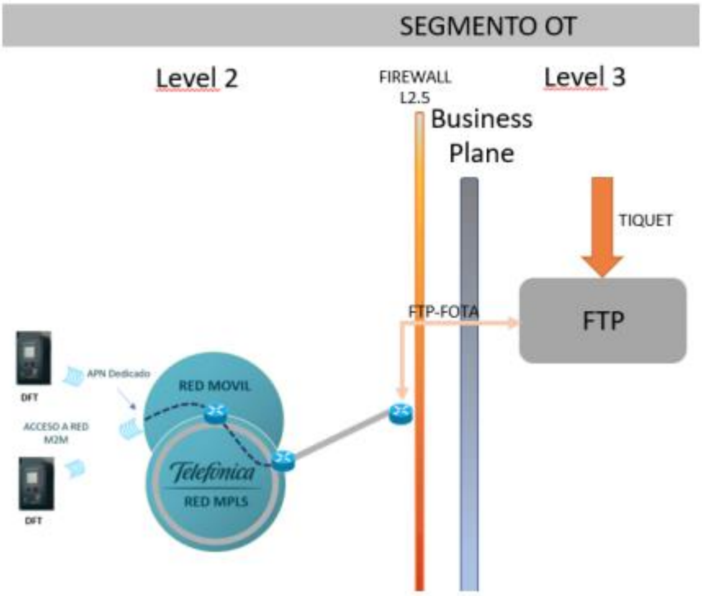

Figure 29.GFD access to the firmware update files in the FTP (Option 1). [5]

- ***Option 2:*** Architecture with integration into the IoT/Edge Hub:

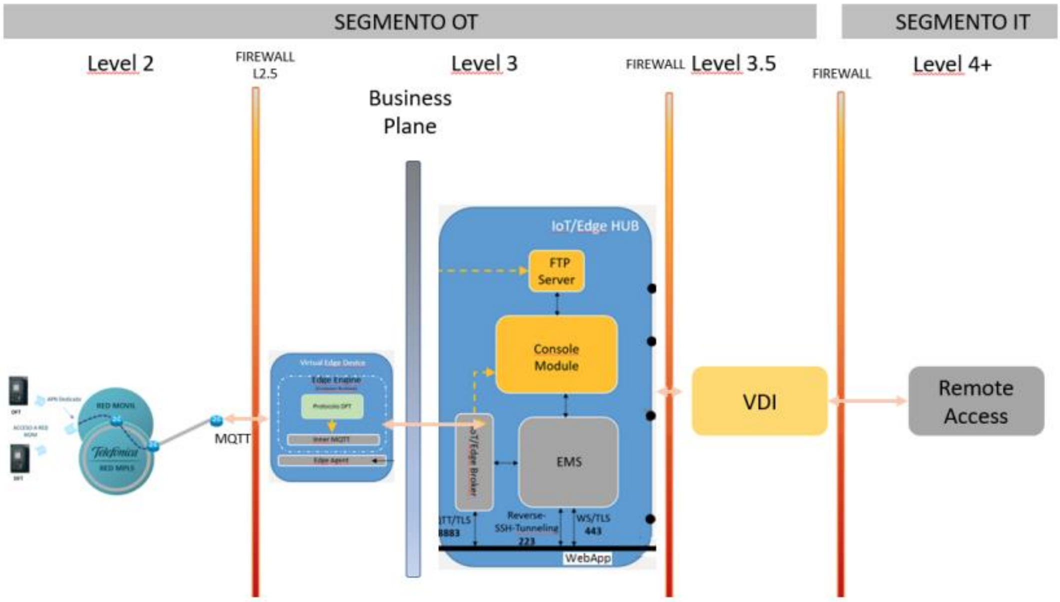

Figure 30. Sending commands to the GFDs devices from the remote access. (Option 2). [5]

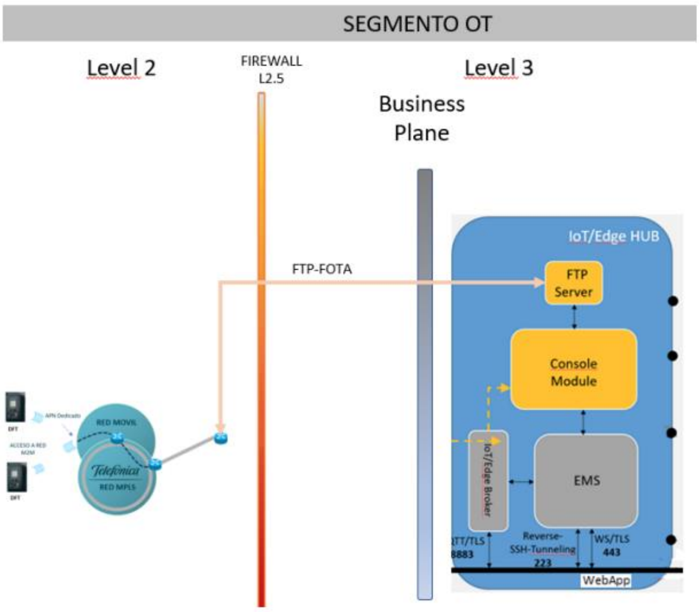

Figure 31. GFD access to the firmware update files in the FTP (Option 2). [5]

2.5.5.2 PERIODIC MEASURES AND EVENTS

This subsection outlines the methodologies employed for the systematic collection and transmission of periodic measures and event data from field devices to IT-level applications. In both structure options, data is also available when is required by users or in response to specific events, adhering to security protocols and maintaining high data integrity. The use of MQTT protocol in both options ensures efficient, reliable message handling across network layers.

- ***Option 1:*** Architecture without integration into the IoT/Edge Hub:

As showed in the following figure, the data is routed from the GFDs (Level 2) through an MQTT Broker at Level 3.5, avoiding the Level 3 business plane for direct transmission to IT services. The IT infrastructure supports various components such as a data lake and GUI, which facilitate comprehensive data analysis and visualization. This setup is primed for efficiency, ensuring real-time data availability upon specific user requests or in the event of an incident that necessitates immediate attention.

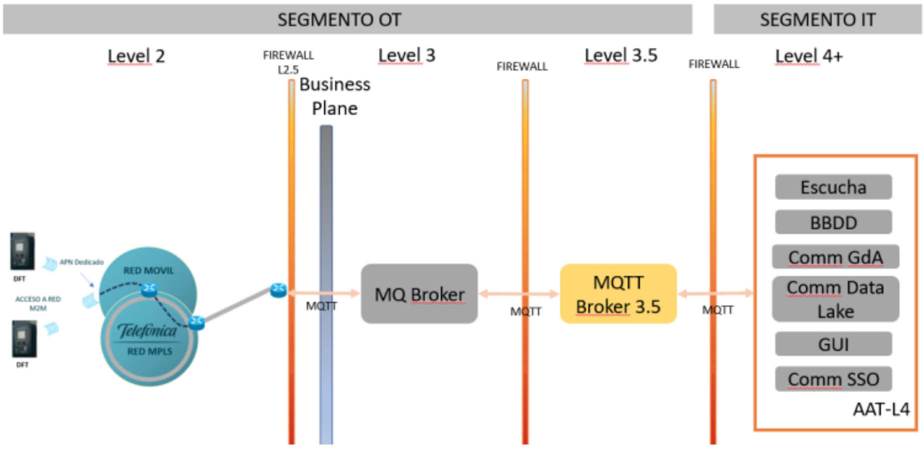

Figure 32. Sending measurements and periodic events. (Option 1) [5]

- ***Option 2:*** Architecture with integration into the IoT/Edge Hub:

Alternatively, as shown in the *Figure 33*, data is transmitted through the internal IoT/data hub at Level 3, incorporating an FTP server and a console module. This hub pre-processes the data before forwarding it to the MQTT Broker at Level 3.5. This method not only reinforces security with additional firewall layers but also allows preliminary data assessment within the OT segment, thereby reducing the computational demand on IT systems and improving response times for real-time data requests.

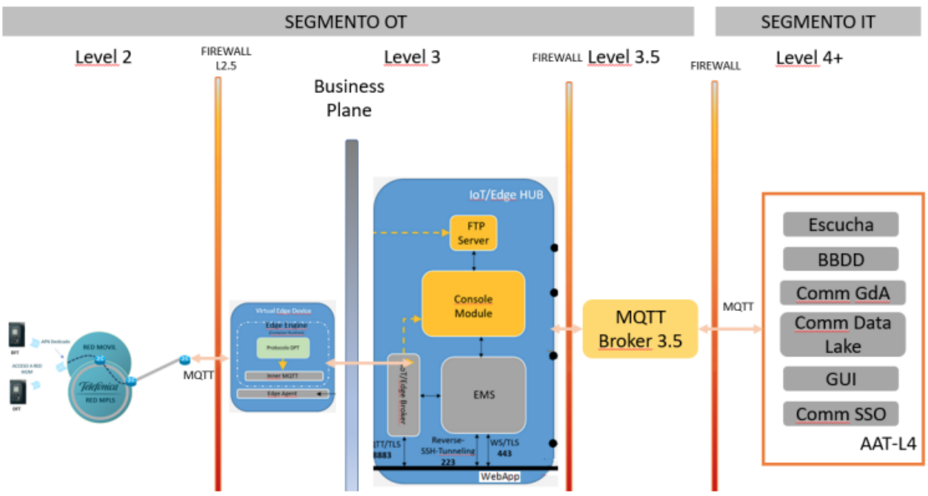

Figure 33. Sending measurements and periodic events. (Option 2) [5]

2.5.5.3 CONTROL COMMUNICATIONS

This subsection outlines the comprehensive control communication protocols employed to manage interactions between field devices and IT-level applications across the system architecture. The methods highlighted ensure robust, secure, and efficient data handling, crucial for system integrity and responsiveness.

Enrolment App

Device enrolment and integration is the initial step in control communications, and it is done using a specific application (App Enrolment). This mobile app assigns a unique identifier to each device, correlating it with an existing entry in the IT database hosted on AAT-L4. This process ensures that each device is correctly identified and tracked across the system, facilitating efficient data synchronization and management. In scenarios where identifiers already exist, the app links new device data to the existing entries, thereby maintaining up-to-date records.

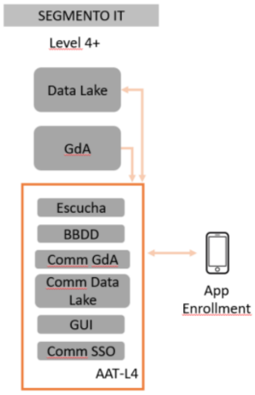

Figure 34. App Enrolment.

Maintenance App

The maintenance management is conducted through an dedicated to monitoring and alerting service conditions at AAT-L4. This application is pivotal in dispatching real-time alerts and updates for potential issues, enabling proactive maintenance measures. By monitoring system performance and predicting possible failures, the app helps to minimize downtime and extend the operational life of equipment.

Figure 35. Maintenance App.

Secure Data Transmission

Control communications also involve the secure transmission of encrypted data from the field devices to AAT-level servers. This encryption ensures that all transmitted data remains protected against interception or unauthorized access, maintaining the privacy and integrity of sensitive operational data. The secure flow from field devices through designated communication channels to IT servers is critical for protecting against data breaches.

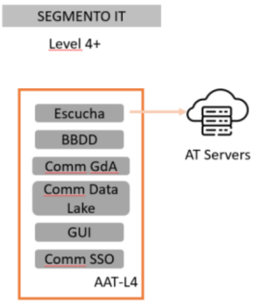

Figure 36. Secure Data Transmission.

Data Flow for Analysis and Visualization

Finally, the management of data flow for analysis and visualization tools is crucial. Data collected from various levels is processed and transmitted securely to specialized applications designed for system analysis and visualization at AT-L4. These tools utilize the data to perform comprehensive analyses, supporting decision-making processes and suggesting system improvements based on real-time and historical data insights.

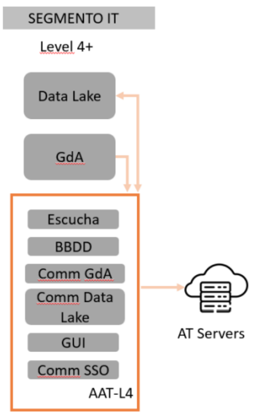

Figure 37. Data flow for analysis and visualization.

By leveraging advanced communication and data management technologies, the system ensures that all control communications are conducted efficiently, securely, and in a manner that supports ongoing operational excellence.

2.5.6 SECURITY IN COMMUNICATIONS

To ensure the security of communications within the system, several comprehensive security measures are implemented across the SIMCET+ architecture. A key strategy is advanced network segmentation, where the network is divided into multiple levels (2, 3, 3.5, and 4+), each fortified with firewalls that regulate and monitor the flow of data. This segmentation prevents unauthorized access and ensures that each network segment is adequately protected.

Robust data encryption is also employed to safeguard data during transit. For firmware updates, FTP transmissions are used, and these FTP sessions are encrypted (FTPS) to protect the confidentiality and integrity of the files during transmission. This ensures that all firmware files are securely transferred and installed without risk of interception or tampering.

In the Demilitarized Zone (DMZ), several critical components are deployed to manage secure communications between various parts of the system. The EMQX broker, an open-source broker, manages messaging between the IoT/EDGE Hub and AAT-L4. It supports TLS/SSL and is compatible with X.509 certificates, providing a secure conduit for communication. Additionally, to prevent direct access from higher levels, remote access to the system must be conducted through the Virtual Desktop Infrastructure (VDI) services deployed in the DMZ at Level 3.5. This setup protects remote access from untrusted networks.

Furthermore, a reverse proxy component manages communication between level 3 and level 4+ applications. In addition to performing basic reverse proxy functions at level 3.5, it provides additional security features such as access limitation to prevent DoS attacks, custom security headers (against XSS, click-jacking, code injection, etc.), and ensures secure connections with a TLS protocol.

These measures collectively ensure that communications within the system are secure, and that critical data is protected against unauthorized access, maintaining the integrity and confidentiality of the information transmitted. By implementing these security protocols and measures, the SIMCET+ system ensures robust protection for data communications, safeguarding against unauthorized access and data breaches.

2.5.7 INTEGRATION WITH IOT/EDGE HUB

The integration of the GFDs with the IoT/Edge Hub allows for centralised communication and improved management of devices and data transmission within the system. This integration facilitates the centralisation of sending maintenance and functional commands from the WebApp to the GFD, optimising the operation and maintenance of devices distributed throughout the grid.

Both periodic and event data are transmitted securely and efficiently to the IoT/Edge Hub using the MQTT protocol. The IoT/Edge Hub acts as a central node, consolidating data from various GFDs, processing it, and forwarding it to central monitoring systems for analysis and action. This centralisation not only reduces the complexity of device communication but also enhances the system's scalability and reliability, ensuring consistent and accurate data and command transmission.

3 PROJECT DEVELOPMENT

3.1 GFD MANAGEMENT APPLICATION (G-DFT)

The Technological Department of UFD has developed the GFD Management Application (*G-DFT*), a sophisticated tool designed to enhance the management and monitoring of the electrical GFD infrastructure. This application plays a critical role in ensuring that electrical systems operate efficiently and safely by detecting and addressing faults that could lead to safety hazards or operational disruptions.

However, the current user manual for the GFD Management Application is outdated, which presents challenges in effectively analysing the data collected by the GFDs. Therefore, there is a need to create an updated and comprehensive user manual that will equip users with the necessary knowledge to fully utilize the application's capabilities. This manual will serve as a resource for various user types, each with specific roles and tools designed to facilitate precise management of electrical faults. The following sections will introduce the primary functionalities for each user type, along with an explanation of how these roles are managed to ensure the correct operation of the Application *G-DFT*

3.1.1 COR USER INTERFACE

The COR (Network Operations Centre) user is primarily responsible for identifying and locating faults within the electrical network. The COR user interface interacts with the system through a main screen that provides access to various tools and information relevant to fault detection. The key functionalities available to the COR user include:

- ***Device Search:*** This feature allows users to locate specific devices within the network using their registration numbers. This is particularly useful for quickly identifying and addressing faults in both single-phase and multi-phase electrical systems.
- ***Fault Reset:*** Users can reset faults by entering information about the affected feeders. This function helps in clearing faults once they have been addressed, enabling the system to resume normal operation.
- ***Filter Application:*** This tool allows users to filter devices based on their location and current operational status. For example, users can view devices that are functioning normally (OK) or those that have an open resistance issue.
- ***Incident Management:*** Users can view all installed GFD devices across the network, monitor their status in real-time, and quickly respond to any detected failures. This feature ensures timely intervention to minimize potential disruptions.

