R2D2

Reliability, Resilience and Defense technology for the griD

D6.1 – Design of the enhanced maintenance and asset management tool

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Executive Summary

This deliverable is a report describing the design of the tools and components composing the EMMA (Enhanced Assets Maintenance And Management Toolkit) product in WP6.

EMMA is one of the four products to be developed in R^2D^2 project, and it aims to improve the reliability of power systems through different tools and approaches. On one hand, EMMA will integrate novel automated technologies (based on UAV and AI) in the equipment inspection, and asset management to enhance the procedure for the assets management, with a special focus on the critical and emergency conditions of the system. On the other hand, it will improve the coordination and planning maintenance intervention in case of outages through novel optimization techniques. Both aspects will contribute to establishing a predictive maintenance approach in the daily process of system operators.

In particular, this document reports the activities performed in Tasks 6.1, 6.2, 6.3 and 6.4 to design the different elements in EMMA, corresponding to the first iteration in the process of the product development (from M7 to M12). The aim is to provide all the technical details useful for the actual development of the product planned later from M13 to M24. In addition, this deliverable will update, when needed, information about Use Cases, requirements and KPIs, provided in Deliverable 2.1. Any change or variation required in this sense will be later reported in D2.3 (M16), while the development of the EMMA product will be described in D6.2 (M24).

For each one of the overmentioned tasks, the internal architecture has been described together with the technical details of the algorithms to be developed and the input/output data of each component.

This deliverable, together with the other technical deliverables D3.1, D4.1 and D5.1, contributes to achieving Milestone #3 “Design of the four products”, due by M12. As a matter of fact, each of these documents describes in detail the design of the product to which it refers along with the methodology and techniques used.

Keywords

Power System Resiliency, Reliability, UAV, Predictive Maintenance, Asset Management, Outage Planning, Remedial Actions, Dynamic Line Rating, IA.

Copyright Statement

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1.3 ACRONYMS

Table 1 – Acronyms

Abbreviation	Definition
AI	Artificial Intelligence
AMI	Advance Metering Infrastructure
API	Application Program Interface
BAU	Business as Usual
CIM	Common Information Model
CSK	Cost Sharing Key
DACF	Day Ahead Congestion Forecast
DB	Data Base
DGA	Dissolved Gas Analysis
DL	Deep Learning
DLR	Dynamic Line Rating
DMS	Distribution Management System
DoA	Description of Action
DSO	Distribution System Operator
EHV	Extra High Voltage
EIC	Energy Identification Coding
EMS	Energy Management System
EPES	Electric and Power Energy Systems
FS	File Server
FTP	File Transfer Protocol
GA	Grant Agreement

GIS	Geographic information system
GUI	Graphic User Interface
HDB	
HMI	Human Machine Interface
HV	High Voltage
IAP	Intelligent alarm processing
IDCF	Infra Day Congestion Forecast
IGM	Individual Grid Model
IR	InfraRed
LF	Load Flow
ML	Machine Learning
NN	Neural Network
NTL	Non-Technical Losses
OF	Operator Fabric
O&M	Operation and Maintenance
OLPF	On-line power flow
OMS	Operation and Maintenance System
OP	Outage Planning
OPA	Outage Planning Application
OPC	Outage Planning Coordination
OPDB	Outage Planning Database
OPR	Outage Planning Processor
PQEL	Power Quality Emission Level
PT	Power Transformer
PV	Photovoltaic
RA	Remedial Actions
RACS	Remedial Actions Cost Sharing
RCC	Regional Coordination Centre
ROSC	Regional Operational Security Coordination
RGB	Red-Green-Blue
RTK	Real Time Kinematic
SCA	Short Circuit Analysis
SCADA	Supervisory Control and Data Acquisition
SE	State Estimation
SOGL	System Operation Guidelines
TP	Topology Processor
TSC	Transient Stability Calculation
TSO	Transmission System Operator
TSP	Traveling Salesman Problem
TSPPP	Traveling Salesman Problem with Priority Prizes
TSPWP	Travelling Salesman Problem with Profits
TTA	Topology Transfer Application
UAV	Unmanned Aerial Vehicle
UC	Use Case
UI	User Interface
YOLO	You Only Look Once

2 Introduction

2.1 PURPOSE AND SCOPE OF THE DOCUMENT

The current deliverable D6.1 "Design of the enhanced maintenance and asset management tool" reports the first results of Tasks 6.1, 6.2, 6.3 and 6.4, each one in charge of the design and implementation of the applications composing the tool suite to be delivered by WP6. The purpose of this deliverable is to detail the functionalities and present the design of the applications composing the EMMA product in WP6. EMMA is a nickname for Enhanced Maintenance and Asset Management, and it is a product devoted to supporting system operators in the management and maintenance of their critical assets. EMMA is basically a toolkit composed of loosely coupled tools developed in tasks T6.1-4. and its main goal is to contribute to the enhancement of the EPES reliability ensuring a fast recovery of the network and to improve management of the physical assets through the adoption of robotic technology and AI. The specifications of teaching tools are based on the use cases and requirements analysis, and assumptions described in Deliverable D2.1 "1st version of the Requirements and Detailed Architecture Design" [1].

This document deep dives into the technical aspects of the different functionalities that form each of the tools, covering the functionalities to be developed and the main features the components will include. Following the strategic objectives of the R^2D^2 projects described in the DoA [2] the purpose of EMMA is to deliver a toolkit to improve the reliability of electrical assets and to contribute to enhancing the resiliency of EPES through advanced data-driven solutions and automated and robotic technologies.

EMMA is composed of several modules corresponding to the activities in each task of the WP6. Each task includes one or several tools which address specific commitments from the UCs. In this sense, for each component within a specific application, the features that are offered to each of the applications' end-users have been defined. An internal architecture of each tool's component is presented as well. This architecture is not intended as an SGAM framework (like in D2.1), but it is an internal representation of the building blocks of each one of the modules. The necessary data inputs and the expected outputs of each component have also been identified to validate that the requirements previously defined will be met. Moreover, each interaction that will occur between different components of the same tool or between different tools is also described in order to make sure that all the required interfaces will be adequately developed.

2.2 STRUCTURE OF THE DOCUMENT

This document consists of six chapters, including Chapters 1 and 2 for the introduction to the deliverable, chapter 5 for the conclusions drawn during its writing and chapter 6 for the consulted references. The core of deliverable D6.1 is provided in chapters 3 and especially chapter 4. Chapter 3 acts as a prelude to chapter 4, where the background is described with the existing technologies already available for each tool in the product and the innovation brought by R^2D^2 in the future tools' development is presented. In addition, this section refers to the requirements and use cases defined in D2.1, to have a clear correspondence for each tool in the product.

In chapter 4 the applications and their components are described in detail providing information about the related features, the internal architecture, the inputs/outputs of data exchanged and preliminary information about the User Interface (UI). The document is finally closed by chapter 5 which recap the main findings on the WP6 activities and the next steps in the upcoming months.

3 State of the Art for EMMA product

3.1 OVERVIEW OF THE PRODUCT

EPES are critical elements that impact the security of infrastructures and persons in many ways. There is a strong correlation between EPES reliability and electrical equipment maintenance, and system operators invest a lot of resources in it. With the advent of new smart grid technologies, the rapid development of big data processes and machine learning in the electricity industry has tremendously increased the number of commercial solutions for maintenance applications and asset management. Today many solutions addressing different aspects or technologies of the power system components are still available.

EMMA toolkit aims at advancing the state of the art of asset management and maintenance, mainly by making use of the increasing amount of data available from the field devices and control systems. This toolkit is conceived to fulfil interoperability features while adopting a data-driven approach to combine big data management and machine learning analytics, considering not only state-of-the-art frameworks, like Tensorflow [3] but also innovative solutions like transformer neural networks.

The EMMA toolkit is composed of a set of independent tools that focus on different elements and dimensions of EPES maintenance and security. EMMA can be considered as a framework of loosely coupled tools, even though some interactions among tools are described In the relevant sections. Each tool can be mapped to a specific task of the work package according to this structure:

- <u>T6.1 Equipment inspection through autonomous image acquisition</u>
  Goal: Automatic recognition of potential degradation, damages and failures of the assets (selected elements, equipment and devices at pilot sites) through multi-spectral image acquisition via UAV and fixed cameras.
  Benefit: Early detection of potential threats that may cause shortage - predictive maintenance
  Tools:
    - EMMA ARGOS
    - EMMA SURVEILLANCE
- <u>T6.2 Optimal Asset Management</u>
  Goal: Provide TSO and DSO with a tool that improves the reliability of the equipment, and the resilience of the overall system.
  Benefit: Early detection of potential threats that may cause a shortage or economic loss - predictive maintenance.
  Tools:
    - EMMA DYML
    - EMMA ETER
- <u>T6.3 Resource management in case of critical events</u>
  Goal: Support the network operator to properly undertake the necessary actions to maintain the electrical system, considering not only the optimization of the common daily scheduled maintenance tasks but also tasks associated with the restoration of the grid after extreme events (weather, sabotage, cyber-attacks, accidents, etc.).
  Benefit: optimized scheduling of the workforce to perform the required maintenance tasks in the best possible way.

Tools:
- EMMA GIMAN

- <u>T6.4 maintenance coordination and planning</u>
  Goal: Tools developed in T6.4 will focus primarily on delivering advanced solutions when it comes to achieving TSO's needs for the outage planning optimisation and planned maintenance.
  Benefit: The main benefit from the adoption of the tool-suite developed in this task is to cover the needs of the larger preventive maintenance framework, by automatizing manually done processes, which will result in having more efficient business processes
  Tools:
  - Outage planning optimization – OP tool
  - Automatic emissions level calculator – PQEL tool
  - Cost-sharing of RA with cross-border impact – RACS tool
  - Automation of transient stability calculations – TSC tool
  - Outage coordination and automated creation of topology files for individual network models – TTA tool
  - DLR integration with IGM and SCADA/EMS – DLR tool

3.2 STATE OF THE ART

This chapter describes the state of the art of the different tools to be developed in WP6. The next section called "Background" (3.2.1) establishes the starting point of the development for each tool, that is the Business-as-Usual (BAU) scenario. In some cases, involved partners will not start their development from scratch, but they start from previous knowledge acquired. As a matter of fact, this experience can be an existing service or product or even technical knowledge or skill in a specific field. References are included to give evidence of the existing knowledge through a website, a scientific paper or an R&D public project. Also, indications of the actual relevance at the industrial or scientific level of the considered tool are provided. In subsection 3.2.2 the actual innovations to be provided through WP6 development are described in order to provide effective contribution for each task and tool by partners in R^2D^2.

3.2.1 Background

Regarding the activities included in Task 6.1, these will be geared toward the development of a software tool for the inspection of power grid components and assets through the use of images acquired from drones. This area represents an important area for the development of new applications in the electrical industry as it allows the entire infrastructure to be analysed using automatic and self-learning methods that enable rapid assessment of the operating conditions of the inspected elements. The relevance resides in the fact power systems are critical infrastructure and the service must be continuous and stable within the given operational ranges. There could be natural (environment, weather, animals, vegetation, etc.) or human (operational, ageing, etc.) threats that may affect the normal status and operation of the network. These factors may have an impact on the mechanical (fatigue, creeping, cracking) electrical (discharge, arcing, overheating) or chemical (corrosion,

contamination) properties of all physical elements involved. The benefits are numerous and allow for increasing the resilience and reliability of power systems, minimizing the time and cost of maintenance activities and ensuring higher standards in the continuity of supply service.
It is possible to find in the literature many examples of UAV and image analysis in power systems [4], through different sensors (thermal. optical, lidar, vibration, etc.[5] [6]) and focused on the several elements composing the system (tower, line, insulators, transformers, etc. [7][8]). Consequently, many techniques have been proposed to analyse and treat the images and data acquired through UAVs.
ETRA is the leader of this task with some previous experience in UAV autonomous flight in land surveillance and territory defence from past R&D national funded projects [9]. Figure 1 is a collage of some pictures taken during such projects, showing the virtual cockpit developed and the devices used. Thanks to these previous activities ETRA is able to take advantage of the knowledge for drone piloting, identifying and selecting the proper sensors to equip to UAV, real-time data management, processes management (in case some pre-processing, or analysis can be embedded in the drone), and image processing and analysis. Apart from this generic knowledge, the tools in this task will be developed from scratch with the aim of obtaining a brand-new product for the Company (see section 4.1 for technical details of the tools).

Figure 1 – Example of previous activities in research projects with drones, by the task leader

Moving to T6.2, the first part of the task deals with the optimal management of the assets. In this task, critical assets in electric substations will be considered, which means a special focus will be put on the Power Transformer (PT), with the aim of understanding in real-time the status of the health of such critical components of power systems. Taking advantage of the big volumes of data generally acquired by SCADA and of the specific additional measures such as the Dissolved Gas Analysis (DGA), this task will predict the status of the health of PTs, through customised AI models described in section 4.2. Once available, this tool will be later integrated into the so-called ETER [10] platform, a Distribution Management System

(DMS) by ETRA I+D as a new functionality, to be developed from scratch. ETER is a "tool designed to control, manage and monitor the grid, improving its flexibility, stability and security, being particularly relevant in scenarios with high penetration of renewable energies. ÉTER offers multiple capabilities in the field of improved grid observability and the use of AI in decision making." ETER takes advantage of the SCADA integration to provide added value services to system operators and microgrid managers. This new functionality from T6.2 will bring predictive maintenance capabilities into asset management, and it will integrate real-time alarms in case of critical conditions of the monitored asset, preventing incipient failures and avoiding interruptions in power supply.

The development of the EMMA-DYML will start from the knowledge acquired through the H2020 Trinity project [11], coordinated by ETRA. In this project among many SW tools for the power system, ETRA developed an application to predict failures in wind turbine generators through Electrical and temperature measurements, and log data. In EMMA-DYML a similar procedure will be applied to PTs, data input will come from a substation SCADA and an AI model will be developed from scratch to be tailored for this very asset (see section 4.2.1 for more details).

The predictive maintenance in power system equipment is extensively described in the literature, especially regarding PT. Most of the literature is mainly focused on HV and EHV oil PTs due to their critical role in the system, therefore adopting Dissolved Gas Analysis (DGA) [12], [13], [14]. Data-driven methodologies have been recently introduced in DGA as well, as witnessed in [15] where a fuzzy logic approach is used to interpret the DGA results, or in [16] where several statistical approaches are adopted in a joint methodology. Fuzzy logic is also used in [17], where authors propose a technique to monitor the deformation of solid insulation to early detect incipient faults. On the other hand, a metaheuristic algorithm is used in [18] while a holistic machine learning solution is proposed in [19], but always based on analysing DGA results.

In the second part of the task, a common problem in electricity metering will be examined: the Non-Technical Losses (NTL). NTLs are mainly due to fraud behaviours from customers like smart metering tampering or illegal connections in the grid and may represent a criticality in developed Countries as well [20]. There are plenty of techniques for trying to detect technical losses [21] [22], some of them deal with power system analysis and calculation (load flow calculation to compare the load profile in the edge nodes and compare it with billing records.) while others are mostly data-driven (applying big data techniques to detect anomalies in demand profile patterns). Both methods have pros and cons, and it is not possible a one-fit-all solution to such a complex problem.
As this problem is tightly bound to the metering system, it is interesting for ETRA, as task leader, to develop a tool to detect NTL to improve its smart metering platform. ETRA has developed its own smart meter product [23], starting from the H2020 project NobelGrid [24]. Later on, the Company had the possibility to deploy this new product in several H2020 projects [25][26][27] to test the actual operational capabilities of the hardware. Bearing in mind that ETRA has no prior experience in the development of tools for NTL detection, the possibility of being able to equip the products currently in its portfolio of services with new fraud-finding capabilities is of great interest to the company; since the NTL calculation needs grids simulation and smart-meters profiles analysis (see section 4.2.2 for more details) it can perfectly couple with two overmentioned products: the DMS (ETER, which already provide the load flow calculation capability) and the smart metering platform(which can provide the load profiles). Figure 2 is presented a screenshot of ETER by ETRA, which can be enriched with NTL can be enriched after R^2D^2 with new functionalities from T6.2

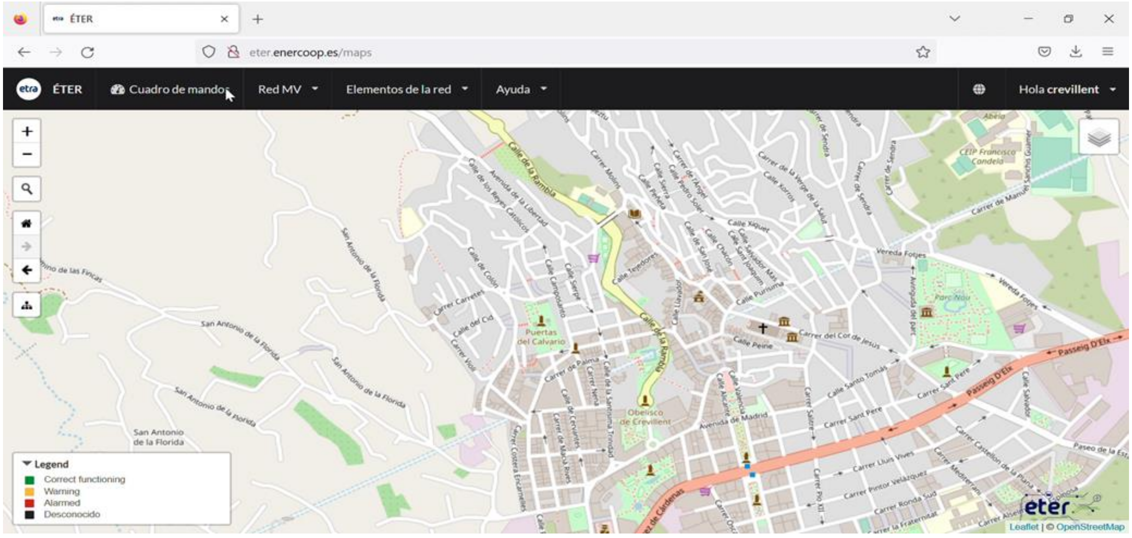


Figure 2 – Screenshot of the product ETER by ETRA

When it comes to T6.3 the focus is on how to organise and prioritize maintenance interventions after certain conditions or events. To this end, the starting point for the task leader is a platform (called GIMAN) to manage the resources (human and equipment) for maintenance. In recent years the magnitude and recurrence of blackouts due to extreme weather events are stressing power grids at a moment when climate policies are increasing the role of electrification in transportation, heating, and industrial processes [28][29]. Moreover, the presence of distributed renewable sources at the distribution level imposes a quicker recovery of the system even at medium and low voltage, to dispatch the energy produced at the edge nodes of the system and enable full exploitation of renewables in critical conditions (i.e. microgrids islanding in case of blackout, and providing flexibility to transmission system [30][31][32]). These assumptions are included in the R^2D^2 strategic objectives, and, more specifically, T6.3 will be responsible to contribute a faster recovery of the grid through the optimization of workforce and asset management. The functionalities described in section 4.3.1 will be developed from scratch but based on some internal skills of the task leader. A tool was developed in the H2020 SYNERGY project [33] to create a priority list in transformer maintenance interventions but based only on electrical parameters and out of any context of system recovery and blackouts due to the impact of extreme events. The tool to be developed in T6.3 will be integrated into the GIMAN platform, a product by ETRA aimed at providing a unique solution for the global management of maintenance for utilities. The product is very mature and consolidated in the company's portfolio, but it is more oriented to other domain applications (public lighting, traffic, etc.) and it can be enriched with new functionalities for distribution grids. This is the starting point for the development of optimization of maintenance resources in T6.3 and the functionality and the tools to enrich GIMAN are reported in section 4.3.1. In Figure 3 a couple of screenshots of GIMAN are shown, where on the right is visible a georeferenced map to visualise work-teams, assets' location, storages etc., while on the left there is an inventory management. More information about the technical specifications of GIMAN is included in section 4.3.1.

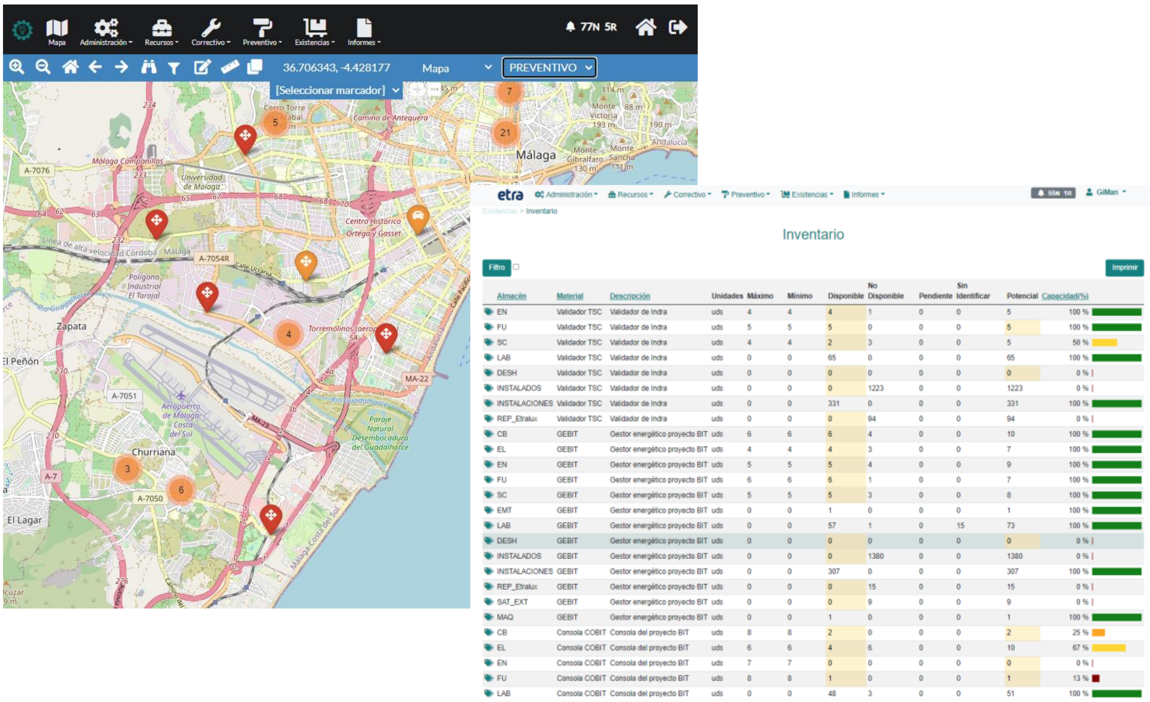


Figure 3 – Two screenshots of the product GIMAN by ETRA

EMMA product will be enriched by T6.4 through a set of six modular components. The background narrative for those six tools is described below.

- OP Tool. Outage planning is one of the most important tasks in the field of operational planning. This type of planning takes place at several time intervals, such as yearly, quarterly, monthly, and weekly.
  Due to its importance, there are several documents that regulate this area, primarily EU regulation on System Operation Guidelines (SOGL). This document foresees that TSOs coordinate outage planning at the national level (which includes cooperation with DSOs, producers and other significant grid users), while RCCs coordinate outage planning at the regional level, with the active involvement of TSOs.
  When planning outages, empirical criteria can be used to prevent problems in the network, but a more advanced way is to use seasonal network models that can be used to numerically analyse whether a planned outage violates the system's safe operation criteria.
  The idea for this tool was inspired by the possibility of using network models in this business process.
- PQEL Tool. Emission levels refer to certain aspects of power quality such as harmonics, flickers and asymmetries. System operators are obliged to keep these power quality distortions at a level in accordance with relevant international standards.
  In order for this to be possible, the system operator must determine the permissible emission levels of harmonics, flicker and asymmetry for each grid user. This is usually done in the process of connecting the object to the system. After that, when the object goes into operation, the system operator measures the power quality at the connection point for each of the mentioned phenomena.

Relevant international standards recommend a methodology for determining emission levels. However, the implementation of this methodology is complex, requiring expert knowledge or specially designed software.
As an alternative, it is possible to use pre-set values of emission values, regardless of the connection point, which are the same for all users of the network (or at least the same according to the type of user). Although it can be said that this approach has advantages, it also has significant disadvantages, so in professional circles, it is considered that it is better to use the methodology from the international standard.

- RACS Tool. During the coordinated regional capacity calculation and when checking the security of system operation at the regional level, it is necessary for the involved TSOs to determine remedial actions with cross-border impact.
  The purpose of this proceeding is to ensure security at the regional level, but also to minimize the total costs of remedial actions that should be borne by the involved TSOs. Since one remedial action also affects elements of the neighbouring network, the European regulation foresees the creation of special mechanisms for cost-sharing between TSOs.
  In order to achieve this, very simple rules can be determined. For example, the TSO in whose control area the remedial action is activated is obliged to bear the costs - this is also the default mechanism that applies if there is no specially agreed mechanism between TSOs. Another simple mechanism is that the remedial action is paid for by the TSO that requested it.
  However, such mechanisms do not reflect the real responsibility of TSOs to remove congestion in the network through remedial actions. Also, remedial actions are expensive, and if there is no fair methodology, it can lead the TSO to avoid the application of remedial actions as much as possible, which is not good for the security of system operation.
- TSC Tool. The European network is well-meshed and interconnected, which minimizes potential problems with stability. Therefore, as a rule, stability is studied on off-line applications and periodically, on an annual or seasonal level.
  One of the forms of stability that are analysed is the transient stability of the rotor angle when failures occur. In these analyses, the critical failure time for which the failure must be isolated is calculated. These values are then compared for settings on the grid elements. Also, these calculations refer to synchronous generators.
  But lately, due to the sudden integration of RES, there are significant changes in the system that threaten the transient stability. Wind farms and solar farms are not synchronously connected to the grid and also contribute to fault currents many times less than conventional generators.
  Therefore, in the future, it can be expected that transient stability testing will be a daily activity as part of the operational planning of the system. Again, this is only possible if this calculation is fully automated.
- TTA Tool. Individual grid models are the basis of the procedures that ensure the operational security of the system. By merging them, a common grid model is created, which is used for contingency analysis and calculation of cross-zonal capacities.
  Individual network models are created by merging files representing grid parameters, production, consumption, cross-border exchange and topology.
  The topology file contains information about the statuses of switches and disconnectors on network elements. It is common for a system to have a default topology that is determined based on average operating conditions.

Topology changes occur as a result of disturbances in the network, planned outages due to maintenance work on network elements and remedial actions to achieve system security. The largest number of topological changes refers to planned works in the network.
These topology changes can be entered manually based on the outage/maintenance plan. A better way would be to automatically create a topology file based on the output files provided by the outage planning software.

- DLR Tool. Dynamic line rating is a technology that has been used more and more lately. It enables the real transmission capacity of lines to be determined in real-time, and some technological solutions also enable short-term prediction of transmission capacity. This technology is mainly used based on the measurement of conductor temperature and meteorological conditions.
  However, independent use of this technology without integration with the business environment limits its effective use. The characteristic of the transmission system is that the network is highly meshed and that in order to ensure the safety of the system, it is necessary to carry out complex calculations on network models.
  These calculations are performed in two ways: 1) in operational planning through network models and 2) in real-time based on the estimation of the state of the network and on the basis of measurements collected by the SCADA system.
  Therefore, it is necessary to enter the transmission capacity calculated by DLR in the network models for the respective transmission lines and in the limits of the SCADA system, in order to perform the security analyses in an appropriate manner.

3.2.2 Innovation to be provided

Following the technological and scientific background introduced in 3.2.1, this sub-section describes the innovations to bring on top of the existing tools or products. At this stage, technical details of the task's activities have not been introduced yet, and it is possible to find them in the next chapter 4. For each task the innovation provided during the implementation phase from M13 until M24 is presented.

Task 6.1

The solution developed in this task will enable system operators and electric industries, in general, to work as contractors in the O&M to improve their everyday processes. The adoption of drones in power system inspection is well demonstrated in the literature [4][5][6][7][8], even though most of the proposed solutions are focused on specific details or aspects. In particular, the focus is on how to analyse specific signals or data acquired by sensors and cameras, or on how to predict faults. Nevertheless, even though the technology is already available many TSOs and DSOs still rely on traditional means (visual inspections and helicopters), for many reasons, as flight range, sensors integration, deep and precise knowledge of the asset to survey, commercial maturity of the service, data integration and interoperability. The solution proposed in T6.1 will be based on an HW-agnostic platform, and a ready-to-go application easily adaptable to any power system assets present in the demo case, and there is no need to pre-upload any information in advance. It means that, for example, in case of PV site inspection (but it is the same for a power line), EMMA-ARGOS is able to detect and recognise autonomously the panels and register a new asset with the identification and position of each panel, without any preliminary information uploaded (project design, diagrams, drawings, etc.).

Additional manual steps are usually required in existing solutions to complete the process. Moreover, it can also work as an offline platform, which means the capture of images can be a different activity from the image analysis in Argos. Until the technical requirements are met (flight and camera specifications) this peculiarity basically brings the drone-agnostic property to the solution. Finally, in overhead lines inspection, many solutions available today focus on one specific aspect (flying mission, sensing, visual data, data uploading, data processing, etc.) and UAVs are usually equipped with one or two types of cameras (optical, or Lidar, or infrared) to inspect specific problems. Argos integrates images acquired from the three of them in a combined way, to give the operator the highest consciousness of what is going on. It will be a fully autonomous end-to-end solution, or a “drone-to-report” solution, able to deliver accurate and frequent insight from the field.
The main advantage of using EMMA Argos in power system O&M can be summarised:

- Reduce Costs of inspections
- Alleviate Safety Concerns
- Maximize Limited Human Resources with Drone Integration
- Improve the continuity of service
- Increasing the Frequency of Power Line Inspections, especially after severe weather events
- Minimize downtime and failures
- Speed up the recovery of the system
- Improve the overall reliability and resiliency of EPES
- Prevent the need for (costly) corrective maintenance

Task 6.2

Both TSOs and DSOs still rely heavily on preventative and corrective maintenance procedures today. The activities outlined in the related technical documentation of the assets (which includes suggestions for the scheduling of modifications) and those prompted by the actual occurrence of damages still control maintenance operations. This approach is primarily driven by a lack of data, particularly when considering distribution networks. In fact, only the most important assets typically have the required sensors and remote-metering systems in place, and the measurements needed to determine the equipment's health status are typically taken manually by skilled maintenance personnel. Preventive maintenance is frequently performed on critical assets of the network (reclosers, disconnectors, voltage regulators, etc.), regardless of the occurrence of anomalies or damage to the equipment's components, based on a number of variables, including (i) the manufacturer's instructions; (ii) available equipment experience (e.g., fault history); (iii) the number of operations; (iv) strain conditions (e.g., heavy loads); (v) technological aspects, vi) peculiarities of the asset (critical node, uninterruptible load, etc.) y and According to national guidelines or standards, the remaining connection and protection components should be preventively maintained at regular periods. Preventive maintenance reduces the likelihood of damage occurring and the effects of any irregularities.
Repairing or replacing these components is the inspection's goal in order to stop damage and the ensuing disruptions. The networks are typically inspected annually, and based on the findings of the inspection, the necessary maintenance or interventions are carried out to repair any damages or anomalies discovered.
Parallel to the aforementioned, Predictive Maintenance (PM) is being pushed for in worldwide practices. With the use of new digital technologies primarily based on Artificial Intelligence (AI), asset maintenance strategies are currently shifting from being mostly condition-based to a predictive-based approach, with practical applications in numerous electrical

components and grid sections [34]. Advanced analytics may assist TSO and DSO by employing real-time data and predictive algorithms to prevent asset failures, optimize resources for essential assets, eliminate unnecessary maintenance work or early equipment replacements, and enhance internal skills and expertise. These advantages can be brought by EMMA DYML, a tool for system operators which can be integrated into DMS or OMS.
The novelty brought by this tool resides in its peculiar design conceived to integrate heterogeneous functionalities with different techniques. In principle, the proposed application implements different features that target the maintenance-responsible operators of DSOs and TSOs, to provide different models that optimize maintenance management by enriching the available data with the results of several analytics and forecasts.
EMMA DYML will be a forthcoming software platform for predictive maintenance in substations, leveraging cutting-edge techniques in both diagnostic and prognostic predictive maintenance. Unlike conventional practices, this platform will employ innovative approaches, utilizing state-of-the-art AI models. In real-time, diagnostic predictive maintenance will forecast the immediate state of transformers, while prognostic predictive maintenance will provide a real-time probability of potential future failures within a defined time frame. Notably, this platform will go beyond traditional methods by incorporating vital data from transformer gas analysis (DGA), enriching the predictive models with comprehensive historical and analytical insights for unparalleled accuracy and reliability.

Task 6.3

The unpredictable increase in demand for electricity has made it challenging to plan and maintain any electrical system at the transmission or distribution level. Population growth, migration, and exceptional weather events place the electrical infrastructure under increasing stress each year, reducing its performance and shortening its life expectancy. In addition, these factors contribute to reduced continuity of service, requiring operators to invest more and more resources in maintenance. In critical situations or after severe natural events, it can happen that resources allocated to maintenance are insufficient or overloaded, lengthening the time to repair damaged elements and reactivate service. As a result, the overall resilience of the system is reduced. It is generally assumed [35] that power sector resilience does not only mean strengthening its ability to anticipate and absorb shocks but also improving its ability to recover from the effects of a hazardous event quickly and efficiently. To achieve this T6.3 will develop a tool to optimize the workforce activities and speed up the process of asset recovery. In case a critical atmospheric event impacts the system, it is expected that many nodes and branches may be affected.
Depending on the size of the outage, operators are faced with the problem of having to reach several even distant sites in order to repair different lines and stations. In cases such as these many times, there is a tendency to act sequentially with the goal of minimizing travel time and not having to move back and forth across the territory. This can be generally reconducted as a typical Travelling Salesman Problem (TSP) [36] (see section 4.3.1 for more details). TSP generally considers only the minimization of the distances, while prioritising maintenance interventions should include also more variables lie: the cost, and the customers with priority of supply (i.e. hospitals, etc.). Therefore, the main innovations from T6.3 will derive from the integration in GIMAN of the new T6.3 tool for the optimal routing of the operators taking into account not only the geographical distance of the assets but also other relevant parameters mentioned before.

