



Reliability, Resilience and Defense technology for the grid

D4.1 – Design of the resilience suite for TSO and DSO

Date: 30/09/2023



Funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them. Horizon Europe Grant agreement N° 101075714.

Deliverable details

Title	Responsible Partner	WP	Version
Design of the resilience suite for TSO and DSO	RTEi	4	2.0

Contractual delivery date	Actual delivery date	Delivery type*	Dissemination**
30/09/2023	30/09/2023	Report	PU

*Delivery type: R: Document, report; DEM: Demonstrator, pilot, prototype; DEC: Websites, patent filings, videos, etc; OTHER; ETHICS: Ethics requirement; ORDP: Open Research Data Pilot.

Dissemination Level: **PU: Public; **CO**: Confidential, only for members of the consortium (including the Commission Services)

Author(s)	Organisation
Kristina Janošević, Predrag Simić, Dušan Prešić	SCC
Tadeja Babnik	ELPROS
Anja Korošec, Jurij Curk	Elektro Ljubljana
Srđan Subotić	EMS Services
Marija Popovic, Igor Bundalo, Goran Jakupović	Institut Mihailo Pupin
Pudjianto, Danny	Imperial College London
César Clause, Olivier Voron, Anouar Guesrami	RTE international

Version	Date	Person	Action	Status*
V0.1	23/05/2023	Ugo Stecchi	Table of Content	Draft
V0.1.1	01/09/2023	All authors	Adaptation for WP4	Draft
V0.2	20/09/2023	César Clause	Version for peer revision	Draft
V0.3	26/09/2023	César Clause	Updated version	Draft
V0.4	28/09/2023	All authors	Additional revision + integration of ICCS revision	Draft
V1.0	28/09/2023	César Clause	Finalization of the document	Final
V2.0	26/06/2024	Anouar Guesrami	Missing reference correction	Final

*Status: Draft, Final, Approved, Submitted (to European Commission).

Executive Summary

The R²D² project's Work Package 4 (WP4) is dedicated to developing the IRIS Resilience Suite, designed to enhance the resilience of Transmission System Operators (TSOs) and Distribution System Operators (DSOs) in the context of the evolving energy landscape. As the integration of Renewable Energy Sources (RES) increases and TSO and DSO operations become more interconnected, the need to enhance collaboration to manage crisis situations (disruptions such as cyberattacks and natural disasters, etc.) becomes crucial. WP4 addresses the challenges faced by TSOs, DSOs, and Regional Security Coordinators / Regional Coordination Centres (RSCs/RCCs) during crises, emergency & restoration processes, and multi-energy planning coordination.

The IRIS suite aims at gathering the different modules developed in the WP4 and detailed in this document in a common and integrated ecosystem, to support TSO and DSO processes. The IRIS suite will especially facilitate information sharing, data exchange, analysis, coordination, and collaborative decision-making. These capabilities are essential for crisis management, enhancing system stability, and optimizing network operations.

This document provides an overview of the concepts of the different modules with the design of the proposed solutions. It highlights the technologies used, the components on which the platform will leverage to provide its beneficiaries, highlighting its role in enhancing the resilience and reliability of Electrical Power and Energy Systems (EPES).

The WP4 is composed of 3 main tasks and an integration activity. The 3 main tasks are derived in modules that are presented in details in the document. Hereunder, a high level description of these modules, the background for the related use cases and the innovative approach they propose on each of these =:

Task 4.1: Optimal resources coordination for TSO and DSO

- IRIS Module1 – DSO-TSO Congestion and Power Quality Coordination in Application of System Services: This tool enables DSOs to monitor distribution network conditions, including voltage limits and potential congestions that can impact the availability of flexibility resources used for ancillary services by TSOs. The innovation lies in DSOs informing TSOs about these limitations, enhancing flexibility resource usage for ancillary services, and promoting cross-network collaboration.
- IRIS Module2 – Upstream Studies to Validate the Use of TSO/DSO Means During Crisis: This module promotes common studies between TSOs and DSOs, enhancing their operational cooperation during crisis scenarios. The innovation lies in leveraging existing practices among TSOs to improve data sharing and crisis response.