3.1.1.1 MAIN SCREEN

The main screen for the COR user provides access to information related to fault location within the network, monitoring, and characterisation of currents in the ground conductor, and associated tools. This main screen can be seen below:

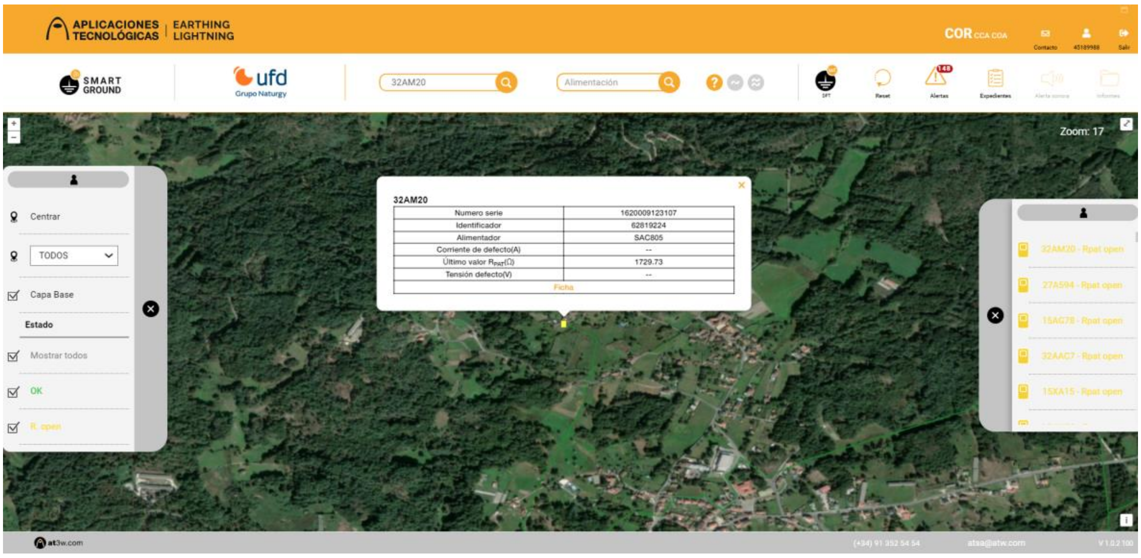

Figure 38.Main Screen using COR user interface.

Using this interface devices can be searched by their registration number of the monitored asset using the search bar located at the top. To perform a search, feeders must be entered separated by ";" and the type of fault, either single-phase or multi-phase, must be selected.

Figure 39. Search Bar for the COR User.

On the *"Main Screen"* users can also reset a fault. To do this, the user must enter the feeders in the same format as before and click the following button:

Figure 40. Reset Button

Filters

On the left side of the "Main Screen," there are the following filters that can be activated or deactivated to control the display of GFDs based on their status:

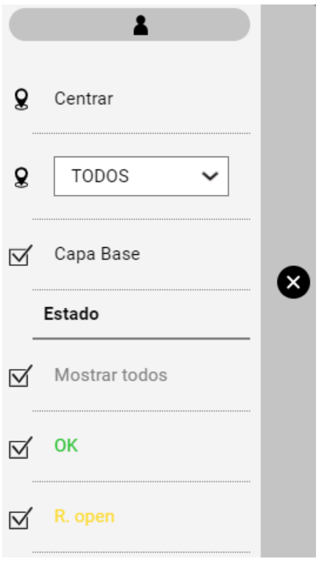

Figure 41. Applicable filters in COR user interface.

In the COR user interface, filtering can be done based on both location and the status of devices, which are categorized into two states:

- ***OK:*** The device is functioning correctly.
- ***R.open:*** Loop resistance > 400 ohms.

On the right side of the "Main Screen," the installed GFD devices within the network are displayed. The registration numbers are shown in the colour corresponding to their current state, and only those devices with statuses selected in the filters are visible. An example is shown below:

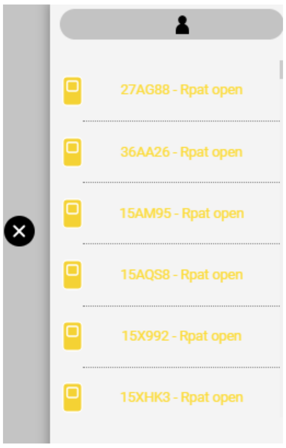

Figure 42. Registration number coloured with the last registered state.

3.1.1.2 DEVICE PROFILE SCREEN

Once a device is selected on the "Main Screen," a pop-up window appears, as shown in the example below:

32AM20

Numero serie	1620009123107
Identificador	62819224
Alimentador	SAC805
Corriente de defecto(A)	--
Último valor $R_{PAT}(\Omega)$	1729.73
Tensión defecto(V)	--
Ficha	

Figure 43. Pop-up for GFD 32AM20.

By clicking on the *"Ficha"* button, you can access the historical data graphs in frequency domain for the selected GFD device, as shown below:

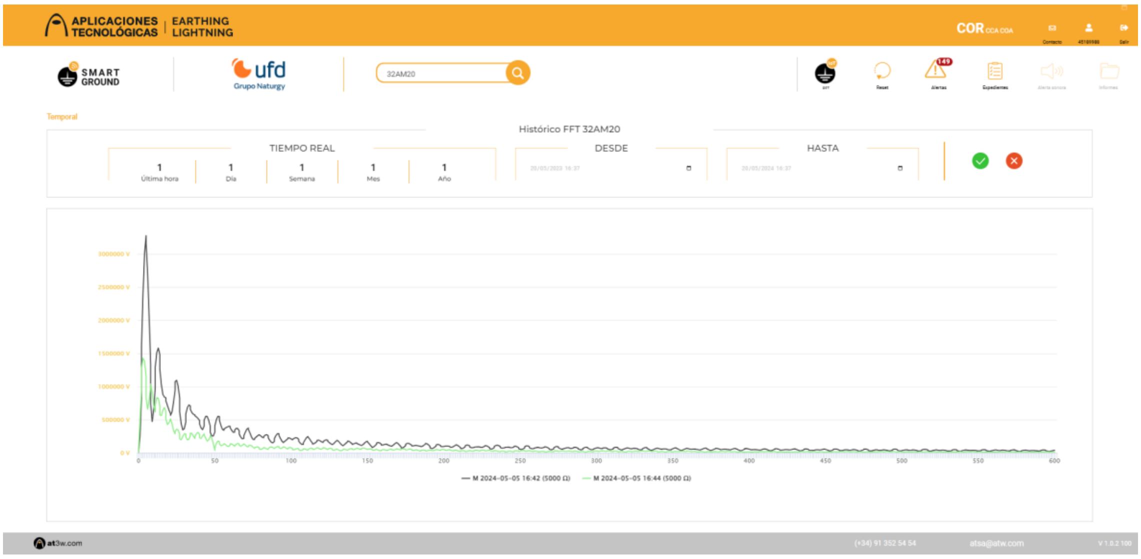

Figure 44. Frequency domain graph of the device 32AM20 using COR user interface.

There is also the option to view this historical data in time domain by clicking on the word *"temporal"* located in the top left corner, resulting in the following graph:

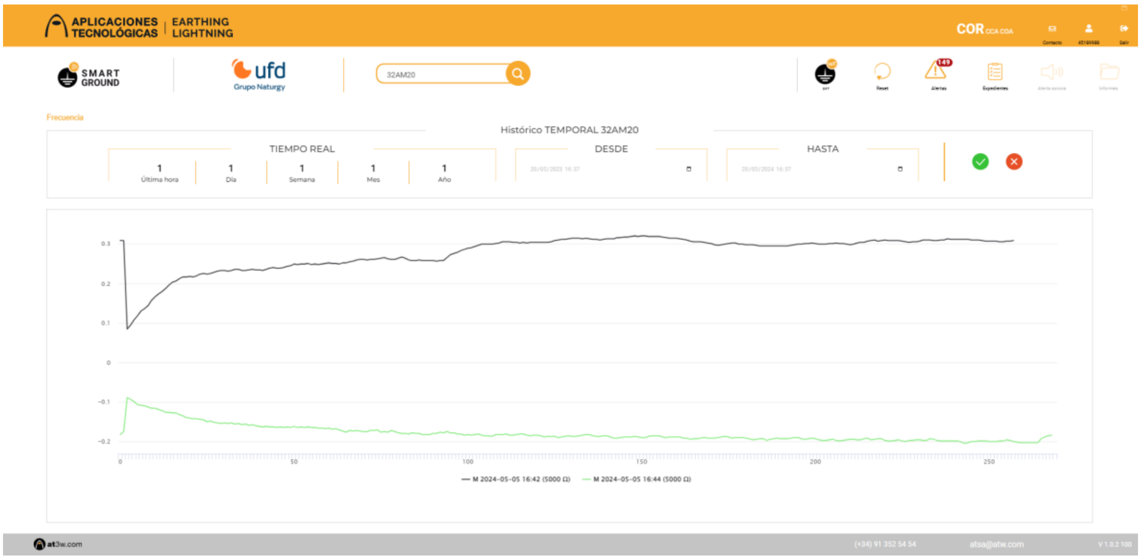

Figure 45. Time domain graph in Device Profile Screen of the device 32AM20 using COR user interface.

3.1.1.1 ALERTS SCREEN

To access to the Alerts Screen there is the following button located on the right upper corner:

Figure 46. Alert Screen button.

Using the top toolbar concrete assets can be selected to analyse (separated using ";"), then the dates range, and a fault button can limit the data to the registered faulted grounds. This screen is shown below and has some filters that can be applicable:

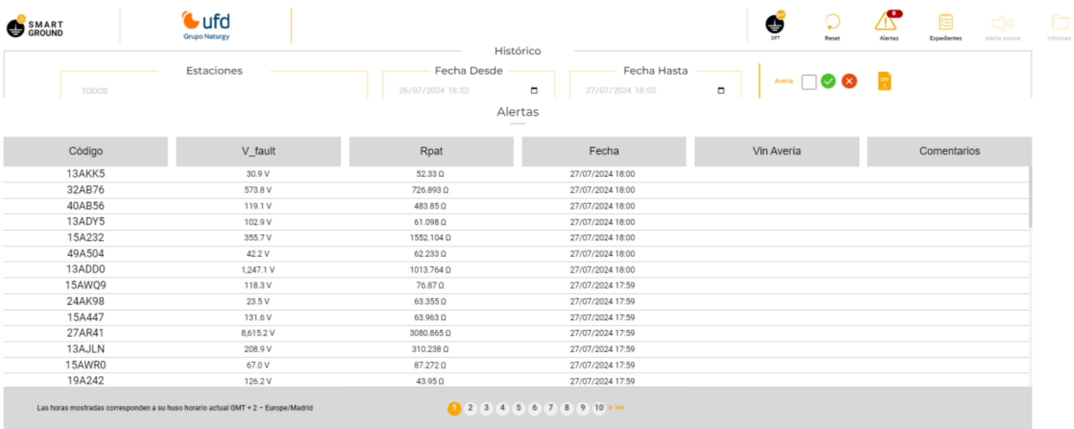

Figure 47. Alerts Screen in COR user interface.

In last place, this data table can be downloaded as a CSV file using the following button:

Figure 48.Button to download the data shown in the Alerts Screes in a CSV File.

3.1.1.2 FILES SCREEN

The Files Screen is one of the most important screens and has the data that will be used later in the registration of GFD devices in other interfaces inside UFD. This screen can be accessed by clicking in the following button located on the right upper corner in all three user interfaces (COR, CCA, COA):

Figure 49. Button to access the Files Screen.

Like in other screens, there is a search toolbar in the upper part. Devices can be search by the registration number of the monitored asset, the file number, or the operational area. This screen has all the registered GFD devices in the *G-DFT* app and can be filter using a date range of the installation dates. The visualization of this screen is shown below:

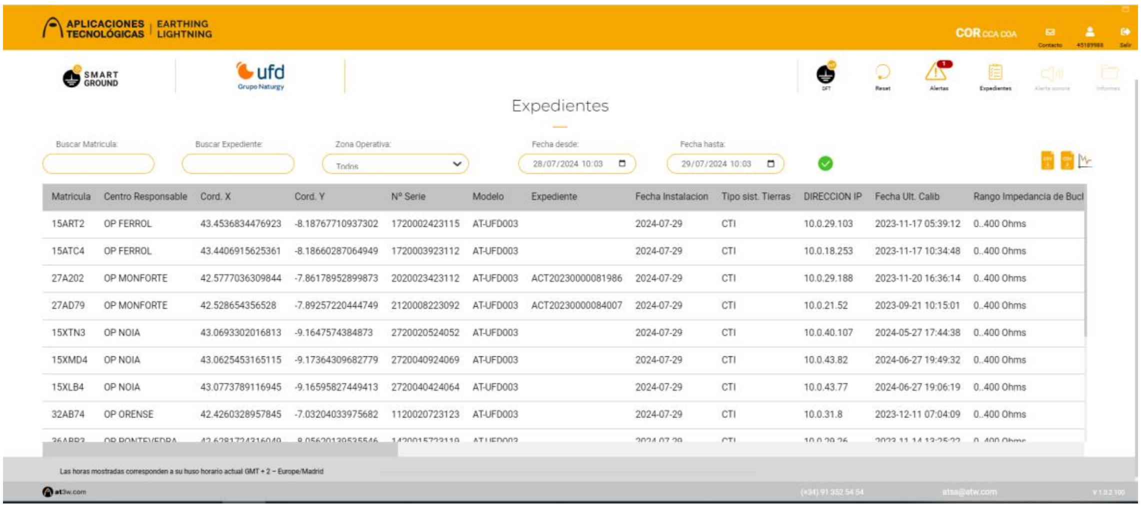

Figure 50. Files Screen visualized in any user interface.

3.1.2 CCA USER INTERFACE

The CCA (Asset Control Centre) user specializes in the measurement of ground resistance and continuity, which are critical for ensuring the safety and effectiveness of grounding systems. This user also handles system alerts, historical data, and performs various analytical tasks. The main tools available to the CCA user interface include:

- ***Device Search:*** Like the COR user, the CCA user can search for devices by their registration numbers. This function aids in locating specific devices for measurement and analysis.
- ***Data Download:*** This feature allows users to download data in CSV format, which includes regulatory values for ground resistance. This data is essential for compliance with safety standards and regulations and will be used later integrating it into UFD's infrastructure.
- ***Filter Application:*** Users can filter devices based on their location and operational status, such as whether they are in a normal state, in an alert condition, or in alarm status. This helps in managing devices more effectively.
- ***Historical Data Visualization:*** This tool provides access to charts and tables that show how ground resistance has changed over time. Detailed analysis of this historical data helps in understanding long-term trends and making informed decisions.
- ***Incident Management:*** Users can view and address incidents related to ground resistance, which improves the system's ability to respond to and resolve issues promptly.

3.1.2.1 MAIN SCREEN

Below is the main screen for the CCA user, which provides access to functions for measuring ground resistance and continuity, as well as alerts, historical data, and other analytical treatments related to ground resistance measurements.