Task 6.4

The innovation provided by each one of the six tools to be developed in this task is hereby reported:

- OP Tool. The innovation this tool offers is reflected in the automation of the process that is currently carried out manually, based on the experience of personnel participating in the outage planning.
  The automation itself will be done by communicating with the power flow software, which will check on the appropriate seasonal models whether the operational safety of the network is met for the set of selected outages.
  It will provide the means for TSO and RCC personnel to quickly analyse some special cases of the outage combinations, while when it comes to the visualization it will significantly improve the business process, automating the procedure of generating outage planning Gantt charts.
- PQEL Tool. The automation provided by PQEL Tool enables the introduction of the methodology for the calculation of the emission levels of flicker, asymmetry and higher harmonics, which is foreseen by the relevant international standards.
  One more thing should be emphasized here. The methodology is very complex and its manual application requires a top expert in this field, which many TSOs do not have at their disposal. However, with this software, this business process can be performed by any electrical engineer with minimal additional training.
- RACS Tool. The innovation of this tool is reflected in the cost-sharing methodology itself which has not been applied so far. This methodology primarily refers to remedial actions that are determined during operational planning in the day ahead or in the intraday process.
  The idea of this methodology is to share the responsibility of TSOs in determining remedial actions based on their real responsibility, as well as to bring the cost-sharing mechanism closer to the mechanism by which remedial actions are optimized.
  It can be said that the methodology has two levels. The first is technical and refers to the determination of triplets: remedial action, contingency, and element with constraint. Each member of this triplet belongs to one TSO, and in the case of an interconnector, there are two TSOs.
  The second part of the methodology is the subject of agreement between TSOs on how the costs should be shared between the TSOs to which the elements of these triplets belong. While the first part is technical and based on PTDF/OTDF matrices and other calculation results, the second is contractual. However, both levels allow fair distribution and socialization of costs.
- TSC Tool. This is another tool whose primary purpose is the automation of the business process and is reflected in the creation of a script that automates the calculation of the critical fault-clearing time for specified buses of the transmission system (power grid).
  It has already been explained that currently calculations of transient stability are carried out periodically, but with the increase of RES integration, conditions may arise that will require the inclusion of these calculations in the regular operational planning portfolio (which should also include activities in the day ahead and possibly intraday time horizon).
  This may be especially true for TSOs operating in smaller synchronous areas, where changes in key quantities are faster.

- TTA Tool. The innovation consists of the automatic uploading of the planned topology in the transmission grid for the purpose of the IGM creation process, which was previously defined in the outage planning process.
  This tool is more significant for other reasons - it reduces the costs of business processes because a lot of time is saved on the manual preparation of the topology file, and besides, it is expected that the accuracy of the topology in individual network models will increase significantly (there are KPIs that monitor the process of creating network models that show the biggest errors are related to the topology).
- DLR Tool. With this tool, one cannot speak of a high innovation, which refers to the idea of integrating the DLR system with individual network models and the SCADA system, in the concrete business environment of the Serbian pilot site.
  On the other hand, the effects of this tool can be extremely large, especially when the planned level of RES integration is reached. In this way, additional transmission capacity can be provided for RES producers (the DLR will be installed in regions with high RES production), which will contribute to more secure operation of the system, reduction of costs of remedial actions and, of course, reduction of pollution.

3.3 RELEVANT USE CASES AND ACTORS

The different components and functionalities composing EMMA products have previously been conceived in relation to the UCs described in Deliverable 2.1 [1]. In this deliverable, all UCs have been defined in their first version (the final version is planned to be delivered in D2.3 in M16) considering the different tools present in the four products, and the needs and characteristics of the pilot sites, under the main framework of the overall project's goal. Table 2 resumes the project's UCs where WP6 tools are employed.

Table 2 – WP6 Use Cases and related actors

ID	Title	Tool/Task	Actors
UC01	Improvement in overhead power lines inspection and maintenance using IA applied to UAV-captured images and data	EMMA ARGOS/T6.1	EMMA ARGOS, UAV inspection operator, UAV, System Operator
UC02	Substation component status of health calculation based on SCADA measurements and DGA data	EMMA DYML /T6.2	EMMA DYML, SCADA, System Operator
UC03	Malfunctioning detection of PV panels through autonomous UAV image acquisition	EMMA ARGOS / T6.1	EMMA ARGOS, DSO, Thermal camera, Inspection Robot, Inspection operator
UC04	Detection of non-technical losses through SCADA and AMI data, from a selected portion of the distribution grid	EMMA ETER /T6.2	EMMA ETER, Advanced metering infrastructure, SCADA, System Operator
UC05	Automated ranking intervention of assets and optimal scheduling (including routing) of intervention workforce to perform maintenance task	EMMA GIMAN / T6.3	EMMA GIMAN, System Operator

UC06	Substation components degradation detection by analysing images (conventional & thermal)	EMMA SURVEILLANCE / T6.1	EMMA ARGOS, DSO, Thermal camera, Inspection Robot, Inspection operator
UC08	Outage planning optimization	EMMA OP/T6.4	TSO, Outage planning participant (Distributor, Producer), EMMA Outage Planning Optimization tool, EMMA communication platform, Outage planning server, Grid Model server
UC09	Automation of calculation of emission levels of electricity quality parameters	EMMA PQEL /T6.4	TSO/DSO, EPES representative, TSO, Grid Model Server, Power Quality Server, EMMA Power Quality Emission Levels (PQEL) Application
UC13	Cost-sharing of remedial actions with cross-border impact	EMMA RACS/T6.4	TSO, RSS, EMMA RA cost-sharing software, EMMA communication platform, Power flow software, Electronic Highway
UC14	Automation of transient stability calculations	EMMA TSC /T6.4	EMMA Transient Stability Calculations (TSC) Script, TSO
UC17	Outage coordination and automated creation of topology files for Individual Network Models	EMMA TTA/T6.4	TSO, EMMA Topology Transfer Application (TTA), Server, Outage planning application
UC20	Physical security enhancement in core network components (Primary HV/MV Substations and Secondary MV/LV substations)	EMMA ARGOS/T6.1	EMMA ARGOS, Surveillance cameras, Sensor devices, SCADA/DMS
UC31	DLR integration with IGMs and SCADA/EMS	EMMA DLR /T6.4	TSO, EMMA DLR Application, DLR Server, SCADA/EMS, IGM server

Similarly to the UCs in T2.1, in T2.2 the requirements have been defined for all products. The full list of the first version of the requirements is included in D2.1, while the final version of the requirements will be available in D2.3 after the products' design. In Table 3 the requirements associated with EMMA have been reported:

NOTE: after SW design activities described in this deliverable, requirements can be changed or updated. In the ID column of table 3 the "*" denotes requirements that have been updated compared with D2.1, while "**" denotes new requirements introduced in this deliverable.

Table 3 – WP6 requirements

ID	Title	Tool/Task
EMM_002	Maintenance UAVs shall fly in manual or autonomous	T6.1
EMM_003	the recorded flight path of the AUV shall be presented on a map	T6.1
EMM_004	EMMA GUI shall feature a credential validation screen allowing open-id	T6.1-3
EMM_005	To have access to a historical dataset of substations measurements (mainly P, Q,V,I)	T6.2
EMM_006	To receive Real-Time measurements (or simulated Real-Time data) from substations (mainly P,Q,V,I)	T6.2

EMM_007	if abnormally high temperatures are captured by UV camera pointing to a transformer an alarm shall be sent in MQTT protocol	T6.2
EMM_008*	To have access to the historical dataset of the photovoltaic plant's aerial images at 50-80 meters and 20 meters from a drone.	T6.1
EMM_00X**	To have access to videos and images of the high-voltage towers and lines of the substation using thermal cameras.	T6.1
EMM_0XX**	To have access to the point cloud representing the corridor of the high-voltage line of the substation.	T6.1
EMM_0XX**	Drones must have RTK hardware to ensure centimetric-level accuracy of the location.	T6.1
EMM_009	(OPC tool) Collection of outage plans from stakeholders (TSOs, RCCs, PES users)	T6.2
EMM_010	EMMA ARGOS component must feature a web application for upload images and videos	T6.1
EMM_011	EMMA ARGOS component shall trigger the image processing task upon reception of new data	T6.1
EMM_012	EMMA ARGOS image processing component shall trigger events and sent to EMMA component when the images analysed contain problems according to the ML models	T6.1
EMM_013	EMMA shall receive periodically a selected set of SCADA signals for grid assets and substations	T6.2
EMM_014	EMMA ARGOS component shall identify when new images or videos have been uploaded and then trigger the image processing process	T6.1
EMM_015	EMMA shall feature a web interface to present the maintenance results and KPIS	T6.3
EMM_016	EMMA signals processing component shall trigger events and store relevant data when the analysis of the signals indicates about problems according to the ML models	T6.2
EMM_017	EMMA signal processing component ML models must support identifying active and future problems in the substation assets	T6.2
EMM_018	EMMA ARGOS image processing component ML models must support identifying active and future problems in the substation assets and overhead lines	T6.1
EMM_019	EMMA component shall generate a ranked list of interventions prioritized according to its criticality	T6.3
EMM_020	EMMA GIMAN component shall schedule the workforce duties according to the information received from EMMA	T6.3
EMM_021	EMMA GIMAN component shall generate workforce activities routing to cary out the duties in the most optimal way	T6.3
EMM_022	Pilot site must deploy metering devices.	T6.2
EMM_023	Pilot sites must identify critical nodes of the grid	T6.2-3
EMM_024	Grid operator must configure in EMMA GIMAN the details of personnel involved in incident management.	T6.3
EMM_025	Maintenance UAV could be controlled in remote	T6.1
EMM_026	EMMA ARGOS ML models should identify problems linked to the presence of forest near the overhead lines according to the images	T6.1
EMM_027	EMMA ARGOS ML models should identify physical (structural or mechanical) problems on tower/poles, conductors and insulators based on the images	T6.1
EMM_028	EMMA ARGOS ML models should identify electrical problems on the conductors and insulators based on the images	T6.1
EMM_029	EMMA DYML component shall import data from DGA analysis	T6.2
EMM_030	EMMA DYML component shall support OPC-UA protocol to gather SCADA measurements	T6.2

EMM_031	EMMA ETER shall be able to import grid topology in CIM format	T6.2
EMM_032	EMMA ETER component shall import historical substation feeder data	T6.2
EMM_033	EMMA ETER component shall be able to identify abnormal or suspicious behaviours of supply points based on data	T6.2
EMM_034	EMMA GIMAN component should feature a web GUI	T6.3
EMM_035	EMMA ETER component should feature a web GUI	T6.2
EMM_036	EMMA must contain a communication platform to provide the following services: 1) All participants can upload and download files 2) files are kept for a certain period of time 3) A conference call can be started	T6.4
EMM_037	EMMA shall contain a tool to calculate the cost sharing related to remedial actions with cross-border impact between the TSOs involved	T6.4
EMM_038	EMMA product must contain outage planning optimization tool (EMMA OP)	T6.3-4
EMM_039	EMMA product must contain an application to transfer topology file	T6.2-4
EMM_040	EMMA product must contain dedicated script created in DIgSILENT environment (DIgSILENT Programming Language) to perform calculations related to transient stability.	T6.4
EMM_041	EMMA product must contain application to perform calculations related to power quality	T6.4
EMM_042	EMMA product must contain an application to transfer Dynamic Line Rating limits into IGMs and SCADA/EMS system	T6.4
EMM_044	Surveillance equipment installed in HV/MV substation must provide 24h live streaming image to EMMA ARGOS	T6.1
EMM_045**	The drone collecting the data must fly in a straight line between two adjacent towers to ensure accurate data collection.	T6.1
EMM_045**	Technicians overseeing the data collection must have access to the GPS location of the towers to guarantee the straight-line flight path, especially in the case of unmanned flights	T6.1
EMM_046**	The LIDAR system must possess sufficient precision to detect cables with adequate resolution, facilitating accurate representation and analysis	T6.1
EMM_047**	The LIDAR must have the capability to penetrate vegetation and store signal intensity data, enabling easy differentiation of lush vegetation from other elements.	T6.1
EMM_048**	The drone flight must provide precise information on the GPS location of detected points, leveraging the Inertial Measurement Unit (IMU) and employing Real-Time Kinematic (RTK) flight when possible, to enhance accuracy	T6.1
EMM_049**	The technician should be capable of supplying detailed technical information about the inspected line, including the minimum and maximum height of the cables, the safety area to be maintained around the vegetation, and specific characteristics of the cables, which might vary between different installations.	T6.1
EMM_050**	To maximize the clarity of the solution, it is recommended to use a LIDAR system equipped with an integrated RGB camera. This addition facilitates subsequent evaluation and analysis of the results, offering a more comprehensive view of the surveyed area	T6.1
EMM_051**	Implementing advanced obstacle detection systems in the drone to prevent collisions with unforeseen obstacles during the flight, ensuring smooth data collection.	T6.1

EMM_051**	The ability for the drone to adjust its flight altitude dynamically based on the topographical variations of the surveyed area, potentially enhancing the accuracy of the collected data	T6.1
GEN_001	All products GUIs should present results in English language	T6.1-5
GEN_002	EMMA should consider the legislative constraints regarding the limited presence of drones near critical infrastructure	T6.1-4
GEN_004	Bidirectional communication between DSO and involved energy stakeholders is established. Supported protocols mainly MQTT/AMQP (via RabbitMQ broker)	T6.2,4
GEN_005	Adequate measuring equipment is installed for proper monitoring of the grid	T6.4
GEN_006	Historical data from smart meters, sensors, metering devices etc. should be available.	T6.2
GEN_007	Metering data by all involved metering devices (AMI, SCADA, storage systems, etc.) should be anonymised	T6.2
GEN_008	The tools developed should be compatible with different operating systems (Windows, Linux, MacOS, etc.).	T6.1-4
GEN_009	Server/virtual machine technical requirements for tools support must be known as soon as possible.	T6.1-4
GEN_010	R2D2 will represent alerts from different products	T6.1-4
GEN_011	A communication channel between DSO - TSO must be existent	T6.4

4 Product Description

EMMA product is intended to support system operators (both TSOs and DSOs) and Regional Coordination Centres (RCC) in their daily activities related to the processes to prevent and/or take action after outages, failures, blackouts and faults. In a nutshell, the product will be helpful to improve the reliability of the system, through the improvement of maintenance, planning the interventions under complex scenarios of outages, and being able to implement the optimal remedial actions after an (planned or happened) event. Through the adoption of EMMA, the product's users will be able to improve their awareness and response before and after a critical event happens, contributing in this way to the enhancement of the system's resiliency.

The next diagram (Figure 4) provides an overall picture of how the different actors and systems in the smart grid are related to the different tools described in this deliverable, always aiming at enhancing the maintenance of the grid assets and the coordination and planning among actors to better managing the grid.

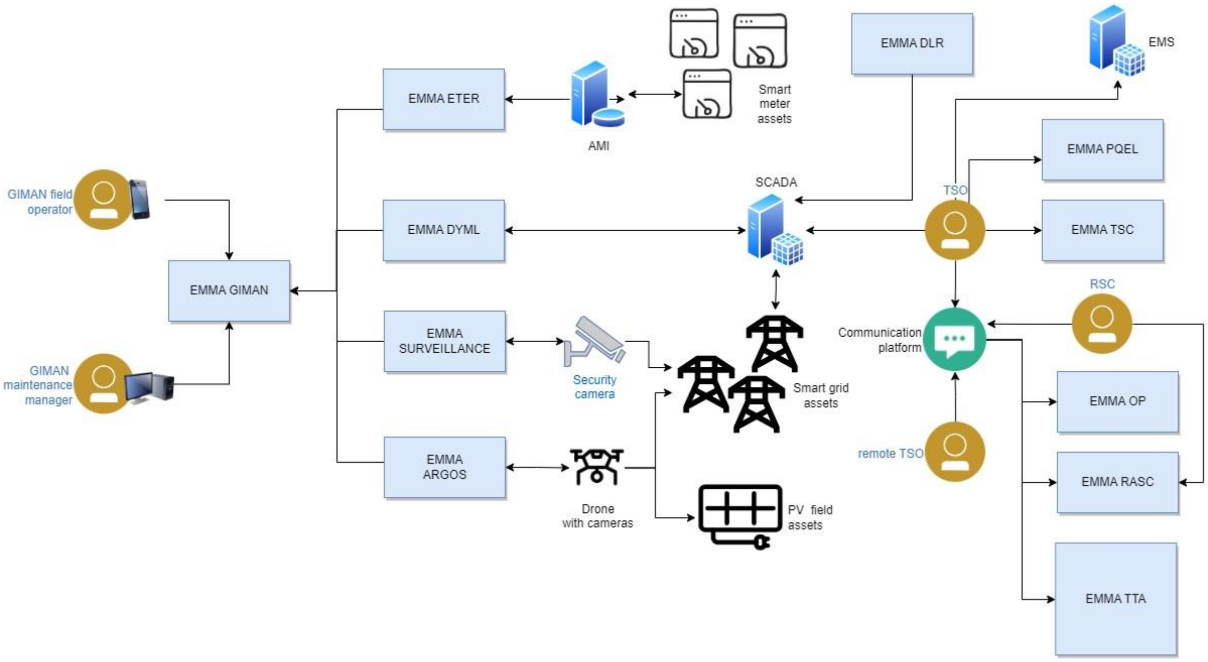


Figure 4 - high-level structure of the EMMA product

The blue boxes correspond to the tools to be developed within R^2D^2. They link to different types of stakeholders, assets, and systems.

The tools more oriented to the enhanced asset maintenance are in the left-hand side, being the EMMA GIMAN a tool that gathers inputs from the other maintenance components and adapts it to for being presented in a uniformed way to the grid maintenance operator. The different maintenance components are specialized in a given dimension of the monitoring: images from drones, security cameras, SCADA systems or smart metering systems (AMI).

On the right-hand side, the tools more oriented to the resilience in the system operation by enhancing the cooperation among actors are presented. This cooperation is enhanced from different perspectives: coordination of outages, cost sharing, topology models exchange, DLR integration in the topology models, etc.

All these tools are described in the next sub-sections.

4.1 TASK 6.1 - EQUIPMENT INSPECTION THROUGH AUTONOMOUS IMAGE ACQUISITION

4.1.1 Tool 1 – EMMA ARGOS Tool

The tool embodies a comprehensive platform strategically engineered to envelop a diverse array of inspection modalities, exemplified by PV Inspections, Power Line Inspections, and beyond. Leveraging cutting-edge artificial intelligence methodologies, it features the automation of several visual algorithms in charge of the parsing and contextualization of data acquired by (semi) autonomous vehicles through different types of sensors (RGB images, thermal images, Lidar, etc. These algorithms are specialized in the identification and categorization of a pre-defined set of anomalies.

The main goal of the tool is to assist in the **predictive maintenance** of the field assets. This type of maintenance aims at detecting hidden failures and ageing conditions, avoiding unnecessary time-based inspections and optimizing the allocation of human resources. This is achieved through the orchestration of advanced automation procedures, that simplify the inspection-related tasks and can be combined with the maintenance duties linked to the human expertise. The main goal is to generate an inspection platform with a full-fledged set of automation tasks, that supports the image-assisted inspection procedures in different domains, advancing beyond the state-of-the-art in the technologies offered. The ambition for the tool is to become a commercial product competing in the market by taking advantage of the innovations developed.

4.1.1.1 Internal Architecture

EMMA ARGOS is designed as a configurable tool with different sections, each one specialized in a given type of inspection of a specific domain. The initial domains considered in R^2D^2 are Line inspection for vegetation detection, line inspection for electrical failure detection, electrical tower inspection and photovoltaic plant inspection.

4.1.1.1.1 Line inspection for vegetation detection

The main goal of this section is to identify forest or vegetation whose proximity to the power lines might imply some danger: could produce structural damage in the power lines, trigger fires in the forests, hurt persons, etc. The visual inspection for this purpose has two main problems: 1) The power lines path could go through locations that are hard to follow by car or even walking (mountains, rivers, etc.), and 2) The power lines could be very long and require quite a lot of time to inspect. A semi-automatic process is proposed here that uses

UAVs to fly through the path of the power lines and evaluate the vegetation-associated risk based on the data captured.

The tool requires as input LIDAR data captured by the UAV, which encapsulates detailed geographical and topographical information. This data will be processed through a series of computational models that will identify various critical components such as power lines, towers, and surrounding vegetation, assisting in the pinpointing of potential invasion of overgrown vegetation.

The pipeline designed to process the LIDAR data will impose certain prerequisites regarding data collection methods and source data quality to appropriately automate and streamline the computational demands of the platform. This approach will enable faster inspection and precise detection, fostering seamless integration within the overarching architecture of the platform. Finally, the solution will present the information in a visually clear manner, letting users easily identify the incidents in the data presented.

The process begins with the collection of LIDAR data using UAV flights. The data acquisition phase is critical, requiring adherence to both mandatory and optional prerequisites (described in section 3.3-Relevant Use Cases and Actors) to ensure accurate and efficient data gathering and minimise the need for additional inspection that might involve extra cost. These prerequisites pertain to the drone's flight path, the role of the technician, the precision of the LIDAR system, and the capabilities of the drone and LIDAR system to discern and document intricate details of the surveyed area.

To create, visualize and process the inspections, the following figure depicts the different components to be developed and how they communicate. Below that, there is a definition of each of these components and their corresponding functionalities.

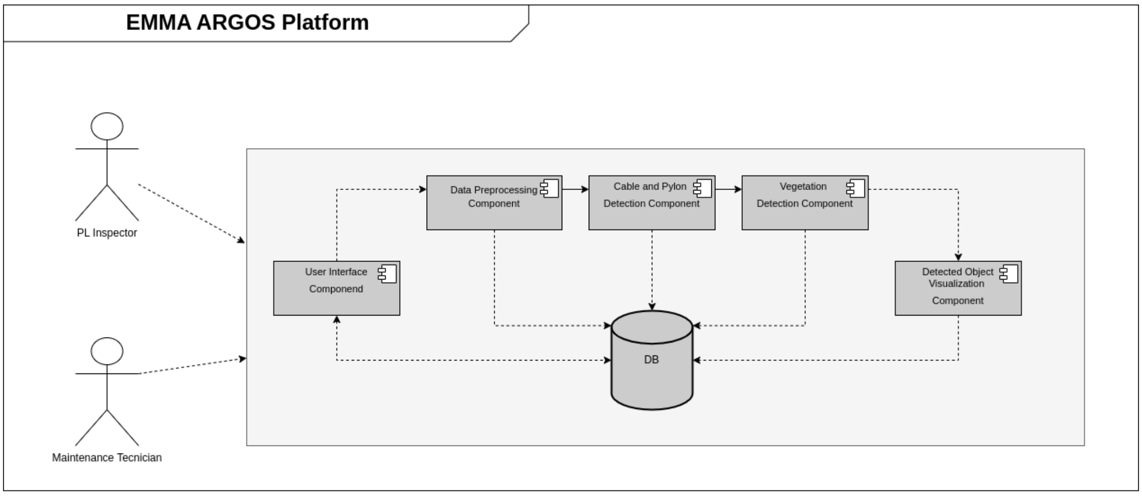


Figure 5 - Components of the power line inspection tool

The different components shown above, are described based on their task and their relevance to the overall pipeline:

- **Data Preprocessing Component**: This initial component handles the segregation and filtration of the incoming data. It employs specific algorithms to segment and filter the data, removing unnecessary data points based on predetermined height thresholds and focusing on the areas surrounding the towers.
- **Cable and Pylon Detection Component**: Following preprocessing, this component identifies potential power lines connecting the towers using the Hough Transform algorithm. The catenary curve model is then applied to validate the genuine cables, distinguishing them from other linear structures nearby.
- **Vegetation Detection Component**: Here, the focus shifts to identifying potential vegetation encroachments. It employs 3D modelling techniques to craft detailed representations of the cables and the exclusion zones surrounding them, pinpointing any vegetation elements that might infringe upon the predefined safety areas.
- **Detected Object Visualization Component:** This component operates in the latter stages of the pipeline, focusing its efforts on the areas directly beneath the power lines or within the projected shadow of the exclusion zone. Its primary function is to facilitate the visualization of elements identified within the point cloud data, mainly vegetation, that are found within the delineated area. Leveraging 3D modelling techniques, it generates detailed representations of these elements using the points involved, whether in the form of geometric shapes or a more faithful reconstruction of the object. This component plays a vital role in enabling a comprehensive view of potential risks and assisting in the formulation of informed and targeted intervention strategies.
- **User Interface Component**: This final component facilitates user interaction with the tool, enabling the uploading of LIDAR data and showcasing the analysis results. It provides a comprehensive view of the analysed area, highlighting potential risk zones due to vegetation encroachments and allowing users to examine the 3D models crafted during the analysis.

All the processed data and analysis results are stored in the EMMA ARGOS database (MongoDB), allowing integration with other components of the ARGOS system.

Within all these components, several techniques and processes will be used to enhance the results obtained in different ways: to improve the accuracy, to generate better visualizations or to simplify the computational complexity of the solution. Among them:

- **Hough Transform**: This technique is utilized for the detection of linear structures in the LIDAR data, primarily focusing on identifying cables between the towers. It forms the basis for delineating the cables in the initial stages of data processing.
- **Catenary Curve Modelling**: A mathematical model employed to represent the natural curve of the cables suspended between towers. This modelling is crucial in accurately representing the physical characteristics of the power lines and aids in determining the exclusion area around them.
- **Rasterization and 2D Top-Down Analysis**: Utilized to segment the data and focus on areas immediately under the power lines or within the projected exclusion zone shadow. This step is vital in narrowing down the data to the most relevant sections for analysis.

- **3D Modelling**: Techniques employed to create three-dimensional representations of identified structures and vegetation, based on the processed LIDAR data. These models assist in visualizing the spatial relationships between the power lines and surrounding vegetation, facilitating targeted intervention planning.

Incorporating seamless communication with other ARGOS system components, the tool operates on standardized protocols that facilitate smooth data exchange processes. It allows for the easy upload of LIDAR data and straightforward retrieval of analytical results. A non-relational database acts as the central hub for all processed data and analytical outputs, ensuring a smooth data flow and robust integration within the overarching ARGOS system.

4.1.1.1.2 Line inspection for electrical fault location.

The main goal of this section is to identify electrical problems in the power lines based on the analysis of the thermal images or videos captured by UAVs. The problems to identify include lines overheating (not only absolute but also considering the electrical status of the lines according to the SCADA data), hot spots on insulators (indicating damaged or potential faults), partial discharge and corona effect.

Initially, the user must upload a thermal video which covers a part of the power line corridor where the lines and pylons are properly visible, this video must be taken with a UAV with RTK to ensure the proper localization of the hotspots in the field.

Once this video has been uploaded to the platform, the *hot-spot detector component* will be invoked to analyse the received data and discover hot spots. After being detected these hot spots will be stored in the EMMA ARGOS Database, to finally let the UI retrieve and display them to the end-user. This process is graphically depicted in Figure 6.

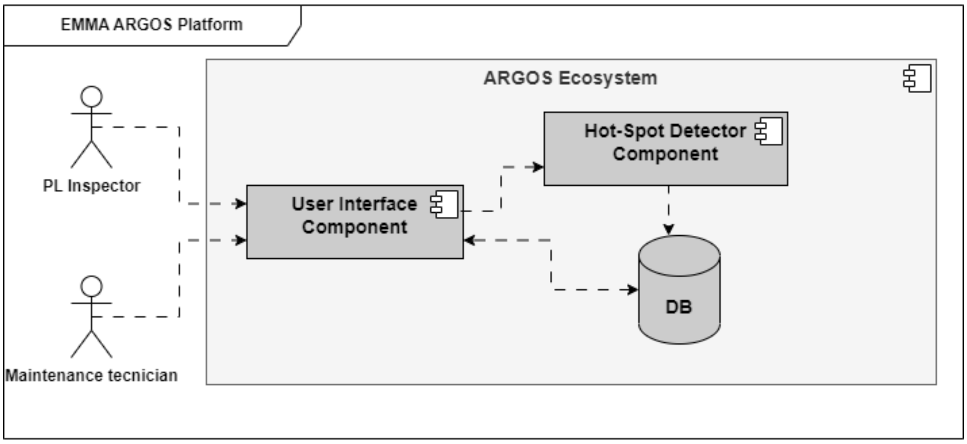


Figure 6 - Components of the hot-spots detection tool and actors' diagram

All the components mentioned above are described next:

- **Hot-Spot Detector Component**: Component in charge of receiving thermal videos and analyse them with the aim of detecting hot-spots in the power lines. To be able to achieve this goal, a temperature threshold will be defined by configuration to mark as a hot spot all parts of the image that are over this temperature value. As other objects can appear in the video, with high temperature values (animals, persons, vehicles, etc.) a YOLO (You Only Look Once) model, which is the state of the art of object detection, will be trained to identify such elements in the input data. So, using this model, it is possible to discard all the high-temperature values associated with these objects and ensure really accurate results in terms of hot spot detection through the power line. Finally, the results will be stored in the EMMA ARGOS database.
- **User Interface Component**: The component in charge of managing the user interaction and displaying all the inspection results. It must be able to allow the user to upload the thermal video mentioned above. Finally, the user must be able to visualize all the uploaded videos separately and modify manually the results obtained from the inspection. All the represented data in the User Interface is going to be obtained from the DB.

4.1.1.1.3 Electrical tower inspection

The main goal of this section is to identify physical (mechanical and/or structural) anomalies in electrical assets: Damage of towers or poles, mechanic deterioration of supports and insulators, presence of obstacles, element deterioration, or “foreign bodies”. Images from UAVs will be used as input for this detection.

The detailed structural analysis of electrical assets requires a very detailed inspection using high-resolution images of all the parts of the electrical tower. These images must be carefully analysed to identify symptoms of deterioration in the different components:

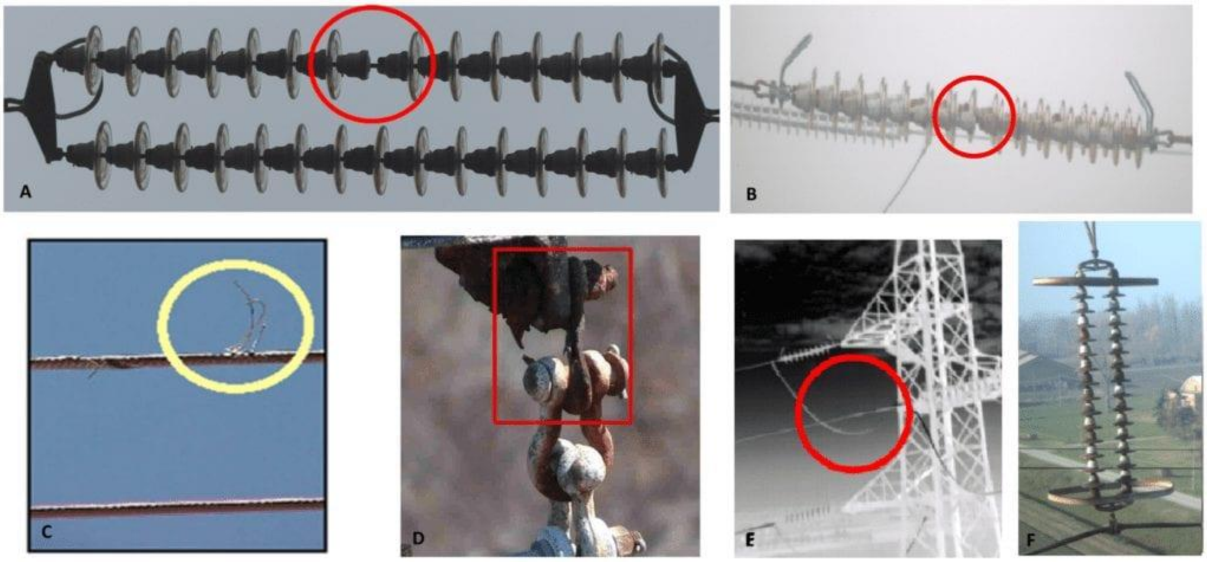


Figure 7 – Samples of images with damages in towers detectable by EMMA ARGOS

These images will be acquired with the use of different types of cameras (RGB & thermal) equipped in UAVs.

Initially, an exhaustive mission flight with the UAV will be carried out by an operator, capturing as many images as possible, from different angles and flying as close as possible to the electrical assets without affecting the security.

In classical asset inspection, the operator analyses visually the complete set of images to detect failures, but this is a time-consuming task and also prone to human errors. In this tool, we will go further and provide an algorithm that automatically identifies damages and problems in the images captured.

Nevertheless, detecting the damages in the images is just one of the steps, because the damage detection in a single image could not be enough for asset identification (in case there are multiple assets of the same type in the same location). To assist the maintenance operator in the unambiguous identification of the pieces damaged in the whole infrastructure, the information will be presented on a 3D model that will present damages and incidents in a context and will let the user navigate through the 3D model to visualize problems and have access to the relevant photos where the damages were detected.

This tool is therefore composed of three modules:

1) **The damage detection tool**. This tool will accept as input a set of images and will start processing them by using different machine-learning techniques. The images will go through a pipeline with the following steps:

    a. The images are segmented to try to identify known parts: insulators, cables, transformers, connectors, etc.

    b. For each detected part, an analysis of potential damages is performed. To do so the system will be trained with a set of images with failures. There will be individual ML models for each of the types of parts considered

    c. The image with the damage or failure detected will be marked, with details of the type of part damaged and the details of the problem detected. This information will be stored in the EMMA ARGOS database

    The segmentation of parts and the detection of failures and anomalies will be based on a machine learning model, that will be created and trained to identify each of these anomalies by using labelled sets of images taken from specialised datasets.