Task 4.2: Emergency & Restoration

- IRIS Module3 – DSO Flexibility System: Improving LV Network Observability: This tool enhances the observability of Low Voltage (LV) networks by using billing metering data, allowing DSOs to take control actions for DERs and consumers on the LV level. The innovation is in improving system security through real-time control and LV network situational awareness.
- IRIS Module4 – DSO Flexibility System: Enhancement in DER Control: This module focuses on enhancing DER control and participation in flexibility procurement

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

schemes, improving network operation security. It enables DSOs to perform control actions on LV networks, ensuring optimal DER response. The innovation lies in optimizing DER contributions to system services.

- IRIS Module5 – Emergency & Restoration – Over-Frequency Protection: This centralized system replaces individual controllers on generators, mimicking the response of the entire power system to over-frequency conditions. The innovation is in ensuring effective over-frequency protection and preserving system integrity, even without modernizing all generators.
- IRIS Module6 – Phasor Angles Monitoring and Prevention of Instability: This tool utilizes Phasor Measurement Units (PMUs) to detect potential instability in network sections with insufficient transmission capacity. The innovation is in real-time instability detection through phasor angle comparison, enabling timely operator intervention.
- IRIS Module7 – Optimization of PMU Installation Points: The innovation here lies in the algorithm that optimizes PMU installation to achieve full system observability while minimizing costs. This tool enhances state estimation accuracy and supports advanced energy applications.
- IRIS Module8 – Emergency & Restoration – System Split Module Upgrade: This tool translates complex disturbance rules into guided proceedings through a communication tool. The innovation is in automating coordination during disturbances, ensuring faster and more efficient crisis response.
- IRIS Module9 – Remedial Action Automation: This module automates predefined Remedial Actions (RAs) and verifies RAs in real-time based on actual system conditions. The innovation is in improving system operator responsiveness and adaptability during crises.

Task 4.3: Multi Energy TSO-DSO planning coordination

- IRIS Module10 – TSO-DSO Cooperation in Individual Grid Model Creation: The innovation involves separating power exchange forecasts into load and distributed generation forecasts, fostering TSO-DSO cooperation. This ensures more accurate network models in the presence of distributed generation.
- IRIS Module11 – TSO-DSO Planning Coordination Suite: This comprehensive suite optimizes multi-energy systems, prioritizes resilience, using distributed energy resources (renewables) and flexible microgrid technologies (demand response, energy storage). The distributed flexibility resources will also be considered in designing efficient transmission grids to maximise and maintain cost-effectiveness. The innovation is in developing a coordinated multi-energy TSO-DSO planning framework to facilitate the development of a robust, low-carbon, and adaptable energy system capable of addressing future challenges.

The IRIS Resilience Suite represents a significant step forward in crisis management and grid resilience, empowering operators with advanced tools and collaborative capabilities to address the evolving energy landscape effectively.

This deliverable, together with the other technical deliverables D3.1, D5.1 and D6.1, contributes to achieve the Milestone #3 “Design of the four Products”, due by M12. As 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

Extreme weather events, Cyberattacks, Resilience, Cybersecurity, IRIS Resilience Suite, Architectural design, Integration, Renewable Energy Sources (RES), Natural disasters, Regional Security Coordinators (RSCs), Regional Coordination Centres (RCCs), Crises management, Emergency and restoration procedures, multi-energy planning coordination, Remedial Actions (RAs), Individual Grid Models (IGMs)

Copyright statement

The work described in this document has been conducted within the R²D² project. This document reflects only the R²D² Consortium view, and the European Union is not responsible for any use that may be made of the information it contains.

This document and its content are the property of the R²D² Consortium. All rights relevant to this document are determined by the applicable laws. Access to this document does not grant any right or license on the document or its contents. This document or its contents are not to be used or treated in any manner inconsistent with the rights or interests of the R²D² Consortium or the Partners detriment and are not to be disclosed externally without prior written consent from the R²D² Partners.

Each R²D² Partner may use this document in conformity with the R²D² Consortium Grant Agreement provisions.