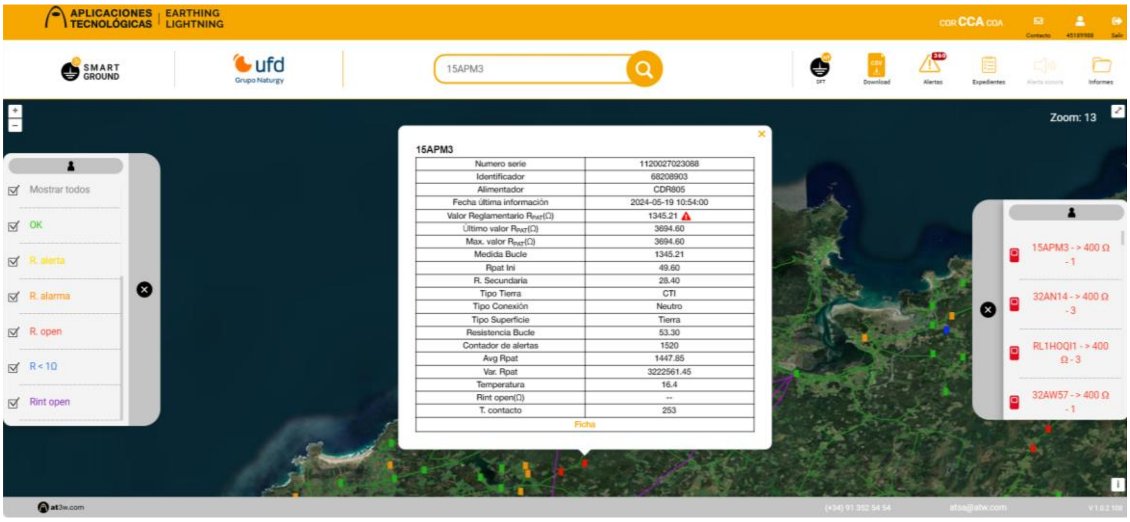

Figure 51. Main Screen using CCA user interface.

From the "Main Screen" using the CCA user, devices can be searched by their registration number using the search bar located at the top:

Figure 52. Search Bar for the CCA User.

In addition to the functionalities described below, a CSV file containing the regulatory values of the ground resistances for the registered secondary substations can be downloaded by clicking on the following icon located in the top right corner:

Figure 53. Button to download grounding values in a CSV File.

The downloaded CSV File will be used to transmit some values of interest to the higher-level interfaces within UFD. This File includes the following values for each device: registration of the monitored asset:

- *Registration number of the monitored asset.*
- *Reglementary grounding resistance.*
- *Maximum grounding resistance.*
- *Average grounding resistance.*
- *Var* R_{PAT}
- *Meter Number.*
- *Temperature.*
- *Latitude.*

- *Longitude.*
- *Date of last information.*

Filters

On the left side of the "Main Screen," there are filters that can be activated or deactivated to control the display of GFDs based on their status.

Figure 54. Applicable filters in CCA user interface.

In the CCA user interface, devices can be filtered based on both location and their operational status. Devices can have the six states that can be seen in *Figure 54*, but these states are being changed by the development team. The $R_{int\ open}$ indicates that the ground resistance is higher than 400 ohms.

On the right side of the "Main Screen," the installed GFD devices within the network are displayed with their registration number. These registration numbers are shown in the colour corresponding to their current status, and only those devices with the statuses selected in the filters are visible. An example is shown below:

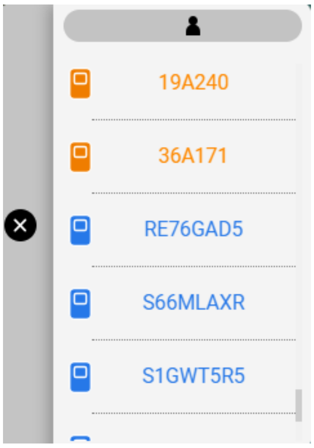

Figure 55. Registration numbers coloured according to their recorded status.

3.1.2.1 DEVICE PROFILE SCREEN

Once a device is selected on the "Main Screen," a pop-up appears as shown in the example below:

15APM3

Numero serie	1120027023088
Identificador	68208903
Alimentador	CDR805
Fecha última información	2024-05-19 11:54:00
Valor Reglamentario R_{PAT}(Ω)	1345.21 ⚠
Último valor R_{PAT}(Ω)	3694.60
Max. valor R_{PAT}(Ω)	3694.60
Medida Bucle	1345.21
Rpat Ini	49.60
R. Secundaria	28.40
Tipo Tierra	CTI
Tipo Conexión	Neutro
Tipo Superficie	Tierra
Resistencia Bucle	53.30
Contador de alertas	1520
Avg Rpat	1447.85
Var. Rpat	3222561.45
Temperatura	16.3
Rint open(Ω)	--
T. contacto	253
Ficha	

Figure 56.Pop-up for Device 15APM3.

By clicking on the *"Ficha"* button, you can access the historical data graphs of the ground resistance for the selected device to analyse the trends, as shown below:

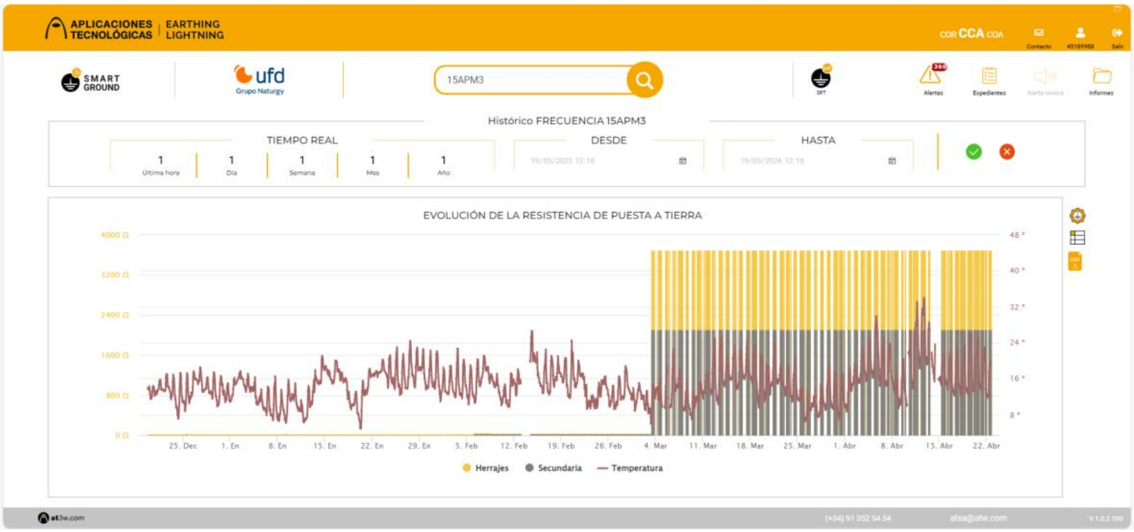

Figure 57Device Profile Screen of the device 15ALVP using the CCA user interface.

At the top, you can select the time intervals to be analysed, and by hovering the cursor over each series, you can view the following measured values:

- *Fittings.*
- *Secondary.*
- *Temperature.*

There is also the option to activate/deactivate the display of a specific series by clicking on it in the legend that appears in the lower section. Also, if the ground resistance must be repaired exists the following button to indicate it and the possibility to add a comment by the user:

Figure 58. Button to indicate that a ground resistance must be repaired.

Figure 59. Window to comment about the failing ground.

Once the desired series for analysis have been selected, exists the possibility to observe data in a table format by clicking into the following button:

Figure 60. Button to visualize data in a table format.

On this screen, as with the graphs, the user can change the date range. This allows for the selection of the treatment to be applied to the data for inclusion or exclusion, specifying the reason for exclusion and adding a comment. Each recorded entry includes four fields:

- ***Date:*** The day and time when the measurement was taken.
- ***R_{PAT}:*** Measurement recorded in ohms.
- ***Treatment:*** This can be categorised as Include, Exclude due to theft, fault discharge, ageing, correction, or other reasons.
- ***Comments:*** Interpretation of the measurement or whether the comment was generated automatically.

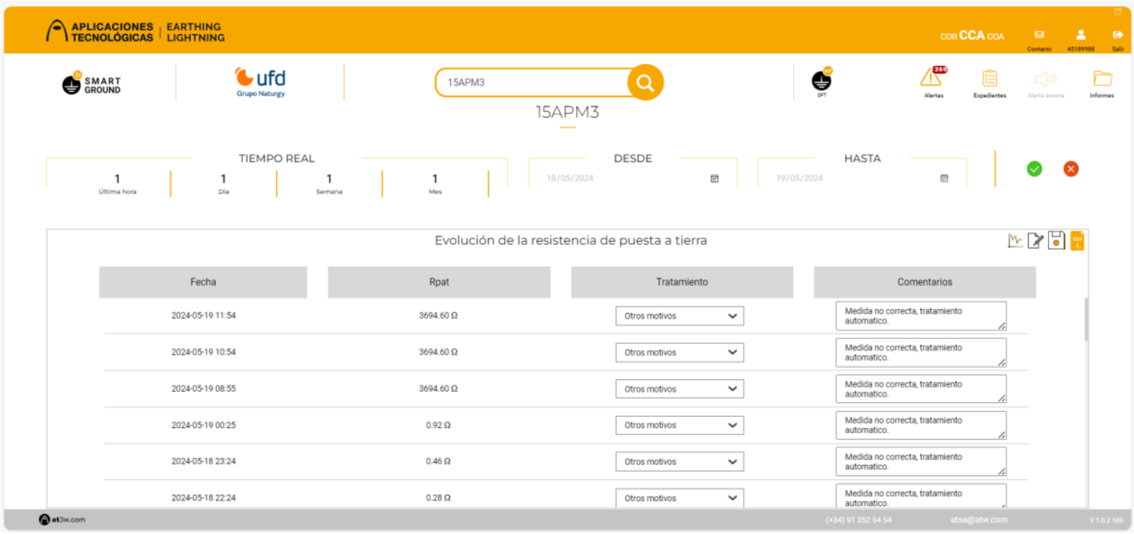

Figure 61.Data displayed in table format.

Also, a CSV file containing the displayed data can be generated by clicking on the following button shown below, located to the right of the graph:

Figure 62. Button to Generate CSV File with Device Data.

To record any changes made, click the button shown below, located in the top right corner of the data table:

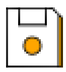

Figure 63. Saving button.

A bulk data treatment can also be performed by selecting the date range of interest, the type of treatment, and any comments the operator wishes to include. Below are shown both the button and the pop-up that appears:

Figure 64.Button to display the bulk data treatment pop-up.

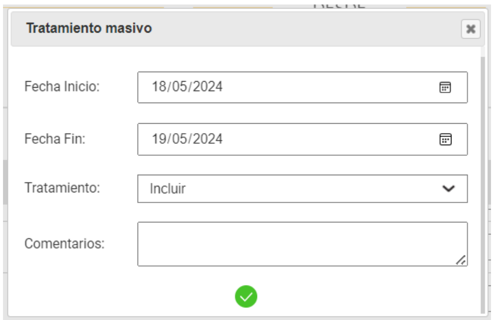

Figure 65. Bulk data-treatment pop-up.

3.1.2.2 ALERTS SCREEN

To access to the Alerts Screen there is the following button located on the right upper corner of the Main Screen, in the same position as using the COR user interface:

Figure 66. Alert Screen button.

This screen is shown below an can be observed some differences compared to the COR user interface:

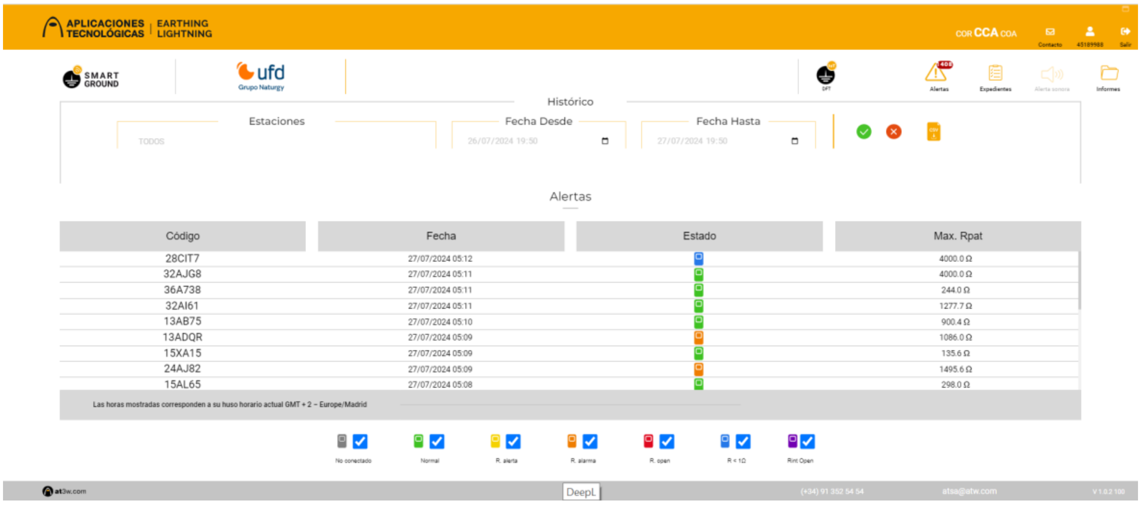

Figure 67. Alerts Screen in CCA user interface.

On this screen, the user can also change the date range selecting the treatment to be applied to the data for inclusion or exclusion by clicking on the legend at the bottom. This screen displays the following four fields:

- ***Code:*** Registration number of the device with the recorded incident.
- ***Date:*** Day and time of the recorded incident.
- ***Status:*** Shows the type of recorded incident using colour codes (see Figure 12).

- ***Max R_{PAT}:*** Maximum recorded ground resistance measurement.

In last place, this data table can be downloaded as a CSV file using the following button located on the right of the date range selection:

Figure 68.Button to download the data shown in the Alerts Screes in a CSV File.

3.1.2.3 REPORTS SCREEN

To access to the Reports Screen there is the following button located on the right upper corner of the Main Screen:

Figure 69. Reports Screen button.

On the "Files Screen," users can perform various actions and view detailed information about the devices and their records. At the top of the screen, there are search bars that allow users to filter the data by specific criteria. The search bar on the left enables users to select a specific responsible centre. On the right, there is a dropdown menu where users can choose between the following options: "Multiple", "CTI", "Paired" or "Supports."

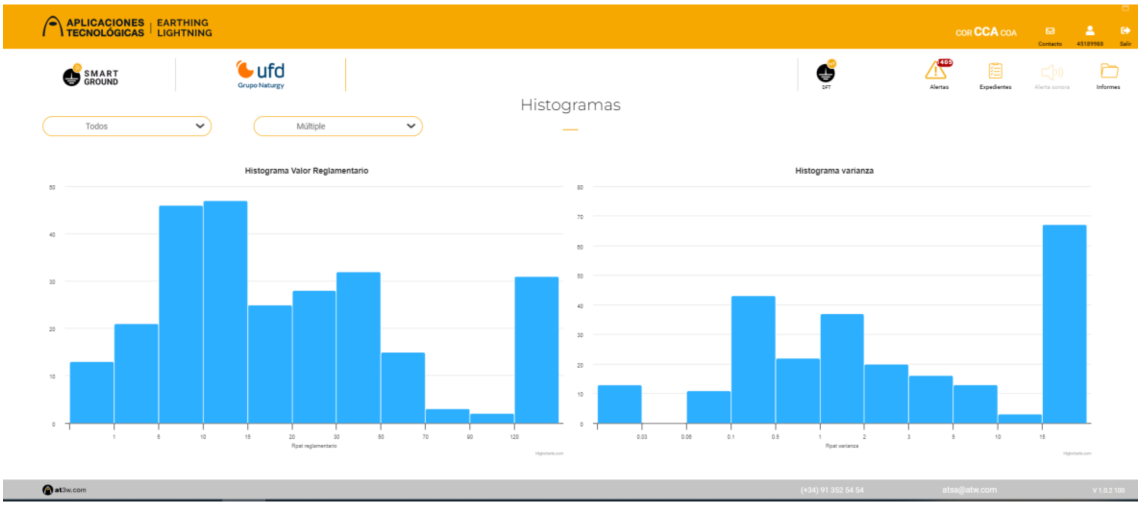

Figure 70.Files Screen.