2) **The 3D model reconstructor**. This tool will get all the images and will generate a pseudo-3D model based on 2D data in the images. The 3D point cloud will be generated using photogrammetry techniques approaches on the 2D images.

3) **User interface**. The user interface will let the user navigate the 3D model.

4.1.1.1.4 Photovoltaic plant inspection

The main goal of this section is to identify anomalies in the PV cells that might require maintenance, using only the images and videos captured by UAVs. This is a real problem for the PV operator, since the number of PV cells in a mid-size photovoltaic installation could be really huge (e.g. ~130000 for a 50 Mw installation), and the exhaustive inspection of each and every asset is really expensive and time-consuming.

The PV Inspections functionality will be served to the final user as a section in the EMMA ARGOS User Interface where the user will be able to upload all the material taken by the UAV in the form of photos or videos for being analysed.

Before the system can start processing images, a precise PV plant outline with assets' locations and structure is required. This will be done in a specific EMMA ARGOS section, the *Plant Creator Component,* where the user must upload a mosaic of images covering the whole PV plant. This mosaic is obtained by combining several images taken during a flight of 50/80m of height depending on camera resolution. This general image is processed to obtain all the PV arrays and their locations, which will afterwards be used for the inspection.

When the plant structure is properly obtained and the location of the PV arrays has been stored, the user can go to *the Anomalies Detector Component* section in EMMA ARGOS to upload all the images to be analysed with the aim of detecting anomalies. These images are generally obtained during a flight of 20 m of height.

The next diagram presents the tools that compose the PV inspection functionality in EMMA ARGOS.

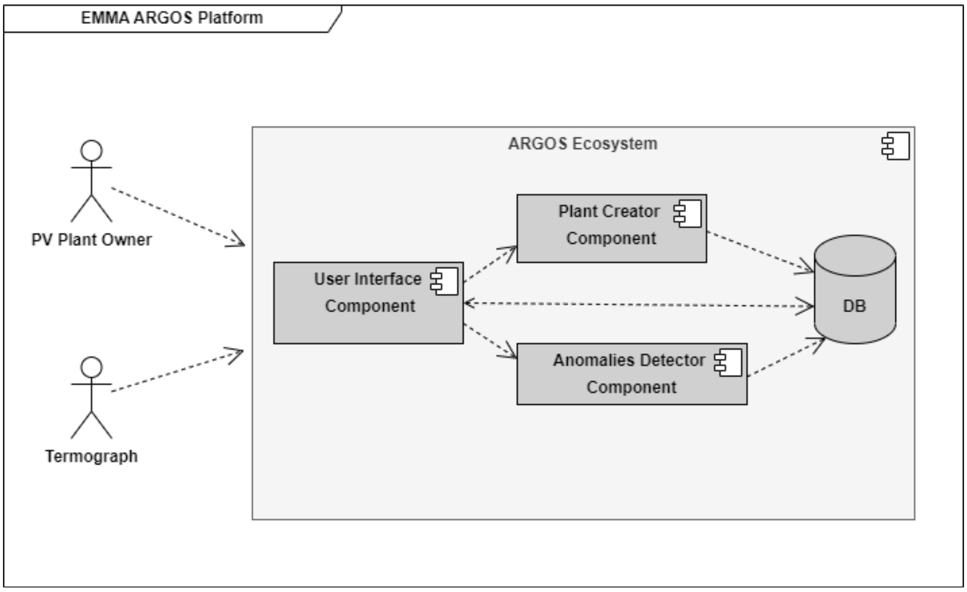


Figure 8 - PV Inspections functionality components and actors' diagram

All the components mentioned are described below:

- Plant Creator Component: The component in charge of receiving a mosaic image where all the PV plant is covered and analysed with the aim of extracting all the visible PV arrays and their locations.

  The PV arrays will be extracted using a neural network based on semantic segmentation, which will be trained with different pre-processed PV plant mosaics. During the training, the data will be pre-processed so that models are general enough to make predictions with images from plants different from the plants used in the training.

When all the arrays have been extracted, they will be sent to another neural network, also built on semantic segmentation, trained to be able to extract all the modules in each PV array. Using the location metadata of the mosaic images and some geospatial python libraries we will be able to extract the exact location of each module. Is important to add that the UAV used to obtain the graphical material from the field must have installed an RTK system to ensure a centimetric error in the associated locations of each photo or video.
Finally, with all the extracted arrays and modules and their respective locations, this information will be stored in the EMMA ARGOS database (based on MongoDB).

- Anomalies Detector Component: Component in charge of receiving images from the 20m height flights of the UAV and analysing them with the aim of detecting one of the pre-defined anomalies (they may change in the future): *Cell, Cracking, Diode, Hot-Spot, Soiling* and *Vegetation.* This detection will be based on a machine learning model, that will be created and trained to identify each of these anomalies by using labelled sets of images taken from specialised datasets.
  Even though the anomalies are detected in the pixels of the images, the anomaly output is associated with individual PV cells (not just images), because the images are geo-referenced, and the location of the PV cells would have been available with the usage of the plant creation component.
  The final step will be for the health status results for the individual PV cells (with all the required details) to be sent and stored in the ARGOS database (MongoDB).
- User Interface Component: The component in charge of presenting the inspection results and allowing user interaction. It will let users upload the mosaic image mentioned above and the pack of images to be analysed to detect anomalies. Also, it will be able to represent in a map the full PV plant and the detected anomalies geolocated on it and highlighted by means of a colour code that corresponds to the anomalies detected. For the manual assessment of the results, the user must be able to visualize all the uploaded images separately to check for the proper identification of anomalies. All the data represented in the User Interface will be obtained from the EMMA ARGOS database.

4.1.1.2 User Interface

The different types of inspections will have specific sections in the EMMA ARGOS tool user interface. At the time this deliverable is written, these sections have different levels of maturity: some of them are just initial concepts whilst others have preliminary versions of the user interface much more advanced. The different user interfaces are described in the next sections:

4.1.1.2.1 Line inspection for vegetation detection

The interface will allow users to create and view vegetation encroachment inspections. In the UI design, a first screen (Figure 9) will allow the user will be allowed to enter details about a new inspection, including location, date, and notes.

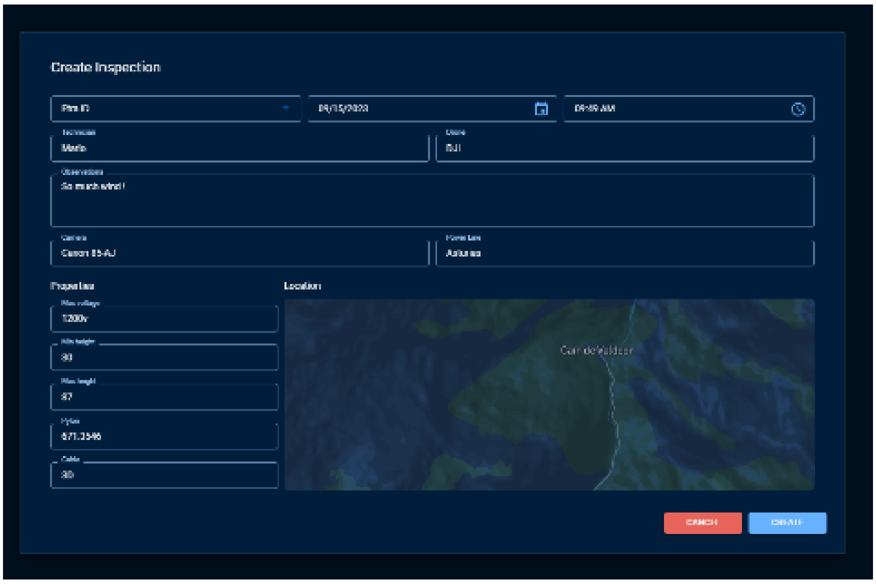


Figure 9 – Mock-up of the UI to introduce information on the inspection

It has been decided to add a second screen to displays inspection data, including a 3D point cloud visualization of the scanned area. This allows users to see a detailed representation of the environment. A tentative UI of this second screen is represented in Figure 10.

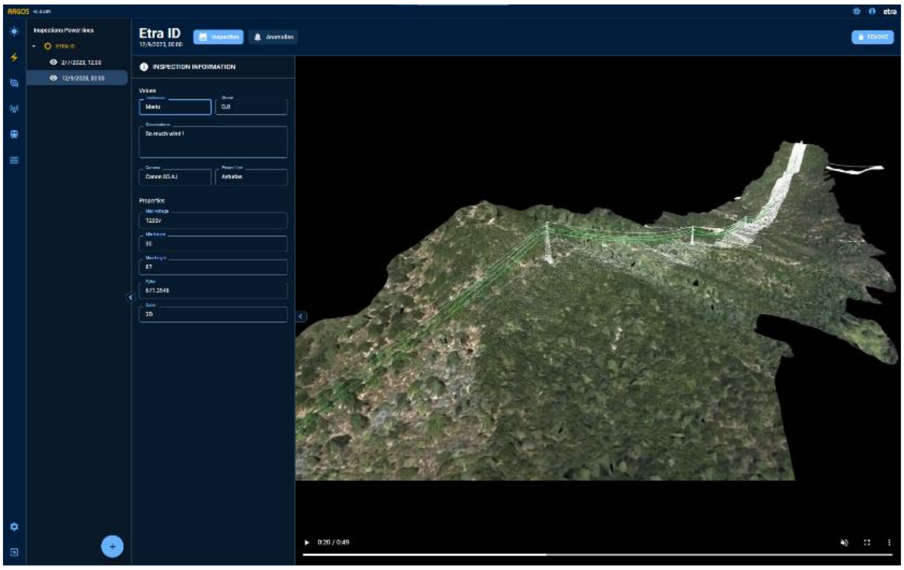


Figure 10 – Mock-up of the inspection visualization screen

Finally, a third screen (Figure 11) will focus on detected anomalies. It will provide tools to visualize and inspect anomalies in more detail, such as isolated views and measurements. Users will be able to tag anomalies for further review.

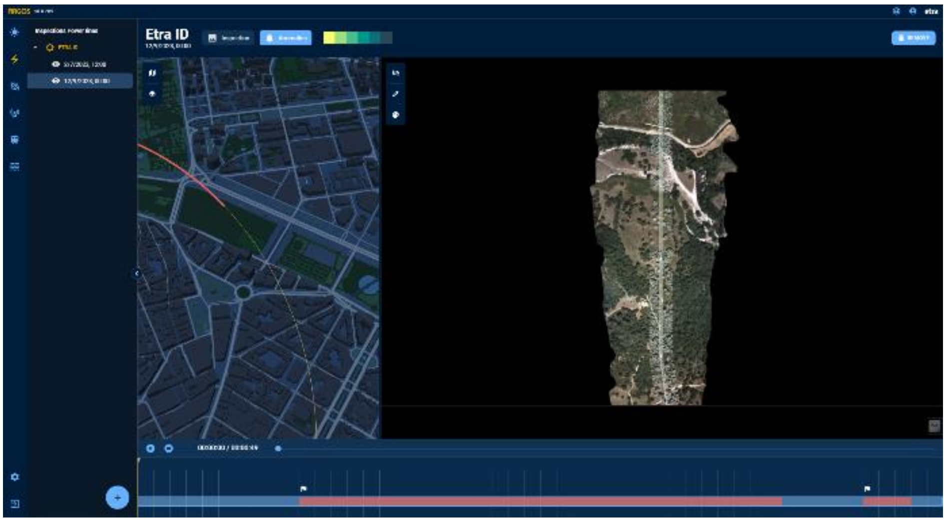


Figure 11 - Anomaly inspection tool

Overall, the mock-up shows a streamlined workflow to create vegetation encroachment inspections, view spatial data for the area, and analyse anomalies. The 3D visualizations and detailed anomaly tools aim to provide actionable information to inspect potential vegetation encroachment issues accurately.

4.1.1.2.2 Line inspection for electrical fault location.

The user interface of this tool consists of a view which allows the end-user to upload a thermal video and click a button to process it. Once this video has been processed it will appear as processed and the end-user can see the video and the respective detected hot spots in a timeline. On the other hand, a map with the drone trajectory during the flight has been displayed in the UI. A mock-up of the hot spot detection tool is represented in Figure 12.

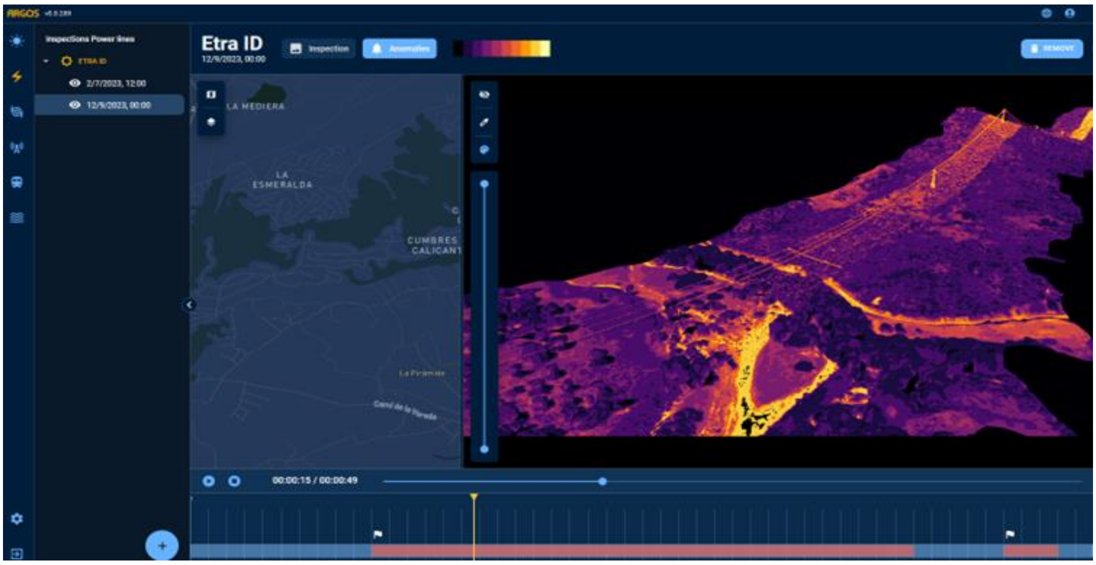


Figure 12 – Mock-up of the hot spot detection view

In this user interface, the location of dangerous vegetation will be pinpointed, letting the user navigate through the cloud of LIDAR points and check the problem.

4.1.1.2.3 Electrical tower inspection

The User interface will be integrated into the EMMA ARGOS tool, and this section will let access to the 3D reconstruction of the electrical tower. In Figure 13 an example of three 2D images and how they are converted to a 3D model is presented:

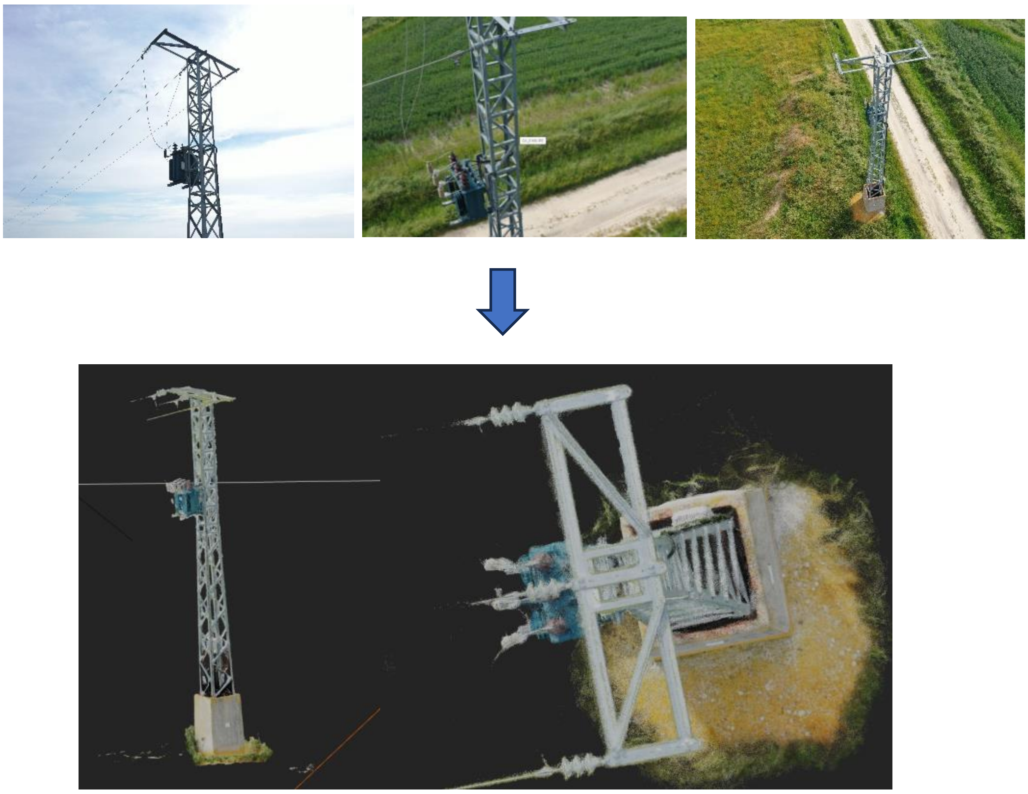


Figure 13 - example of 3 raw 2D images (top) and result of the 3D reconstruction (bottom)

The user interface for this section can be accessed from the EMMA ARGOS application and its appearance will look like in Figure 14:

Figure 14 – Electrical tower inspection UI mock-up

The original set of images and the 3D model will be presented and can be navigated in the user interface (zoom-in/out, pan/tilt, move, drag, etc.).

In case there is any damage automatically detected in inspection, this will be presented in the 3D interface so that the maintenance operator can see potential issues in context and easily navigate to the relevant images by clicking on the 3D model labels. This action will make the corresponding 2D raw images to be present on the right-hand side of the user interface.

Finally, this tool will allow for two more things: It will let the maintenance operator manually introduce anomalies in a given image, and it will let the user confirm whether or not the anomalies are automatically detected.

4.1.1.2.4 Photovoltaic plant Inspection

The User Interface for this section will consist of two applications. An application for plant management and an application for performing the inspections. They are two applications because the users of each one will be different. The management application is intended for plant managers and the inspection application is intended for inspectors.

The plant management application will allow new plants to be registered in the system. The plant to be inspected must be registered before the first inspection. An ortho-mosaic image of the plant must be uploaded during the registration phase. This image will be analysed to identify the modules and a unique identifier will be assigned to each module. Figure 7, a first approach to the plant management application. As can be seen, the modules are detected from the mosaic. This will allow us to identify automatically the anomaly modules during the inspection process.

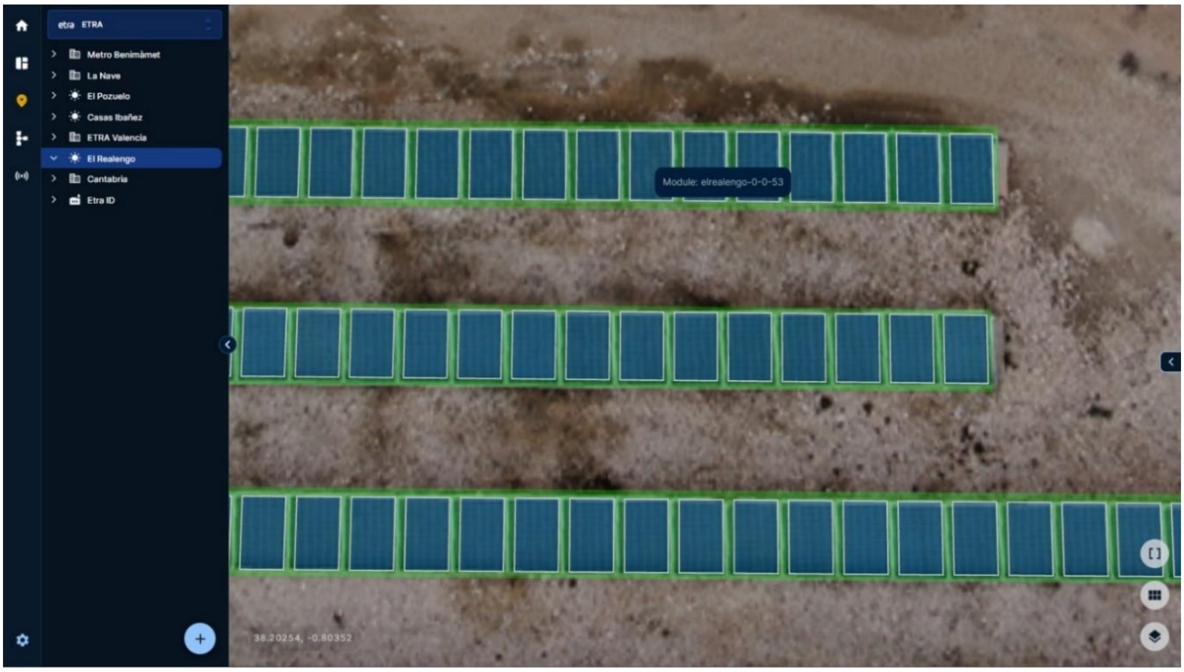


Figure 15 - Segmented PV plant.

The inspection application is going to be composed of two main sections. The first section called Frames is going to be used to upload and visualise the images taken by the drone. The second section called Anomalies is going to be used for examining the detected anomalies.

The Frames section will consist of a drop zone for uploading images, a list of already uploaded images, and an image view component where the images will be displayed. Also, it is going to be possible to see the images geolocated on the mosaic. A first approximation of the Frames section is shown in Figure 16 - Frames section.

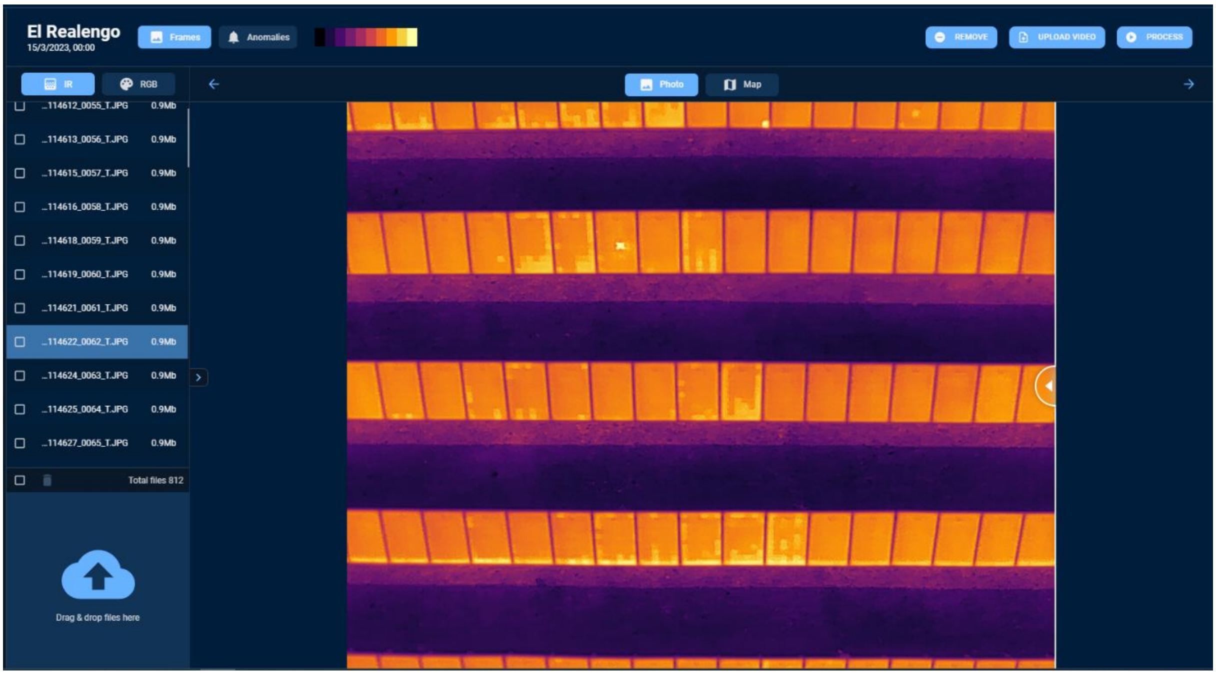


Figure 16 - Frames section.

The images will be separated by type. There will be a list of thermal images and a list of RGB images. In Figure 16 can be seen the thermal images list. The displayed list can be switched from the IR and RGB buttons (ubicated above the list). For thermal images, it will be possible to change the colour palette. Also, it is going to be possible to delete already uploaded images.

Once the user has already uploaded all the images that have to be processed, it will be possible to send them to the Anomalies Detector Component using the Process button (ubicated at the top right corner in Figure 8). When this button is pressed, it will appear the task completion percentage inside the button to inform the user of the status of the task.

Once the images are processed, the detected anomalies are going to appear in the Anomalies section (Figure 17). The Anomalies section will consist of a list of the anomalies (positioned on the left), a view of the image when there is a selected anomaly (positioned below the list) and a map view where the modules with detected anomalies are highlighted on the mosaic.

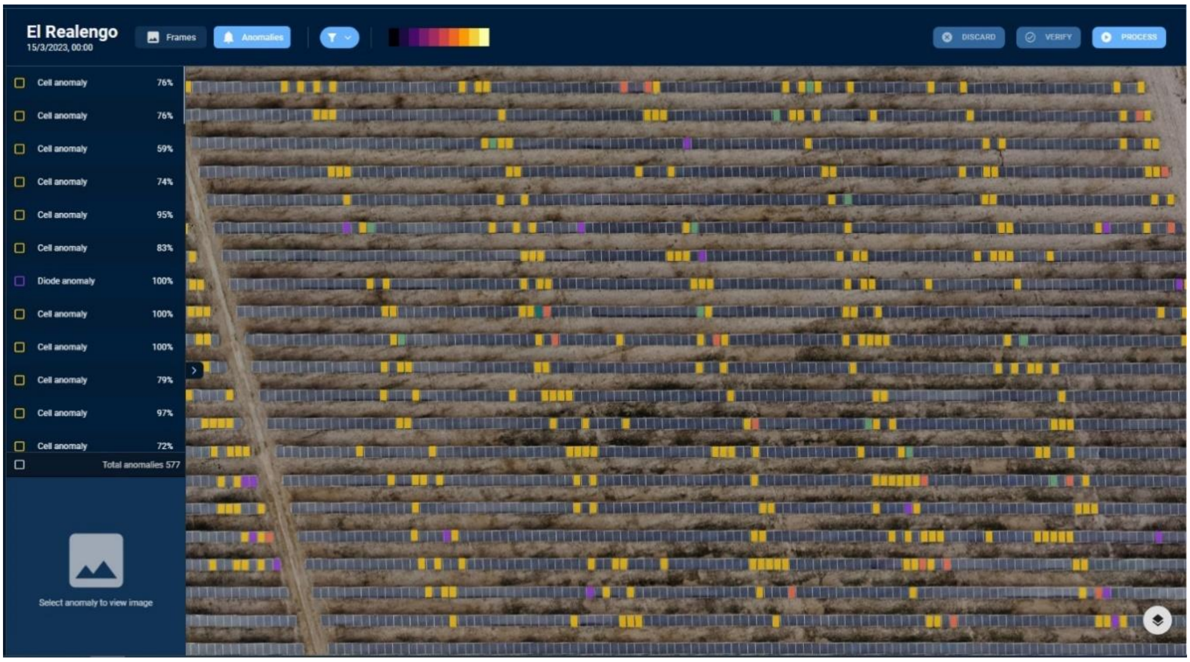


Figure 17 – Anomalies section.

It will be possible to select anomalies from the list or from the map. When an anomaly is selected, additional information about it will be displayed. To display these anomalies an additional window will be created. The idea is to have a portion of the window with a panel with anomaly information (i.e. the module identifier, the type of anomaly, the probability predicted by the neural network, etc..) Images of the module will be also displayed in the panel. The list of anomalies will be also displayed on the image taken by the drone from which the anomaly has been detected. Finally, the affected module will be marked with a rectangle on the image.

The UI will allow the user to verify or discard the anomalies detected by the neural network. It will also be possible to change the predicted type of the anomaly and to add comments. Figure 18 shows a preliminary idea of how the anomalies editor may look like in the future.

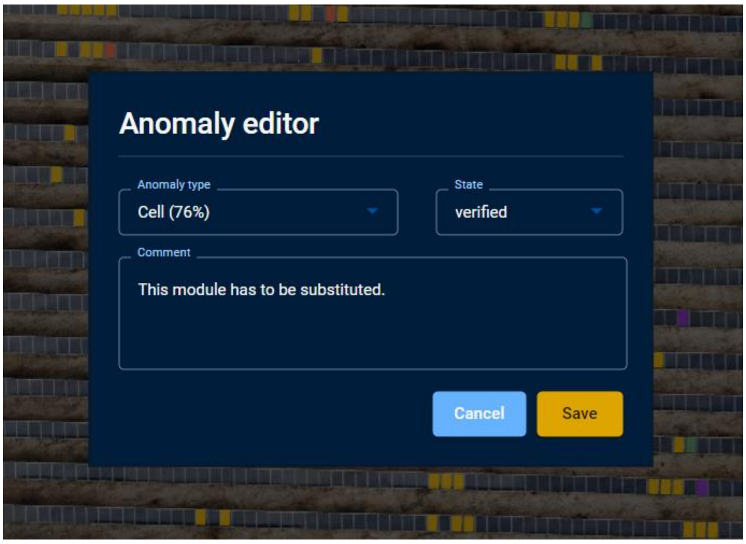


Figure 18 - Preliminary graphics for the anomaly editor form.

4.1.1.3 Resources

4.1.1.3.1 Vegetation Detection Tool:

To facilitate the development of the Power Lines Inspections tool, the following software resources and libraries will be employed to ensure efficient data processing and visualization:

Development Environment and Libraries

- **Python**: This programming language will be utilized as the core development environment, mainly for the processing components. It is renowned for its versatility and the availability of a plethora of libraries that cater to various computational and data analysis needs.
- **NumPy**: A fundamental package for scientific computing with Python, it will be employed to handle large, multi-dimensional arrays and matrices, facilitating complex mathematical operations on these data structures.
- **Laspy**: This library will be used for reading, modifying, and writing LAS files, which are primarily utilized for storing LiDAR data.
- **SciPy**: A library used for high-level computations and technical computing. It will assist in the statistical analysis of the data, helping in the extraction of insightful information from the collected data.
- **Scikit-Image (skimage)**: A library for image processing in Python, it will be utilized to detect linear structures in the point cloud data, which is crucial in the identification of power lines and pylons.

Visualization and Web Framework

- **Potree**: An open-source point cloud viewer written in JavaScript, it will serve as the primary tool for visualizing the 3D point clouds within the web browser, offering users a comprehensive view of the analysed data in 3D format.

- **Raster Graphics**: Utilized for creating detailed 2D visualizations, they will facilitate a more in-depth analysis by providing realistic representations of the surveyed areas. These resources have been selected to ensure a cohesive development environment that caters to the specific requirements of the tool, fostering a seamless workflow from data collection to visualization and analysis.

4.1.1.3.2 Line Inspection for electrical fault

To facilitate the development of the Line inspection tool, the following software resources and libraries will be employed:

- **Python:** The primary programming language used for implementing various components of the tool such as
- **MQTT Protocol:** Protocol used to send information between python components and the web application.
- **Pytorch:** Utilized library to create deep learning models.
- **Scikit-learn, numpy, geopandas, camera transform:** Utilized python libraries to process all data and obtain desired results.
- **YOLO (You Only Look Once):** An advanced object detection algorithm in the field of artificial intelligence. It's employed for real-time object detection in the camera footage.
- **Database (unspecified type):** Stores the collected video feed for subsequent analysis and reference.
- **HTTP/API-REST protocols:** Utilized for inter-platform communication.

These software resources collectively form the backbone of the tool, enabling it to perform tasks such as segmentation, image classification, video acquisition, data transfer, storage, analysis, and communication. Their seamless integration ensures the tool's functionality and effectiveness in monitoring and alerting for potential anomalies in the PV plants.

4.1.1.3.3 Electric Tower Inspection

This tool will use the following software resources:

- **Python:** The primary programming language used for implementing various components of the tool such as
- **OpenMVS** (OpenMVS, s.f.) **and COLMAP** (COLMAP, s.f.) for the 3D image reconstruction
- **React and REACT-TREE** for the visualization
- **Scikit-learn, numpy, geopandas, camera transform:** Utilized python libraries to process all data and obtain desired results.
- **Database (unspecified type):** Stores the collected video feed for subsequent analysis and reference.

4.1.1.3.4 Photovoltaic Plant Inspection

To facilitate the development of the PV Inspections tool, the following software resources and libraries will be employed:

- **Python:** The primary programming language used for implementing various components of the tool such as
- **MQTT Protocol:** Protocol used to send information between python components and the web application.
- **Pytorch:** Utilized library to create deep learning models.
- **Scikit-learn, numpy, geopandas, camera transform:** Utilized python libraries to process all data and obtain desired results.
- **FastAPI:** Utilized library to implement an API and allow the internal system communication.
- **Database (unspecified type):** Stores the collected video feed for subsequent analysis and reference.
- **HTTP/API-REST protocols:** Utilized for inter-platform communication.

These software resources collectively form the backbone of the tool, enabling it to perform tasks such as segmentation, image classification, video acquisition, data transfer, storage, analysis, and communication. Their seamless integration ensures the tool's functionality and effectiveness in monitoring and alerting for potential anomalies in the PV plants.