1 Table of Contents

1	Table of Contents.....	6
1.1	List of tables	7
1.2	List of figures.....	7
1.3	Acronyms.....	9
2	Introduction.....	10
2.1	Purpose and scope of the Document.....	10
2.2	Structure of the Document.....	10
3	Background.....	11
3.1	Overview of the product.....	11
3.2	State of the Art.....	13
3.2.1	Background.....	13
3.2.2	Innovation provided.....	17
3.3	Relevant Use Cases and Actors.....	21
4	Product Description.....	25
4.1	Task 4.1 – Optimal resources coordination management for TSOs and DSOs during crisis 26	
4.1.1	IRIS Module1 – DSO – TSO congestion and power quality coordination in application of system services.....	26
4.1.2	IRIS Module2 – Upstream studies to validate the use of TSO/DSO means during crisis situations.....	27
4.2	Task 4.2 – Emergency & Restoration.....	35
4.2.1	IRIS Module3 – Improving of LV network observability based on billing metering system by means of secure interface with SCADA-ADMS system.....	35
4.2.2	IRIS Module4 – Enhancement in DER control and management systems to participate in flexibility procurement schemes for DSO and TSO to improve network operation security.....	38
4.2.3	IRIS Module5 – Emergency & Restoration – Over-Frequency Protection module	39
4.2.4	IRIS Module6 – Phasor angles monitoring and prevention of instability – EMSS.....	47
4.2.5	IRIS Module7 – Optimization of PMU installation points – EMSS.....	51
4.2.6	IRIS Module8 – Emergency & Restoration – System Split module upgrade – EMSS	54
4.2.7	IRIS Module9 – Remedial Action Automation – EMSS.....	60
4.3	Task 4.3 – Multi-energy TSO-DSO planning coordination.....	66
4.3.1	IRIS Module10 – TSO-DSO cooperation in Individual Grid Model creation via TSO- DSO communication platform.....	66
4.3.2	IRIS Module11 – TSO-DSO planning coordination suite.....	71



D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

4.4	Implementation and deployment Plan.....	77
5	Conclusions and next steps.....	78
6	References.....	79

1.1 LIST OF TABLES

Table 1	– Acronyms.....	9
Table 2	– IRIS Resilience Suite Use Cases and related actors.....	21
Table 3	– WP6 requirements.....	22
Table 4	– Table 4.2.7.1: Data exchange protocols between RAA components.....	65
Table 5	– Implementation and Deployment Plan of IRIS Resilience Suite.....	77

1.2 LIST OF FIGURES

Figure 1	– IRIS high level coordination platform.....	25
Figure 2	– tool architecture – Architecture of IRIS Module1.....	26
Figure 3	– Simplified description of the process.....	28
Figure 4	– Detailed workflow Step 1.....	29
Figure 5	– Detailed workflow Step 2.....	30
Figure 6	– Detailed workflow Steps 3 & 4.....	31
Figure 7	– Detailed workflow Step 5.....	32
Figure 8	– First screen of the coordination process.....	34
Figure 9	– Second screen of the coordination process.....	34
Figure 10	– Architecture of IRIS Module3.....	35
Figure 11	– UniFusion platform concept.....	36
Figure 12	– Architecture of IRIS Module4.....	38
Figure 13	– Architecture of the OFPM tool.....	40

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

Figure 14 - Control scheme for the reduction of active power production on generators.....	44
Figure 15 - Control scheme for remote disconnection of the generator	45
Figure 16 - Control scheme of OFP resetting on protection devices	46
Figure 17 - UI, Business and Data Storage layer of IRIS Module6	48
Figure 18 - Equal area criterion.....	49
Figure 19 - Architecture of the IRIS Module7	51
Figure 20 - The OPPA optimisation algorithm	53
Figure 21 - ER tool architecture - Architecture of IRIS Module8 'ER'	56
Figure 22 - Data flow in ER toll	59
Figure 23 - Architecture of IRIS Module9 'Remedial Action Automation tool architecture Automation'	62
Figure 24 - Remedial Action Automation tool algorithm	63
Figure 25 - Data flow between RAA tool components.....	64
Figure 26 - Architecture of IRIS Module10 'TSO-DSO Communication Platform'.....	67
Figure 27 - TSO-DSO Production Unit Information Process Flow	68
Figure 28 - TSO-DSO Forecast Process Flow	68
Figure 29 - TSO-DSO Data exchange and protocols	69
Figure 30 -: OpFab display.....	70
Figure 37 - OperatorFabric UI used in IRIS Module10.....	70
Figure 32 - MEMG resources considered for providing network services and improving energy system resilience	72
Figure 33 - Architecture of IRIS Module11 DSO Planning Suit	72
Figure 34 - Virtual Power Plant concept.....	74
Figure 35 - Characterisation process of VPP	75
Figure 36 - Illustration of the input data format	76