This screen features a section where histograms are displayed to summarise the data visually. The "Histogram of Regulatory Value" shows the distribution of the regulatory values, while the "Histogram of Variance" illustrates the distribution of variance values. These graphical tools help users to quickly understand the trends and variations within the dataset. The user can display a list of all the devices included in any bar by clicking in it, accessing a list with the registration numbers as it's shown below:

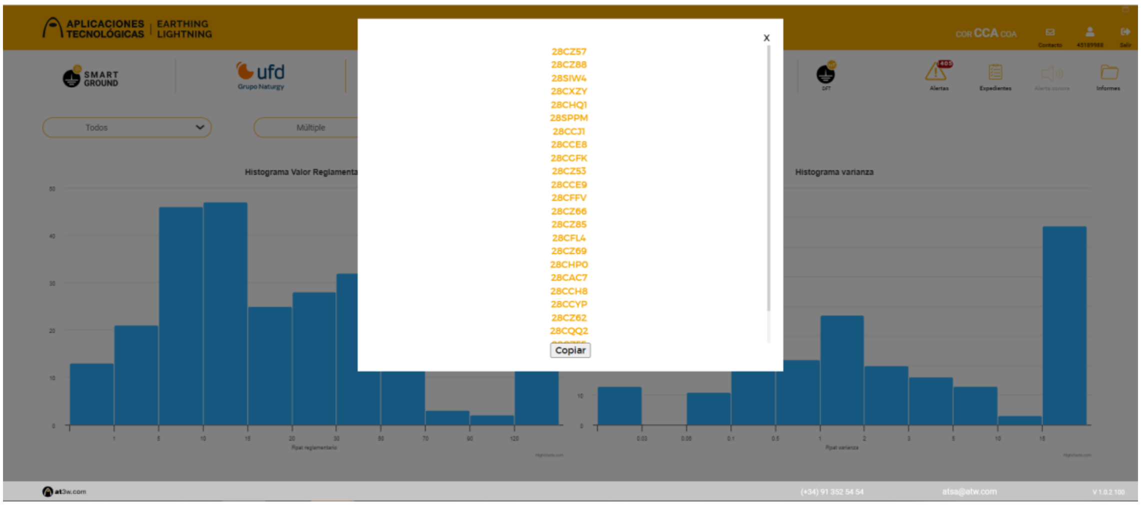

Figure 71. List of the devices included in a specific bar.

Finally, clicking again on any registration number will access the "Device Profile Screen" described before showing the trends in ground resistance and temperature.

3.1.2.4 FILES SCREEN

The Files Screen is the same as the one defined using the COR user interface and can be read in the ***3.1.1.2 Files Screen*** section.

3.1.3 COA USER INTERFACE

The COA (Asset Operations Centre) user manages the digital assets associated with the GFD system, ensuring that the equipment is properly maintained and adapted as needed. This role involves overseeing the overall inventory and operational status of the devices. Key functionalities for the COA user include:

- ***Device Search:*** This feature allows the COA user to search for devices using their registration numbers, which aids in managing and tracking inventory.
- ***Filter Application:*** The COA user can filter devices based on their operational status, such as disconnected, communication issues, or internal errors. This helps in identifying and addressing specific problems.
- ***Incident Management:*** Users can monitor and handle alerts related to the equipment, ensuring that any issues are promptly addressed to maintain system integrity.
- ***Historical Data Visualization:*** This tool provides access to historical operational data through charts and tables. Analysing this data helps in making informed decisions about maintenance and adaptation of the equipment.

3.1.3.1 *MAIN SCREEN*

The Main Screen for the COA user interface, through which the digital asset is managed by providing relevant information about the equipment and tools for its adaptation is shown below:

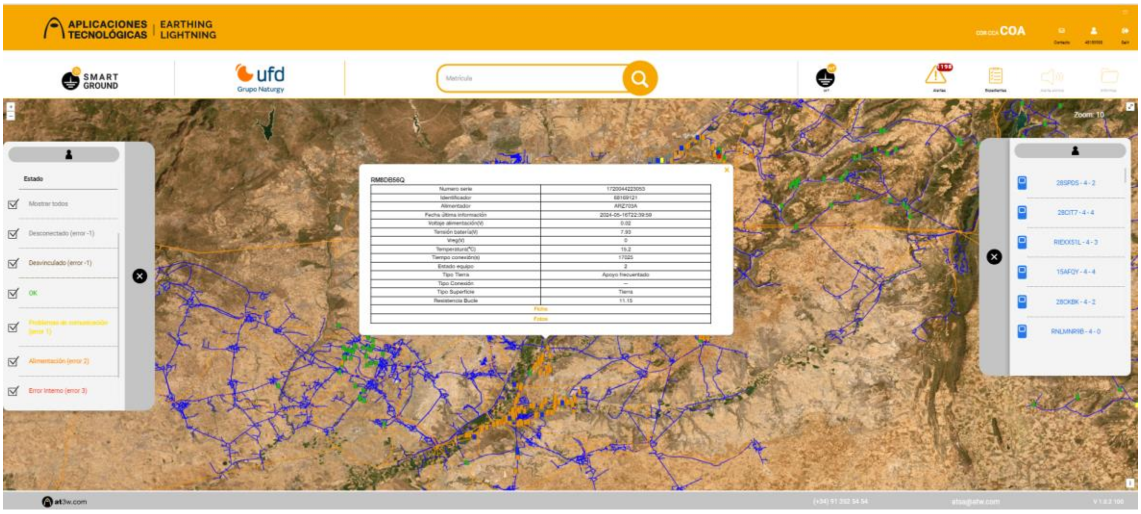

Figure 72. Main Screen using COA user interface.

From this screen, the devices can be searched by their registration number using the search bar located at the top, just like with the other user interfaces. This search bar can be seen below:

Figure 73. Search bar using COA user interface.

<u>Filters</u>

On the left side, there are filters that can be activated or deactivated to control the display of GFDs based on their status.

Figure 74. Applicable filters in COA user interface.

In the COA user interface, devices can be filtered by both location and their operational status, indicating whether they are functioning correctly or have errors. Devices can have seven statuses, with errors classified into five types:

- ***OK:*** The device is functioning correctly (green colour).
- ***Error -1:*** The device is disconnected or unlinked (grey and brown colours, respectively).
- ***Error 1:*** The device has communication issues (yellow colour).
- ***Error 2:*** The device has a power failure (orange colour).
- ***Error 3:*** The device has an internal error (red colour).
- ***Error 4:*** The GFD sensor has a fault (blue colour).

When analysing the progress of the campaign by operational base, devices with a red status (error 3) and others (all other statuses) are examined. The priority is to increase the implementation of GFDs in the field while reducing the number of devices with internal errors (error 3).

On the right side of the main screen, the installed GFD devices within the network are displayed with their registration numbers. The registration numbers are shown in the colour corresponding to their currently status, and only those devices with the statuses selected in the filters are visible. An example is shown below:

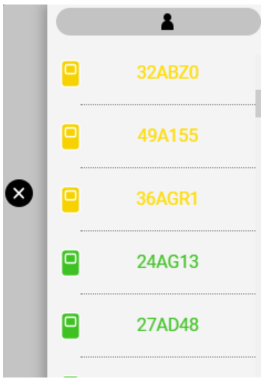

Figure 75.Registered numbers coloured with the currently status.

3.1.3.2 DEVICE PROFILE SCREEN

Once a device is selected on the main screen, a pop-up appears as shown in the example below:

15APM3

Numero serie	1120027023088
Identificador	68208903
Alimentador	CDR805
Fecha última información	2024-07-29 13:40:00
Voltaje alimentación(V)	11.95
Tensión batería(V)	8.05
Vreg(V)	0
Temperatura(°C)	33.7
Tiempo conexión(s)	15186
Estado equipo	4
Tipo Tierra	CTI
Tipo Conexión	Neutro
Tipo Superficie	Tierra
Resistencia Bucle	53.30
Código Error	6145
Ficha	
Fotos	

Figure 76. Pop-up of the device 15APM3.

By clicking on "Fotos" the user access to some pictures of the device installation. Also, there is a *"Ficha"* button, used to access the historical data graphs for the device, where the evolution of the data related to the device's operation can be observed.

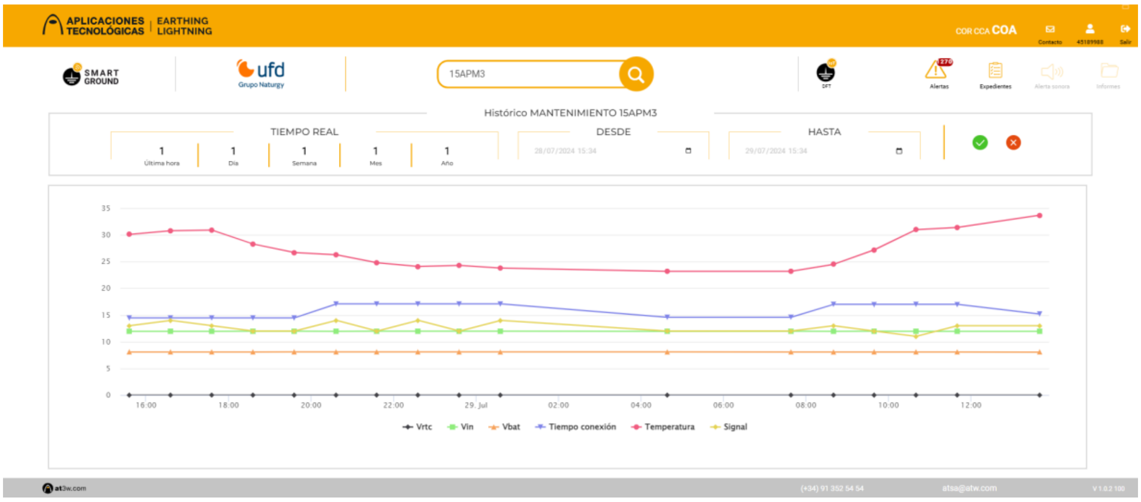

Figure 77. Device Profile Screen of the device 15APM3 using the COA user interface.

At the top, you can select the time intervals to be analysed. By hovering the cursor over each series, the measurements taken for each hour can be observed for the following values:

- V_{RTC}.
- V_{IN}.
- V_{BAT}.
- *Connection time.*
- *Signal.*

There is also the option to activate/deactivate the display of a specific series by clicking on it in the legend that appears in the lower section. Once the desired series for analysis have been selected, a CSV file containing the displayed data can be generated by clicking on the button shown below, located to the right of the graph:

Figure 78. Button to generate CSV file with device data.

3.1.3.3 ALERTS SCREEN

To access to the Alerts Screen there is the following button located on the right upper corner of the Main Screen, in the same position as using the COR or CCA user interfaces:

Figure 79. Alert Screen button.

This screen is shown below and can be observed some differences compared to the COR or CCA user interfaces:

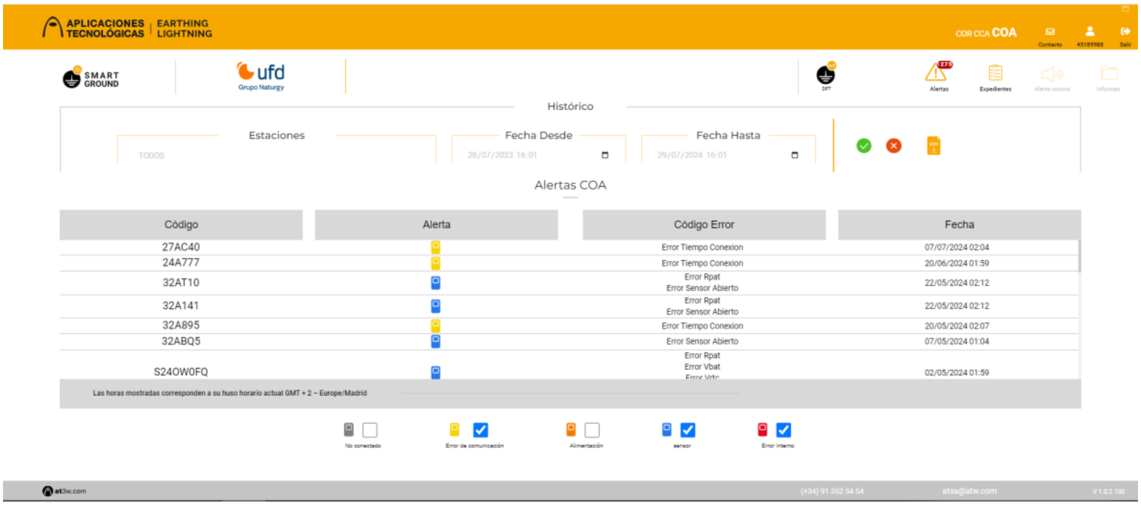

Figure 80.Alerts Screen using COA user interface.

Once on the alerts screen, the time range of incidents to be viewed can be selected again, and five fields appear for each device with some error status associated:

- ***Code:*** Refers to the registration number of the affected device.
- ***Alert:*** An icon appears with the colour assigned to the registered error.
- ***Error code:*** Some specifications of the registered error appear.
- ***Date:*** Day and time when the incident was recorded.

3.1.3.4 FILES SCREEN

The Files Screen is the same as the one defined using the COR user interface and can be read in the ***3.1.1.2 Files Screen*** section.

3.2 INTELLIGENT NETWORK SYSTEM (ESIR)

The Intelligent Network System (eSIR) is a sophisticated UFD tool used to monitor and manage digital and remotely controlled assets within the electrical grid of UFD. It assists administrators by identifying malfunctioning equipment through programmable rules and criteria tailored to the network's needs. By providing a comprehensive overview of the operational status of almost all assets, eSIR ensures a timely detection and resolution of issues, significantly enhancing the network's reliability.

eSIR is indispensable for managing the vast amounts of data generated by all the deployed assets of UFD, including the GFDs. It facilitates continuous monitoring and in-depth analysis of data, enabling administrators to efficiently oversee the network's performance and promptly address any issues. The insights provided by eSIR support a strategic decision-making, further strengthening the grid's robustness.

To support various types of assets, eSIR incorporates a comprehensive data structure and a set of generic functionalities. These features allow for efficient management of asset data and handling their associated incidents. Each type of asset requires specific parameterisation of this data structure to ensure accurate and effective management.

This section provides a detailed parameterization of this new asset type. It outlines the essential data required to manage these assets and their incidents, offering a comprehensive template to be completed. This approach ensures that all relevant information is systematically captured, facilitating better decision-making and operational efficiency.

To achieve this, UFD has standardised templates for the creation of new grids within the eSIR system. These templates stipulate the necessary data fields and configuration settings required to integrate new asset types effectively. It is important to note that while these templates provide a comprehensive framework, certain data fields may not be relevant or necessary for every asset type. As such, specific sections may be omitted or considered non-essential depending on the characteristics and requirements of the particular asset being integrated.

3.2.1 DATA ASSOCIATED WITH THE ASSET TYPE

3.2.1.1 DATA SOURCES

To effectively integrate and manage GFDs within the eSIR system, it is necessary to identify and detail the data sources associated with these assets. The information specified in this section ensures that all relevant data is accurately integrated into the system. The following table outlines the required fields and their descriptions for the data sources:

Data Source Type	Origin	Label	File Name	Periodicity	Estimated Volume	Format	Critical File
Inventory	IGEA	[IGEA]	-	Manual	-	-	-
Inventory	GDA	[GDA]	-	Manual	-	-	-
Operation	G-DFT	-	-	-	-	-	-

Table 3. Data source template for creating a new grid in eSIR.

By having a structured approach to data sources, the system can effectively track and verify the origin and periodicity of data, ensuring accuracy and reliability in its operations.

3.2.1.1 ASSET DATA

The configuration of asset data involves specifying various fields that capture detailed information about each asset, including inventory, operational, and calculated data. These data fields ensure that all relevant information is systematically captured, facilitating effective monitoring, maintenance, and incident management.

The asset data for GFDs includes several key parameters, such as identifiers, installation details, geographical information, technical specifications, and operational status. Each data field is categorized and defined using the following table, in order to provide a clear understanding of its purpose and importance.