4.1.2 Tool 2 – EMMA SURVEILLANCE Tool

The primary objective of this tool is twofold:

- It aims to perform manual segmentation of photos captured at regular intervals (approximately every hour) by a fixed camera pointed at a substation, utilizing thermal imaging. This segmentation will be conducted by a knowledgeable professional familiar with the substation environment to identify hot spots on the substation components. These hot spots will serve as triggers, raising alarms when temperatures surpass predefined thresholds.
- The tool will employ YOLO (You Only Look Once) model-based analytics [37] on the camera footage. YOLO is an advanced object detection algorithm in the field of artificial intelligence. Unlike traditional object detection methods that involve multiple passes over an image, YOLO divides the image into a grid and predicts bounding boxes and class probabilities for each grid cell in a single forward pass. This results in incredibly fast and efficient real-time object detection. Using YOLO, the tool can accurately and swiftly identify various entities within the camera feed, including people, animals, fires, and smoke. Upon detecting any of these presences, the tool will promptly generate alerts, allowing for timely responses to potential safety or security

concerns. This integration of YOLO enhances the tool's capabilities, enabling it to provide comprehensive surveillance and monitoring functionalities.

4.1.2.1 Internal Architecture

The visual representation, illustrated in Figure 19, outlines the step-by-step process from data acquisition to alert generation. Each stage plays a crucial role in ensuring the seamless flow of information and the timely detection of potential anomalies.

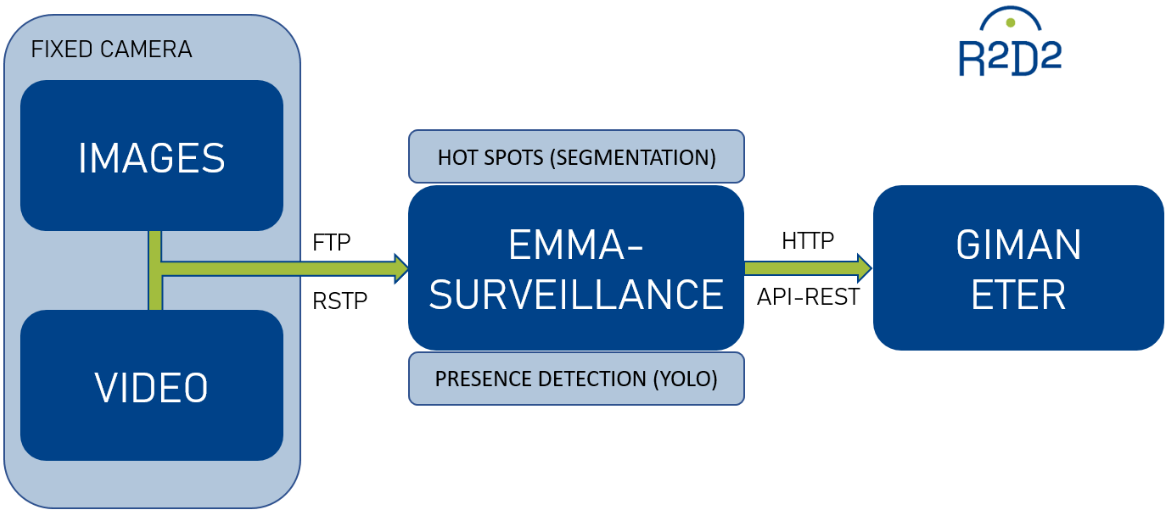


Figure 19 – Internal architecture of the EMMA Surveillance tool

The process begins with the acquisition of images and videos from the camera. These visual inputs serve as the primary data source for the system. The detailed architecture can be split into next steps:

- **Data Acquisition:** Real-time video feed from the camera is continuously collected. This stream of visual data serves as the foundation for subsequent analysis.
- **Communication Protocol:** To seamlessly connect this data with the platform, the tool employs FTP (File Transfer Protocol) for images and RTSP (Real-Time Streaming Protocol) for video footage. FTP ensures swift and efficient transfer of images, while RTSP facilitates the streaming of real-time video data from the camera.
- **Data Storage and Management:** The collected data is then stored directly within the platform's dedicated database. This serves as a centralized repository for all visual inputs, ensuring easy accessibility and reference.
- **Automated Analysis and Alert Generation:** The platform conducts a series of automated analyses of the stored data. This includes two critical processes: manual segmentation for images and YOLO-based object detection of real-time video acquisition. The manual segmentation module allows for the identification of hot spots by a domain expert. Simultaneously, the YOLO model is deployed for real-time object detection, identifying entities such as people, animals, fires, and smoke.

- **Alarm Triggering:** The analysis results, which include identified anomalies and hot spots, are then used to trigger alerts. These alerts are specifically designed to notify maintenance personnel promptly in response to identified instances of elevated component temperatures or the detection of animals, individuals, fires, etc.
- **Inter-Platform Communication:** Additionally, the platform establishes communication with GIMAN and ETER systems using HTTP/API-REST protocols. This connection facilitates the dissemination of alerts to maintenance personnel, ensuring that they are promptly informed of any potential concerns or issues.

This integrated pipeline ensures a seamless flow of data from the camera to the platform, culminating in the generation of timely alerts for necessary action. The combination of manual and automated analyses enhances the tool's ability to provide comprehensive surveillance and monitoring capabilities.

4.1.2.2 User Interface

While the tool won't feature a dedicated user interface in its initial deployment, it will offer an essential visual component. In real time, the video feed captured by the camera will be accessible for verification purposes, allowing for visual confirmation of YOLO model detections.

This direct visual feedback is invaluable in ensuring the accuracy and reliability of the automated detection system. Operators can verify whether the identified entities - be they people, animals, fires, or smoke - align with the actual visual information provided by the camera. This not only serves as a crucial quality control measure but also allows for on-the-spot validation of alerts generated by the system.

In addition to the YOLO model-based analytics, a small but significant module will be developed to verify hot spots. This module empowers domain experts to manually identify and confirm hot spots, leveraging their deep understanding of the substation environment. By incorporating this manual verification step, we enhance the tool's accuracy and reliability, providing an extra layer of assurance in the identification of critical areas.

As the tool evolves, considerations for an intuitive and user-friendly interface may be incorporated in subsequent phases. This could involve the development of dashboards, charts, and additional visual aids to enhance the monitoring process. The goal will be to provide operators with a clear, comprehensive, and easily interpretable representation of the detected entities and potential anomalies within the camera feed.

This phased approach ensures that the tool is not only functional but also adaptable to the evolving needs and requirements of the monitoring process. As it progresses, user feedback and operational insights can inform the development of an interface that maximizes the tool's utility and effectiveness.

4.1.2.3 Resources

- **Python:** The primary programming language used for implementing various components of the tool such as

- **YOLO (You Only Look Once):** An advanced object detection algorithm in the field of artificial intelligence. It's employed for real-time object detection in the camera footage.
- **FTP (File Transfer Protocol):** Used for efficient transfer of images captured by the camera to the platform for analysis.
- **RTSP (Real-Time Streaming Protocol):** Facilitates the streaming of real-time video data from the camera to the platform.
- **Database (unspecified type):** Stores the collected video feed for subsequent analysis and reference.
- **HTTP/API-REST protocols:** Utilized for inter-platform communication, allowing for the dissemination of alerts to maintenance personnel.

These software resources collectively form the backbone of the tool, enabling it to perform tasks such as real-time object detection, image and video acquisition, data transfer, storage, analysis, and communication. Their seamless integration ensures the tool's functionality and effectiveness in monitoring and alerting for potential anomalies in the substation environment.

4.2 TASK 6.2 - OPTIMAL ASSET MANAGEMENT

4.2.1 Tool 3 - EMMA DYML Tool

The DYML platform aims to create a framework to perform predictive maintenance by generating alarms for possible malfunctions of the substation's components. This is made through the analysis of tabular data coming from:

- **SCADA system** is a control system architecture comprising computers, networked data communications and graphical user interfaces for high-level supervision of machines and processes. It also covers sensors and other devices, such as programmable logic controllers, which interface with process plants or machinery. Data gathered by SCADA are **physical quantities** of the components that make up the substation (voltages, currents, temperatures, etc.) and **events** occurring in the substation (alerts, errors, warnings, etc.).
- **DGA analysis** is an examination of electrical **transformer oil contaminants**. Insulating materials within electrical equipment liberate gases as they slowly break down over time. The composition and distribution of these dissolved gases are indicators of the effects of deterioration, such as pyrolysis or partial discharge, and the rate of gas generation indicates the severity.

4.2.1.1 Internal Architecture

EMMA DYML is based on the usage of **artificial intelligence models** for making predictions. This means that there is an initial phase in the whole process where these models are built. For this, historical data from the SCADA system and DGA analyses are used to learn the typical behaviours of components. Failure dates from this history are also employed to learn from these malfunctions and anticipate their recurrence. Python is the programming language that best suits this use case. Specifically, models that perform well with time series data include those associated with libraries like Tensorflow [3], XGBoost [40], and Scikit-learn [41].

The process for creating machine learning models is composed of the following phases:

1. **Data Cleaning**: In this phase, the raw data collected for the project is carefully processed to eliminate errors, inconsistencies, and missing values. This involves tasks such as imputing missing data, handling outliers, and rectifying any inaccuracies that could adversely affect model performance. Data cleaning ensures that the subsequent analysis is based on accurate and reliable data.
2. **Feature Extraction**: Feature extraction involves selecting and transforming the relevant attributes or features from the cleaned dataset that will serve as inputs for the machine learning models. During this phase, domain knowledge is crucial for identifying the most informative features, which can sometimes mean either reducing the data's complexity or introducing new variables to account for previously overlooked factors. Extracted features should capture meaningful patterns and relationships within the data, improving the model's ability to generalize from the training data to new, unseen data.

3. **Model Creation**: During the model creation phase, we choose and apply machine learning algorithms to the prepared dataset, which includes the features used for training and the target variable—the component temperatures. Our objective here is real-time anomaly detection by predicting these temperatures. Various algorithms, such as regression, decision trees, neural networks, or ensemble methods, are explored to identify the best fit for the problem. The dataset is divided into training and validation sets for model training and performance evaluation. It's important to note that the alarms triggered for anomalies are not generated directly by the prediction model itself. Instead, they are derived from a set of statistical rules that consider the distribution of residuals. These residuals represent the differences between the temperature predictions made by the model and the real-time temperature obtained from the SCADA system. This approach ensures effective anomaly detection when significant deviations occur.
4. **Model Deployment**: Once a satisfactory model is created and evaluated, the next step is to deploy it into a production MLflow environment. This phase involves integrating the trained model into the system where it will be used to make predictions on new data. Model deployment requires careful consideration of factors like scalability, real-time performance, and robustness. Monitoring the model's performance in production and implementing mechanisms to retrain or update the model as new data becomes available is also part of this phase.

The machine learning models stored in MLFlow are the starting point of the whole EMMA DYML processes, but they will evolve during project life, as new data appears and the test-and-error experience allows them to evolve and enhance the models. MLFlow allows for handling properly the set of models and lets applications use always the most up-to-date and accurate models.

For real-time operation, these pre-built models will be used and there is only a need for real-time data (from SCADA) and the last DGA analysis data whenever it is available. The data ingestion and intermediate storage will be done by using the CITRIC interoperability platform. This is a reactive and real-time data interoperability platform developed by ETRA that features a number of functionalities, protocols drivers and databases that will facilitate the tasks in EMMA DYML. In this case, the CITRIC platform will be configured to:

- Connect to the SCADA
- Store the measurements received
- Transform this data to a known data model (based on JSON)
- Send the new data to the different submodules (or microservices), so that they can act accordingly. EMMA DYML will be one of the microservices that will receive SCADA measurements

The architecture of CITRIC is depicted in Figure 20:

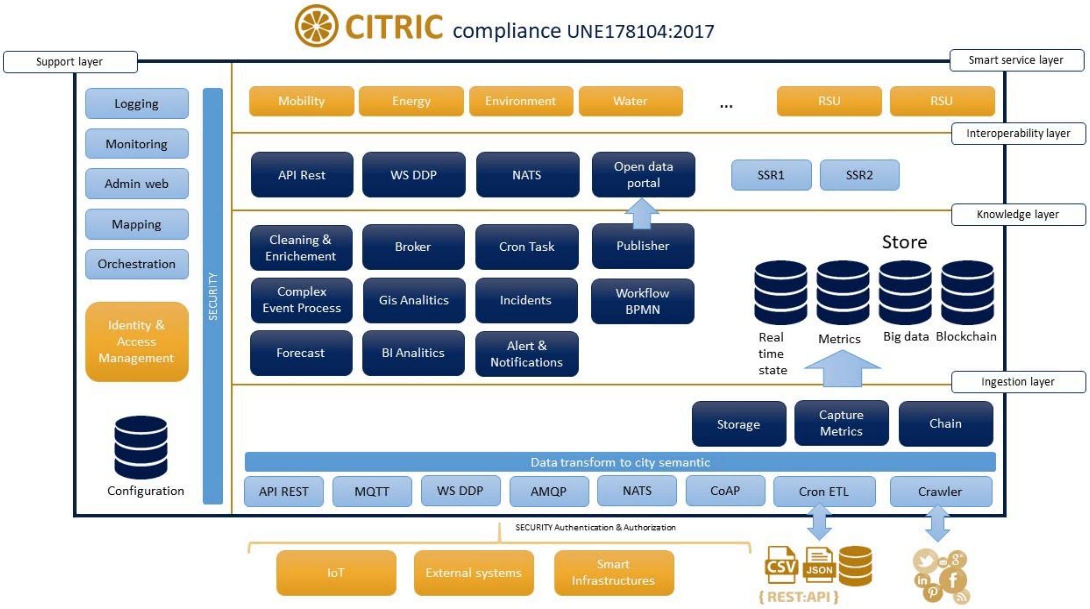


Figure 20 – Architecture of the CITRIC platform

As part of R²D², an OPC-UA connector for the SCADA system will be developed. The data will flow through the whole platform and reach a new microservice (EMMA DYML) to be developed as part of R²D² that will apply the appropriate machine learning model to the data received from the SCADA. The usage of CITRIC will allow the EMMA DYML functionality to focus just on machine learning models and let the tasks of data ingestion, storage, formatting, etc. to CITRIC. The architecture of the platform is shown in Figure 21.

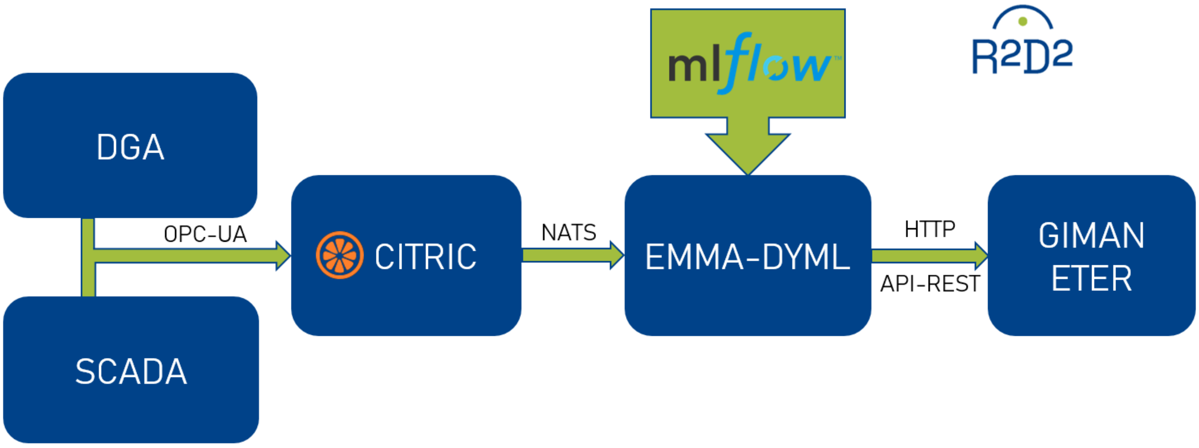


Figure 21 - Internal architecture of EMMA-DYML platform.

Once the data is sent to the DYML component, it takes care of processing this data. A feature extraction is performed to create new variables that provide more information on the system and artificial intelligence models are used to make the appropriate predictions to verify the integrity of the substation components. These models are downloaded from the MLflow server, which allows the creation of a repository to store the artificial intelligence predictors with the best results, it allows a series of experiments to be generated in order to optimise the management and development of the models as well.

When alerts/alarms are obtained, a converter to the EMMA-GIMAN and EMMA-ETER protocol is used at the output of the DYML platform to standardise the alarm codes and to alert the maintenance staff in an optimal way. Communications between DYML and GIMAN/ETER are via http/api-rest. EMMA GIMAN is described in Tool 5 - EMMA GIMAN

4.2.1.2 User Interface

Initially, there are no plans to incorporate a graphical interface into this platform. Instead, our focus lies on a core functionality: real-time diagnosis of the operational and structural state of each one of the components and subcomponents within the substation. This approach translates into a robust capability to continuously monitor and assess the performance and integrity of all critical elements of the substation, enabling early detection of potential issues and ensuring safe and efficient operation.

However, the MLFlow server has a graphical interface that allows the predictive models to be organised and arranged according to a set of user-defined parameters and metrics, Figure 22. This makes it easy to choose the optimal predictive models for production on the same platform.

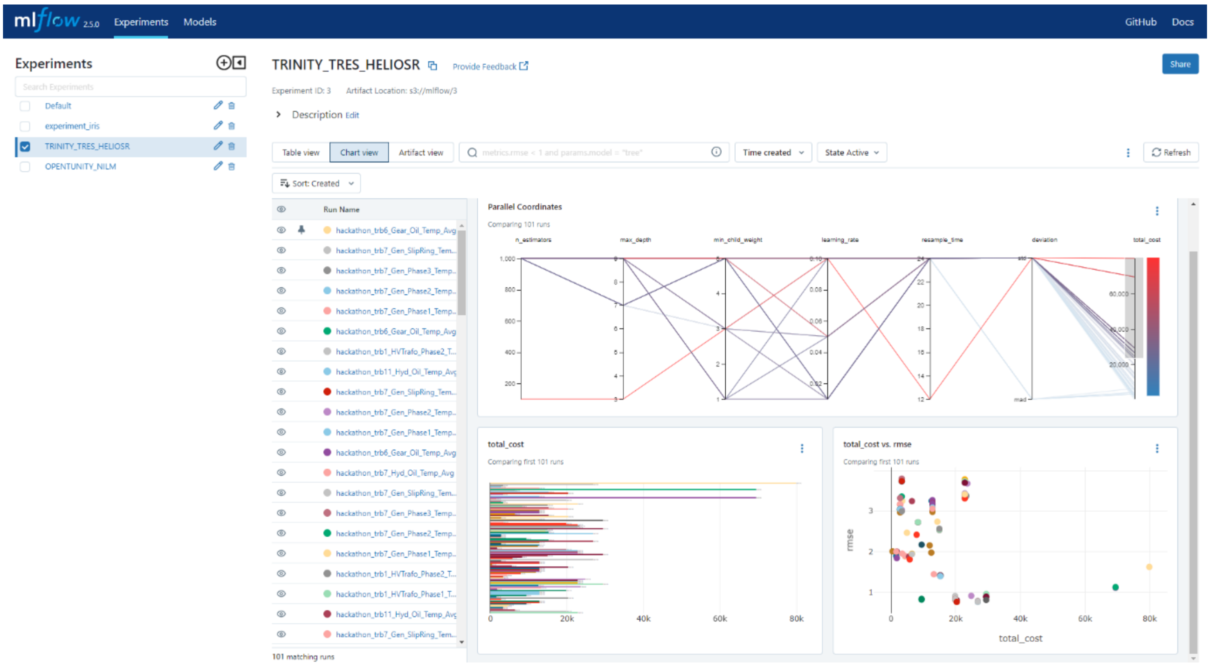


Figure 22 - MLflow user interface.

A similar solution has been developed for turbine components predictive maintenance as shown in Figure 23 as an example, to present how a series of alarms are raised over time due to malfunction.

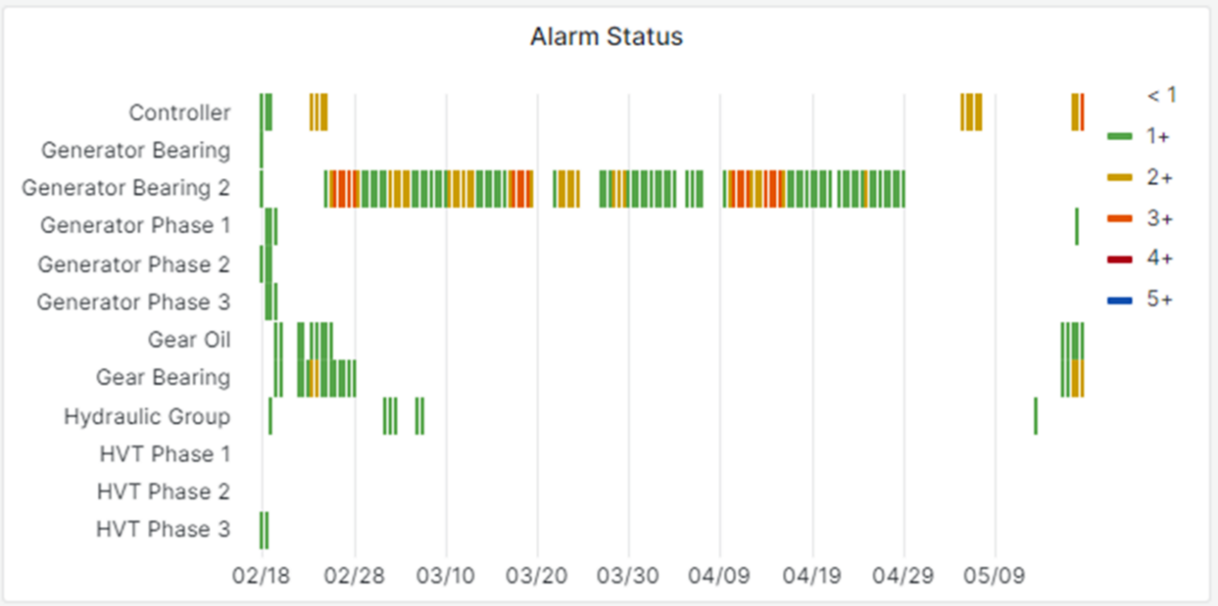


Figure 23 - Example of a UI of predictive maintenance for components of a wind turbine. Status plot.

4.2.1.3 Resources

The resources to be used in the EMMA-DYML platform can be divided into four categories:

- **Messaging: NATS** will be employed for messaging purposes. **NATS** is a high-performance messaging system that facilitates communication between different components of the application. It excels in scalability and simplicity, making it an excellent choice for reliable messaging.
- **Model Storage and Monitoring: MLflow** will be utilized for storing and monitoring machine learning models. **Mlflow** is an open-source platform that simplifies the end-to-end machine learning lifecycle. It allows tracking experiments, packaging code, and sharing models, providing a streamlined approach to model management.
- **AI Model Development:** For developing AI models, various Python packages will be employed, including:
  - **Tensorflow:** Popular open-source library for high-performance numerical computations. It's widely used for building and training deep learning models.
  - **XGBoost:** Efficient and scalable implementation of gradient boosting. It's particularly well-suited for solving machine learning problems.
  - **Scikit-learn:** Comprehensive machine learning library in Python. It provides a wide range of tools for tasks such as classification, regression, clustering, and more.
- **Deployment:** The application will be deployed using **Docker**, a containerization platform that allows for easy packaging and deployment of applications in a consistent and isolated environment. **Docker** ensures that the application runs reliably across different environments, making it an essential tool for efficient deployment strategies.

4.2.2 Tool 4 - EMMA ETER Tool

EMMA Eter is an ETRA portfolio product for distribution system operators, aiming at facilitating the monitoring and control of the modern grid effectively. The application can be categorized as a DMS (Distribution management system), and as such, it features several specialized functionalities. The most relevant could be:

- Geographic information system (GIS)
- Topology processor (TP)
- Intelligent alarm processing (IAP)
- On-line power flow (OLPF);
- Short-circuit analysis (SCA);
- State estimation (SE);
- Fault location, isolation, and service restoration (FLISR);
- Volt/VAR optimization (VVO);
- Optimal Network Reconfiguration (ONR);
- Switch order management (SOM);
- Emergency load shedding (ELS); and
- Short-term load forecasting (STLF).

4.2.2.1 Internal Architecture of the Tool

The aforementioned functionalities are designed in ETER as independent software modules and subsystems that communicate and coordinate with each other to build the complete platform and fulfil its requirements. This approach is commonly known as micro-service-based architecture, and presents a number of advantages compared to traditional monolithic architectures:

- Facilitates maintenance of the software modules
- Minimize the impact of failures
- Avoids vendor lock-in
- Increases reusability of the developments from the design phase

The next picture depicts the main components or services of EMMA ETER:

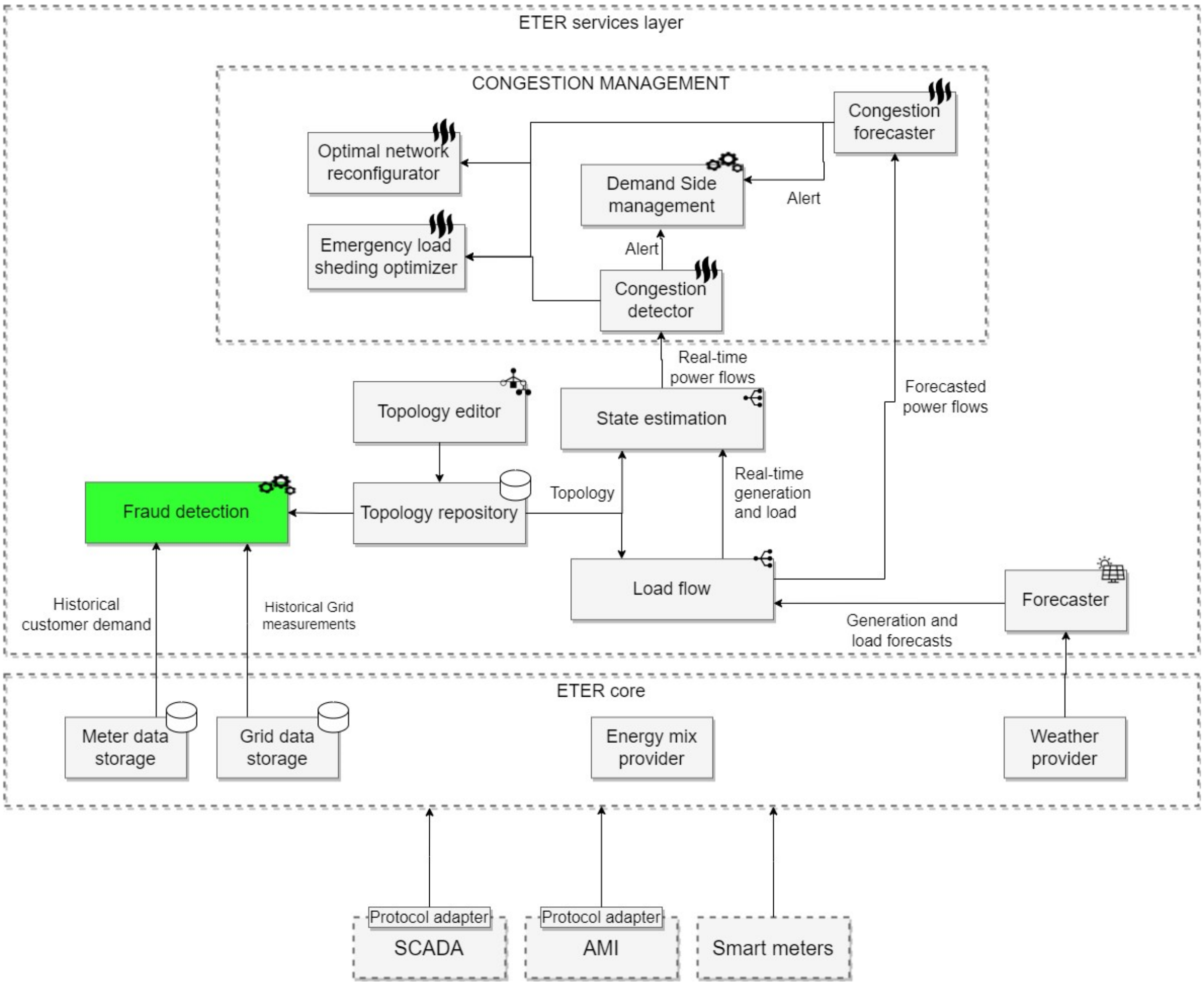


Figure 24 – ETER product architecture with the new NTL module

In the following screenshots, some examples of the ETER application are presented:

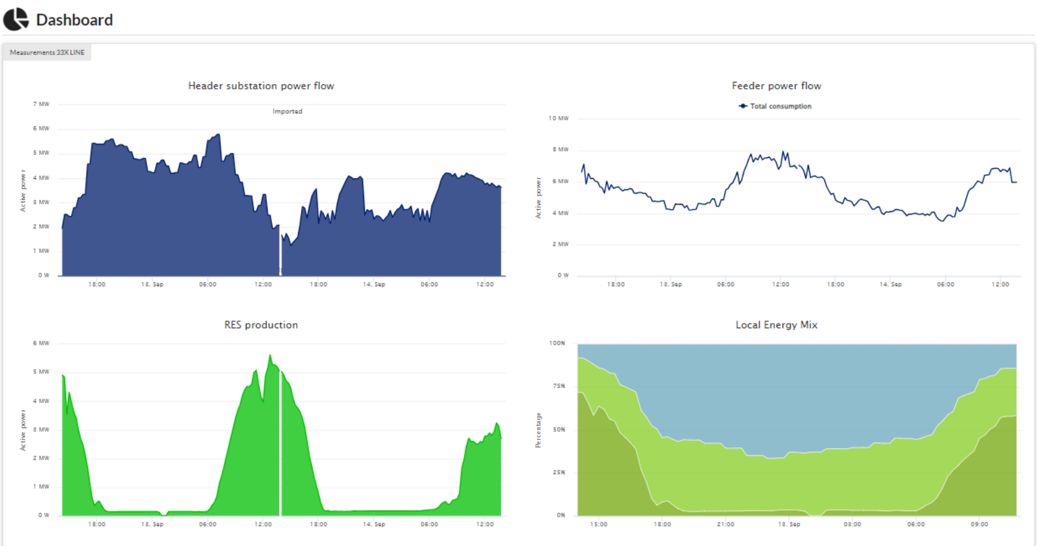


Figure 25 - ETER dashboard example in Xanthi pilot

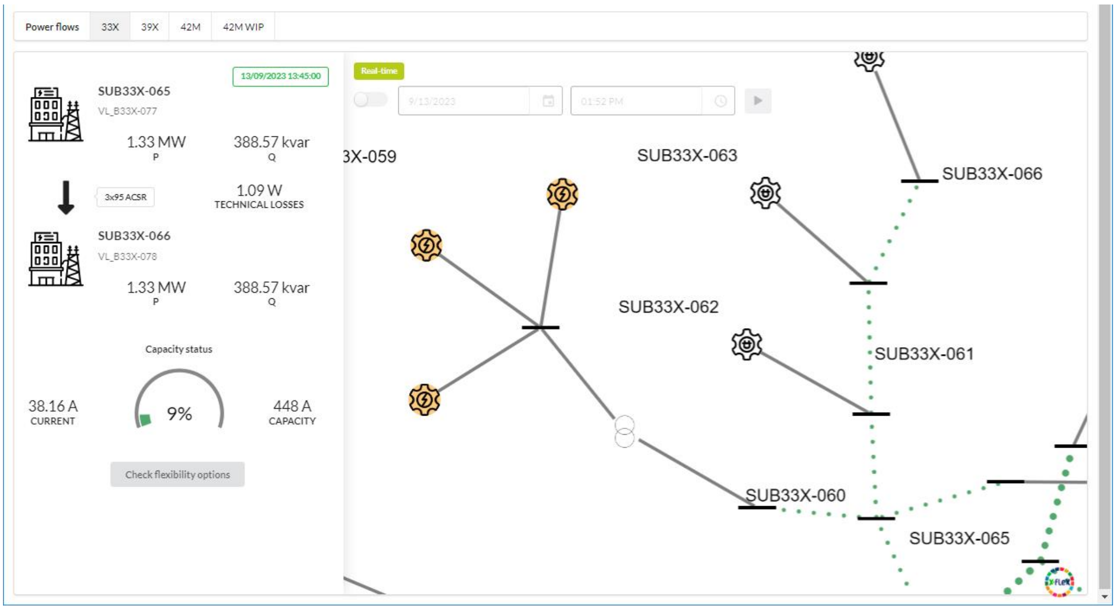


Figure 26 - ETER power flow grid example in Xanthi pilot

Figure 27 - ETER smart meter details example in Xanthi pilot

A functionality commonly used by system operator and currently missing in EMMA ETER is the identification of non-technical losses or fraud detection. Technical losses are inherent to the transmission and consist mainly of the dissipation of electricity in transportation, transformation, distribution, and energy measurement. Non-technical losses (NTL) correspond to any electrical energy consumed and not invoiced and can therefore be considered as a result of fraud or energy theft. The NTL detection component in the ETER product will be developed as part of the R^2D^2 project.

Several solutions exist in commercial products and in the literature for detecting fraud in energy delivery. This interest is mainly because it is something that impacts the economic revenues of the energy actors. EMMA ETER will incorporate a module that will perform fraud detection given the portfolio of metered users and the monitored network. It will make use of other components and databases already existing in EMMA ETER:

- The meter data storage: This database contains the historical measurements (normally hourly-based) of energy consumption for all the electricity customers. This data is either coming from an existing AMI system (in case EMMA ETER is integrated by connecting to an existing AMI) or directly from the Smart meters (When EMMA ETER is acting as an AMI). This database will be InfluxDB. This database is very efficient at storing huge amounts of data in the form of time series.
- Grid data storage: This database contains the historical measurements of the network SCADA. This is information captured by physical devices and sensors deployed close to the network elements. Examples of such sensors could be: RTUs, EIDs, PMUs or PLCs, and they always communicate with the SCADA by using standardised protocols. The granularity of the data is much more detailed than the meter data and here the problem is that the historical database could grow huge quite fast, and normally database's old data is deleted or compacted periodically. This database will also be InfluxDB.