1.3 ACRONYMS

Table 1 – Acronyms

Acronyms	Meaning
ADB	Application Database
AMS	Asset Management System.
API	Application Programming Interface
CA	Contingency Analysis
CRA	Curative Remedial Actions
DER	Distributed Energy Resources.
DSO	Distribution System Operator
EAS	ENTSO-E Awareness System
EMS	Energy Management System.
ENTSO-E	European Network of Transmission System Operators for Electricity
GUI	Graphical User Interface
HMI	Human-Machine Interface.
ICCP	Inter-Control Center Communication Protocol
TASE2	Telecontrol Application Service Element 2.
IEEE	Institute of Electrical and Electronics Engineers
MILP	Mixed-Integer Linear Programming
Mosel	Modelling and Optimization Language
PMUs	Phasor Measurement Units
PRA	Preventive Remedial Actions
RAs	Remedial Actions
RCC	Regional Coordination Centre

2 Introduction

2.1 PURPOSE AND SCOPE OF THE DOCUMENT

The R²D² project's WP4 aims at providing a suite for TSO and DSO resilience. The EPES resilience becomes a key challenge, as more and more RES are integrated and TSO and DSO processes are more and more interlinked, ensuring they can withstand disruptions such as cyberattacks or natural disasters. It addresses challenges faced by Transmission System Operators (TSOs), Distribution System Operators (DSOs), and Regional Security Coordinators / Regional Coordination Centres (RSCs/RCCs) during crises, emergencies, restoration, and multi-energy planning coordination.

IRIS includes tasks and use cases such as:

- Optimal Resources Coordination Management for TSOs and DSOs During Crises.
- Emergency and Restoration.
- Multi-Energy TSO-DSO Planning Coordination.

The WP4 modules will be integrated, if needed, in the IRIS COORDINATION PLATFORM, including information sharing, data exchange, analysis, coordination, and collaborative decision-making. These capabilities are crucial for managing crises, enhancing system stability, and optimizing network operations.

This document serves as a precursor to deliverable D4.2, which will encompass the complete development of the IRIS Resilience Suite, demonstrate the results of its tools at the designated demo sites, and showcase the integration of its components into a unified User Interface, scheduled for M24 of the R2D2 project.

2.2 STRUCTURE OF THE DOCUMENT

The Background section introduces the product, explaining its features and innovations. It also discusses the existing state of the field and presents relevant use cases and key actors.

The core of the document is the Product Description section, subdivided into tasks. Task 4.1 focuses on coordinating resources for TSOs and DSOs during crises, including specific tools (Tool 1 and Tool 2) with detailed explanations. Task 4.2, titled Emergency & Restoration encompasses multiple tools (Tool 3 to Tool 9) for various aspects of emergency management and system restoration. Task 4.3 highlights multi-energy TSO-DSO planning coordination, featuring Tool 10 and 11 for improved energy distribution planning.

3 Background

3.1 OVERVIEW OF THE PRODUCT

The primary objective of the IRIS Resilience Suite is to support the existing and coming needs for coordination among system operators, especially in situations involving security concerns. In the energy industry, system operators are responsible for managing and ensuring the security and reliability of the EPES (Electrical Power and Energy Systems). However, during critical events or security threats, it becomes crucial to have a mechanism in place to facilitate coordinated actions and responses among these operators.

Beneficiaries: The IRIS Resilience Suite is intended to be used by all the different system operators (TSO, DSO, RCC/RSC).

These operators act as central hubs for gathering and disseminating critical information and facilitating coordination, particularly during crises or emergencies. The IRIS Resilience Suite provides tools and functionalities that empower these operators to effectively communicate and collaborate with each other's when security-related challenges arise.

In essence, IRIS serves as a specialized suite of tools and resources that system operators and coordination centres can utilize to exchange vital information, synchronize their actions, and make swift, well-informed decisions in situations where security of the energy grid is at risk. This suite plays a critical role in bolstering the resilience and dependability of the energy grid, benefiting both the operators responsible for its functioning and the end-users who rely on a secure and stable energy supply.