Data Type	Name	Source	Type	Description	Mandatory	Detail	Editable	Evolution
Inventory	IDENTIFIER	[GDA]	Text	GDA Code	yes	yes	no	no
Inventory	REGISTRATION	[IGEA]	Text	Registration number of the point where the digital equipment is located	yes	yes	no	no
Inventory	SUPERIOR INSTALLATION	[IGEA]	Text	ID of the superior secondary installation when applicable (registration or labelling code)	yes	no	no	no
Inventory	PROVINCE	[IGEA]	Text	Province where the digital equipment is located	yes	yes	no	no
Inventory	MUNICIPALITY	[IGEA]	Text	Municipality where the digital equipment is located	yes	yes	no	no
Inventory	RESPONSIBLE CENTRE	[IGEA]	Text	Responsible centre for the digital equipment	yes	yes	no	no
Inventory	POSTAL CODE	[IGEA]	Number	Postal code where the digital equipment is located	yes	no	no	no
Inventory	X	[IGEA]	Number	X-coordinate where the digital equipment is located	yes	no	no	no
Inventory	Y	[IGEA]	Number	Y-coordinate where the digital equipment is located	yes	no	no	no
Inventory	SERIAL NUMBER	[GDA]	Number	Serial number of the digital equipment	yes	yes	no	no
Inventory	MANUFACTURER	[GDA]	Text	Manufacturer of the digital equipment	yes	yes	no	no
Inventory	MODEL	[GDA]	Text	Model of the digital equipment	yes	no	no	no
Inventory	MANUFACTURE DATE	[GDA]	Date	Date when the equipment is manufactured	yes	yes	no	no
Inventory	SERVICE START DATE	[GDA]	Date	Date when the equipment is installed at a specific location	yes	yes	no	no
Inventory	STATUS	[GDA]	Text	Status of the equipment	yes	yes	no	no
Inventory	ORIGINAL FIRMWARE VERSION	[GDA]	Text	Original firmware version in operation	yes	no	no	no
Inventory	EARTH SYSTEM TYPE	[GDA]	Text	Types of earth systems define the calculation algorithm for the reference ground, they can be complex, paired or isolated	yes	yes	no	no
Inventory	SECONDARY EARTH TYPE	[GDA]	Text	The type of earth that closes the loop, can be structural, auxiliary or neutral	no	no	no	no

Inventory	IP ADDRESS	[GDA]	IP	IP address of the GFD	yes	yes	no	no
Inventory	LAST CALIBRATION DATE	[GDA]	Date	Date of the last calibration of the equipment	no	no	no	no
Inventory	MATERIAL	[GDA]	Text	Compatible unit data for the material of the digital equipment	no	no	no	no
Inventory	LOOP IMPEDANCE RANGE	[GDA]	Text	Range of values for loop impedance measurement in Ohms	no	no	no	no
Inventory	CURRENT MEASUREMENT RANGE	[GDA]	Text	Range of values for current measurement in mA/A	no	no	no	no
Inventory	TEMPERATURE RANGE	[GDA]	Text	Range of values for temperature measurement in ºC	no	no	no	no
Inventory	INJECTION FREQUENCY	[GDA]	Number	Injection frequency value in Hz	no	no	no	no
Inventory	ANALOGUE-DIGITAL PORTS	[GDA]	Number	Number of analogue-digital ports	no	no	no	no
Inventory	DIGITAL PORTS	[GDA]	Number	Number of digital ports	no	no	no	no
Inventory	EXPANSION PORTS	[GDA]	Number	Number of expansion ports	no	no	no	no
Inventory	DIMENSIONS	[GDA]	Text	Dimensions of the digital equipment in mm	no	no	no	no
Inventory	WEIGHT	[GDA]	Text	Weight of the digital equipment in kg	no	no	no	no
Inventory	OPERATING TEMPERATURE RANGE	[GDA]	Text	Range of values for temperature measurement in ºC under normal conditions	no	no	no	no
Inventory	IP PROTECTION RATING	[GDA]	Number	IP protection rating	no	no	no	no
Inventory	ENCLOSURE MATERIAL	[GDA]	Text	Enclosure material of the digital equipment	no	no	no	no
Inventory	SUPPLY VOLTAGE	[GDA]	Text	Supply voltage of the digital equipment	no	no	no	no
Inventory	POWER SUPPLY VOLTAGE	[GDA]	Text	Power supply voltage of the digital equipment	no	no	no	no
Inventory	AVERAGE CONSUMPTION	[GDA]	Text	Average current consumption	no	no	no	no
Inventory	INTERNAL BATTERY	[GDA]	Text	Internal battery capacity of the digital equipment	no	no	no	no
Inventory	COMMUNICATION TYPE	[GDA]	Text	Communication type of the digital equipment	no	no	no	no
Inventory	COMMUNICATION PROTOCOL	[GDA]	Text	Communication protocol	no	no	no	no
Inventory	STORAGE TYPE	[GDA]	Text	Information storage system in the digital equipment	no	no	no	no
Inventory	CAPACITY	[GDA]	Text	Storage capacity in the digital equipment in GB	no	no	no	no
Operation	INCIDENT NUMBER	[EDIT]	Number	eSIR incident ID associated	no	no	no	no
Operation	INCIDENT STATUS	[EDIT]	Text	eSIR incident status associated	no	no	no	no
Operation	INCIDENT SYMPTOM	[EDIT]	Text	eSIR incident type associated	no	no	no	no
Operation	GDA FILE	[EDIT]	Text	eSIR incident request associated	no	no	no	no
Operation	COMMENTS	[EDIT]	Text	Comments	no	no	no	no
Inventory	CURRENT FIRMWARE VERSION	(G-GDT)	Text	Last firmware version in operation	yes	no	no	no
Operation	PENDING CALIBRATION	(G-GDT)	Text	Equipment pending calibration/Normal operation	no	no	no	yes
Operation	LAST AUTOCALIBRATION DATE	(G-GDT)	Date	Calibration date	no	no	no	no
Operation	DAYS WITHOUT COMMUNICATION	(G-GDT)	Number	Number of days without modem communication	no	no	no	yes
Operation	REGULATORY STATUS	(G-GDT)	Text	Regulatory resistance warning yes/no	no	no	no	yes
Operation	REGULATORY ACTION PROPOSAL	(G-GDT)	Text	Proposed solution for regulatory resistance	no	no	no	no
Operation	24H COMMUNICATION ERROR	(G-GDT)	Text	Communication error (24h rate)	no	no	no	yes
Operation	COMMUNICATION ERROR ACTION PROPOSAL	(G-GDT)	Text	Proposed solution for communication error	no	no	no	no
Operation	24H POWER SUPPLY ERROR	(G-GDT)	Text	Error in input/output voltages (24h rate)	no	no	no	yes
Operation	POWER SUPPLY ERROR ACTION PROPOSAL	(G-GDT)	Text	Proposed solution for power supply error	no	no	no	no
Operation	INTERNAL ERROR	(G-GDT)	Text	Data transfer error (24h rate)	no	no	no	yes
Operation	INTERNAL ERROR ACTION PROPOSAL	(G-GDT)	Text	Proposed solution for internal error	no	no	no	no
Operation	SENSOR ERROR	(G-GDT)	Text	Temperature error	no	no	no	yes
Operation	SENSOR ERROR ACTION PROPOSAL	(G-GDT)	Text	Proposed solution for sensor error	no	no	no	no

Operation	CERTIFICATION VALIDITY	(G-GDT)	Boolean	0 - Valid: The GFD is correctly installed and communicates; 1 - Not Valid: The GFD does not communicate or has a measurement problem	yes	no	no	no

Table 4. Asset Data template for creating a new grid in eSIR.

The categories of asset data are outlined below, providing an overview of the types of information included for the effective management of GFDs within the eSIR system. These categories help organize the data in a way that supports efficient operation and maintenance of the assets:

- ***Identifiers and Registration:*** This includes fields such as the GDA code *(IDENTIFIER)*, registration number *(REGISTRATION)*, and serial number *(SERIAL NUMBER)*, which uniquely identify each GFD.
- ***Location Details:*** Fields like province *(PROVINCE)*, municipality *(MUNICIPALITY)*, responsible centre (*RESPONSIBLE CENTRE*), postal code (*POSTAL CODE*), and geographical coordinates (*X* and *Y*) provide the exact location of each device.
- ***Installation and Technical Specifications:*** This encompasses the manufacturer *(MANUFACTURER)*, model *(MODEL)*, firmware version *(ORIGINAL FIRMWARE VERSION)*, and various technical parameters such as loop impedance *range (LOOP IMPEDANCE RANGE)*, current measurement range *(CURRENT MEASUREMENT RANGE)*, temperature range *(TEMPERATURE RANGE)*, injection frequency *(INJECTION FREQUENCY)*, and others.
- ***Operational Status:*** This category includes fields related to the status of the equipment *(STATUS)*, calibration dates *(LAST CALIBRATION DATE)*, material specifications *(MATERIAL)*, power supply details *(SUPPLY VOLTAGE)*, communication protocols *(COMMUNICATION PROTOCOL)*, and battery information *(INTERNAL BATTERY)*.
- ***Incident Management:*** Specific fields are designated for incident tracking and management, including incident numbers *(INCIDENT NUMBER)*, status *(INCIDENT STATUS)*, symptoms *(INCIDENT SYMPTOM)*, associated GDA files *(GDA FILE)*, comments *(COMMENTS)*, and proposed actions for various types of errors and issues.

These asset data fields are necessary to create a comprehensive and functional grid within the eSIR system. Specifying each parameter ensure precise monitoring and effective management of GFDs.

3.2.1.2 GENERAL CONFIGURATION

The general configuration of GFDs includes key settings that ensure the devices are properly integrated and functioning as expected. This section covers the common fields applicable to all asset types and optional tabs available in the detailed view of the asset. The *''Identifier of the asset''* is the only mandatory row, and the only necessary one for the GFD grid in eSIR.

Function	Field Name
Identifier of the asset	BDI Description
Coordinate X	-
Coordinate Y	-
Root Asset	-
Upper Asset	-
Criticality of the Asset	-

Table 5. General Configuration template for creating a new grid in eSIR.

In addition to the primary fields, there are two optional tabs available in the asset detail view. These tabs provide additional historical context and operational insights, enhancing the ability of administrators to track incidents and service orders. The following table outlines the optional tabs that are required:

Required	Historic
Yes	Incident History
-	Service Order History

Table 6. Optional Tabs in asse detail view.

This structured approach supports both immediate operational needs and long-term maintenance and incident resolution efforts, ensuring the stability and reliability of the network.

3.2.2 DATA REQUIRED FOR INCIDENT MANAGEMENT

3.2.2.1 INCIDENT DATA

In the eSIR system, managing incidents related to the GFDs requires specific data fields to ensure that all relevant information is captured accurately. While the table fields are important for the detailed recording and effective resolution of incidents, only the following fields are mandatory for creating any incident: province, municipality, postal code, zone, sector, responsible centre, and parent asset.

Name	Type	Description	Asset Field	Incident Detail	Incident Detail Tab
ID	String	Identifier of the incident	NOT APPLICABLE	YES	General
ASSET_ID	String	Identifier of the asset	Registration	YES	General
ASSET_INST	String	Identifier of the asset installation (root)	Name	YES	General
PRIORITY	String	Priority	NOT APPLICABLE	YES	General
STATUS	String	Status	NOT APPLICABLE	YES	General
ASSIGNMENT SYMPTOM	String	Symptom that generated the incident	NOT APPLICABLE	YES	General
OPENING DATE	String	Date the incident was created	NOT APPLICABLE	YES	General

CLOSING DATE	String	Date the incident was closed	NOT APPLICABLE	YES	General
PROVINCE	String	Province where the asset is located	-	NO	General
MUNICIPALITY	String	Municipality where the asset is situated	-	NO	General
POSTAL CODE	String	Postal code where the asset can be found	-	NO	General
ZONE	String	Zone	-	NO	General
SECTOR	String	Sector	AT Sector	NO	General
RESPONSIBLE CENTER	String	Responsible centre for MT	-	YES	General
PARENT ASSET	String	Parent asset or root asset	Name	YES	General

Table 7. Incident Data template for creating a new grid in eSIR.

The descriptions of the fields can be seen below:

- ***Name:*** The specific name of the data field, indicating its content and purpose within the system.
- ***Type:*** The format of the data, such as string, number, or date. This ensures proper data handling and storage.
- ***Description:*** A brief explanation of the data field's content and its significance.
- ***Asset Field:*** Indicates whether the data field is linked to a specific asset attribute or identifier.
- ***Incident Detail:*** Specifies if the field requires detailed information for the incident.
- ***Incident Detail Tab:*** Indicates the tab or section in the incident detail view where this data field is displayed.

By detailing each aspect of incident data, the eSIR system can provide timely and accurate responses to any issues that arise, thereby maintaining operational integrity and efficiency.

3.2.2.2 RESOLUTION

In the eSIR system, resolving incidents related GFDs involves specific data fields that capture all necessary information for an effective resolution process. These fields are crucial for documenting the resolution steps and ensuring that the incident is handled appropriately. The most typical failures and available solutions are detailed below:

Real Causes
Firmware update error
Power failure
Battery failure
Communication failure
Autocalibration failure
SD card failure / internal fault
Measurement failure (voltages, temperatures)
Digital input failures
Analog input failures
Ground breakage
Internal loop breakage
Excess temperature
Inadequate temperature pattern

Actions
Local firmware update
Remote firmware update
Power issue corrected
Equipment replacement
Communication bus repaired
Template configuration change / remote adjustment
Template configuration change / local adjustment
Cable / connector correction
Local restart
Remote restart
Resolved without action with field visit
Resolved without action with field visit
Solar panel correction

Table 8. Resolution Data template for creating a new grid in eSIR.

These data fields ensure that every aspect of the resolution process is documented thoroughly, allowing for precise tracking and analysis of incident resolutions.

3.2.2.3 GENERAL CONFIGURATION

In this section, we focus on the general configuration settings required for the incident management of GFDs within the eSIR system. These settings include optional tabs in the incident detail view and assignable workflows to streamline incident management and resolution processes.

The following table outlines the optional tabs available in the incident detail view. These tabs provide additional context and historical data, aiding in a more thorough understanding and analysis of each incident:

Historic	Required
Service Order History	No
Timeline	Yes
Resolution	Yes
Evolution	Yes

Table 9. Optional tabs in incident detail view in eSIR.

The next table has the assignable workflows that define the specific steps and procedures to be followed for incident resolution. This ensures a structured and efficient approach to managing incidents:

Assignable Workflow	Required
General	Yes
Subtasks	No
Remote Operation	No
OOSS Farms	No
OOSS Farms ZEUS	No
OOSS Supplies	No
OOSS Supplies ZEUS	No
Platform	No

Table 10. Assignable workflows for incident resolution in eSIR.

These configurations are critical for customizing the incident management process within the eSIR system. By defining optional tabs and assignable workflows, the system can provide a tailored approach to monitoring, managing, and resolving issues, ensuring a comprehensive and efficient operational framework.

3.3 INTEGRATION AND MANAGEMENT IN UFD SYSTEMS

3.3.1 OTHER UFD'S DIGITAL TOOLS

Apart from eSIR explained in the last section some of the most relevant tools within UFD for this project are IGEA and GdA. Both are briefly explained below in order to understand the rest of the section:

3.3.1.1 IGEA

IGEA is the Geographic Enterprise Application used by UFD, designed to integrate both graphical and alphanumeric information for all installations and assets involved in the distribution network, including high, medium, and low voltage lines, as well as telecommunications. IGEAWEB, an integral component of the IGEA suite, enhances this functionality by offering a web-based interface that allows for the representation of geographic information and provides various tools for querying and editing the data managed by the system.

IGEA serves as a comprehensive repository that provides a unified view of all network components, accessible from multiple locations, ensuring that administrators and field operators can efficiently retrieve and utilize relevant data. This accessibility facilitates better decision-making, efficient management, and coordination of UFD's extensive distribution network, thereby significantly enhancing overall operational efficiency.

IGEAWEB is highly adaptable, allowing UFD to tailor it to specific business functions or data models. It does not impose a predefined data model, giving UFD the flexibility to define its own relational data model. The system administrator can configure the metamodel, including entity names, attributes, and relationships, to ensure the application functions correctly according to UFD's needs.