According to [21], all the existing NTL or fraud detection techniques could be categorised into two different groups: Data-oriented solutions and network-oriented solutions, whilst some can lie partially in both categories and can be considered as a hybrid. The next diagram shows the different techniques adopted for NTL.

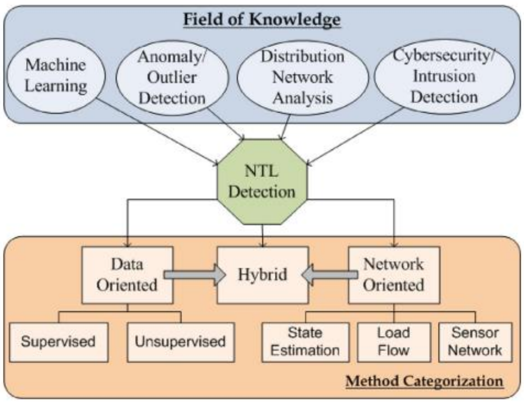


Figure 28 - NTL detection algorithm categories [21]

Data-oriented and network-oriented methods can be further divided into subcategories, according to the main concept behind NTL detection. Data-oriented methods are divided into supervised and unsupervised. Methods that make use of both labels (known positive/fraud and negative/not-fraud classes) are supervised, while methods that make no use of labels are unsupervised. Normally, the scarcity of the positive label (fraud) prohibits the use of supervised learning methods. The lack of confirmation labels in the model training of the unsupervised methods is solved by using different techniques oriented to identify the suspicious behaviours, like fuzzy c-means clustering and outlier detectors.

Network oriented techniques are based on network analysis and the physical rules that describe such systems. These methods are categorized according to the main concept/algorithm used, i.e. state estimation, load flow or special sensors for detecting fraud.

Hybrid methods use a combination of both approaches and are the solution that we are going to use in EMMA ETER:

1) In the first stage, our algorithm will try to identify the parts of the grid that are likely affected by NTL. For this, we will compare the historical evolution of state estimation measurements at the substation feeders with the aggregation of meter readings for the same periods (a combination of SCADA and AMI data). In case of large discrepancies, this feeder will be marked as potentially affected by NTL.
2) A second stage of the algorithm will try to identify the fraudulent meter or at least the part of the grid affected. The statistical load profiling analysis (data-oriented method) of the meters in the region will be used as the baseline of the analysis, but some more elaborated techniques, mainly network based, will be investigated to complement it and provide a more robust solution able to detect not only the fraudulent meters but also the fraudulent connections with no meters. The techniques/technologies to investigate for this will include (among others): Voltage drop analysis, power line communication response time analysis and wavelet analysis.

For the testing of the algorithm, two approaches will be used:

1) We will make use of general datasets from the scientific community to test our algorithms and compare them with other approaches. This is necessary because, given the number of measurements handled by the system operators, NTL occurrence is hard to identify and this scarcity is a problem for the algorithms training. NTL samples in the literature and open data are a must for the development of the solution.
2) Pilot sites will provide access to relevant databases (AMI and SCADA) for the requested period. Examples of NTL detections will also be provided by them so that the algorithms can be trained and evaluated. Figure 29 is an example of an NTL case identified by the Spanish pilot, with the profile of the load of the tampered line.

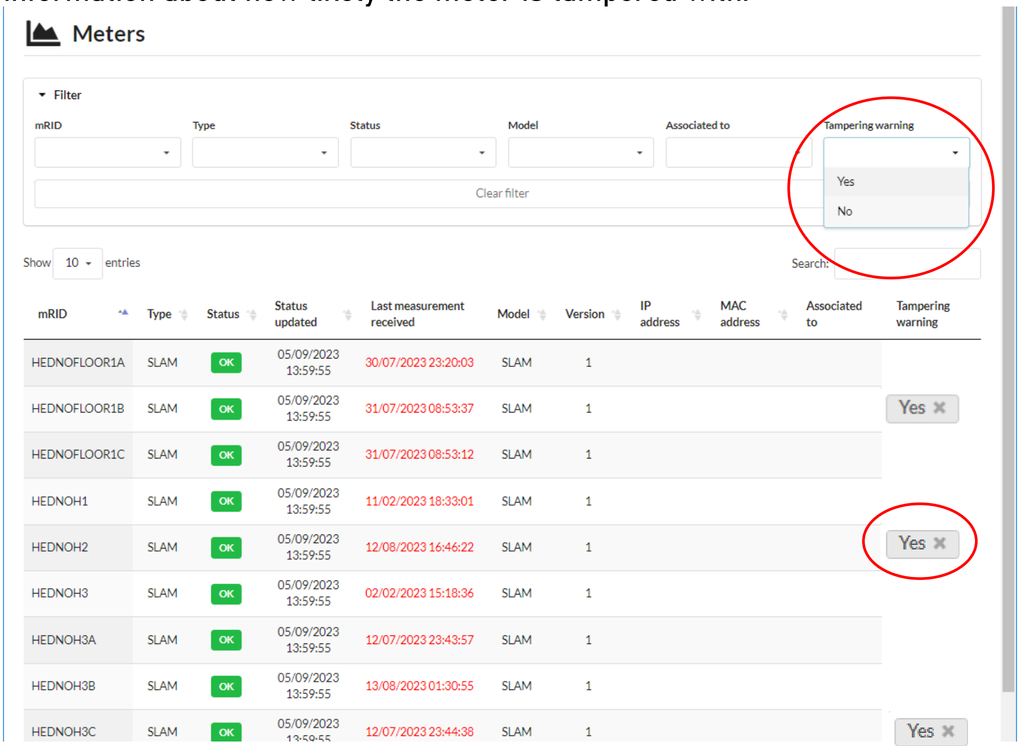
Figure 29 – consumption profile in a line affected by NTL

In the chart can be seen that the differences (green line) from the substation measurements compared to the aggregated meter measurement decrease significantly after the NTL problem is solved. The red circle highlights the load profile with the disconnection of the illegal load.

4.2.2.2 User Interface

The existing ETER product user interface will be expanded to include the results of the NTL analysis (Figure 30). This will make some of the application pages and forms change to include the new results. In the following figure, a screenshot of how the UI can be updated is shown, and the following changes can be considered for future implementation:

1) The section in the application that presents the list of meters will include information about how likely the meter is tampered with:



mRID	Type	Status	Status updated	Last measurement received	Model	Version	IP address	MAC address	Associated to	Tampering warning
HEDNOFLOOR1A	SLAM	OK	05/09/2023 13:59:55	30/07/2023 23:20:03	SLAM	1				
HEDNOFLOOR1B	SLAM	OK	05/09/2023 13:59:55	31/07/2023 08:53:37	SLAM	1				Yes
HEDNOFLOOR1C	SLAM	OK	05/09/2023 13:59:55	31/07/2023 08:53:12	SLAM	1				
HEDNOH1	SLAM	OK	05/09/2023 13:59:55	11/02/2023 18:33:01	SLAM	1				
HEDNOH2	SLAM	OK	05/09/2023 13:59:55	12/08/2023 16:46:22	SLAM	1				Yes
HEDNOH3	SLAM	OK	05/09/2023 13:59:55	02/02/2023 15:18:36	SLAM	1				
HEDNOH3A	SLAM	OK	05/09/2023 13:59:55	12/07/2023 23:43:57	SLAM	1				
HEDNOH3B	SLAM	OK	05/09/2023 13:59:55	13/08/2023 01:30:55	SLAM	1				
HEDNOH3C	SLAM	OK	05/09/2023	12/07/2023 23:44:38	SLAM	1				Yes

Figure 30 – Screenshot of the potential updating of ETER smart meters UI, including information about NTL

For each meter, the corresponding row will include or not the tampering tag. There will be also the possibility to filter the table in order to show only the meters potentially affected by NTL.

2) The section in the application that presents the topology will also include information on the substation/feeder affected by NTL

4.2.2.3 Resources

- **Development**:
  - The solution will be developed in Python language.
  - Official InfluxDB, MongoDB and NATS python clients will be used to communicate with the rest of the EMMA ETER components

    - For the numerical analysis and implementation of the data-oriented mechanisms, Numpy and Pandas libraries will be used.
    - For the network-oriented solutions, including power flows, calculation of technical losses, etc., Pandapower and PowSyBL libraries will be used

- **AI Model Development:** For developing AI models, various Python packages will be employed, including:
    - **Tensorflow:** Popular open-source library for high-performance numerical computations. It's widely used for building and training deep learning models.
    - **XGBoost:** Efficient and scalable implementation of gradient boosting. It's particularly well-suited for solving machine-learning problems.
    - **Scikit-learn:** Comprehensive machine learning library in Python. It provides a wide range of tools for tasks such as classification, regression, clustering, and more.
- **Deployment:** The application will be deployed using **Docker**, a containerization platform that allows for easy packaging and deployment of applications in a consistent and isolated environment. **Docker** ensures that the application runs reliably across different environments, making it an essential tool for efficient deployment strategies.

4.3 TASK 6.3 - RESOURCE MANAGEMENT IN CASE OF CRITICAL EVENTS

4.3.1 Tool 5 - EMMA GIMAN Tool

The main responsibility of a system operator is the management of the assets that compose the smart grid (substations, cables, smart meters, etc..). This duty corresponds to the maintenance staff (also known as workforce or field operators). This staff is normally composed of several specialized technicians, often working together in small teams, that cope with all maintenance required tasks, using the necessary tools, materials and vehicles.

While the smart grid grows bigger and the maintenance deserves more attention and resources, a management tool for the maintenance staff becomes necessary to handle the complexity of the workforce organization and the optimal scheduling of the daily tasks to perform.

This management tool is a complex piece of software that has to deal with a lot of concepts and data that have an influence on smart grid maintenance:

- **Asset information**, including inventory and details of the grid equipment, sensors and meters.
- **Workforce/field operator information**. This includes the working hours, holiday calendar, operator skills and capacities, base location, vehicle information, etc. This information requires a continuous update
- **GIS information**, including the assets' location, base location, operator routes, and the capacity to automatically generate travelling routes
- **Stock information**, with the availability and amount of materials, pieces and tools. This information requires a continuous update
- **Active Incidents information**
- **Scheduled/periodic maintenance calendar**

ETRA has a workforce/incidents management product in its portfolio that covers these requirements and will be used within R^2D^2. The product name is GIMAN, and the adaptation of the tool to meet the project requirements will be called EMMA GIMAN.

4.3.1.1 Internal Architecture

The architecture of the EMMA GIMAN product is presented in the following image:

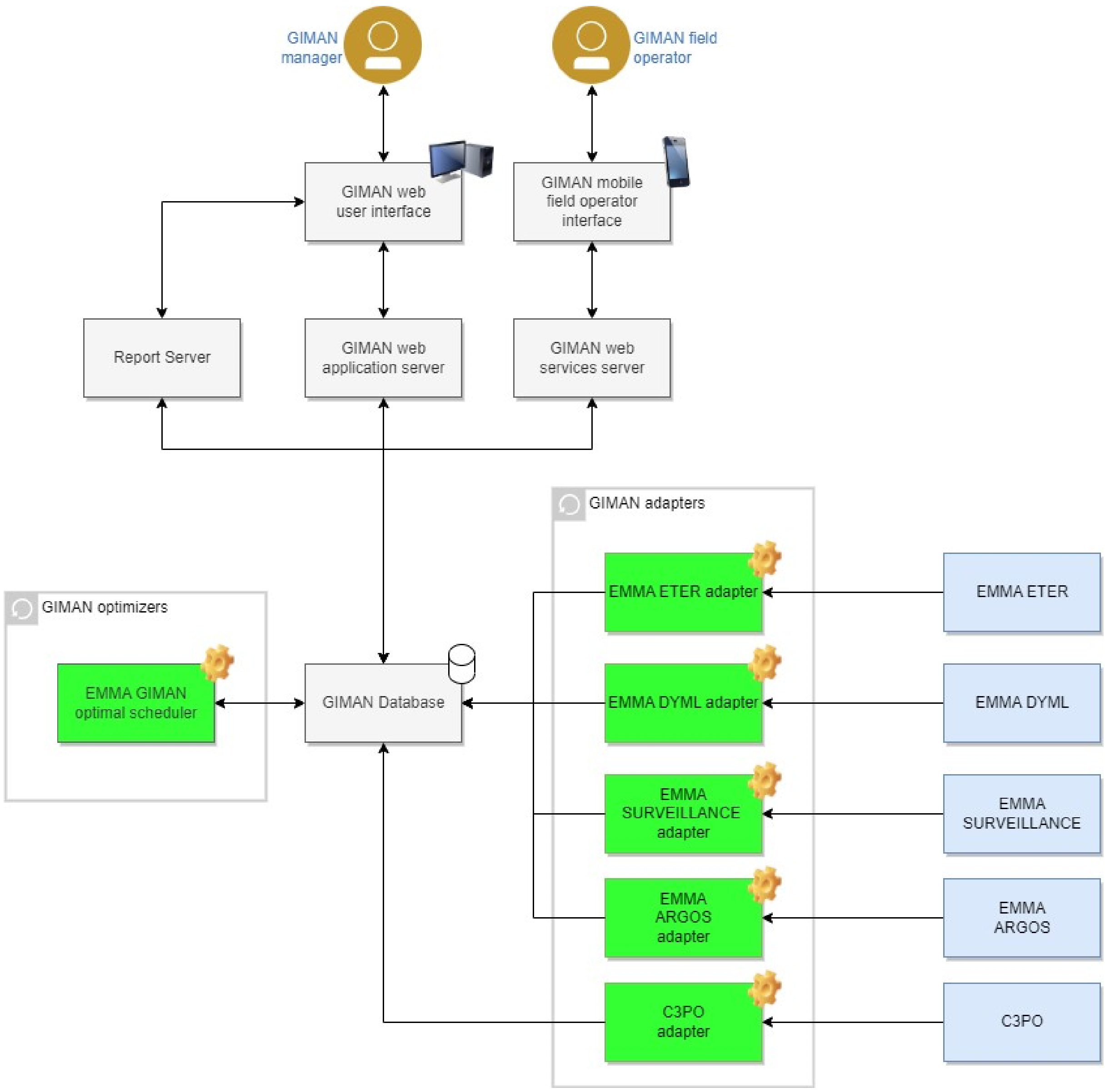


Figure 31 - EMMA GIMAN tool integration within the GIMAN product from ETRA

The core of the GIMAN application, including the web interface for management and the mobile application is already developed. Most of the complexity of the solution is in the database, which besides storing the data also features several internal stored procedures to prepare, clean and adapt the data appropriately.

The extension points of GIMAN to include all the new functionalities and adapt them to R^2D^2 needs are coloured in green. There are two main categories of new functionalities to develop:

- There will be different R^2D^2 applications responsible for the inspection, surveillance and continuous monitoring of the grid assets, using different mechanisms (Drone images, fixed cameras or SCADA data). These applications are described in sections (4.1.1, 4.1.2, 4.2.1 & 4.2.2), and they will eventually identify problems or incidents as a result of their analysis. This output must be converted to the GIMAN data model so that the required interventions in the assets (visual inspection, repairs, etc.) can be scheduled with the rest of the actions to be carried out by the field operators in the grid. The different adaptors to be developed in R^2D^2 refer to the specific translators of the corresponding application to EMMA GIMAN.

- The C3PO product linked to Task 3.3 "Spatial and temporal modelling and quantification of cascading physical events", under certain critical scenarios (storms, wildfires, etc) will simulate the propagation and impact of the events on the power systems, modelling the fragility of the components potentially affected. This simulation will be utilised by EMMA-GIMAN as input to organise the system recovery after the simulated event. The EMMA GIMAN optimal scheduler will use the fragility curves of the damaged nodes and lines from C3PO simulation, to prioritise the interventions for the restoration and organise the workforce.
- The number of incidents and alarms to tackle and the number of tasks to be performed by the workforce can be really big, as new maintenance tasks appear as part of the R^2D^2 results. An optimal scheduler will be developed as part of R^2D^2, aiming at gathering all the required tasks and optimising the scheduling of its resolution, given the availability of human and material resources and minimizing the travel time of operators assigned. The most important constraint here is to solve first the issues with the highest priority, like outages or damaged assets that might be dangerous.

In the field of workforce management, the maintenance tasks to be performed by the field operators can lie within three different categories:

Corrective maintenance is the most obvious one: Whenever there is a failure or damage in one of the assets or systems, all the necessary action must be undertaken to solve this issue. Normally is the maintenance task with the highest priority and involves the immediate mobilization of human resources, as it might produce damage to other assets, persons or the environment. The repairing cost can be high because could require the complete replacement of the damaged assets. This maintenance cannot be predicted and can happen as a result of asset degradation or due to external reasons: Extreme events, weather conditions, sabotage, accidents, human errors, etc.

Equipment failures can be costly, so different strategies have been identified to try to avoid them. The first approach is using **preventive maintenance** actions. This type of maintenance is a proactive approach to maintaining equipment and facilities. It involves regularly scheduled inspections, tests, and other activities that are designed to identify and correct potential problems before they can cause failures or other issues. Preventive maintenance can be viewed as an added expense, but the upfront costs outweigh the significant advantages of long-term equipment reliability and efficiency. This type of maintenance of often known as time-based maintenance, as it relays pre-scheduled tasks that could be defined: 1) by law, 2) by the asset manufacturer or 3) by the internal policies of the system operator. In any case, the actions will be pre-scheduled by calendar and the workforce can easily be assigned to these tasks even with days in advance.

A third category of maintenance is **predictive maintenance**. This aims at predicting failures before they happen, allowing time for remedial action to be undertaken. It goes beyond preventive/time-based maintenance by making use of the data obtained by the monitoring of the assets. This type of maintenance is performed when the equipment shows signs of wear or degradation, caused by activities like increased vibration or temperature, or when sensors or other monitoring systems indicate that maintenance is needed.

This degradation is not always evident from the raw data coming from the sensors. Usually, this information is obtained after an exhaustive and complex analysis of the sensor data, offline measurements, images and sometimes even this condition is inferred by the monitoring of other assets (indirect detection). The core of predictive maintenance is the different techniques applied to extract the signs of stress or degradation (also known as state of health) from the system monitoring and prioritize the correction based on the likelihood of failure. After this is achieved, the necessary actions to prevent further damages can be scheduled so that they are handled in the same way as the predictive maintenance actions.

Currently, the GIMAN product does not cover predictive management. Within R^2D^2, the functionalities that will be developed as part of the products EMMA ARGOS, EMMA DYML and EMMA ETER can be considered predictive maintenance techniques, each one focused on a specific type of measuring or sensor (SCADA, Drone or database). On the other hand, the EMMA SURVEILLANCE product will identify corrective actions that must the handled as soon as possible.

Thus, as a summary, the EMMA GIMAN will:

1) Get the state-of-health, degradation indicators and alarms from the aforementioned EMMA products and the C3PO product (tool from T3.3),
2) Define the necessary actions to solve them (this is done by the different adapters), One single alarm or problematic assets might require multiple actions to be run in parallel or in sequence.
3) Rank them according to different criteria (likelihood to happen, severity, cascading effects, repairing cost),
4) Store them within the GIMAN database,
5) Optimise the field operator's working plans to include the new actions, considering the severity ranking, location, etc. The final working plan and its assignment to field workers will be optimal according to some pre-defined criteria.
6) Manage the life cycle of the actions in the working plans until they are finalised.

The EMMA GIMAN optimal scheduler will be responsible for the optimisation of the maintenance tasks to be carried out and their assignation to the working plan of different field workers. This optimisation can be seen as a combination of two typical mathematical problems: the **Traveling Salesman Problem (TSP)** and the **job assignation problem**.

The TSP is among the most widely studied problems in network optimization and has a wide variety of practical applications. The problem consists of defining an optimal tour that visits a predefined set of customers from a depot. In our case, the customers will be the location of the assets that require any type of maintenance. Several models and methods have been proposed to effectively represent and solve large problem instances in an optimal and time-efficient way.

In the case of R^2D^2, the basic TSP algorithm does not really fit our problem for two main reasons:

- Not all the actions or interventions have the same priority. In traditional TSP problems, all 'customers' visits are treated the same

- The task execution plans will be calculated daily for the entire workforce, but there could be so many maintenance actions in the backlog that some of them are left for another day. This is not possible with the traditional TSP problem formulation, which always covers the complete set of 'customer' visits, not considering working hours constraints.

In EMMA GIMAN, the solution will be built based on the combination of two TSP variants and its implementation as linear programming optimization problems:

1) The Traveling Salesman Problem with Priority Prizes (TSPPP) [42], is an extension of the classic TSP, in which all customers (nodes) have to be visited by the travelling salesman and the order of the customer's visits is directly taken into account in the objective function. A prize p_{ki} is received by the travelling salesman if customer *i* is visited in the k^{th} order of the tour, while a travel cost c_{ij} is incurred when travelling from customer *i* to customer *j* in the tour. Note that p_{ki} can include a prize that the travelling salesman gets when visiting node *i*, independently of the order k in which *i* is visited, plus a priority prize that he/she collects when visiting node *i* at the k^{th} order of the route, which is dependent on his/hers visit order. The objective of the TSPPP is to find a maximum profit sequence of the n-customer visits, considering the prizes and costs involved in the tour. In our case, the maintenance actions with the highest priority will be assigned a bigger price, so that the optimal solution will always favour visiting them at the beginning.
2) A slightly different approach is the variant of the Travelling Salesman Problem with Profits (TSPWP) [36]. Here the different customers are assigned with a profit value that is gained when the visit occurs. This may be seen as bicriteria TSPs with two opposite objectives, one pushing the salesman to travel (to collect profit) and the other inciting him to minimize travel costs (with the right to drop vertices). Viewed in this light, solving TSPs with profits should result in finding a non-inferior solution set, i.e., a set of feasible solutions such that neither objective can be improved without deteriorating the other. This variant does not assume that all the interventions must be optimized, and some of them could be left aside (for instance, when the solution has a profit above a given threshold)

The other classical problem the EMMA GIMAN optimal scheduler will be linked to is the **Job assignment problem**. The assignment problem deals with assigning machines to tasks, workers to jobs, soccer players to positions, and so on. The goal is to determine the optimum assignment that, for example, minimizes the total cost or maximizes the team's effectiveness. The assignment problem is a fundamental problem in the area of combinatorial optimization and will be modelled using state-of-the-art problem solvers.

4.3.1.2 User Interface

The next screenshots (figures 32-37) present some of the functionalities of the EMMA GIMAN tool:

1) The workforce management section is depicted below:

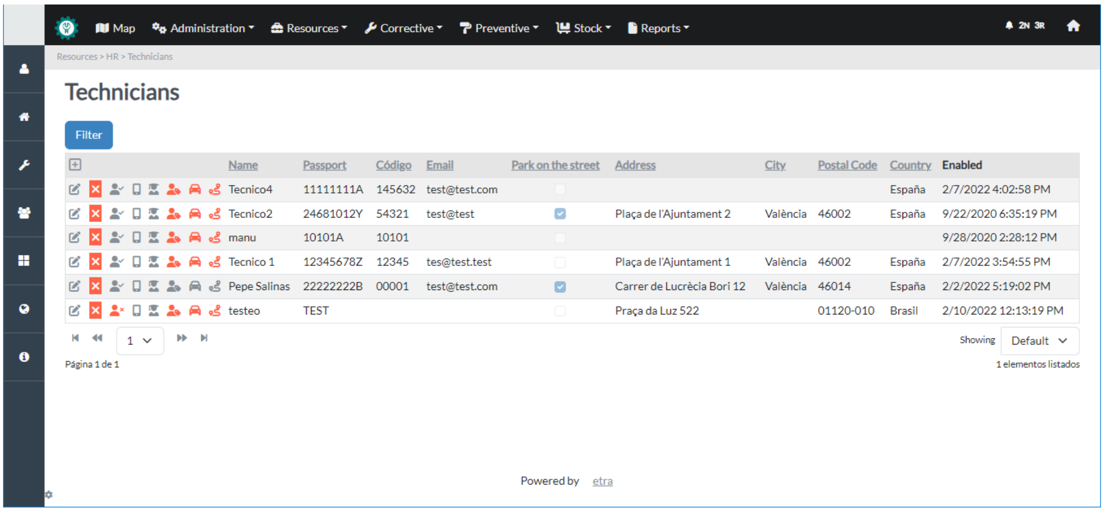


Figure 32 - workforce management section in GIMAN product by ETRA

2) In the following Figure, the workforce skills management section allows for the definition of different skills:

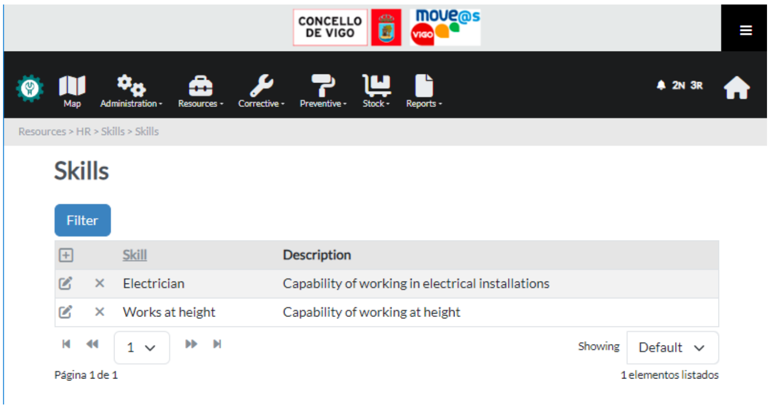


Figure 33 – Workforce skills management screenshot

3) The types of entities section are shown in the next figure:

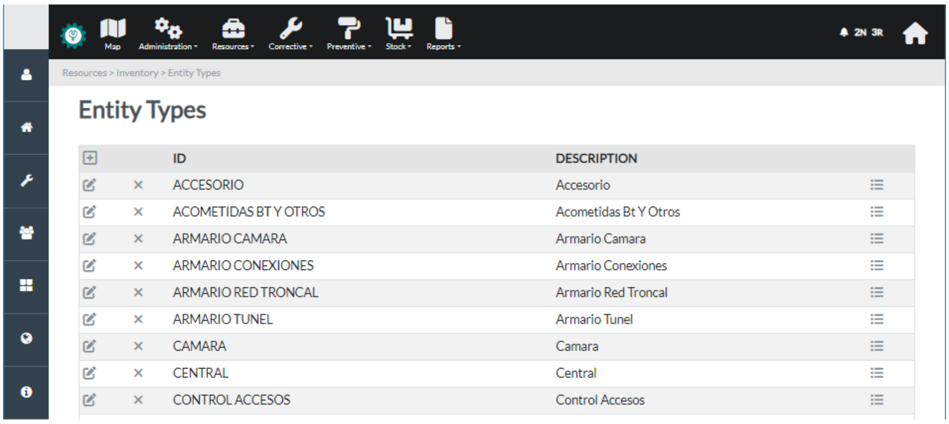


Figure 34 – Types of entities

4) The entities section:

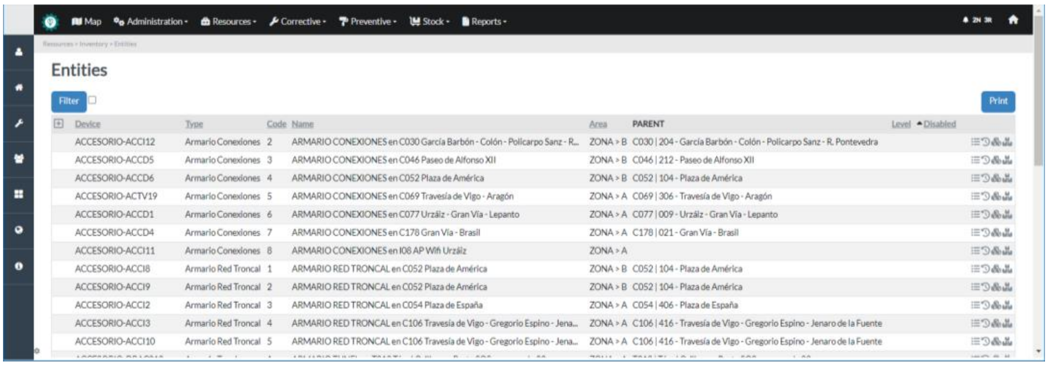


Figure 35 – List of entities added

5) The list of incidents and tasks to perform:

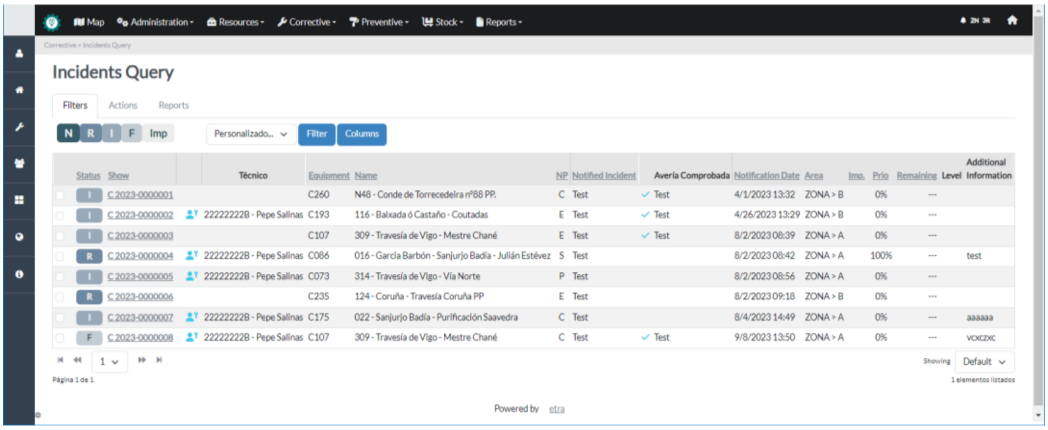


Figure 36 – list of incidents

6) The list of regularly scheduled maintenance tasks

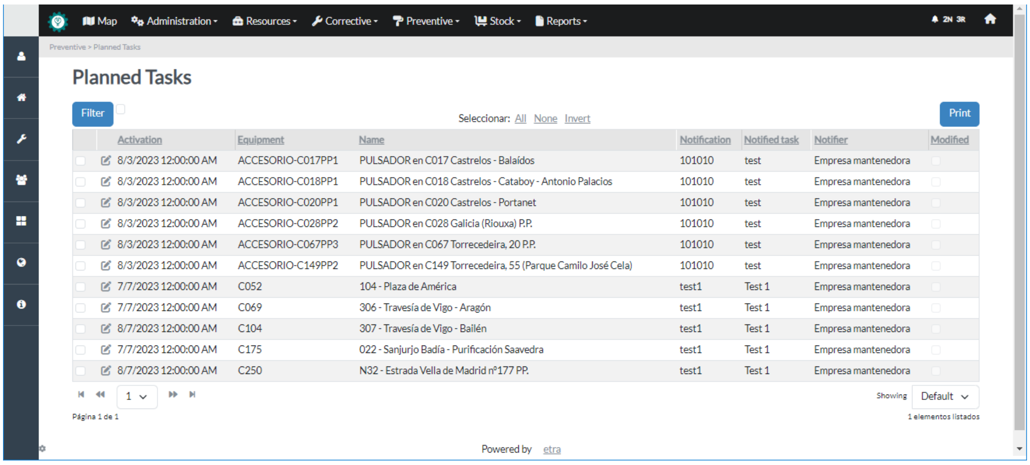


Figure 37 – maintenance tasks list

7) Details of a task to perform

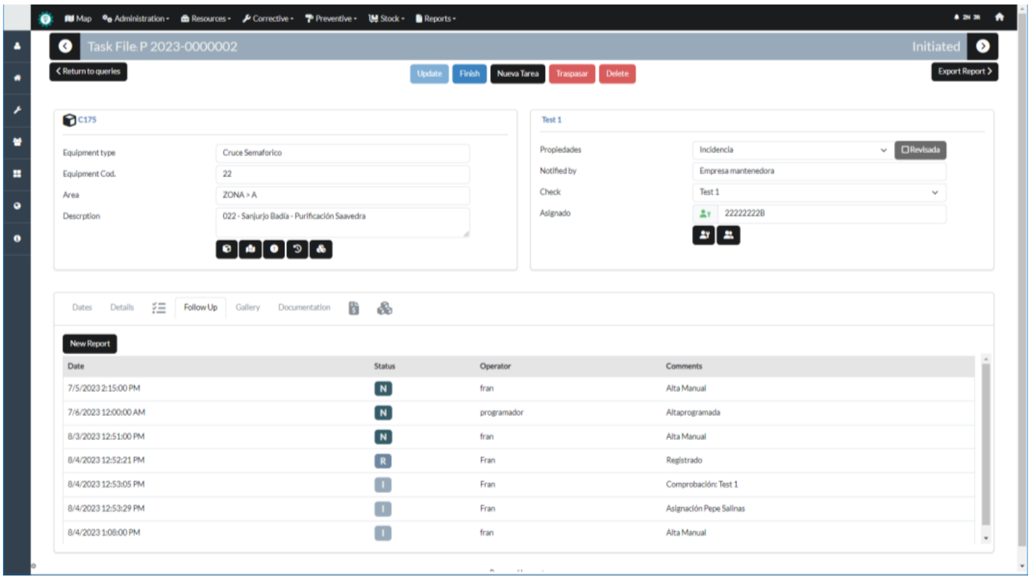


Figure 38 – details of the maintenance task

The new tasks that will be created with predictive maintenance will be presented in the user interface in the same way they are presented now. The only difference will be that they won't be generated by hand or scheduled, but they will come automatically from the results of the other R²D² EMMA components.