In summary, IGEA is a powerful and flexible tool that enhances UFD's ability to manage and visualize its distribution network. Its adaptability, combined with its advanced functionalities for data querying, editing, and user management, makes it an indispensable resource for ensuring the operation of UFD's electrical infrastructure.

3.3.1.2 ASSET MANAGEMENT INTERFACE (GDA)

The Asset Management Interface (GdA) is an important component in the management of equipment within the network. This system organises equipment hierarchically based on the network elements to which they belong. This hierarchical organisation enables a systematic approach to managing and integrating all equipment within the network, facilitating better oversight and operational efficiency.

Hierarchical Organisation of Equipment

In the GdA system, equipment is categorised into different levels of hierarchy depending on the type of network element they are associated with. The primary network elements include:

- ***Lines:*** These are the circuits that transport electricity across the network. Equipment associated with lines is categorised under the *"Lines"* hierarchy.
- ***Parks:*** Typically refers to substations or areas where electrical energy is transformed or distributed.
- ***Substations:*** Points within the network where voltage levels are adjusted, crucial for maintaining the stability of electrical distribution.
- ***Secondary Substations:*** These centres house the transformers that reduce voltage levels for distribution to end-users.
- ***Transformers:*** The devices that step down voltage from higher transmission levels to lower distribution levels.

Hierarchy Levels in GdA

The GdA system follows a hierarchical structure with multiple levels (N1 to N4) to organise equipment effectively:

- ***N1 Level:*** Represents the highest level, encompassing major network elements such as circuits, secondary substations, and substations.
- ***N2 Level:*** This level includes segments of circuits and specific components within secondary substations or substations.
- ***N3 Level:***
    - ***N3-GFD SS Aggregator:*** An aggregator for N4 devices installed in secondary substations (SSs).
    - ***N3-GFD Lines Aggregator:*** An aggregator for N4 devices installed along the lines.
- ***N4 Level:***
    - ***N4-GFD SS:*** Represents the physical equipment installed in secondary substations.
    - ***N4 - GFD Lines:*** Represents the equipment installed along the network lines.

This hierarchical structuring ensures that each piece of equipment is correctly associated with its corresponding network element, allowing for efficient management, and troubleshooting within the GdA system.

Configuration and data filling

In the GdA system, configuring new elements involves assigning them to the correct hierarchical level and ensuring they inherit the necessary characteristics. The N3 levels, which are aggregators, are primarily fictitious entities within the system. These aggregators do not have physical characteristics but are essential for organising data and equipment.

Also, ELA and MEI codes or parameters are used within the system to populate characteristics in the N3 levels, ensuring consistency and accuracy in data reporting.

3.3.2 INTEGRATION OF A NEW GFD

If a new asset requires a GFD, the next process needs to be followed in order to integrate it correctly into the network.

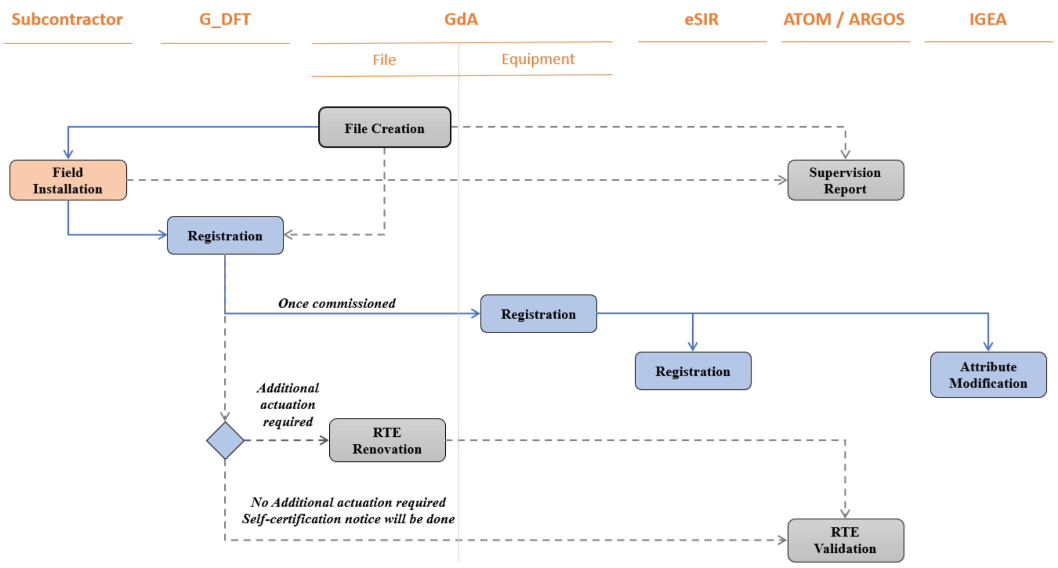

Figure 81. Flowchart of the integration of a new GFD.

The integration of new GFDs into the UFD network begins with the creation of a case file in the GdA system, specifying the locations where the device should be installed. This case file communicates with the manufacturer's application, *G-DFT*, ensuring seamless data flow and coordination.

When a subcontracted company proceeds with the field installation, they use the *Enrolment App* to scan the barcode of each device. This barcode scan automatically populates the installation records with the device's details. Before finalizing the installation, a review is conducted through the ATOM/ARGOS system to ensure compliance and proper setup. Once the GFD is operational and successfully communicating, it is registered in the GdA system. Subsequently, the device is also registered in the eSIR system, and the attributes of the monitored asset are updated in the IGEA system. This integration ensures that all systems are synchronized and the new GFD is fully functional within the UFD network.

The commissioning of devices has two potential pathways than can be followed for further actions:

- ***Standard Procedure:*** If no additional actions are required beyond the installation, an auto-certification notice is issued. The case file in GdA is updated to reflect the completion and then validated in ATOM/ARGOS.
- ***Extended Procedure:*** If further actions are necessary, such as additional configurations or tests, the case file in GdA is modified to include these tasks. Upon completion, these modifications are also validated in ATOM/ARGOS.

3.3.3 DECOMMISSIONING OF THE MONITORED ASSET

If a GFD needs to be decommissioned due to modifications or decommissioning of the monitored asset, the next procedure is followed:

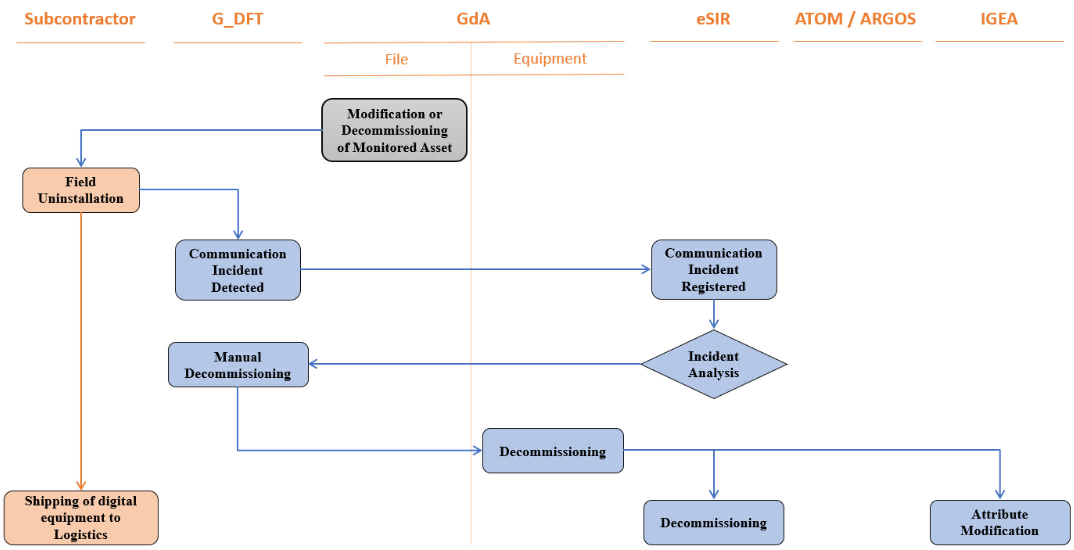

Figure 82. Flowchart of the removal of a GFD due to a decommissioning of the monitored asset.

A case file is created in the GdA system, specifying the changes or decommissioning activities to be carried out on the monitored asset. Following this, the subcontracted company is tasked with going to the field to do the correspondent tasks including the uninstallation of the GFD. If the removed device is still in good conditions, then is sent to the logistics team for further handling.

Upon uninstallation, the *G-DFT* application will detect a communication failure with the device. This incident will appear in the eSIR system, where it will be reviewed by the COA (Asset Operation Centre) department. Upon verifying that there is an active case file for the decommissioning or modification of the monitored asset, the GFD will be manually decommissioned in the *G-DFT* application.

Subsequently, the GFD also will be decommissioned in the GdA system, followed by its decommissioning in the eSIR system. Finally, the attributes of the formerly monitored asset will be updated in the IGEA system.

3.3.4 CORRECTIVE MAINTENANCE

When a GFD experiences a fault and requires field inspection, the following process is followed:

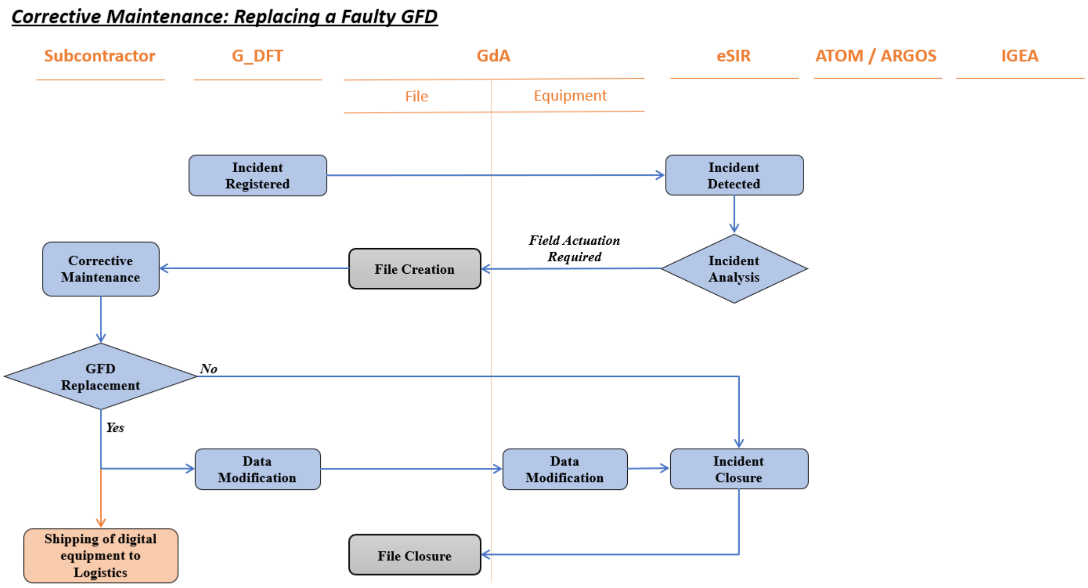

Figure 83. Flowchart of replacing a faulty GFD due to a corrective maintenance.

First, there is a detection of an incident in the *G-DFT* application, which automatically communicates the issue to the eSIR system. The COA (Asset Operation Centre) department then analyses the incident. If it is determined that field action is necessary, a case file is created in the GdA system.

Upon receiving the task, the subcontracted company proceeds to the field to address the issue. Corrective maintenance can follow two different paths:

- ***Replacement of the GFD:*** If the maintenance involves replacing the faulty device, the old device is uninstalled and sent to the logistics team for further handling. The *G-DFT* application is then updated to reflect the installation of a new device, including its serial number and other details. Following this, the equipment data in the GdA system is also updated to ensure consistency across all management platforms. Finally, the incident is closed in the eSIR system, marking the completion of the corrective action.
- ***No Replacement of the GFD:*** If the corrective maintenance involves addressing the incident without replacing the device, then the device's data remains unchanged in all

systems. The incident is then directly closed in the eSIR system, indicating that the issue has been solved without the need of a new GFD.

In both scenarios, once the corrective maintenance is completed and verified, the case file in the GdA system is closed. This closure means the end of the process and allows for the processing of payment to the subcontracted company for their services.

3.4 PERFORMANCE ANALYSIS OF INSTALLED GFDS

3.4.1 PERFORMANCE ANALYSIS OF INSTALLED GFDS

In this subsection, we analyse the installation progress and budget compliance for each year from 2021 to 2024. The data on the number of GFDs budgeted, installed, and their operational status are presented through comprehensive figures for each year of deployment Additionally, specific tables found in ***Annex B*** provide a detailed breakdown of the performance by responsible centres, which refer to the subcontracted companies assigned to specific geographic areas for GFD installation. This breakdown allows for an in-depth evaluation of the overall effectiveness of the GFD implementation across different regions.

2021 Installation Overview

In 2021, there were no budgeted devices, yet installations occurred as part of pilot tests to evaluate the system's functionality and integration with existing infrastructure. During this period, 137 devices were installed, of which 128 were disconnected (93.43%) shortly after installation. Only 6 devices were operational (OK), while 3 devices faced power supply issues. This initial phase highlighted significant challenges in the deployment process and the reliability of installations. Below can be seen a figure where *axis y* represents the number of deployed devices and *axis x* the month of the year:

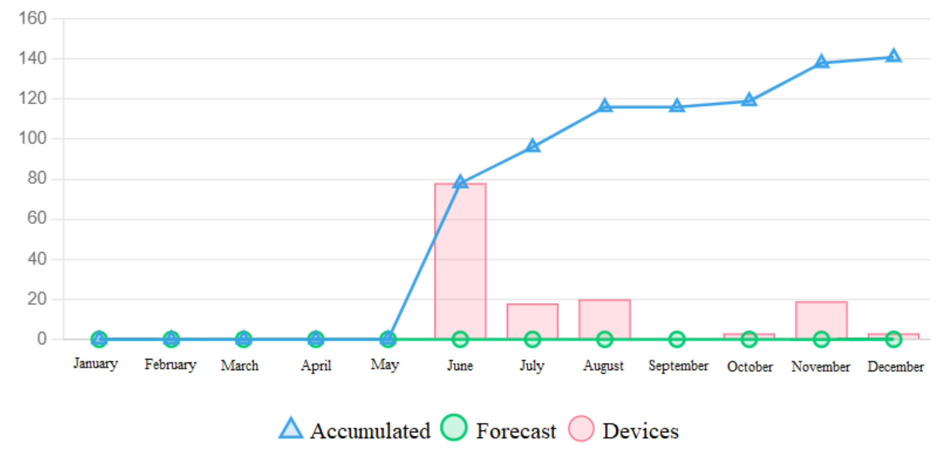

Figure 84. Yearly Overview of Budgeted, Installed, and Cumulative GFDs for 2021.

2022 Installation Overview

Similar to 2021, the year 2022 had no budgeted devices. However, 10 devices were installed as part of ongoing pilot tests. Out of these, 9 devices were disconnected (90%), and only 1 device remained operational (OK). The power supply issue affecting one device was identified as a critical area needing improvement before a larger-scale rollout. Below can be seen a figure where *axis y* represents the number of deployed devices and *axis x* the month of the year:

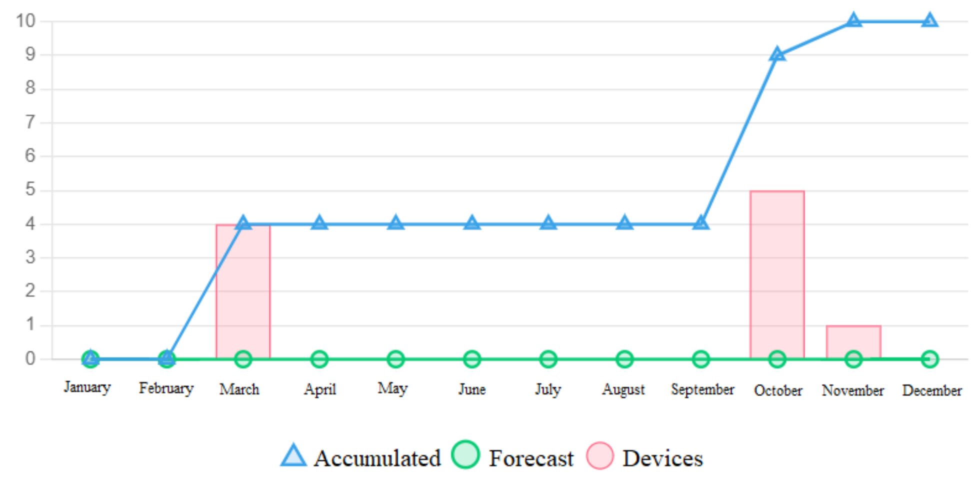

Figure 85. Yearly Overview of Budgeted, Installed, and Cumulative GFDs for 2022.

2023 Installation Overview

By 2023, the project made significant progress with initial deployments across various responsible centres. Out of 5000 budgeted devices, 1738 were installed, marking an installed percentage of 34.76%. However, the primary focus was ensuring operational effectiveness, with 788 devices marked as OK, resulting in an operational effectiveness of 15.76%. Below can be seen a figure where *axis y* represents the number of deployed devices and *axis x* the month of the year:

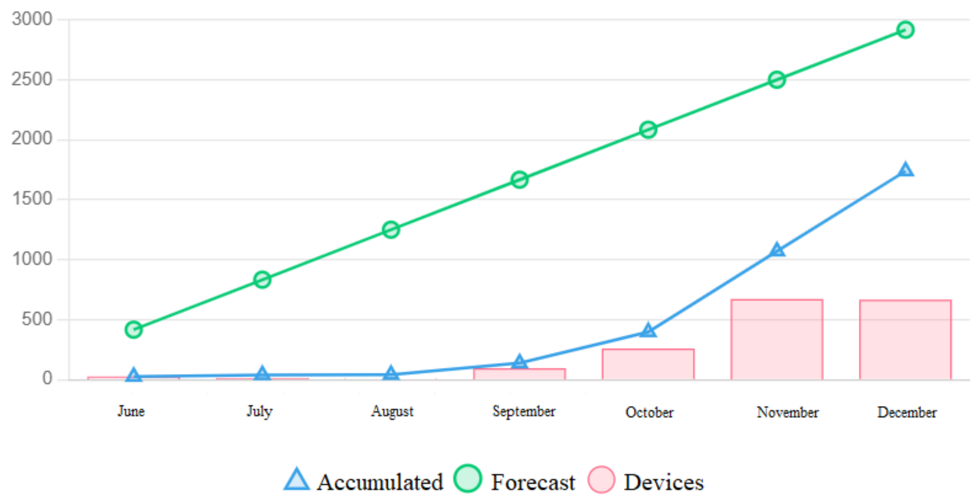

Figure 86. Yearly Overview of Budgeted, Installed, and Cumulative GFDs for 2023.

Responsible centres with high effectiveness in 2023:

- ***OP MAD MUNICIPIOS NORTE:*** This centre demonstrated outstanding performance, achieving an effectiveness of 77.53% (69 OK devices out of 89 budgeted) and an installation rate of 143.82% (128 installed out of 89 budgeted). This indicates that the centre managed to operationalize more devices than originally planned.

- ***OP C. REAL OESTE:*** Showed strong performance with an effectiveness of 58.37% (150 OK devices out of 257 budgeted) and an installation rate of 79.77% (205 installed out of 257 budgeted), reflecting a solid effort in ensuring the installed devices were operational.
- ***OP SANTIAGO:*** Demonstrated notable performance with an effectiveness of 47.06% (72 OK devices out of 153 budgeted) and an installation rate of 111.76% (171 installed out of 153 budgeted), showing strong operational outcomes despite installing more devices than initially budgeted.
- ***OP FERROL:*** Showed an effectiveness of 37.75% (57 OK devices out of 151 budgeted) and an installation rate of 77.48% (117 installed out of 151 budgeted), indicating good operational performance.
- ***OP C. REAL ESTE:*** Achieved an effectiveness of 31.99% (127 OK devices out of 397 budgeted) and an installation rate of 50.38% (200 installed out of 397 budgeted), reflecting a commendable effort in operationalizing the deployed devices.
- ***OP CORUÑA OEST***: Demonstrated solid performance with an effectiveness of 30.38% (24 OK devices out of 79 budgeted) and an installation rate of 91.14% (72 installed out of 79 budgeted), showing a strong effort in making the installed devices operational.

Responsible centres facing challenges in 2023:

- ***OP MAD CAPITAL SUR:*** This centre had the poorest performance with an effectiveness of 0%, having no GFDs operational despite a budget of 56 devices and an installation rate of 21.43% (12 installed out of 56 budgeted).
- ***OP NOIA:*** This centre struggled with an effectiveness of 0.61% (1 OK device out of 165 budgeted) and an installation rate of 3.03% (5 installed out of 165 budgeted).
- ***OP ILLESCAS:*** Faced significant challenges with an effectiveness of 2.13% (2 OK devices out of 94 budgeted) and an installation rate of 13.83% (13 installed out of 94 budgeted), indicating major difficulties in getting devices operational.
- ***OP PONTEVEDRA:*** Despite installing a moderate number of devices, this centre had an effectiveness of 2.46% (3 OK devices out of 235 budgeted) and an installation rate of 18.72% (44 installed out of 235 budgeted).
- ***OP VIGO NORTE:*** This centre faced significant difficulties with an effectiveness of 3.69% (3 OK devices out of 82 budgeted) and an installation rate of 40.24% (33 installed out of 82 budgeted), showing that many of the installed devices were not operational.

2024 Installation Overview

By 2024, further improvements and adjustments were expected. Out of 7116 budgeted devices, 2557 were installed, marking an installed percentage of 35.93%. Despite the lower installation percentage compared to 2023, there was a higher focus on ensuring that the devices were operational. 1472 devices were marked as OK, resulting in an operational effectiveness of 20.68%. Below can be seen a figure where *axis y* represents the number of deployed devices and *axis x* the month of the year:

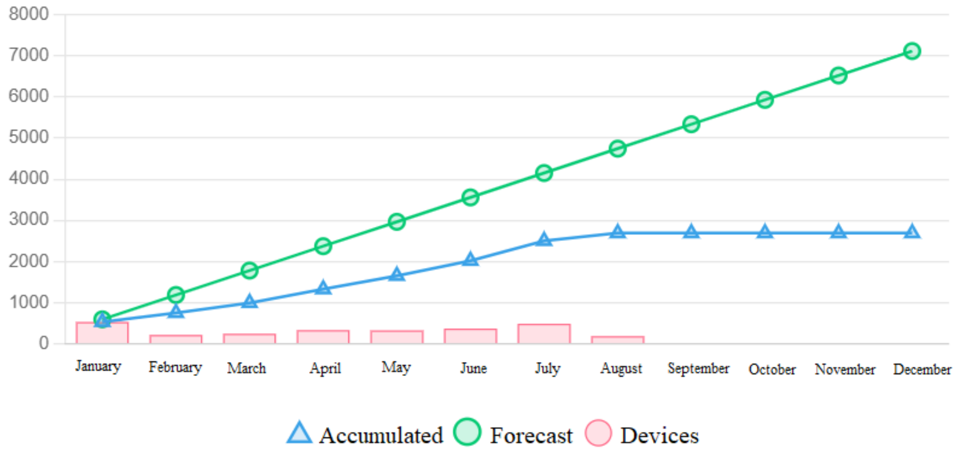

Figure 87. Yearly Overview of Budgeted, Installed, and Cumulative GFDs for 2024.

Responsible centres with high effectiveness in 2024:

- ***OP MAD MUNICIPIOS NORTE:*** This centre showed extraordinary performance, with an effectiveness of 266.67% (8 OK devices out of 3 budgeted) and an installation rate of 566.67% (17 installed out of 3 budgeted). This suggests that the centre managed to operationalize more devices than originally planned.
- ***OP VIGO NORTE:*** Demonstrated strong performance with an effectiveness of 50% (41 OK devices out of 82 budgeted) and an installation rate of 53.66% (44 installed out of 82 budgeted), showing a solid operational outcome.
- ***OP FERROL:*** Showed an impressive performance with an effectiveness of 45,45% (65 OK devices out of 143 budgeted) and an installation rate of 61.54% (88 installed out of 143 budgeted), reflecting a strong effort in making the installed devices operational.
- ***OP GUADALAJARA CUENCA:*** Achieved an effectiveness of 36.71% (152 OK devices out of 414 budgeted) and an installation rate of 40.58% (168 installed out of 414 budgeted), indicating a good level of operational success.
- ***OP SEGOVIA:*** Reached an effectiveness of 34.44% (52 OK devices out of 151 budgeted) and an installation rate of 48.34% (73 installed out of 151 budgeted), reflecting a commendable operational performance.

- ***OP CORUÑA EST:*** Achieved a 31.71% effectiveness (137 OK devices out of 432 budgeted) and an installation rate of 58.8% (254 installed out of 432 budgeted), showing significant improvement and a high operational outcome.

Responsible centres facing challenges in 2024:

- ***OP MAD CAPITAL SUR:*** This centre had the poorest performance with an effectiveness of 0%, having no GFDs operational despite a budget of 52 devices and an installation rate of 0%.
- ***OP MAD CAPITAL NORTE:*** This centre also had significant difficulties, with again an effectiveness of 0% and an installation rate of 5.26% (1 installed out of 19 budgeted).
- ***OP C. REAL OESTE:*** This centre struggled significantly, achieving an effectiveness of just 3.37% (15 OK devices out of 445 budgeted) and an installation rate of 6.52% (29 installed out of 445 budgeted).
- ***OP C. REAL ESTE:*** This centre faced challenges as well, with an effectiveness of 31.99% (127 OK devices out of 397 budgeted) and an installation rate of 50.38% (200 installed out of 397 budgeted).
- ***OP CORUÑA OEST:*** Faced significant challenges with an effectiveness of 4.42% (8 OK devices out of 181 budgeted) and an installation rate of 8.29% (15 installed out of 181 budgeted), indicating difficulties in ensuring the installed devices were operational.

Total Installation and Performance Analysis

Across the analysed period from 2021 to 2024, significant variations in the installation and operational states of GFDs were observed. The total number of budgeted devices over these years was 8854, with 4442 devices installed, marking an overall installation percentage of 50.17%. Out of these, 2266 devices were reported as operational (OK), indicating an overall operational effectiveness of approximately 25.59%.

Responsible centres with high effectiveness in the total deployment:

- ***OP MAD MUNICIPIOS NORTE:*** This centre exhibited an extraordinary performance, with an effectiveness of 63.36% (83 OK devices out of 131 budgeted) and an installation rate of 206.11% (270 installed out of 131 budgeted). This suggests that the centre managed to operationalize more devices than originally planned.
- ***OP FERROL:*** Demonstrated strong performance with an effectiveness of 46.92% (122 OK devices out of 260 budgeted) and an installation rate of 78.85% (205 installed out of 260 budgeted), showing a solid operational outcome.
- ***OP VIGO NORTE:*** Showed impressive results with an effectiveness of 46.15% (42 OK devices out of 91 budgeted) and an installation rate of 58.24% (53 installed out of 91 budgeted), reflecting a strong effort in making the installed devices operational.

- ***OP GUADALAJARA CUENCA:*** Achieved an effectiveness of 38.79% (192 OK devices out of 495 budgeted) and an installation rate of 50.30% (249 installed out of 495 budgeted), indicating a good level of operational success.
- ***OP SEGOVIA:*** Reached an effectiveness of 37.64% (67 OK devices out of 178 budgeted) and an installation rate of 56.18% (100 installed out of 178 budgeted), reflecting a commendable operational performance.
- ***OP CORUÑA EST:*** Achieved a 32.97% effectiveness (150 OK devices out of 455 budgeted) and an installation rate of 60.88% (277 installed out of 455 budgeted), showing significant improvement and a high operational outcome.

Responsible centres facing challenges in 2024:

- ***OP MAD CAPITAL SUR:*** This centre had the poorest performance with an effectiveness of 0%, having no GFDs operational despite a budget of 64 devices and an installation rate of 18.75% (12 installed out of 64 budgeted).
- ***OP MAD CAPITAL NORTE:*** This centre also had significant difficulties, with an effectiveness of 4.76% (1 OK device out of 21 budgeted) and an installation rate of 28.57% (6 installed out of 21 budgeted).
- ***OP VIGO SUR:*** This centre struggled with an effectiveness of 7.54% (13 OK devices out of 172 budgeted) and an installation rate of 30.23% (52 installed out of 172 budgeted), indicating significant challenges in getting devices operational.
- ***OP ARANJUEZ-OCÁÑA:*** The centre had an effectiveness of 10.32% (22 OK devices out of 678 budgeted) and an installation rate of 15.77% (107 installed out of 678 budgeted), indicating considerable difficulties in ensuring that the installed devices were operational.
- ***OP CORUÑA OEST:*** This centre faced challenges with an effectiveness of 12.5% (8 OK devices out of 64 budgeted) and an installation rate of 18.75% (12 installed out of 64 budgeted), indicating major difficulties in getting devices operational.

The total deployment analysis of GFDs from 2023 to 2024 reveals some patterns in the performance across various operational centres. Some centres, like *OP MAD MUNICIPIOS NORTE* and *OP FERROL*, have excelled, not only meeting but exceeding expectations in both installation rates and operational effectiveness. The high performance in these centres suggests that their implementation strategies (perhaps involving effective project management, resource allocation, and technical training) could serve as a model for other centres that are struggling. Similarly, *OP VIGO NORTE* and *OP GUADALAJARA CUENCA* demonstrated strong performance, likely due to robust support infrastructures or localized expertise.

On the other hand, significant challenges were evident in centres like *OP MAD CAPITAL SUR* and *OP MAD CAPITAL NORTE*, where operational effectiveness was negligible despite installation efforts. These underperforming centres raise critical questions about the underlying causes, which might include environmental challenges, insufficient technical support, or gaps in project planning. Addressing these issues will likely require targeted interventions, such as enhanced training, closer monitoring, or adjustments in deployment strategy. *OP ARANJUEZ-OCÁÑA* and *OP VIGO SUR* also faced difficulties, achieving low operational effectiveness despite moderate installation rates. This suggests potential issues with installation quality, ongoing maintenance, or initial deployment assessments that need to be further investigated and corrected.

Looking at the overall trends, an operational effectiveness of 53.47% across the total deployment is concerning, as it indicates that nearly half of the installed devices are not functioning as intended. The disparity in performance between different operational centres suggests that a one-size-fits-all approach to GFD deployment may not be effective. Instead, strategies should be tailored to the specific conditions and challenges of each centre, with successful centres sharing best practices and insights to help underperforming ones.

Strategically, these findings suggest that UFD should adopt a more flexible approach to GFD deployment. This might involve piloting projects in underperforming centres, increasing training for technical staff, or conducting more rigorous pre-installation assessments. Given the significant investment in GFDs, continuous monitoring and evaluation are essential to ensure that the devices meet expected operational standards. UFD may need to implement more frequent audits and performance reviews to promptly identify and address these issues, ultimately improving the reliability of new installations.

These insights, derived from a comprehensive analysis of the total deployment data, highlight both the successes and areas for improvement in the project. By proactively addressing the challenges identified, UFD can enhance the effectiveness of its GFD installations and strengthen the overall reliability of the network.

3.4.2 INTEGRATION WITH *G-DFT* APPLICATION AND ESIR SYSTEM

In this section, we will evaluate the effectiveness of the integration of GFDs within the previously described eSIR system. This analysis will focus on comparing the number of devices registered in the *G-DFT* application with those recorded in eSIR. Additionally, the presence of duplicated devices in eSIR to identify any potential issues in the current implementation will be examined.

According to current data, *G-DFT* application currently registers a total of 4,335 devices with no instances of duplication. This indicates that the registration process within *G-DFT* is functioning correctly, ensuring that no serial numbers are duplicated and that no two GFDs are monitoring the same asset.