4.3.1.3 Resources

- **Development**:
  - The solution will be developed in Python language.
  - Some of the functionalities will imply changes in the GIMAN database stored procedures (SQL Server), using Transact SQL language
  - For the optimization, OrTools and Pulp libraries will be used. In case we face performance problems a commercial solver (Gurobi) will be used
  - Pandas, Numpy and other general purpose python libraries will
  - Official Python SQL Server connector will be used
  - The travelling time will be obtained from the Google Maps API
- **Deployment:** The application will be deployed using **Docker**, a containerization platform that allows for easy packaging and deployment of applications in a consistent and isolated environment. **Docker** ensures that the application runs reliably across different environments, making it an essential tool for efficient deployment strategies.

4.4 TASK 6.4 - MAINTENANCE COORDINATION AND PLANNING

4.4.1 Tool 6 – OP Tool

Following the discussion with TSO and RCC experts who are performing the Outage Planning Coordination (OPC) process on the national and regional levels (respectively), it was concluded the following:

- The biggest challenge of the national OPC process is extensive communication with actors that maintain high-voltage equipment and various (technical and non-technical) factors that influence decisions about outage approval.
- When all non-technical factors are considered, decisions about outage approval are usually taken based on the engineer's experience, because these engineers have significant experience with real-time management of the system, and they are fully aware of forbidden states of national (and even regional) power system topology (at least for of 400kV and 220kV voltage level), so any kind of additional security analyses for a majority of cases seems redundant.
- Although there is an official national procedure in place, there are a certain number of compromises in practice (e.g. already approved outage has to be moved to some other period due to the delayed application of high priority actor). A similar thing is experienced on the regional level during bilateral or trilateral discussions between TSOs, where their national outage plans for next year should be aligned (e.g. TSO who delivered their national outage plan categorically refuses to change anything in it).
- There are a lot of iterations and repeating of the process, and this heavily depends on human interaction and the negotiation skills of participants.
- OPC process is performed on several time horizons (yearly, quarterly, monthly, weekly) in a similar way.

Considering all these specificities of national and regional OPC process, the Outage Planning (OP) tool should have the following traits:

- The tool should be general as much as possible in order to satisfy the basic needs of TSO and RCC OPC experts because any kind of specific features with too many details will not bring benefit (especially for TSO experts) but rather make the job more difficult.
- In terms of security analysis, the tool should help to quickly analyse some special cases of outage combination, which TSO experts did not experience during dispatcher work. On the other hand, RCC engineers that are part of the regional OPC process usually lack experience from the dispatcher centre, so quick manipulation with a tool, creation of desired Outage Planning Scenario (OPS) and quick run of security analysis would be a significant improvement compared with existing solutions.
- In terms of visualisation, the tool could make significant improvements in business processes, especially for TSO experts, since all Gantt charts are created manually.

4.4.1.1 Internal Architecture

The OPC process is performed on several time horizons which have similar steps, and the OP tool should be general enough to cover all of them. For the sake of simplicity, here will be explained the yearly national OPC process:

1. The business process starts with TSO requests towards maintenance entities to express their need for outages for the next year – OP admin connects to the Operator Fabric (OF), a platform used for the coordination of all relevant participants in the energy network and sends an informative notification.
2. Maintenance entity user through the OF interface chooses network elements (from the drop-down menu) and proposes desired time periods when they should be disconnected from the network. There are no backup time intervals, only primary time periods.
3. When the deadline for delivery of the desired list of outages is reached, an initial UAP file is generated (this should be initiated based on the action of OP admin in OF, not based on time trigger), which is then stored on a File server. UAP file is structured based on the official file format defined by ENTSO-E [43]. UAP file in essence contains proposed outages – a list of network elements with proposed time period for their disconnection. This file format could be imported/exported from the pan-European OPC tool, which means that the OP tool is compatible with the official ENTSO-E tool for the OPC process (TSO could upload the final UAP file on the OPC platform directly, while RCC could download UAP file from OPC platform, import it in OP tool and run regional OPC process).
4. OP admin imports the UAP file and UAP information is displayed on the Outage Planning Application (OPA), a web application used for the outage planning request manipulation, as Gantt chart in hourly resolution.
5. Based on information from the Gantt chart, the OP admin prepares input data (CGMs, CON lists and MON lists) which will be used for the upcoming Outage Planning Incompatibility (OPI) assessment. OPI assessment represents security analysis on a reference model in which proposed outages are applied. This security analysis is performed using a modified network model (base case CGM where proposed outages are applied), CON list (contingency list – elements which disconnection will be simulated during OPI assessment) and MON list (monitoring list – elements which will be monitored in order to detect overload after a simulation of contingency). OP admin stores CGMs, CON lists and MON lists on the dedicated File server location.
6. For each hour in the Gantt chart OP admin has 4 options (buttons on UI):
    a. Check if OPI input data are available – OP tool checks whether on the dedicated location are there CGM, CON and MON lists for selected hours.
    b. Initiate manual OPI mode (see separate explanation below)
    c. Initiate automatic OPI mode (see separate explanation below)
    d. See OPI results.
7. After successful (automatic or manual) OPI mode execution, OP admin has the following options via OPA:
    a. Export final UAP file on File Server
    b. Clear all information in the Gantt chart and reset the tool.
8. If there is a need to organize a teleconference with some maintenance entity users in order to discuss ongoing issues during OPI assessment, the OP admin could connect to the OF and create an informative notification.
9. The final step in the process is for the OP admin to connect on OF, upload the final UAP file and send the informative notification to all maintenance entities.

The described business process is illustrated in Figure 39.

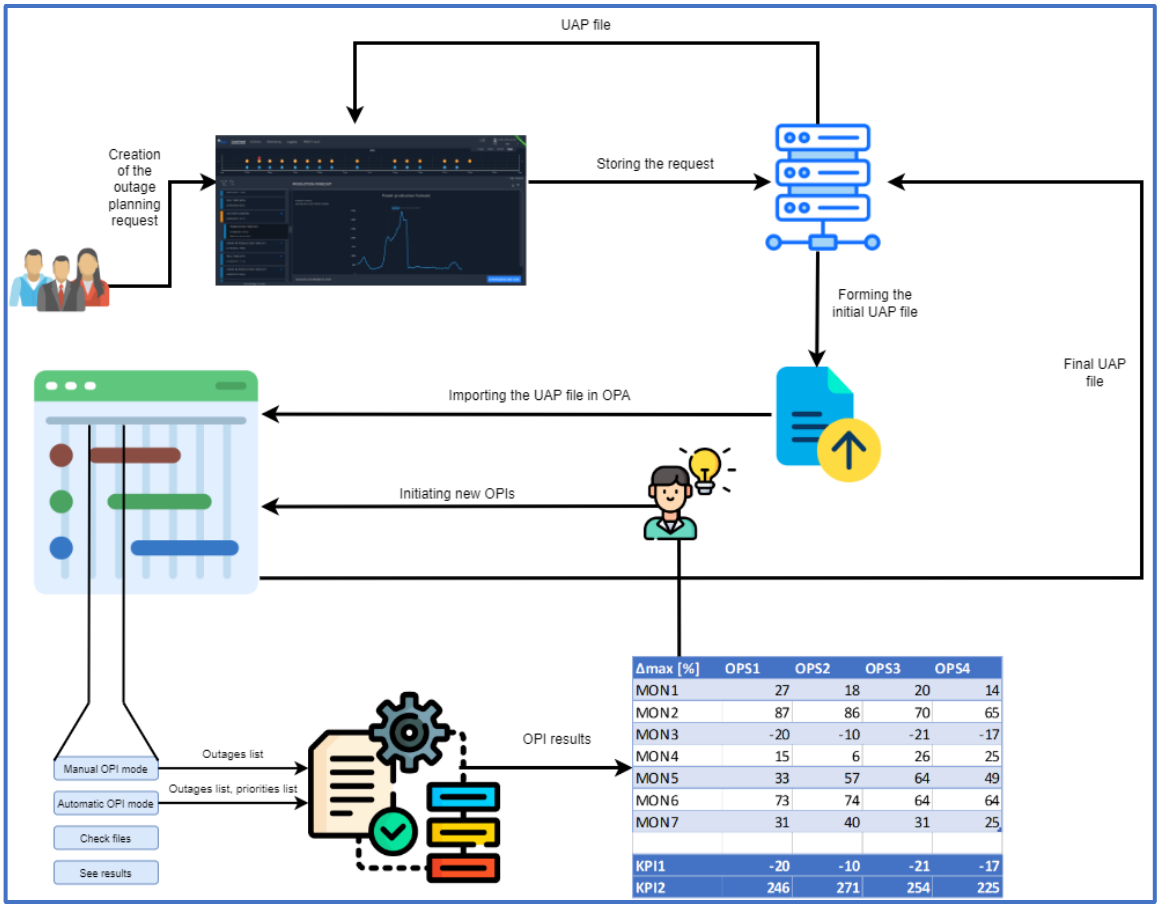


Figure 39 - OPC Business process

The proposed architecture of the tool will consist of three main layers: User Interface (UI) layer, Business Logic layer and Data Storage layer (Figure 40).

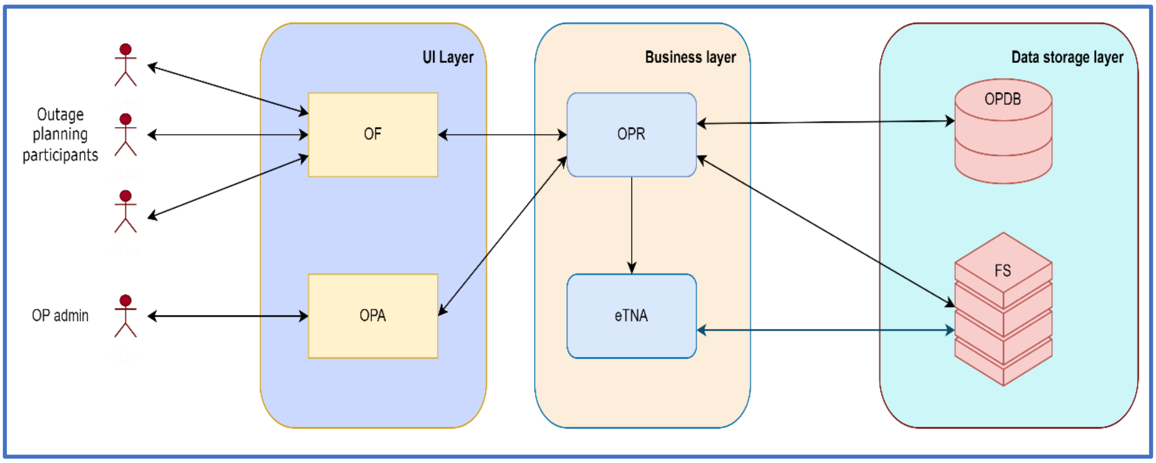


Figure 40 - OP Tool architecture

The UI layer is the presentation layer of the application - all the interaction with end users will be established in this layer, which is designed in a way that two user interface applications will be utilised:

1) OF – used for gathering outage planning requests and for obtaining final outage planning lists after the optimization process is over
2) OPA – used as a visualisation tool for the outage planning requests, their manipulation, and for displaying the results of the optimization process

The business logic layer is the layer containing all the logic needed for the outage planning optimization, as well as for the processing of outage planning requests and the communication with other layers - this is the core layer of the OP tool.

The data storage layer is used for storing, managing and retrieving structured data (OPDB) and unstructured data (FS).

OP tool consists of the following modules:

- Operator Fabric (OF) – a publicly available communication platform used to facilitate communication and coordination between different participants in the energy network
- Outage Planning Processor (OPR) – an internal module used for processing outages, manipulating eTNA, preparing OPS, displaying OPI results
- Outage Planning Application (OPA) – a web application where outage planning requests will be displayed in the form of Gantt charts
- eTNA – a specialised operational planning tool used for fast and reliable execution of security analysis
- Outage Planning Database (OPDB) –storage for outage planning requests, OPI results, metadata
- File Server (FS) – a storage for various files that need to be exchanged between different modules of OP tool

OF is an open-source platform created to facilitate communication and coordination between participants in different domains (electricity, water, and other utility operations). It integrates all needed screens for exchanging information into one common platform, reducing the time needed for switching between different applications. OF is based on the concepts of cards – representing exchanged notifications, which can contain simple text, pictures, charts etc. OF will be used for defining the outage planning requests by outage planning participants, through a predefined template where users can fulfil all necessary information needed for creating the outage planning request. Different participants will be able to log in to OF, to create the requests and to send them to the authority in charge of handling the requests. The users' management mechanism integrated in OF – Keycloak, will be utilised in the OP tool. OF allows defining the third-party applications that can communicate with OF – that way the information gathered in OF can be processed and returned back to OF. That kind of communication will be established between OF and OPR, through a defined API for exchanging the data.

OPR is the main module of the OP tool, which will be used for processing the outage planning requests and communication with other modules of the OP tool.

OPR will perform the following set of functionalities:

1. Processing of the outage planning requests and eTNA results
    - Creating the OPC CON file based on the initial/modified outage requests for the chosen hour
    - Processing LF and N-1 results
    - Preparing OPI results
2. Communication with OF
    - Getting the outage planning requests
    - Sending the final list of planned outages
3. Communication with eTNA
    - Sending commands for importing CGM, CON, and MON lists
    - Sending commands for performing Load Flow (LF) calculation on the original CGM
    - Sending commands for exporting LF results to FS
    - Sending commands for importing OPC CON files from FS
    - Sending commands for performing Scale OPC function (applying outages from the OPC CON file to the CGM which results in forming the modified CGM containing outages)
    - Sending commands to export modified CGM to FS
    - Sending commands for performing N-1 security analysis
    - Sending commands for exporting N-1 results to FS
4. Communication with OPA
    - Receiving requests for manual/automatic OPI
    - Sending OPI results
5. Communication with FS
    - Exporting OPC CON files
    - Exporting UAP files
    - Importing LF, N-1 results

OPA is the visualisation interface of the OP tool. This is a web-based application where OP admin will be able to visualise outage planning requests, manipulate the data which will be sent to eTNA N-1 analysis and display the results. The interface will be described in more detail in the section *User Interface*.

eTNA is software designed for operations of validating, fixing, and merging the load flow data sets, load flow and contingency calculations, NTC calculations, PTD/Maxflow calculations, as well as short circuit analyses [44]. For the OP tool, eTNA will be utilised for providing LF calculations, N-1 security analysis, and creating the modified CGM file based on OPC CON files and default CGMs.

OPDB will store outage planning requests, OPI results and metadata (EIC vs. CIM reference table, config paths for files).

FS will store the following files:

1. UAP files

   These files contain information on all relevant assets that are scheduled to be part of the outage planning process for the respective time frame.

2. CGM, CON and MON files with an hour resolution

3. OPC CON files

   OPC CON file is needed as the input for eTNA in order to create the modified CGM file. It is created based on the list of outage planning requests for the chosen hour, using the EIC – CIM cross-reference table for transforming the elements IDs from EIC codes to CIM IDs, since eTNA will only receive the OPC CON list containing CIM IDs.

4. LF results files

   AC Load Flow (Newton Raphson) The Load Flow function is intended for the determination of network state variables of unbalanced and balanced networks, on the basis of known root voltage and the data about consumption (load) of all nodes. These files contain the results of the LF function.

5. N-1 results files

   N-1 Criterion means the rule according to which elements remain in operation within TSO's Responsibility Area after a Contingency from the Contingency List must be capable of accommodating the new operational situation without violating Operational Security Limits.
   N-1 Situation means the situation in the Transmission System in which a Contingency from the Contingency List has happened.
   N-1 Contingency List (CON List) and N-1 Monitoring list (MON List) are necessary for N-1 Calculation.
   The N-1 results consists of Monitoring Elements in Base Case, Overloaded elements, Resolved elements and Contingencies – Base Case Power Flow.

Tool development techniques and algorithms

Indicators

Before explaining the methodology that will be used for the outage planning requests' optimization, indicators that will be calculated and used during the optimization process for deciding the optimal solution should be described.

1. KPI1 – minimal value of remaining capacity on the most critical MON elements after simulation of the most influential CON element:

$$KPI_1 = min\{\Delta_{max}\}$$

Where:

$$\Delta_{max} = I_{max} - I_{load\ max}$$

2. KPI2 – the total sum of remaining capacities on all MON elements after simulation of the most influential CON element:

$$KPI_2 = \sum \Delta_{max}$$

Methodology

OP tool will have 2 operational modes: automatic and manual OPI mode. In manual mode, the OP admin will be able to decide which outages will be applied on the original CGM – this will be done completely manually based on the admin's actions. Automatic mode implies having the priorities for outage planning requests – there will be 2 possible priorities, where requests of 1st priority are mandatory and should be applied on the CGM, while the requests of the 2nd priority could be modified – OP tool will provide the calculations for all combinations of the network elements belonging to the 2nd priority and return OPI results containing OPSs which will be compared using previously mentioned indicators.

1. Manual OPI mode

Preconditions:

- UAP file imported in OPA module
- CGMs, CON and MON lists are prepared

For each hour, based on the Gantt chart in OPA module, OP admin could decide which outages will be applied in CGM, and which will not be applied. This could be done by checking and unchecking boxes for each displayed network element in Gantt chart for that specific hour. After making all decisions manually, OPI mode for that particular hour is executed using the corresponding button. This action will cause the execution of the N-1 analysis with relevant data and after it is finished, OPI results will be available, containing OPS with calculated indicators. Based on these results, OP admin will decide whether some additional analysis should be performed by changing the status of network elements for that hour and starting the analysis once again.

2. Automatic OPI mode

Preconditions:

- UAP file imported in OPA module
- CGMs, CON and MON lists are prepared

Automatic OPI mode should provide OP admin ability to compare several different OPSs, based on which optimal solution could be proposed by the OP tool. In order to perform this mode, OP admin firstly has to determine priority of N proposed outages for the selected hour. There are 2 priority options with the following meaning:

- 1st priority – M network elements will be always applied in all combinations of OPSs,
- 2nd priority – K network elements will change status ON and OFF in order to create all possible combinations of OPSs.

Automatic OPI mode algorithm (Figure 41) is described below:

1. Using the Gantt from OPA, OP admin chooses the particular hour for which the security analysis will be run.

2. For that hour, OP admin assigns priorities for outage planning requests - with a total number of N requests, M elements will have 1st priority, while remaining K elements will have 2nd priority.
3. OPI assessment will be first performed using CGM with all N applied outages – this is the most optimistic scenario, if the OPO criteria are satisfied, then the optimization process is complete.
4. If the OPO criteria are not satisfied, OPI assessment will be performed again, but this time with M applied outages of the 1st priority. This is done because we want to make sure that the chosen M outages can be applied before moving on to further analysis 5. If that is not the case, the optimization process is returned to the 2nd step and the OP admin should choose different combinations of M and K values.
5. In this step, an OPI assessment will be performed $2^K - 2$ times, having the combinations of ON/OFF status for K elements, with the exception of a scenario when all K elements are OFF (covered in 3. steps), and for a scenario when all K elements are ON (covered in 4. step).
6. After all calculations are finished, OPI results are calculated and displayed in OPA. If Outage Planning Optimization (OPO) criteria is satisfied, the optimization process is finished. If that is not the case, the process should be returned to step 2., where OP admin will choose different priorities for network elements.

OPO criteria is satisfied if $KPI_1 \geq 0$. Optimal solution is determined for a set of OPS that satisfies OPO criteria using following formula:

$$max\{KPI_2\}$$

Otherwise, the OP tool should inform the user that the optimal solution could not be found and the process of priority selection should be repeated (K should increase).

This mode does not provide proposals for different time intervals for disconnection of the given network elements since users have enough information (OPI results and indicators) and knowledge to propose it and test it using manual or automatic OPI mode.

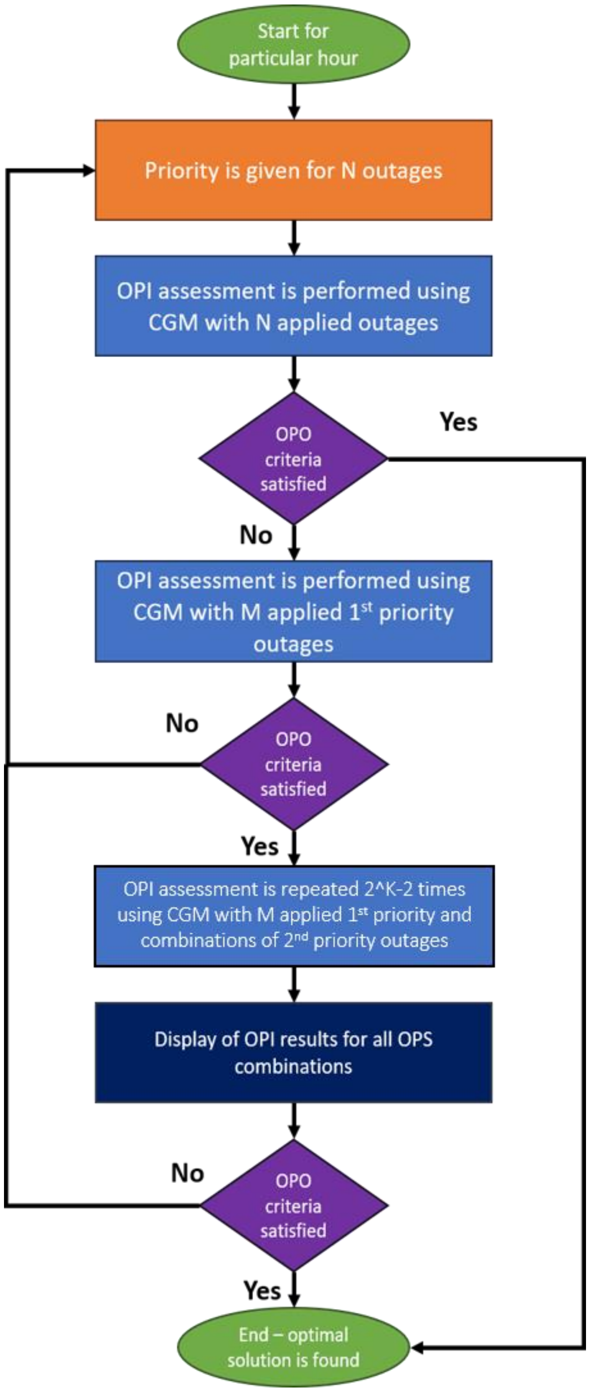


Figure 41 - Automatic OPI mode

Data exchanges, communication with other tools and/or products (data flows and protocols)

The communication between OPR and OPA, as well between OPR and OF will be established through REST APIs – architectural style for an application program interface (API) that uses HTTP/HTTPS requests for dealing with data. This is a widely adopted standard for exchanging the information between different software services, providing the scalability and flexibility needed for developing the OP tool.

OPR and FS, as well as eTNA and FS will communicate using the FTP/SFTP protocol. File Server will be used as an intermediate component between OPR and eTNA – all data needed to be exchanged between these two modules will go through File Server.

OF and OPR data exchange:

- Outage planning requests – Maintenance entity users will be able to submit outage planning requests using the OF interface and these requests will be transmitted to OPR.
- Final UAP files – When the final UAP containing approved outage planning requests is formed, OP admin will be able to login to OF and upload that file. Final UAP will contain a subset of outage planning requests from the initial UAP file.

OPA and OPR data exchange:

- OPI assessment requests – These requests will contain the chosen hour of the particular day of the year, list of outage planning requests, list of priorities if the automatic OPI mode is chosen.
- Files check requests – The response will contain the information whether CGM, CON and MON files for the chosen hour are present in File Server (YES/NO).
- OPI results – The results will contain the list of MON elements and for each MON element OPS will be returned containing calculations done by Business logic module.

File Server and OPR data exchange:

- UAP files – When the optimization process is over and the final UAP file has been formed by OPR, it is stored on File Server.
- OPC CON files – OPR will generate OPC CON file every time when N-1 security analysis is needed, in order for that file to be processed by eTNA.
- N-1 results – eTNA will store the results of N-1 analysis in File Server, in order for them to be processed by OPR.
- LF results - eTNA will store the results of LF calculations to File Server, in order for them to be processed by OPR.

OPDB and OPR data exchange:

- Outage planning requests – these requests will be sent to OPDB after OPR processes them. They will also be obtained from the OPDB whenever OPR needs to prepare them for OF / OPA / eTNA processing.

eTNA and FS data exchange:

- LF, N-1 results
- CGM, COM and MON files

Data exchanged between different components within the OP tool is represented on Figure 42.

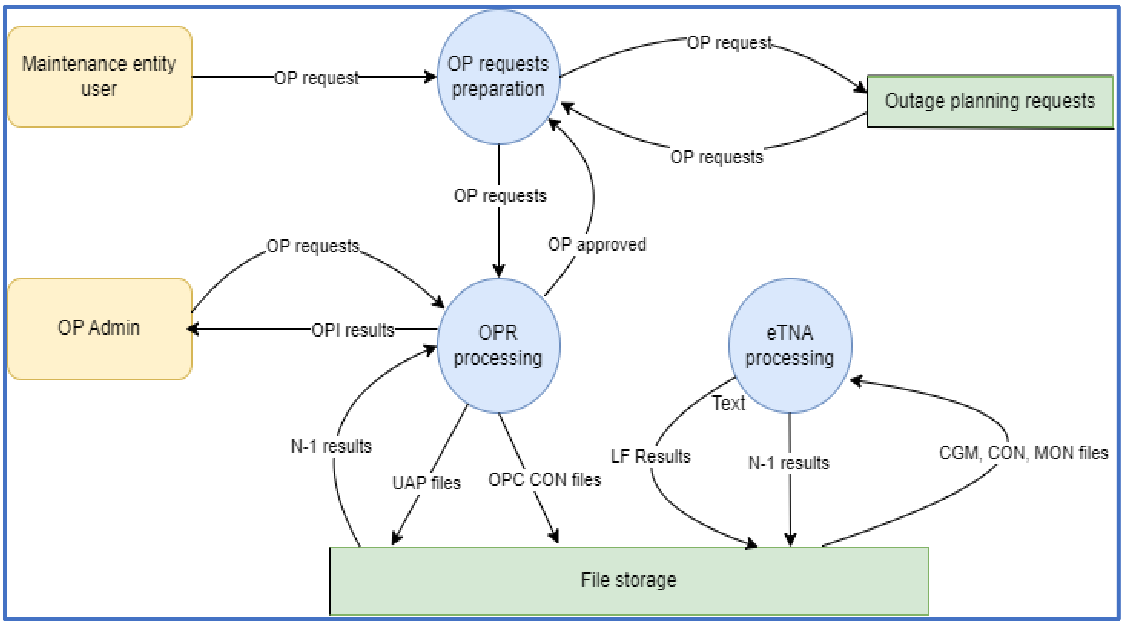


Figure 42 - OP Tool Data exchange

4.4.1.2 User Interface

There are two user interfaces that will be used in OP tool:

1. OF – used by outage planning participants to fill outage planning requests
2. OPA – used by OP admin for displaying Gantt with outage planning requests, initiating manual or automatic OPIs and displaying OPI results

OF interface will utilize H2020 TRINITY Project results as a starting point for further developments – in this project the Outage Planning Coordination Process was covered in the dedicated module in charge of the communication between primarily TSOs and RES producers (T-COORD-RES module). However, it did not include the business logic needed for the optimization of the requests – the whole process was done completely manually, having the admin who can accept, update or reject requests through OF. The user interface part will be also adapted in order to be in line with the TSO/RCC requirements.

OPA interface is consisted of following windows/tabs:

- Gant chart window – default display which has following:
  - Gantt chart with two possible views:
    - Gantt chart with 8760 columns representing hours and X rows representing all outages from UAP file (Figure 43). Each row has additional 2 fixed header columns where human readable name and EIC code of outage are presented. Each column has 1 fixed header row where timestamp information is provided. Fixed dimensions of this table are 744 columns (maximal monthly number of hours) times 100 rows – all remaining cells could be seen using vertical and horizontal scroll bars.

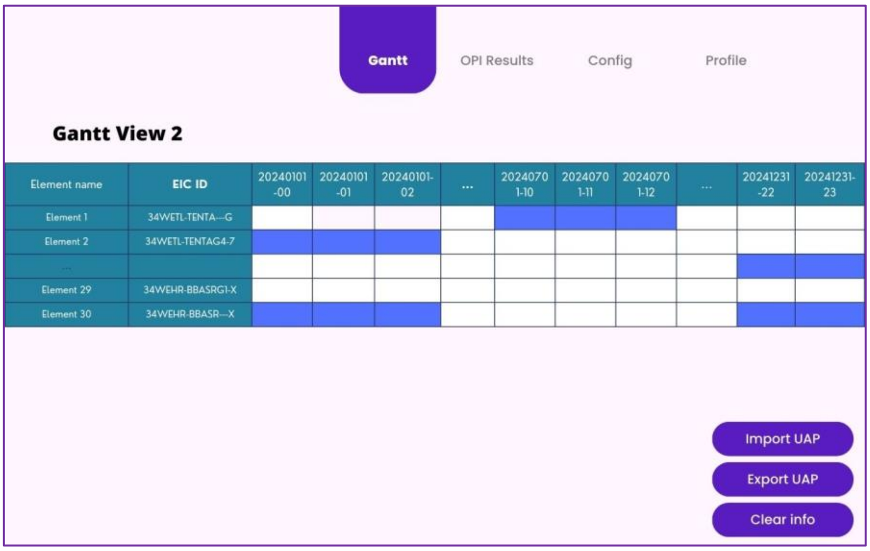


Figure 43 - Gantt view - hour resolution

- Gantt chart with 365 columns representing days and X rows representing all outages from UAP file (Figure 44).

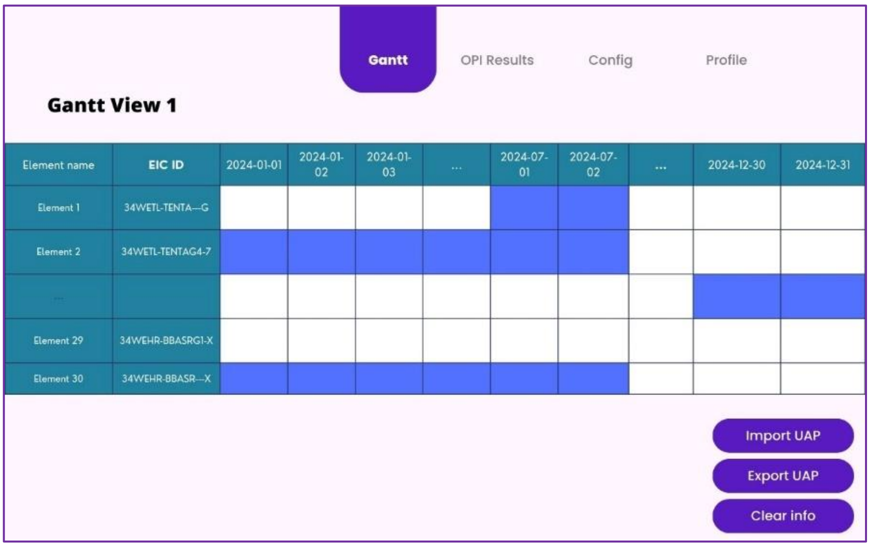


Figure 44 - Gantt view - day resolution

- General buttons: *Import UAP file, Export UAP file, Clear info*
- Button for each hour of Gantt chart: *Check OPI input*, *Start manual OPI Start automatic OPI, See OPI results* (Figure 45)

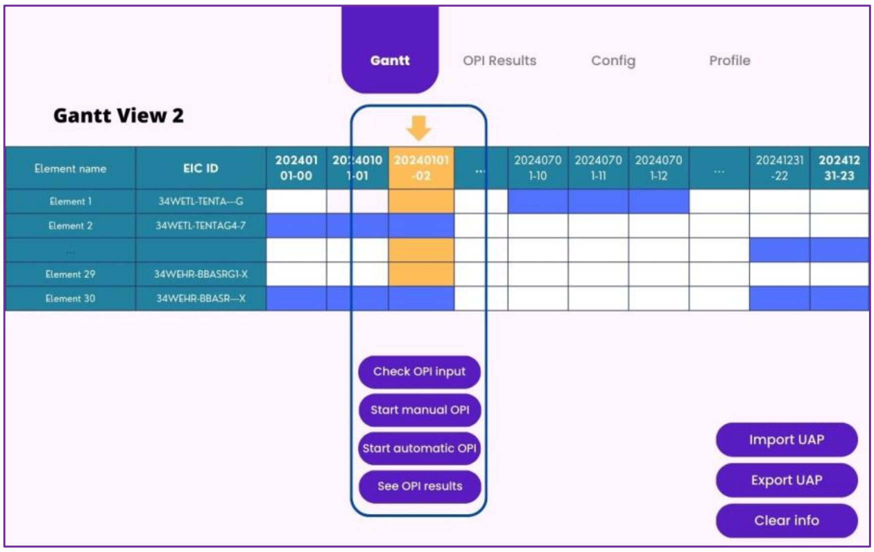


Figure 45 - Gantt chart - actions on column level

- OPI results – tab which is populated only when OPI is performed, and which is open after clicking "See OPI results" button from Gantt chart window. OPI results are displayed in table where rows represent MON elements, columns represent OPS, while cells in matrix represent loading values in percentages (Figure 46).

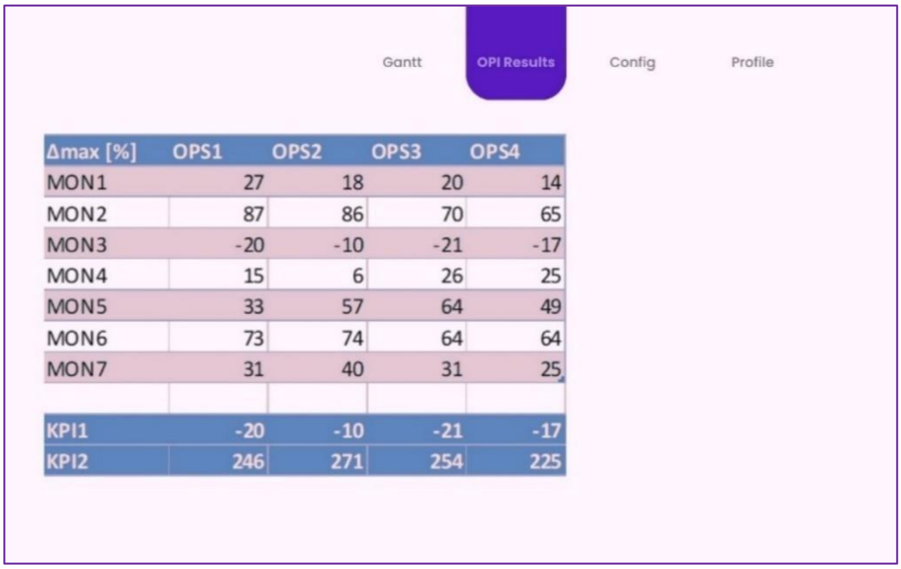


Figure 46 - OPI results

- Config module (Figure 47) – a tab where OP admin could:
    - change location paths for import/export
    - perform import of new EIC vs. CIM ID cross-reference table

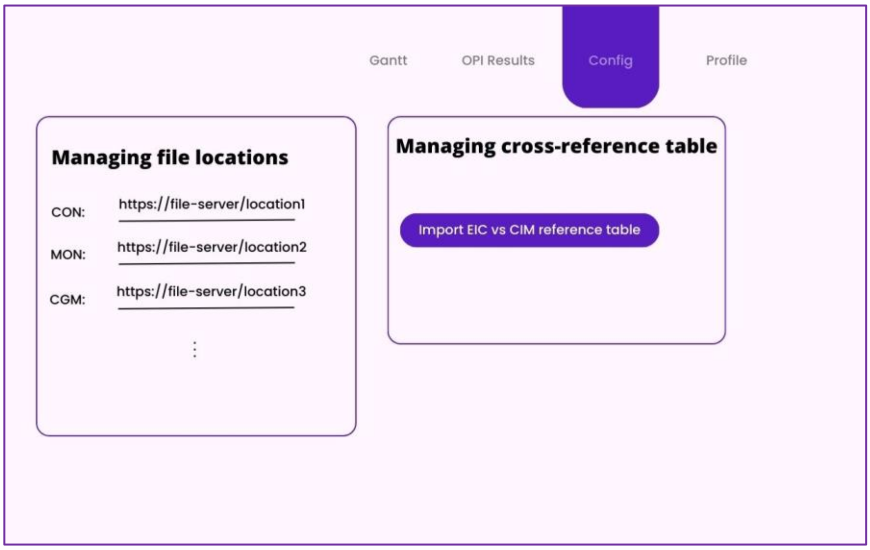


Figure 47 - Config area

- Profile module – information about the user (Figure 48)

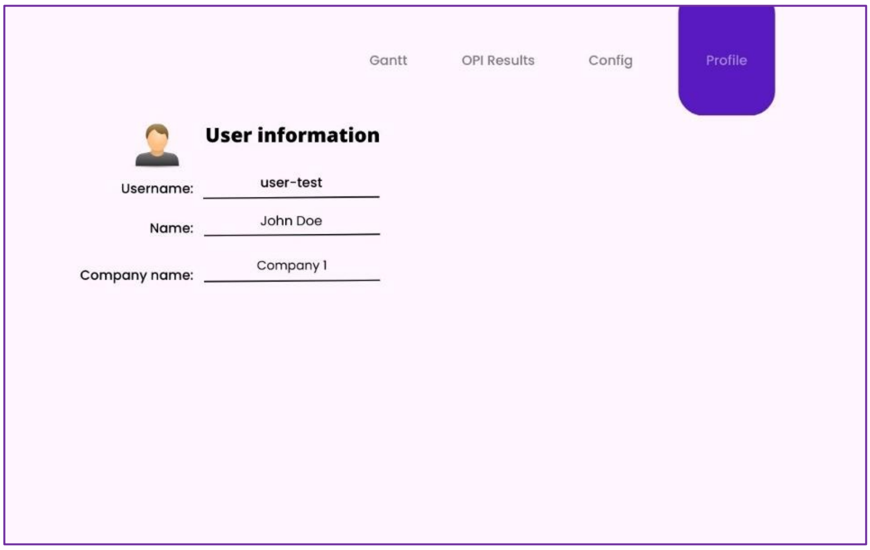


Figure 48 - Profile area

The previously displayed figures represent only a prototype of how the application can be realized; the final design has yet to be determined.

4.4.1.3 Resources

For OPA development following libraries will be used:

a. React - a library used for developing interactive user interfaces. This library has configurable smaller units which can be used for building reusable components – the user interface consists of multiple components, enabling a modular design, which makes code less prone to errors and easier to debug.

b. MUI - a React UI library which offer a wide range of interactive components, which usage will result in having a modern and an easy to use user interface.

For OPR development, the following libraries will be used:

a. Node.js – an open-source, server-side JavaScript runtime environment
b. Express – a web framework for Node.js

For OF development, handlebars template files will be used for creating the outage planning related cards.

Visual Studio Code will be used as a source-code editor while developing the OPR and OPA module, since it provides a great support for debugging, code refactoring, and embedded git.

Git will be used as a distributed version control system, in order to manage the code during the development.

4.4.2 Tool 7 – PQEL tool

The aim of the Power Quality Emission Levels (PQEL) Application is to automate the calculation of power quality parameters emission levels. The automated calculation will be used in the connection process (for the purposes of compliance simulation checks), as well as in a real-time operation (in the compliance testing/monitoring process).

In the process of connecting facilities to the transmission system, the calculation results for the specific point of connection of the new facility are compared with the data obtained from the equipment manufacturer of the new production module or the customer's facility that is connected to the transmission system, and in this way, it is possible to indicatively detect violations of emission value limits and define the necessary corrective measures.

In the process of monitoring compliance in real-time operation, the results of calculations are compared with real-time measurements, and in this way, possible non-compliance is detected.

4.4.2.1 Internal Architecture of the Tool

For the internal architecture of this tool, it is possible to consider three basic layers, i.e. UI layer, Business layer and Data storage layer. This is shown on Figure 49.

Figure 49 – PQEL Tool architecture

PQEL Application will provide a proper user interface in the UI layer. The core of the calculation power quality emission levels methodology represents the Business Layer. The results are stored in corresponding files on the Power Quality server. The Grid Model server is used to read grid parameters.

PQEL Application consists only of software that calculates power quality parameters emission levels.

PQEL Application will be installed on the operator's PC. Full automation of the calculation of power quality parameters emission levels would require communication of PQEL Application with Power Quality Server and Grid Model Server.

PQEL Application reads selected network models stored on the Grid Model Server. Next, PQEL Application carries out the calculation of emission levels of quality parameters for the selected node (connection point to the transmission grid) and saves the results on the Power Quality Server (Compliance simulation is requested within the connection process).

The compliance monitoring scenario requests that the PQEL Application reads measured data from the Power Quality Server. PQEL Application then reads calculated data from the Power Quality Server. At the end of the process, the PQEL Application performs comparison of the measured and calculated emission levels of power quality parameters and saves the results of compliance check on the Power Quality Server.

UI will be described in the corresponding section *User Interface (4.4.2.2)*.

Tool development techniques and algorithms

Checking the parameters of the power quality takes place through two compliance-checking processes: simulation (within the study of connecting the facility to the transmission system) and measurements in a continuous operation (during the operational life).

The maximum permissible values of the level of voltage asymmetry, higher harmonics, and flicker are defined by the Transmission Grid Operation Code, while their maximum permissible emission values are defined by the Transmission Connection Code.

The PQEL Application calculation methodology is based on the methodology described in standards IEC 61000-3-6, IEC 61000-3-7 and IEC 61000-3-13.

The international standards IEC 61000-3-6, IEC 61000-3-7, and IEC 61000-3-13 propose an algorithm for calculating the emission levels of the specified parameters at each point of the transmission system, based on the adopted planned values of the power quality parameters and network topology. In order to check the compliance of the operation of the facilities that will be connected to the transmission system with the requirements of the

Transmission Grid Operation Code, it is necessary to create an automated process that, based on the planned values, uses the algorithm recommended by international standards, calculates the emission levels of the power quality parameters.

Additionally, this tool will perform an automated calculation of the minimum three-phase short-circuit power/current in the sub-transient mode in each point of the transmission grid. This calculation will also determine the equivalent impedance of the rest of the system in the form of the R/X ratio for each point of the transmission grid.

The calculation algorithm is represented in Figure 50.

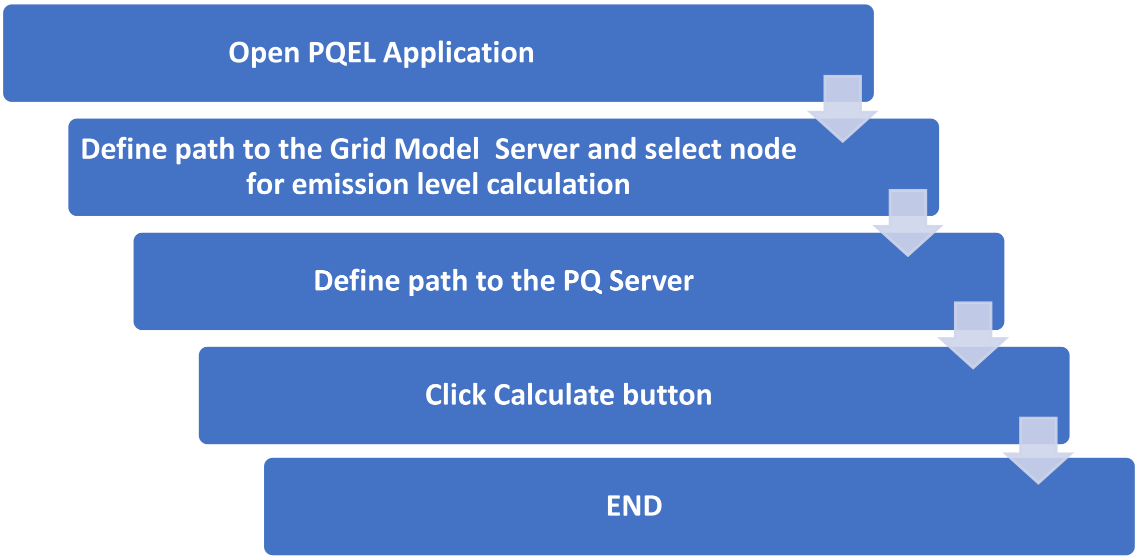


Figure 50 - PQEL calculation algorithm

The computer on which PQEL Application will be installed and the Power Quality server on which the results will be stored will be connected by an Ethernet connection, and files will be exchanged using the SFTP protocol. The same goes for PQEL Application and the Grid Model server.

In a case of compliance-checking processes, when PQEL Application executes simulations to check compliance of the new facilities with the defined connection requirements, the simulation model (.pfd format) import will be performed between the Grid Model server and PQEL Application, while the final simulation results will be exported to the Power Quality server. Described data flow is presented in Figure 51.

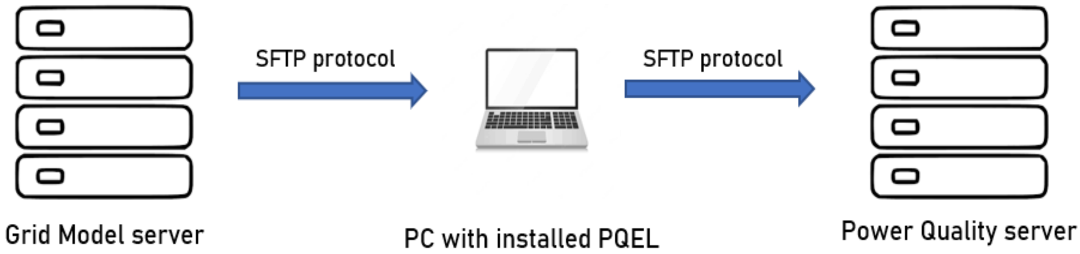


Figure 51 - Data flows and protocols

When the compliance monitoring process is executed - this is a separate and continuous process, when TSO observes if connection requirements related to power quality are fulfilled, the following data is exchanged between PQEL Application and the Power Quality server:

1. Inputs - measured and calculated data is imported from PQ server to PQEL application
2. Results, calculated by performing the compliance check, are exported from PQEL application to PQ server

Resulting file for the emission levels calculation will contain limit values for the selected node, and it will be exported in both .txt and .xslx format. The resulting file for the compliance monitoring will contain a message about the compliance check and values in case of non-compliant node and it will be exported in both .txt and .xslx format.

4.4.2.2 User Interface

User interface will contain two sections: one for the emission levels calculation and one for the compliance monitoring process. On the user interface, the following options will be shown:

- For the emission level calculation:
  - Definition of the path to the folder in which the simulation model is stored
  - Selection of the nodes for emission level calculation
  - Definition of the path to the folder in which results will be exported
  - Calculation button for the simulation execution
- For the compliance monitoring:
  - Definition of the path to the measurements file
  - Definition of the path to the file containing emission level limits
  - Calculation button for the comparison execution

4.4.2.3 Resources

PQEL Application will be developed in Python programming language. No other means of PQEL Application development are required.

4.4.3 Tool 8 – RACS Tool

The aim of RA cost-sharing (RACS) tool is to automate the calculation of costs incurred in the Regional Operational Security Coordination (ROSC) process. This process was designed to resolve security risks in the operation of the transmission system at a regional level. One component of this process is the Cost-Sharing Key (CSK) methodology which is used in the ROSC process after optimizing remedial actions (RAs) at the regional level. This methodology is necessary to define the reallocation of RA costs (and revenues) between involved TSOs after activation of RAs on national level and it is developed within the R^2D^2 project.

4.4.3.1 Internal Architecture of the Tool

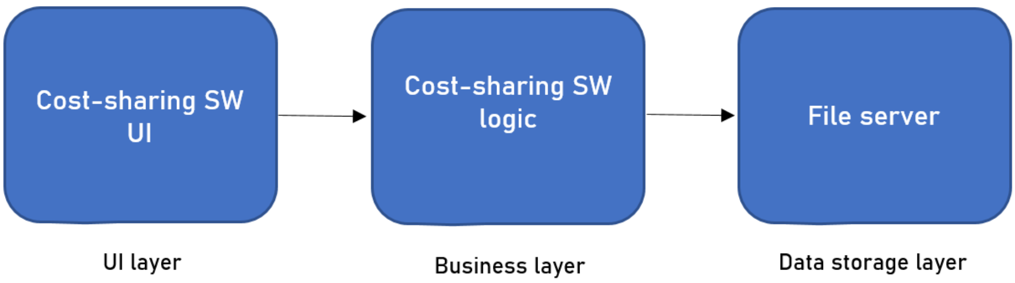


Figure 52 - RASC Tool architecture

RACS tool architecture is presented in Figure 52 and it consists of a UI layer, business layer and data storage layer.

The RACS tool consists only of Cost-Sharing software that calculates the distribution of costs between the involved TSOs and is intended to be installed on the operator's PC. In this project, the connection of the application with the environment is not foreseen due to the lack of resources and because the essence of this tool is in the CSK methodology itself. Therefore, the operator will manually enter certain input data, i.e. files. Full automation would require RACS software communication with power flow and voltage calculation software located on a separate server and loading prepared network models stored on another server.

Cost-sharing SW will provide a proper user interface in the UI layer while the core of CSK methodology will be placed in the Business Layer.

Cost-sharing results will be stored in a corresponding file on a dedicated file server.

Tool development techniques and algorithms

The aforementioned CSK methodology is used for the development of this tool, which is quite complex. Therefore, only the basics of this methodology will be presented here. The methodology itself is written so that it can be easily translated into an algorithm.

CSK methodology is based on 4 elements:

1. Contingencies (CNTs) that require RAs activation
2. Cross-border relevant network element with contingency (XNECs) due to a CNT
3. RAs costs

4. TSOs involved (TSOs in which control areas are CNTs, XNECs and applied RAs)

CSK methodology has 2 levels:

1. The first level is technical in nature and serves to decompose the costs of all implemented RAs to each XNEC – CNT pair (or only to XNEC for base case constraints)
2. The second level is social in nature and serves to redistribute the cost calculated in the first level to involved TSOs

Unlike some methodologies (for instance Requester Pays All), this methodology relies on strong socialization of RA costs between involved TSOs. Involved TSOs are:

- RA.TSO – TSO activating RA
- XNEC.TSO – TSO in which the Control Area is XNEC
- CNT.TSO – TSO in which the Control Area is CNT

The basic idea of cost socialization is incorporated in the cost-sharing level 2, which is presented in Figure 53.

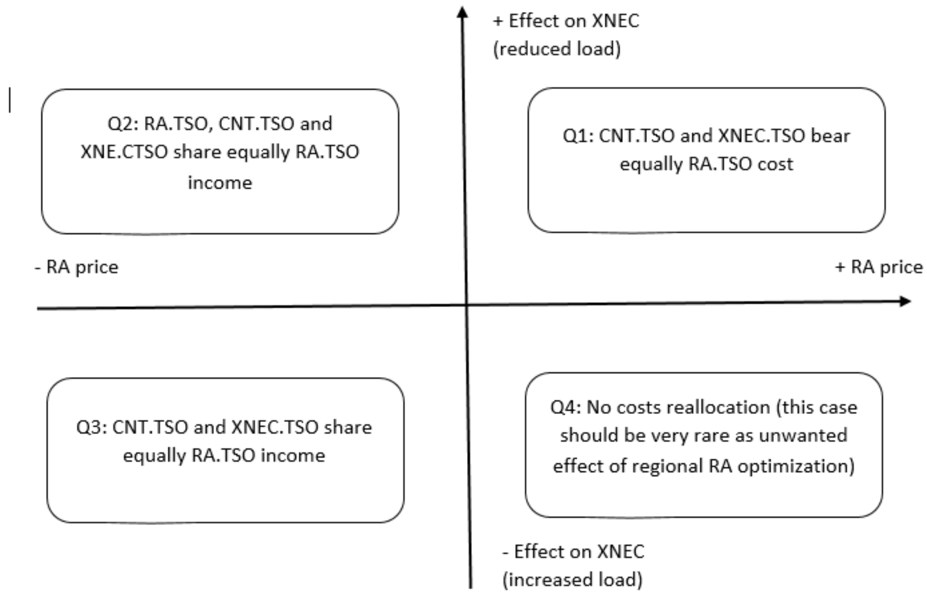


Figure 53 - The basic idea of CSK methodology level 2 in case of constraint

CSK methodology's first level consists of four steps.

In the first step a table is formed as follows (this table refers to all CNTs requiring RAs):

- The column header is inserted for each XNEC due to any CNT there is one column
    - Each XNEC is assigned to a TSO owner (a tie-line is assigned to both TSOs)

- A row header is inserted for each activated RA. For each RA the following input data is needed:
    - RA price (the value is positive if TSO pays to RA provider or negative if RA provider pays to TSO)
    - RA average hourly quantity (in MWh) and direction (upwards or downwards)
    - Total RA cost is calculated as:

      $$RA\ price\ [€/MWh]\ x\ RA\ average\ hourly\ quantity\ [MWh]$$

    - Control Area (TSO) in which RA is activated
- In table cells PTDF factors are entered – these factors reflect the impact of 1 MW of RA on a XNEC. This factor can be positive or negative according to the sign convention of the PTDF matrix (in the example given below, we will consider the value positive if RA reduces the load on an XNEC).
- For each table cell a quadrant is defined (see Figure 53) as follows:
    - Q1: positive RA price, positive influence of RA on XNEC
    - Q2: negative RA price, positive influence of RA on XNEC
    - Q3: negative RA price, negative influence of RA on XNEC
    - Q4: positive RA price, negative influence of RA on XNEC

One example of the first step is presented in Figure 54.

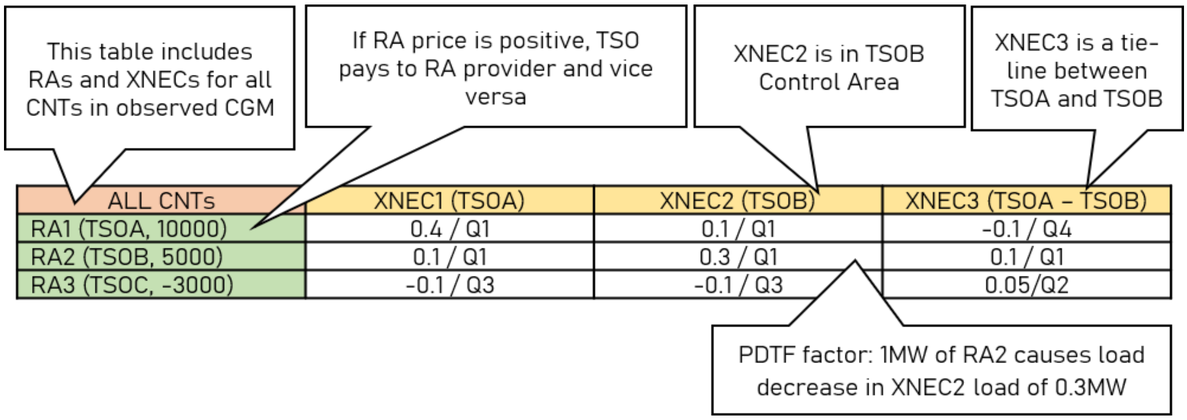


Figure 54 – CSKm: The first step

To align with CSK methodology in the second step it is needed to:

- Convert negative PTDF factors into 0 for Q4 cells
- Convert negative PTDF factors into positive in Q1, Q2 and Q3 cells

The idea behind this conversion is that we multiply RA price XNEC and PDTF factor to get:

- Positive value if TSO RA provider is to be compensated by TSO users (owners of CNTEs and XNECs) – q1

- Negative value if TSO RA provider shares/transfers RA incomes with/to TSO users (q2 and q3)
- 0 value, if there is no cost reallocation (q4)

This is subject to step 3. In the example, this way we get the values presented in Table 4.

Table 4 - CSKm: The second step

ALL CNTs	XNEC1 (TSOA)	XNEC2 (TSOB)	XNEC3 (TSOA – TSOB)
RA1 (TSOA, 10000)	0.4	0.1	0
RA2 (TSOB, 5000)	0.1	0.3	0.1
RA3 (TSOC, -3000)	0.1	0.1	0.05

In the third step, RA costs are redistributed to different XNECs. To do so, in each cell a PTDF factor is multiplied by RA cost and divided by the sum of all PTDF factors in this row.

In our example, we get values shown in Table 5 and Table 6.

Table 5 - CSKm: The third step (calculation)

ALL CNTs	XNEC1 (TSOA)	XNEC2 (TSOB)	XNEC3 (TSOA – TSOB)
RA1 (TSOA, 10000)	10000·0.4/(0.4+0.1)	10000·0.1/0.5	0
RA2 (TSOB, 5000)	5000·0.1/(0.1+0.3+0.1)	5000·0.3/0.5	5000·0.1/0.5
RA3 (TSOC, -3000)	-3000·0.1/(0.1+0.1+0.05)	-3000·0.1/0.25	-3000·0.05/0.25

i.e.

Table 6 - CSKm: The third step (final values)

ALL CNTs	XNEC1 (TSOA)	XNEC2 (TSOB)	XNEC3 (TSOA – TSOB)
RA1 (TSOA)	8000	2000	0
RA2 (TSOB)	1000	3000	1000
RA3 (TSOC)	-1200	-1200	-600

In the fourth step, the initial table is divided into several sub-tables. A sub-table is formed for each contingency, and if there is a constraint in the base case scenario (before the contingency, that is, in the zero contingency), there will be an additional sub-table.

These sub-tables are formed according to the following rule:

- The value in the cell [ROW 'i', COLUMN 'j'] in a sub-table corresponding to a contingency 'k' (or base case) is equal to:
  - The value of cell [ROW 'i', COLUMN 'j'] in the initial table, multiplied by
  - The overload [%] caused on XNEC corresponding to COLUMN 'j' due to contingency 'k' or in the base case and
  - Divided by the sum of the overloads [%] due to each contingency 'k' and in the base case on this XNEC

This way, the value in the cell [ROW 'i', COLUMN 'j'] in the initial table is equal to the sum of cells [ROW 'i', COLUMN 'j'] in all sub-tables.

In our example, there is a sub-table for CNT1 in TSOA and another sub-table for CNT2 in TSO B. In addition, there is the base case sub-table CNT0 corresponding to the tie-line constraint in the base case scenario. Unlike constraints caused by a contingency, the base case constraint cannot be assigned to any specific TSO. Applying the rules given above for transforming the initial table into sub-tables, we get the content shown in Figure 55.

CNT1/CNT2/CNT0 overload on XNEC1 is 8%/2%/0%

CNT1/CNT2 /CNT0 overload on XNEC2 is 0%/10%/0%

CNT1/CNT2/CNT0 overload on XNEC3 is 4%/4%/2%

CNT1 (TSOA)	XNEC1 (TSOA)	XNEC2 (TSOB)	XNEC3 (TSOA – TSOB)
RA1 (TSOA)	8000·8/(8+2+0)	2000·0/(0+10+0)	0
RA2 (TSOB)	1000·8/(8+2+0)	3000·0/(0+10+0)	1000·4/(4+4+2)
RA3 (TSOC)	-1200·8/(8+2+0)	-1200·0/(0+10+0)	-600·4/(4+4+2)

CNT1 (TSOA)	XNEC1 (TSOA)	XNEC2 (TSOB)	XNEC3 (TSOA – TSOB)
RA1 (TSOA)	6400 / Q1	0	0
RA2 (TSOB)	800 / Q1	0	400 / Q1
RA3 (TSOC)	-960 / Q3	0	-240 / Q2

CNT2 (TSOB)	XNEC1 (TSOA)	XNEC2 (TSOB)	XNEC3 (TSOA – TSOB)
RA1 (TSOA)	1600 / Q1	2000 / Q1	0
RA2 (TSOB)	200 / Q1	3000 / Q1	400 / Q1
RA3 (TSOC)	-240 / Q3	-1200 / Q3	-240 / Q2

CNT0	XNEC1 (TSOA)	XNEC2 (TSOB)	XNEC3 (TSOA – TSOB)
RA1 (TSOA)	0	0	0
RA2 (TSOB)	0	0	200 / Q1
RA3 (TSOC)	0	0	-120 / Q2

Figure 55 - CSKm: The fourth step

Cost-sharing of decomposed CNT/XNEC/RA costs/incomes is performed according to basic principles (see Figure 53) and the following additional rules:

- If the tie-line is CNT or XNEC, then both TSOs are equally involved
- Same rules are applied for Curative RA and Preventive RA

As explained before, all necessary input data, i.e. files, are to be manually entered into the tool, namely:

- PTDF matrix for the time interval for which re-dispatching cost redistribution is calculated between TSOs for the respective region
- All applied costly RAs (entity designation, power change direction, TSO cost/revenue amount at the national level)
- All contingencies for which security limits are violated
- All network elements with constraint
- For each network element with constraint, detected overloading for each relevant contingency

- For each network element with constraint, contingency and entity providing RA, the designation of TSO to which it belongs.

On the other hand, output data will be included in an output file that will be stored on the local server. The output file will contain the mark of the market interval for which the calculation was performed and the summary positions of the mutual payment between all involved TSOs.

The computer on which the operator will work and the server on which the results will be stored will be connected by an Ethernet connection, and files will be exchanged using the SFTP protocol.

All of this is supposed to take place in the Regional Coordination Centre (RCC). Communication between RCC and TSOs is done by electronic mail (information about activated RAs, RA costs, and delivery of output files).

4.4.3.2 User Interface

When starting SW, a dialogue box opens in which the operator needs to enter the number of applied RAs and the number of network elements with constraints, as well as the total number of contingencies (including the base case) for which constraints have been detected.

After that, for each RA are entered:

- The identifier of the re-dispatching entity
- Re-dispatched active power and direction (upward/downward)
- RA cost/revenue at the national level of the TSO for the activated RA.

Next, a label is entered for each network element affected by the constraint.

After these activities, the interface should enable the import of the PTDF matrix, from a predetermined folder, for the relevant period for which the costs are calculated (for example, the names of the files in that folder are visible, and they are named to contain the date and time of the network model for which is the calculated PTDF matrix).

Then the interface must enable the opening of a table in which the rows correspond to contingencies (including the base case) and the columns correspond to the elements with the constraint due to a contingency. The interface should allow the operator to enter the overloads on the network elements for the corresponding contingency in the fields of this table.

At the very end of the calculation procedure, the interface allows the operator to call the output files to save them to the appropriate folder.

4.4.3.3 Resources

As already mentioned, this tool consists only of software that calculates the distribution of costs between the involved TSOs, which is installed on the operator's PC in the RCC.

It has not yet been decided in which programming language this software will be developed.

4.4.4 Tool 9 – TSC Tool

The goal of the Transient Stability Calculation (TSC) tool/script (under the DIgSILENT Power Factory program) is to automate the calculation of the critical fault clearing time for a desired set of busbars for two types of busbar faults: permanent, which are switched off by the usage of protective devices, and temporary self-extinguishing, which disappear by themselves (without switching off the primary equipment).

The critical duration of a fault on a bus is the maximum duration of a fault (usually of the three-phase short circuit type) which still does not lead to the outage of any synchronous machine (due to loss of synchronism) in the power system.

The critical fault clearing time depends, among other things, on whether the fault disappears or is switched off by the action of the protection devices. In order to check the compatibility of busbar protection settings with the operation of synchronous generators in terms of stability, for the characteristic operating regimes, critical fault-clearing time calculations are performed for specified busbars of the transmission system.

Based on the results of these calculations, the introduction of new protection devices is proposed, for example, the introduction of differential protection of busbars.

4.4.4.1 Internal Architecture

The TSC tool architecture is presented in Figure 56.

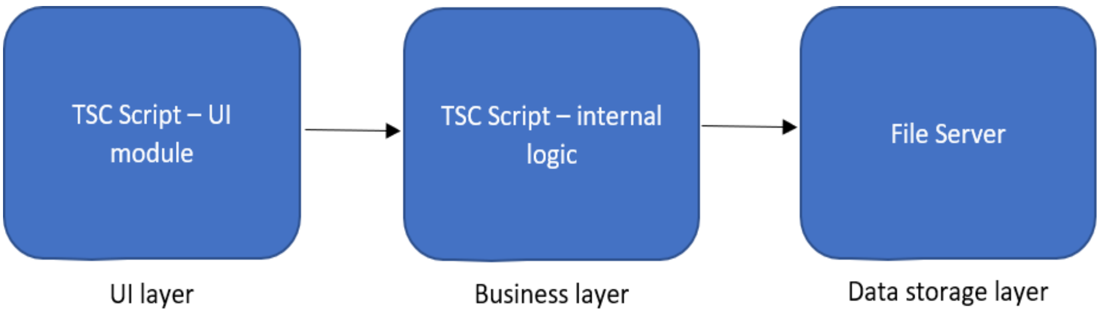


Figure 56 - TSC Tool architecture

The UI module of the TSC script is in fact a UI part of the PowerFactory program (UI window after the script is started). This is already predefined, as the first thing that pops up when the script is started in the so-called “input window”. Actually, when the script is started, the “Basic Options” part of the script is selected by default, and this is where the input parameters will be given, and also where the “set of buses” will be selected.

As for the internal logic, more details are given in the section below. The idea is to find the biggest time interval (the longest fault duration) for which there will be no “loss of synchronism” of observed synchronous machines in the network.

The results of the calculation can be included in a proper report and stored on the destination File server.

Tool development techniques and algorithms

It is necessary that the programming environment has the ability to calculate the electrical quantities of the network that describe its behaviour in the following time domains and in a sufficiently good way: immediately before, during, and after the bus failure simulation.

A dynamic network model is needed for this type of calculation. To indicate the critical fault clearing time, DIgSILENT PowerFactory "out of step" indicator of the generators is used. It provides information on whether the generator is "in" or "out of synchronism", with respect to the rest of the system during the simulation.

The critical fault-clearing time calculation technique is based on the method of "halving the simulation interval"until the final solution is reached. The initial time period (interval) of the simulation is one of the input parameters of the TSC script (simulation duration).

During the simulation multiple checks are performed – TSC script is checking whether at least one conventional source (synchronous generator) "falls out of synchronism" for an actual fault duration, or maybe it's better to say for an actual simulation duration.

And, as it was already said, setting the fault duration is done using the method of halving the interval, until the calculation difference in the last two iterations is less than the specified error.

In mathematics, the interval halving method bisection method or dichotomy method is a root-finding method that applies to any continuous function for which one knows two values with opposite signs. The method consists of repeatedly bisecting the interval defined by these values and then selecting the subinterval in which the function changes sign and therefore must contain a root. It is a very simple and robust method, but it is also relatively slow. Because of this, it is often used to obtain a rough approximation to a solution which is then used as a starting point for more rapidly converging methods. This method is presented in Figure 57.

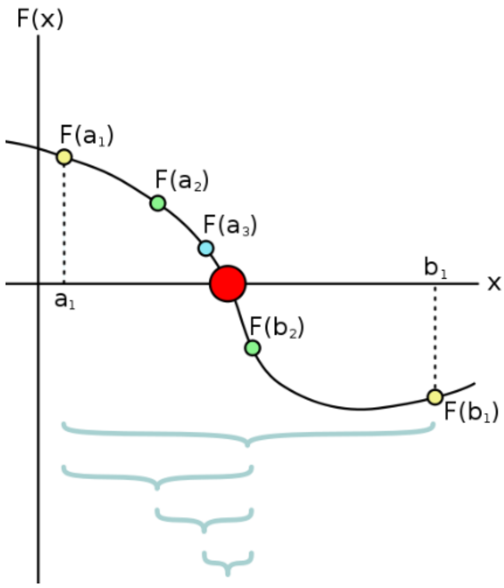


Figure 57 - Interval halving method

Regarding the data exchange, the main input data set of the TSC script is the dynamic model of the system itself, in which the transient stability conditions are checked.