On the other hand, the eSIR system has 3,442 devices registered. Among these, there are 36 instances of duplicated serial numbers and 6 devices that do not have a BDI registration number, meaning the specific location of these assets is not being recorded. This means that, of the 4,335 devices registered in *G-DFT*, only 3,406 have been correctly registered in eSIR, leaving a gap of 929 devices that are either unregistered or incorrectly registered in the eSIR system.

The integration process reveals a significant discrepancy between the devices registered in *G-DFT* and those in eSIR. Ideally, the number of devices registered in both systems should match. However, with 3,406 out of 4,335 devices correctly registered in eSIR, approximately 78.56% of the GFDs have been properly integrated. The remaining 21.44%, which includes the 929 unregistered or incorrectly registered devices, as well as the 36 duplicated entries and the 6 devices lacking location information, indicate areas where further refinement and checks are necessary. Improving these aspects is crucial to ensure the full and accurate integration of GFDs across all UFD systems.

4 CONCLUSIONS

These conclusions will analyse the development of the initially proposed objectives for this dissertation and provide a summary of the achievements and challenges encountered throughout the implementation of Ground Fault Detectors (GFDs) in UFD's network. These insights not only reflect the technical aspects of the project but also offer guidance for future improvements. The following points summarize the key findings and strategic implications of the work undertaken, aligning with the initial objectives set out at the beginning of the project.

1. Automating Data Collection:

The project successfully implemented processes for the automated collection of data from GFD devices. This automation not only enhanced the real-time monitoring capabilities of the network but also ensured that data consistency and accuracy were maintained. The successful automation of data collection has led to improved incident response times and more reliable fault detection, aligning with UFD's goals of enhancing network safety and reliability.

2. Analysing the Performance of GFD Devices:

The analysis of GFD devices installed across UFD's network revealed a mixed performance outcome. While certain operational centres, such as *OP MAD MUNICIPIOS NORTE* and *OP FERROL*, demonstrated exceptional effectiveness with over 60% of devices operating successfully, other centres like *OP MAD CAPITAL NORTE* and *OP MAD CAPITAL SUR* exhibited significant challenges with nearly 0% effectiveness. This variance highlights both the potential of GFD technology and the need for targeted support and further refinement in implementation strategies to ensure consistent performance across all centres. This objective was partially achieved, as the performance analysis provided critical insights but also indicated areas for improvement.

3. Consolidation and Organisation of GFD Documentation:

A significant achievement of this project is the successful consolidation and organization of GFD-related documentation within UFD. In the course of this work, a comprehensive and structured overview of the GFD initiative was developed, drawing together information from a variety of sources. This effort included a thorough examination of the technical specifications of GFDs, the relevant regulations and standards, the data communication framework, and the operation of the manufacturer's data collection application (*G-DFT*).

Given the challenges associated with the fragmented and proprietary nature of GFD implementation across different companies, this project effectively addressed a critical need within UFD. The organized documentation now provides a clearer and more accessible repository of GFD knowledge, which will significantly support UFD's ongoing and future operations.

4. Automating Integration of New GFD Devices into Management Systems:

The integration of new GFD devices into UFD's Asset Management Interface (GdA) and Intelligent Network System (eSIR) was successfully automated, streamlining the process and reducing manual input errors. The automatic integration has significantly improved the efficiency of incorporating new devices into the system, ensuring that all relevant data is accurately reflected in real-time. This has been a significant step forward in modernizing UFD's network management capabilities. The objective was fully achieved, providing a foundation for future digitalization efforts.

Key Insights and Strategic Implications:

The implementation of GFDs within UFD's network, while technically successful in many areas, has revealed opportunities for improvement, particularly in achieving consistent operational effectiveness across different centres. The overall effectiveness rate of 53.47% underscores the potential of GFD technology and highlights the importance of developing tailored strategies to address the specific challenges faced by lower-performing centres.

The project has made significant strides in digitalizing UFD's infrastructure, particularly through the successful automation of both integration and data collection processes. These advancements have established a strong foundation for continued digitalization efforts, contributing to improved network management and operational efficiency.

While the deployment has shown varying levels of effectiveness, the experience gained, and the insights uncovered through this project provide valuable guidance for future enhancements. By focusing on optimizing technical performance and ensuring consistent results across all centres, UFD is well-positioned to further capitalize on the benefits of GFD technology.

In conclusion, this project has marked substantial progress in advancing UFD's digitalization objectives. The lessons learned will be crucial in guiding future strategic decisions, enabling UFD to continue leading in innovation and ensuring the long-term success of its network management initiatives.

5 ANNEXES

ANNEX A - ALIGNMENT WITH THE SUSTAINABLE DEVELOPMENT GOALS (SDGS)

The integration of GFDs in UFD's distribution network aligns with several United Nations Sustainable Development Goals (SDGs), emphasizing sustainable, dependable, and efficient energy solutions. This project primarily aligns with the following points:

- ***SDG 7: Affordable and Clean Energy***

Ensure access to affordable, dependable, sustainable, and modern energy for all. The implementation of GFDs enhances the reliability and efficiency of the energy supply by improving fault detection and response times, thereby reducing downtime, and ensuring a more stable and continuous energy supply to consumers in case of a ground fault on the electrical grid.

- ***SDG 9: Industry, Innovation, and Infrastructure***

Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. This project supports the development of a robust and modern energy infrastructure through the integration of advanced GFD technology, fostering innovation in energy management and infrastructure resilience.

- ***SDG 11: Sustainable Cities and Communities***

Make cities and human settlements inclusive, safe, resilient, and sustainable. By improving the detection and management of ground faults, the GFDs contribute to the safety and resilience of electrical infrastructure in urban areas, reducing the risk of electrical failures and enhancing the reliability of the energy supply in communities.

- ***SDG 13: Climate Action***

Take urgent action to combat climate change and its impacts. The implementation of GFDs reduces the need for unnecessary field interventions by providing continuous monitoring and remote fault detection. This decrease in field operations significantly cuts down on the emissions associated with travel and manual inspections, supporting the reduction of greenhouse gas emissions, and promoting more sustainable operational practices.

Through all these alignments, the project not only advances UFD's operational goals but also contributes to global efforts in achieving a sustainable and resilient energy future.

ANNEX B – PERFORMANCE ANALYSIS DATA

				State				
Responsible Center	***Installed Percentage***	***Budgeted Devices***	***Installed Devices***	***Disconnected***	***OK***	***Power Supply***	***Internal Error***	***Sensor Error***
OP ARANJUEZ-OCAÑA	-	0	0	0	0	0	0	0
OP C. REAL ESTE	-	0	0	0	0	0	0	0
OP C. REAL OESTE	-	0	0	0	0	0	0	0
OP GUADALAJARA CUENCA	-	0	0	0	0	0	0	0
OP ILLESCAS	-	0	0	0	0	0	0	0
OP LA BAÑEZ	-	0	0	0	0	0	0	0
OP MAD CAPITAL NORTE	-	0	0	0	0	0	0	0
OP MAD CAPITAL SUR	-	0	0	0	0	0	0	0
OP MAD MUNICIPIOS NORTE	-	0	115	106	6	3	0	0
OP PONFERRADA	-	0	0	0	0	0	0	0
OP SEGOVIA	-	0	0	0	0	0	0	0
OP CORUÑA EST	-	0	0	0	0	0	0	0
OP CORUÑA OEST	-	0	0	0	0	0	0	0
OP FERROL	-	0	0	0	0	0	0	0
OP MONFORTE	-	0	22	22	0	0	0	0
OP NOIA	-	0	0	0	0	0	0	0
OP ORENSE	-	0	0	0	0	0	0	0
OP PONTEVEDRA	-	0	0	0	0	0	0	0
OP SANTIAGO	-	0	0	0	0	0	0	0
OP VIGO NORTE	-	0	0	0	0	0	0	0
OP VIGO SUR	-	0	0	0	0	0	0	0
OP VILLAGARCIA	-	0	0	0	0	0	0	0
OP XINZO	-	0	0	0	0	0	0	0
TOTAL		0	137	128	6	3	0	0

Figure 88. Performance and status of GFD installations by responsible centre for 2021.

				State				
Responsible Center	***Installed Percentage***	***Budgeted Devices***	***Installed Devices***	***Disconnected***	***OK***	***Power Supply***	***Internal Error***	***Sensor Error***
OP ARANJUEZ-OCAÑA	-	0	0	0	0	0	0	0
OP C. REAL ESTE	-	0	0	0	0	0	0	0
OP C. REAL OESTE	-	0	0	0	0	0	0	0
OP GUADALAJARA CUENCA	-	0	0	0	0	0	0	0
OP ILLESCAS	-	0	0	0	0	0	0	0
OP LA BAÑEZ	-	0	0	0	0	0	0	0
OP MAD CAPITAL NORTE	-	0	0	0	0	0	0	0
OP MAD CAPITAL SUR	-	0	0	0	0	0	0	0
OP MAD MUNICIPIOS NORTE	-	0	10	9	0	1	0	0
OP PONFERRADA	-	0	0	0	0	0	0	0
OP SEGOVIA	-	0	0	0	0	0	0	0
OP CORUÑA EST	-	0	0	0	0	0	0	0
OP CORUÑA OEST	-	0	0	0	0	0	0	0
OP FERROL	-	0	0	0	0	0	0	0
OP MONFORTE	-	0	0	0	0	0	0	0
OP NOIA	-	0	0	0	0	0	0	0
OP ORENSE	-	0	0	0	0	0	0	0
OP PONTEVEDRA	-	0	0	0	0	0	0	0
OP SANTIAGO	-	0	0	0	0	0	0	0
OP VIGO NORTE	-	0	0	0	0	0	0	0
OP VIGO SUR	-	0	0	0	0	0	0	0
OP VILLAGARCIA	-	0	0	0	0	0	0	0
OP XINZO	-	0	0	0	0	0	0	0
TOTAL		0	10	9	0	1	0	0

Figure 89. Performance and status of GFD installations by responsible centre for 2022.

				State				
Responsible Center	***Installed Percentage***	***Budgeted Devices***	***Installed Devices***	***Disconnected***	***OK***	***Power Supply***	***Internal Error***	***Sensor Error***
OP ARANJUEZ-OCAÑA	19.49%	554	108	12	22	13	54	7
OP C. REAL ESTE	50.38%	397	200	25	127	23	22	3
OP C. REAL OESTE	79.77%	257	205	25	150	8	19	3
OP GUADALAJARA CUENCA	22.19%	365	81	22	40	8	6	5
OP ILLESCAS	13.83%	94	13	1	2	2	5	3
OP LA BAÑEZ	53.7%	257	138	37	50	29	19	3
OP MAD CAPITAL NORTE	28.57%	21	6	1	1	0	1	3
OP MAD CAPITAL SUR	21.43%	56	12	2	0	0	10	0
OP MAD MUNICIPIOS NORTE	143.82%	89	128	22	69	17	12	8
OP PONFERRADA	41.25%	80	33	13	11	5	4	0
OP SEGOVIA	31.03%	87	27	4	15	0	1	7
OP CORUÑA EST	5.96%	386	23	4	13	6	0	0
OP CORUÑA OEST	91.14%	79	72	17	24	23	7	1
OP FERROL	77.48%	151	117	18	57	32	10	0
OP MONFORTE	20.25%	484	98	19	38	13	26	2
OP NOIA	3.03%	165	5	0	1	2	2	0
OP ORENSE	24.17%	451	109	26	35	16	31	1
OP PONTEVEDRA	18.72%	235	44	9	7	13	15	0
OP SANTIAGO	111.76%	153	171	31	72	26	40	2
OP VIGO NORTE	27.27%	33	9	3	1	1	4	0
OP VIGO SUR	15.57%	122	19	4	3	5	7	0
OP VILLAGARCIA	45.07%	213	96	18	40	23	11	4
OP XINZO	8.86%	271	24	6	10	1	7	0
TOTAL	34,76%	5000	1738	319	788	266	313	52

Figure 90. Performance and status of GFD installations by responsible centre for 2023.

				State				
Responsible Center	*Installed Percentage*	*Budgeted Devices*	*Installed Devices*	*Disconnected*	*OK*	*Power Supply*	*Internal Error*	*Sensor Error*
OP ARANJUEZ-OCAÑA	17.72%	570	101	11	40	22	22	6
OP C. REAL ESTE	6.38%	470	30	4	18	7	1	0
OP C. REAL OESTE	6.52%	445	29	7	15	3	2	2
OP GUADALAJARA CUENCA	40.58%	414	168	7	152	7	2	0
OP ILLESCAS	47.27%	165	78	5	51	10	9	3
OP LA BAÑEZ	32.61%	414	135	7	106	14	7	1
OP MAD CAPITAL NORTE	5.26%	19	1	0	0	1	0	0
OP MAD CAPITAL SUR	0	52	0	0	0	0	0	0
OP MAD MUNICIPIOS NORTE	566.67%	3	17	5	8	3	0	1
OP PONFERRADA	34.16%	161	55	5	32	9	6	3
OP SEGOVIA	48.34%	151	73	6	52	8	6	1
OP CORUÑA EST	58.8%	432	254	18	137	78	21	0
OP CORUÑA OEST	8.29%	181	15	0	8	5	2	0
OP FERROL	61.54%	143	88	2	65	14	7	0
OP MONFORTE	38.73%	790	306	31	140	100	32	3
OP NOIA	53.43%	350	187	11	106	54	13	3
OP ORENSE	57.75%	613	354	53	152	117	29	3
OP PONTEVEDRA	41.59%	452	188	13	108	42	22	3
OP SANTIAGO	9.39%	309	29	0	23	6	0	0
OP VIGO NORTE	53.66%	82	44	0	41	0	3	0
OP VIGO SUR	24.12%	199	48	4	15	16	13	0
OP VILLAGARCIA	54.01%	237	128	13	56	34	24	1
OP XINZO	49.35%	464	229	16	147	37	27	2
TOTAL	35,93%	7116	2557	218	1472	587	248	32

Figure 91. Performance and status of GFD installations by responsible centre for 2024.

				State				
Responsible Center	*Installed Percentage*	*Budgeted Devices*	*Installed Devices*	*Disconnected*	*OK*	*Power Supply*	*Internal Error*	*Sensor Error*
OP ARANJUEZ-OCAÑA	30.83%	678	209	23	62	35	76	13
OP C. REAL ESTE	34.33%	670	230	29	145	30	23	3
OP C. REAL OESTE	0,36	650	234	32	165	11	21	5
OP GUADALAJARA CUENCA	50.3%	495	249	29	192	15	8	5
OP ILLESCAS	51.12%	178	91	6	53	12	14	6
OP LA BAÑEZ	49.46%	552	273	44	156	43	26	4
OP MAD CAPITAL NORTE	0,28	25	7	1	1	1	1	3
OP MAD CAPITAL SUR	18.75%	64	12	2	0	0	10	0
OP MAD MUNICIPIOS NORTE	206.11%	131	270	142	83	24	12	9
OP PONFERRADA	45.36%	194	88	18	43	14	10	3
OP SEGOVIA	56.18%	178	100	10	67	8	7	8
OP CORUÑA EST	60.88%	455	277	22	150	84	21	0
OP CORUÑA OEST	34.39%	253	87	17	32	28	9	1
OP FERROL	78.85%	260	205	20	122	46	17	0
OP MONFORTE	47.97%	888	426	72	178	113	58	5
OP NOIA	54.08%	355	192	11	107	56	15	3
OP ORENSE	64.13%	722	463	79	187	133	60	4
OP PONTEVEDRA	46.77%	496	232	22	115	55	37	3
OP SANTIAGO	41.67%	480	200	31	95	32	40	2
OP VIGO NORTE	58.24%	91	53	3	42	1	7	0
OP VIGO SUR	30.73%	218	67	8	18	21	20	0
OP VILLAGARCIA	67.27%	333	224	31	96	57	35	5
OP XINZO	51.84%	488	253	22	157	38	34	2
TOTAL	50,17%	8854	4442	674	2266	857	561	84

Figure 92. Actual performance and current status of GFD installations by responsible centre.

6 REFERENCES

Naturgy Internal Documents

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