In addition, it is necessary to manually enter all the arguments of the transient stability calculation. These arguments relate to the following:

- Minimum duration of fault
- The maximum duration of fault
- Time step, i.e. the difference of the critical fault durations for the last two given fault duration values (error)
- Simulation start time
- Simulation duration
- Set of buses for which the critical fault time is to be calculated

The output of the TSC script is the critical failure times for the selected buses. They are presented in the output window, and it is additionally possible to include them in an output file (text file) that can be further stored on a predetermined file server.

4.4.4.2 User Interface

When running the TSC script, a dialog window should be opened in which the user should manually enter the specified calculation arguments.

Within the Power Factory DIgSILENT program, it is necessary to have the desired network model (input data) active, on which the calculation of the critical fault clearing time will be carried out.

The TSC script would therefore be part of the Power Factory DIgSILENT project, which contains, among other things, the desired network model. It is enough to display the output results in the Power Factory DIgSILENT program window provided for that purpose (Output Window).

4.4.4.3 Resources

The technical background for the operation of this tool is represented only by a computer on which the Power Factory DIgSILENT program would be installed (whose script would perform the aforementioned calculation of the critical fault time for the desired set of buses).

The script itself will be carried out in DIgSILENT PF programming language (for short DPL – DIgSILENT Programming Language). This language is used for the automation of PowerFactory tasks, with reference documentation well explained in DigSILENT PF software package.

4.4.5 Tool 10 – TTA

The aim of this tool is the improve the quality of IGMs with automated creation of topology files through the Topology Transfer Application (TTA).

Every day Serbian TSO (EMS) creates 24 DACF (Day Ahead Congestion Forecast) models and 24 D2CF (2 Days ahead) models, as well as at least 3 IDCF (Intraday) models. The topology file is one of the 4 input files used to create the IGM in the CGMES format. At the moment, the topology file is created manually.

In the coming years, the number of models that need to be produced is planned to further increase. Manually creating topology files for so many timestamps is unacceptable, as it would lead to many errors and take too much time.

TTA takes the default topology file and modifies it with outage data to get a topology file necessary for model creation. The application also enables users to display outage data for a certain date or period and to display and export generated topology files.

4.4.5.1 Internal Architecture

This tool contains software which imports data on planned outages, creates a topology file and exports it in a predefined time and on the user's request.

In addition, this tool includes a TTA web application that displays imported data on planned outages, displays and exports topology files for a chosen date and displays planned outages for a chosen date or period. The application also provides the possibility of uploading the default template file. The TTA architecture is shown in the Figure 58.

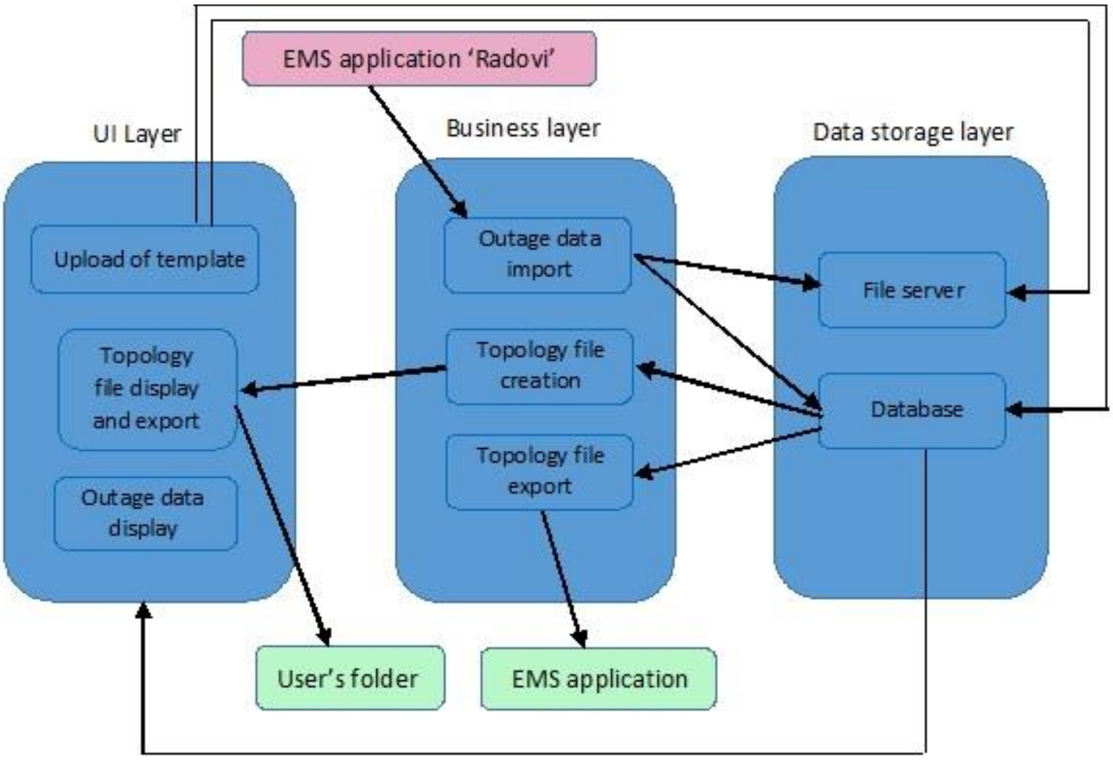


Figure 58 – TTA Tool architecture

The outage data import module, as its name says, is used to import data on planned outages. EMS application "Radovi" (*Works*) generates data on planned outages and can export them in a file. TTA application imports data on planned outages from those files or takes data directly from EMS application's database. If outage files are used, they are taken from a shared folder and stored on the file server before reading. In both cases, data on planned outages will be written in the TTA application's database.

Module for *Topology file creation* uses a default topology file as a template for generating a new topology file. The template file is in csv format and contains information on all modelled elements with their default status. Data from the default topology file can also be stored in the database. To create a topology file, default topology file is modified with outage data from the database. Topology file for a chosen date contains all the modelled elements with their status for every hour. Status "1" means that element is on, and status "0" means that element is off.

Every day at 14h, module for the *Topology file export* exports topology files for the next 7 days. At the start of the exporting procedure, module for generating topology files is used to create files. Generated topology files will be stored on the file server and exported to another EMS application. Files can be exported by copying on shared folder or by some other appropriate way.

Outage data display module enables the user to get data on planned outages for selected date or period. Outage data are generated in the EMS application "Radovi" and imported into TTA application's database. This part of user interface enables user to check input data of TTA application.

Module for *Topology file display and export* is part of the user interface used for presentation of resulting topology file. Before displaying topology data for chosen date, module for generating topology file is used to create data. On this page, the user can also select option for exporting topology file for chosen date. Exported file will be stored on the folder chosen by the user.

Upload of template as part of the user interface is used for uploading of the new default topology file. From time to time, default topology file may change. Using this page, the user can upload new default topology file from a chosen location. Uploaded file is stored on the file server. Data from the new template can also be stored in the database. Uploaded template will be used in generation of the next topology files.

On the *File server* are stored default topology files, imported files with outage data and generated topology files.

Database contains outage data and history of default topology files.

Tool development techniques and algorithms

The TTA algorithm should appropriately convert the input data into output data for the topology file. In order to explain the algorithm, one should first look at the input data, which is given in the next paragraph.

Imported outage data (Figure 59) will contain:

- Element name: Contains the names of transformers, couplers and transmission lines that are in the model.
- CIM Id: Contains a series of letters and numbers and represents a unique code that is associated with each element individually. Each element has its own CIM ID.
- Start date: It refers to the starting date of the works on a certain element (for example, switching on, or switching off an element).
- End date: It refers to the ending date of the works on a certain element (for example, switching on, or switching off an element).
- Start time: Refers to the starting time of switching off/on a certain element. For example, if it is switched off from 7 a.m. to 15 p.m. in the topology file it will be switched off from 8th hour.
- End time: Refers to the ending time of switching off/on a certain element.
- Outage type (Daily, Continuously): If the outage type is marked as Daily, the element will be switched off every day between Start date and End date, in the period from the Start time to the End time. If the outage type is marked as Continuously the element will be switched off all the time between Start date and End date (starting from the Start time and ending at the End time).
- Element type (DV, DVP, TR, TRP): Element type defines the type of element on which works are performed. DV refers to transmission line, DVP refers

to transmission line bay, TR refers to transformer, TRP refers to transformer bay.

Naziv elementa	CIM Id	Datum od	Datu do	Vreme od	Vreme do	Tip isključenja	Tip radova
216 Obrenovac - SP TENT A	_a9b449f3-51a6-675e-27b0-57ad32e480fb	2023-01-03	2023-12-04	7	18	Continously	DVP
401_2 Djerdap 1 - Drmno	_76d3ef67-6b3a-6a7d-c29b-21589b94caf5	2023-06-01	2023-06-30	9	15	Daily	
402 Bor 2 - Djerdap 1	_1c17abee-f4b5-3642-cc31-85d48a889e10	2023-06-10	2023-06-30	10	15	Daily	DVP
405 Djerdap 1 - Portile De Fier	_9886983d-8088-2664-8794-2a80aad8b837	2023-06-15	2023-07-10	10	17	Daily	DVP
206_1 Pljevlja - B_Basta	_6b60ee31-bb07-3b60-d897-e9c9dd89b5fb	2023-06-20	2023-07-10	10	17	Continously	

Figure 59 - Imported outage data

In addition, before the algorithm is explained, the content of the topology file, which is given in the next paragraph, and having that information in mind, the rules by which input data is converted into output data will be explained.

The topology file has a list of elements with status for every hour of the day. Status "1" means that the element is on, status "0" means that element is off.

Topology file contains:

- CIM ID: Contains a series of letters and numbers and represents a unique code that is associated with each element individually. Each element has its own CIM Id.
- Name: Contains the names of transformers, generators, couplers, transmission lines that are in the model.
- Type: Defines the element type. It can be defined as LINE, TR2 or TT. LINE refers to transmission line or coupler, TR2 refers to transformer and TT refers to the current tap position on tap changing transformer.
- Node Id: Refers to the CIM Id of a node. Elements (transformers, couplers and transmission lines) are located between two different nodes. Each end of an element has different Node Id (CIM Id).
- Node name: Refers to the name of the node with witch the element is connected, according to the UCT nomenclature. For example, JBBAST21 – the first character, letter J refers to Serbia. Another five characters are associated with the name of the substation. Seventh character can be 1, 2 or 5. Number 1 refers to voltage level of 400 kV, number 2 refers to voltage level of 220 kV and number 5 refers to voltage level of 110 kV. Eighth character shows to which bus system the element is connected.
- End: It refers to the end number (1 or 2).
- Substation: Refers to the name of the substation.
- Hours 1 – 24: Represents the table for 24 hours a day for which we will enter switching statuses for elements (0-status off, 1- status on).

Topology file contents are presented in Figure 60.

Version: 2.0.0.0																				
							Switching Status by hours (0-OFF 1-ON)													
CIM ID	Name	Type	Node Id	Node nam	End	Substatior	1	2	3	4	5	6	7	8	9	10	11	12	13	14
_53e93698	296 Obren	LINE	_d8d832c8	JTENTB2	1	TENT B	0	0	0	0	0	0	0	0	0	0	0	0	0	0
_53e93698	296 Obren	LINE	_703f01e6	JOBREN23	2	Obrenova	0	0	0	0	0	0	0	0	0	0	0	0	0	0
_a9b449f3	216 Obren	LINE	_587d0e2(	JOBREN22	1	Obrenova	1	1	1	1	1	1	1	1	1	1	1	1	1	1
_a9b449f3	216 Obren	LINE	_ecd6bfb9	JTENTA2	2	TENT A	1	1	1	1	1	1	1	1	1	1	1	1	1	1
_9e3c0306	209_1 B_B	LINE	_6eba716b	JBBAST21	1	Bajina Bas	1	1	1	1	1	1	1	1	1	1	1	1	1	1
_9e3c0306	209_1 B_B	LINE	_25e6222c	JSMIT221	2	Sremska M	1	1	1	1	1	1	1	1	1	1	1	1	1	1
_f2900c98	1231 S_Mi	LINE	_98a99521	JSMIT252	1	Sremska M	1	1	1	1	1	1	1	1	1	1	1	1	1	1
_f2900c98	1231 S_Mi	LINE	_ad7de96	JSSTIL5	2	Sirmijum S	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 60 - Topology file data

Now that all the input and output data is explained, the rules that will comprise the algorithm are following:

a. Rules relating to the topology in accordance with which types of network elements are the subject of the request for disconnection (this applies to network models in the hours for which the disconnection is applied according to the rules below):
   i. If the transmission line is requested to be disconnected, then in the topology file this transmission line must be disconnected at both ends
   ii. If the disconnection of the transmission line bay is requested, then in the topology file this transmission line must be disconnected and additionally in the substation where this bay is, it is simulated in an appropriate way that one of the bus systems is disconnected)
   iii. If disconnection of the transformer is requested, then in the topology file this transformer must be disconnected at both voltage levels
   iv. If disconnection of the transformer field is requested, then in the topology file this transformer must be disconnected and additionally, at both voltage levels it is simulated that one of the bus systems is disconnected
   v. If disconnection of the coupling bay is requested, then one bus system is appropriately simulated to be disconnected
   vi. If disconnection of the coupling field is requested, then one bus system is appropriately simulated to be disconnected

   Note: These are only general rules, additional rules can be defined for individual substations if they have specific switchyards

b. Rules related to the topology according to when the disconnection is requested:
   i. In case of a Daily outage, start and end time from imported outage data will determine off hours (hours with zeros) in the topology file
   ii. In case of Continuous outage:
      - If the start date of the outage is before the date of topology file, start time in the topology file is first hour
      - If the start date of outage is the same as the date of the topology file, start time in the topology file is the start time from outage data
      - If the end time of outage is after the date of the topology file, end time in the topology file is hour 24
      - If the end date of outage is the same as the date of the topology file, end time in the topology file is end time from outage data

Data on planned outages is imported from EMS application “Radovi” (OP server). Uploading of default topology is provided in web application.

The topology file is exported for the selected date on location (Grid Model server) where other software can import it.

Exchange of files between OP server, TTA and Grid Model server is done through SFTP protocol.

The input and output data for the TTA are already defined in the previous section.

4.4.5.2 User Interface

User interface is going to have four parts:

1. Input data
    a. Display of imported outage data for a selected date

2. Topology file
    a. Display of a created topology file for a selected date
    b. Export of the topology file for selected date

3. Reports
    a. Display of planned outages for a selected date (Figure 61)
    b. Display of planned outages for a selected period (Figure 62)

Date: 6/19/2023

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
216 Obrenovac - SP TENT A	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
401_2 Djerdap 1 - Drmno	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off
1007 Zrenjanin 2-TETO Zrenjanin										off	off	off	off	off	off	off	off	off	off	off	off	off	off	off

Figure 61 - Display of planned outages for selected date

	3.6.2023.	4.6.2023.	5.6.2023.	6.6.2023.	7.6.2023.
216 Obrenovac - SP TENT A	7-10	7-10	7-10	7-10	7-10
401_2 Djerdap 1 - Drmno	8-24	00-24	00-24	00-24	00-8
1007 Zrenjanin 2-TETO Zrenjanin		8-19	8-19		

Figure 62 - Display of planned outages for selected period

4. Settings
    a. Selection and uploading of a default topology file

4.4.5.3 Resources

For TTA application (software for importing outage data, creating and exporting topology file) development PHP will be used. Additionally, TTA Web application will be developed in PHP and JavaScript. PHP (Hypertext Processor) is a general-purpose scripting language and interpreter that is freely available and widely used for a web development [46]. JavaScript is a scripting language, primarily used on the web.

On the other hand, TTA application's database will be based on MariaDB, which is an open-source relational database management system that is a compatible drop-in replacement for the widely use MySQL database.

4.4.6 Tool 11 - DLR Tool

In the Serbian TSO (EMS), there is an ongoing pilot project whose goal is to install and use DLR system on several transmission lines. The technical solution of the Ampacimon Company was applied, which is based on the measurement of meteorological parameters on conductors in the most critical line sections.

Through the statistical analysis of data from the DLR system in the previous two years, it was established that the values obtained from the DLR system often differ with a large amplitude from the average seasonal limit of the transmission line.

Bearing that in mind, in order to make the most of the DLR system, it is necessary to create DLR tool/application with the following functionalities:

- Automatic updating of current limits in the SCADA system (this is related to the alarming application, as well as to real-time security analyses) in National Control Centre
- Change of current limits in individual network models (IGM) in the process of intraday security analysis, as well as day-ahead analysis (i.e. it is necessary to create software that will place the corresponding record from the CSV file in the appropriate place in the network model)

4.4.6.1 Internal Architecture

Figure 63 shows detailed architecture of the DLR tool and its environment.

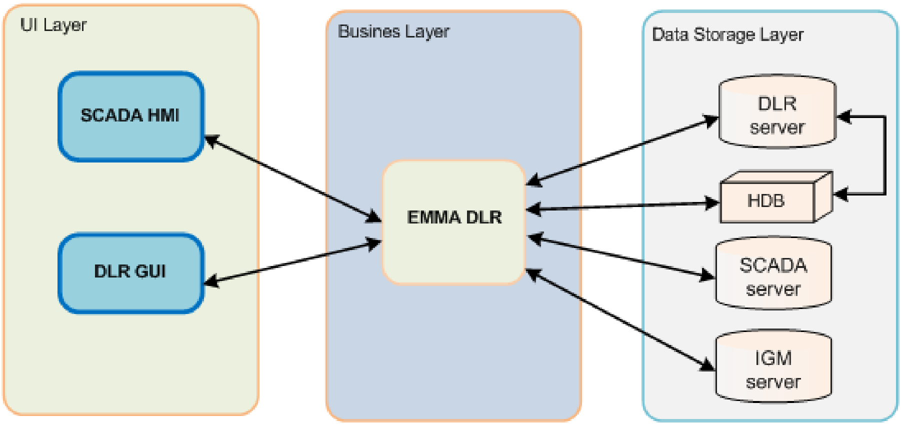


Figure 63 - DLR Tool architecture

DLR tool consists of the following components (See Figure 63):

- User Interface (UI) Layer:
  - SCADA HMI – The main user interface to the SCADA system, provides real-time data presentation on dynamic pictures with vector graphics, user-defined graphs, or alarm lists. Execution of complex control functions is made easy using specialized dialogues directly from dynamic pictures.
  - DLR GUI – Used for configuring the EMMA DLR application.

- Business layer consists of DLR tool (application) – This application is used to transfer DLR limits from DLR server into SCADA/EMS and IGMs.
- Data Storage level consists of:
  - DLR server – This server contains information about DLR of the transmission lines, sends those values to SCADA systems, and exports CSV files for each line.
  - HDB – SCADA/EMS Database containing data about current limits from SCADA and DLR system.
  - SCADA server – Supervisory control and data acquisition (SCADA) is a control system architecture comprising computers, networked data communications This server contains static file which contains static seasonal current limits for each line.
  - IGM server - Individual Grid Model means a data set describing power system characteristics (generation, load and grid topology) and related rules to change these characteristics during capacity calculation, prepared by the responsible TSOs, to be merged with other individual grid model components in order to create the common grid model. This server will be used for storing OPL file used for import of new current limits into IGM.

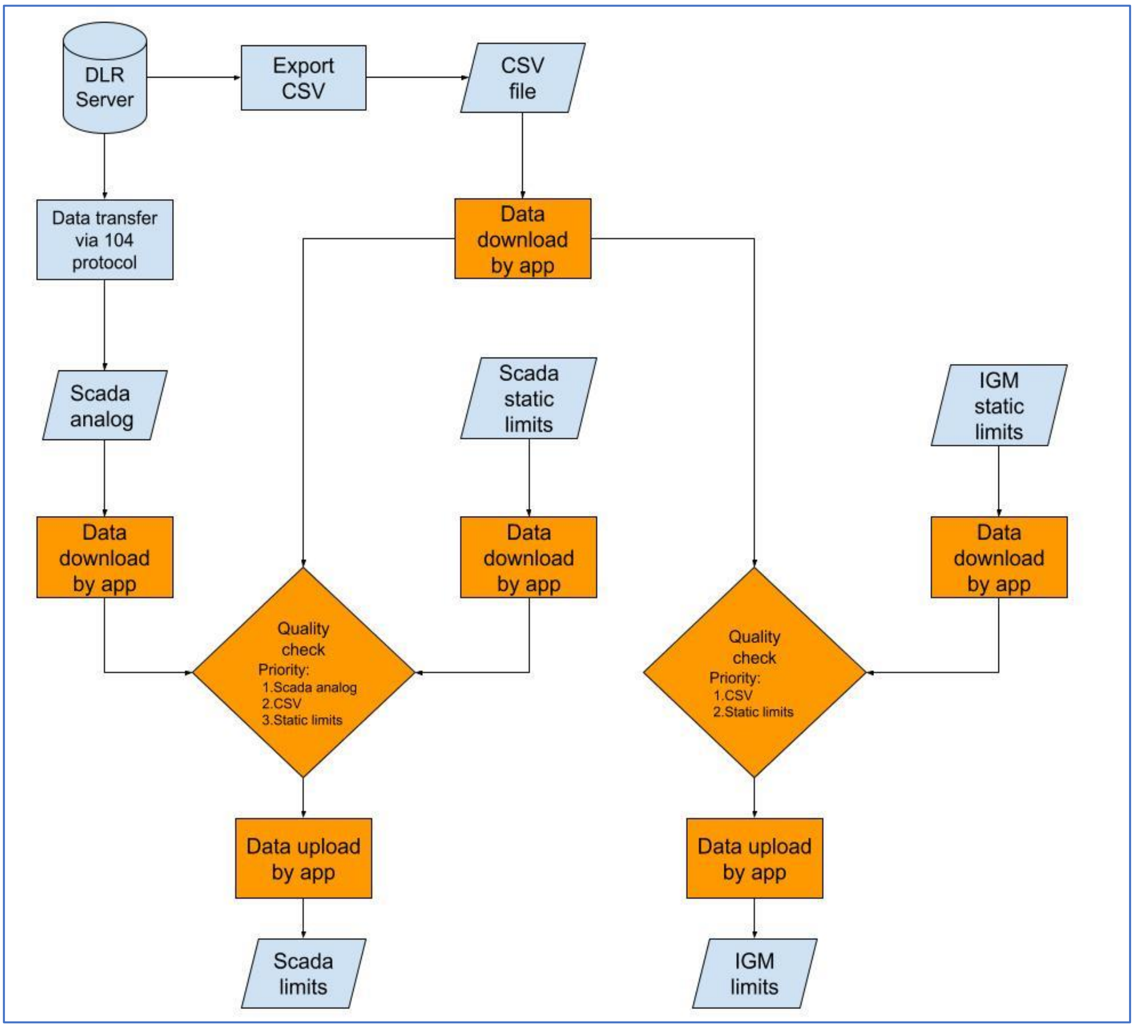


Figure 64 - DLR Tool algorithm

Tool development techniques and algorithms

DLR server contains information about dynamic current limits. It has communication with SCADA while HDB database contains information about dynamic limits, but as analogue values.

DLR application reads DLR values from HDB database using the *hdbexport* command. If value from HDB is not valid, DLR application will try to read that value from CSV file, exported from DLR server. If that value is also not valid, DLR application will take the static value.

DLR application will input the previously read value back into the HDB database, but this time as a specific line limit. Also, the DLR application will write that value into the OPL file, which allows us to use dynamic limits in IGM models.

Once dynamic limit values are loaded, SCADA/EMS applications will use those values in their calculations (RTNET – real time state estimation, RTCA – real time contingency analyses…).

Everything mentioned above is presented in Figure 64.

The e-terra habitat is a software environment that supports the development and operation of highly available, real-time control systems. The database subsystem within the *e-terrahabitat* is called “Hdb”. The e-terrahabitat contains many databases rather than a single massive database.

Two commands from the Habitat environment, *hdbexport* and *hdbimport*, are used to read and write values to the SCADA system.

The *hdbexport* command exports binary data from an “Hdb” database to an ASCII formatted file. The format of the exported ASCII file can be configured using various command options.

Hdbexport is designed to work bi-directionally with *hdbimport*. The *hdbexport* default operation creates a full ASCII database export file that *hdbimport* can import to reproduce the same database content.

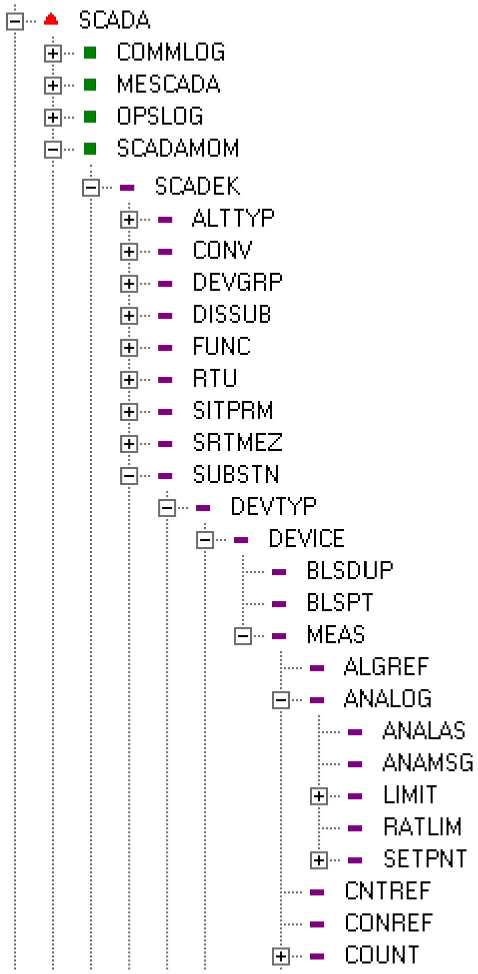


Figure 65 - SCADA hierarchy

Figure 65 shows that the limit is hierarchically below the analogue record and in this case we can't use the file we got from export for an import, and we have to modify it. The modification of the obtained data differs in the following way: one analogue quantity (data from DLR) can be linked to one or more currents (sometimes for a transmission line we only get the current of one phase, and sometimes the currents of all three phases), currents exist at both ends of the transmission line and finally one limit obtained from the DLR system, must be entered into two types of limits, alarm and warning. In Serbian TSO the rule was adopted that the limit received from DLR is divided into two limits according to the following rule:

$$Alarm = DLR\ limit \cdot 1.1$$

$$Warning = DLR\ limit \cdot 0.95$$

From the options mentioned above, the question arises as to how the application can know which transmission lines receive forecasted limits from DLR applications and to which currents and how many of them those limits will be entered, etc. For this reason, there is a configuration file in the application that should contain: SCADA codes of transmission lines that have DLR sensors, all currents and their SCADA labels, SCADA names of limit types (warning/alarm) and coefficients by which the limit is multiplied in order to receive a warning and an alarm.

Finally, when the limits are entered in the corresponding SCADA fields, they are available for all network applications. On the SCADA/EMS system, SCADA limits are automatically copied to the NETMOM database in RTNET (State Estimator) and then forwarded to RTCA (Contingency Analysis), VVD (Voltage/Var dispatching) and RMTNET (Outage Analysis for several hours ahead) applications where they are used in calculations.

Table 7 presents the data exchange between the DLR application and the components in its environment. In the first column, the sender's data is provided, while the receiver of the data is marked in the top row.

Table 7 - Data exchange between DLR application and its environment

	DLR application	DLR server	SCADA	IGM server
DLR application	Local stored static limits	N/A	Import final limits/ IPC	OPL file/ SFTP
DLR server	Current DLR limits/ SFTP		N/A	N/A
SCADA	Export DLR values/ IPC	N/A		N/A
IGM server	Static limits from IGM/ SFTP	N/A	N/A	

All given data is exchanged via SFTP protocol.

4.4.6.2 User Interface

The user interface (DLR GUI) would be located on the SCADA server. It would be used to add/modify/delete data about new transmission lines with DLR sensors, their connection with SCADA application, and for entering the static ampacity (limits) into a file, which the

EMMA DLR application later uses as one of the inputs. Also, the UI would be used to change parameters in the application itself.

4.4.6.3 Resources

The following resources are needed for DLR tool development:

- Python scripts - Python script is a file that generally contains a short self-contained set of instructions, i.e., lines of code that perform a specific task. They are called scripts because they are read and interpreted by Python line-by-line in order from the first line to the last.
- SCADA HMI Configuration Tool - It allows users to create customized graphical interfaces that display real-time data, alarms, and controls for the monitored systems. Engineers can design intuitive and user-friendly screens to visualize complex industrial processes.
- SCADA Database Configuration Tool – It is a specialized software application designed to manage and configure the database components of a Supervisory Control and Data Acquisition (SCADA) system.

4.5 IMPLEMENTATION AND DEPLOYMENT PLAN

The implementation and deployment of the EMMA product are organised into 8 main Activities in the next year of the project as represented in Figure 66:

Activity 1: Basic development: This step will include the development of SW components and the coding of the algorithms at the core of each tool as described in the sub-sections of Chapter 4. The activities will be based on the principles described in the abovementioned parts of the deliverable, and the requirements reported in D2.1 and section 3.3. This step will last 6 months, starting soon after the submission of this deliverable (M13) and finishing in M18 in March 2024.

Activity 2: User Interface development: The second step is devoted to the development of the UI of the product. For each one of the tools composing the EMMA, the definitions and the instructions described in the respective "User Interface" paragraphs in 4.x.x.2 sections, will be followed. This Activity will last 5 months, from M18 till M22.

Activity 3: Continuous SW quality and security dependency: The R^2D^2 project aims at improving the resiliency of the EPES, especially regarding cyber security, Therefore, it is recommended to follow secure coding guidelines and best practices during the development phase. that guarantee a superior level of security and quality. In this step, it will be regularly performed code reviews to identify and address security and quality issues through:

- Utilize dedicated tools (e.g. SonarQube, etc.) to automate static code analysis and identify code vulnerabilities and quality issues.
- Integrate proper tools (e.g. MendBolt, Dependency checker, Coverity, etc.) to scan for security vulnerabilities and dependencies with potential weaknesses.
- Integrate a tool (e.g. Mend Renovate) to regularly update the libraries used in the project to stay up to date.
- Evaluate the CVSS scores of identified vulnerabilities and prioritize based on risk (using Mendbolt, Coverity or similar SW)

Activity 4: KPIs at component level: This step is aimed at verifying the performance of the developed product to preliminary check whether it will be feasible to achieve the KPIs internal to the component (not a project level). This step will last almost 2 months, from M18 to M19.

Activity 5: Testing: This activity is devoted to performing the testing of the developed tools and products. Unit testing is mandatory for all components while, depending on the specific needs and contingencies, other categories of tests can be done (performance, communication, integration, security, etc.). Task leaders and partners involved in the SW development are in charge of deciding which extra tests may be needed and to perform them. The activity will last 6 months, from M18 till M23

Activity 6: early SW delivery: With the completion of this step, a preliminary version of the product will be available with all the functionalities and requirements defined. Minor changes and fine-tuning are still possible since this is a kind of beta release of the product. This activity has to be completed by the half of M22.

Activity 7: SW documentation & deliverable preparation: This activity is devoted to preparing the next deliverable D6.2 due by M24. The deliverable will be finalised by the half of M24, while the last two weeks will be dedicated to peer reviewing.

Activity 8: Final SW delivery: After the early delivery of the product, this step will be in charge of finalising EMMA according to the functionality described in this document and following the successful completion of Activities 4 and 5.

Months	M13 - Oct.23				M14 - Nov.23					M15 - Dec.23				M16 - Jan.24				M17 - Feb.24					M18 - Mar.24				M19 - Apr.24				M20 - May24					M21 - Jun.24				M22 - Jul.24				M23 - Aug.24					M24 - Sep.24			
Weeks	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Activity 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																										
Activity 2																							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									
Activity 3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									
Activity 4																							X	X	X	X	X	X	X																							
Activity 5																							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Activity 6																															X	X	X	X	X	X	X	X	X	X	X											
Activity 7																																						X	X	X	X	X	X	X	X	X	X	X	X	X		
Activity 8																																										X	X	X	X	X	X	X	X	X	X	X

Figure 66 – Scheduling of EMMA development activities

5 Conclusions and next steps

The purpose of the deliverable D6.1 "Design of the enhanced maintenance and asset management tool" is to describe in detail the functionalities and to present the design of the different tools composing EMMA product. EMMA is one of the four products to be developed in R^2D^2 project dealing with the reliability of the assets in power system, enhancing their maintenance and the management.

After introducing the objectives and scope of this deliverable, a full description of the background is presented (chapter 3). In this section a general context of the scientific and industrial scenario of each tool composing the product is presented. In particular, the current state-of-the-art for the considered tool is described with information of what is already existing, and the BAU activities carried out to meet the goals of the tools. After that, the innovations brought by the tools to be developed are reported, in order to present the improvements to achieve compared to the BAU, through the development activities. After the background, a complete technical description of the modules is present in chapter 4. Responsible partners have reported each of the EMMA components using the following structure:

- the functionalities in details
- the internal architecture
- the methodology for the SW development,
- information about algorithms and models,
- preliminary information about user interface
- the SW and HW resources needed.

All this information will serve as the basis upon which the work in WP6 will be continued. The next step in the WP is starting with the development of the tools (from M13 to M24). The different activities for this second step are described in section 4.5, with a Gantt chart.

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