The Task 4.1 will encompass the following different tools:

- **IRIS Module1 (DSO-TSO congestion and power quality coordination in application of system services)** aims at facilitating coordination between Distribution System Operators (DSO) and Transmission System Operators (TSO) to prevent congestion and power quality issues in the distribution network, ensuring that ancillary services remain available. The tool comprises smart meters, a measurement data centre, a SCADA/AMS system, and a flexibility management system with a Traffic Light System.
- **IRIS Module2 (Upstream studies for TSO/DSO coordination in crisis situation)** is designed to validate the use of TSO/DSO means during crisis situations, enhancing coordination and enabling the exchange of network models. It includes components like a coordination function, validation function, and an analysis function. The concept relies on the use of power flow computations, such as PowSyBl, and relies on specific communication protocols.

The Task 4.2 embeds the tools 3IRIS Module3 to 9, which are delivering the following features.

- **IRIS Module3 (Improving of LV network observability based on billing metering system by means of secure interface with SCADA-ADMS system)** focuses on improving the observability of Low Voltage (LV) networks and enhancing system security based on billing metering data, enabling automatic actions. Components include smart meters, a measurement data centre, a SCADA/AMS system, and a flexibility system based on the UniFusion platform.

- **IRIS Module4 (Enhancement in DER control and management systems to participate in flexibility procurement schemes for DSO and TSO to improve network operation security)** is designed to enable Distributed Energy Resources (DER) to participate in system services, enhancing network operation security. It relies on a flexibility management system, SCADA, and communication with aggregators.
- **IRIS Module5 (Emergency & Restoration – Over-frequency Protection Module)** is designed to reduce power production during high frequencies, acting as a replacement for controllers on generating units.
- **IRIS Module6 (Phasor Angles Monitoring and Prevention of Instability)** aims to enhance power system stability by employing Phasor Measurement Units (PMUs). Two PMUs are placed at the production and consumption centres to monitor power flow. If a critical angle difference between them is reached, an alarm is triggered, prompting operators to adjust power injections for system stability. The critical angle is determined through offline simulations based on the equal area criterion, which assesses transient stability.
- **IRIS Module7 (Optimization of PMU Installation Points)** is designed to optimize the placement of Phasor Measurement Units (PMUs) in power systems to achieve full observability while minimizing the number of required PMUs. It offers three modes: basic calculation, N-1 calculation, and incorporating existing PMUs. The optimization process involves mathematical models and algorithms, such as Linear Programming (LP) and Mixed-Integer Linear Programming (MILP), to recommend efficient PMU placements.
- **IRIS Module8 (Emergency & Restoration – System Split Module Upgrade)** addresses major disturbances in power systems, aligning with ENTSO-E rules and new European regulations. It includes components like Network Topology Processor (NTP), real-time application database (ADB), SCADA HMI, and a coordination platform. Algorithms and techniques identify system splits and blackouts, utilizing a binary connectivity matrix and voltage thresholds. The tool communicates through protocols like IEC 60870-6 TASE.2. Coordination is facilitated via a notification-based coordination platform, assisting operators during system restoration.
- **IRIS Module9 (Remedial Action Automation)**. This will serve as a critical component in the ENTSO-E Regional Operational Security Coordination (ROSC) methodology [11]. Its primary objective is to enhance the security and reliability of power systems by automating the process of determining and executing Remedial Actions (RAs). Traditionally, RAs are based on pre-calculated models from day-ahead or intraday scenarios. However, these models may become obsolete in real-time operations due to unforeseen system changes. EMSS addresses this challenge by enabling rapid RA determination and execution, even for fast RAs, which are currently defined qualitatively. This automation enhances system resilience during critical situations.

The task 4.3, aims at proposing a framework for multi energy planning coordination between TSO and DSO. It relies on the following modules:

- **IRIS Module10 (TSO-DSO Cooperation in Individual Grid Model Creation via TSO-DSO Communication Platform)** aims to improve the accuracy of Individual Grid Models (IGMs) by considering production at the distribution level. Instead of forecasting power flow at the TSO-DSO interface, it focuses on separately forecasting and modelling distribution load and distributed generation. It involves several steps, including initial consumption and production forecasts, harmonization between TSO and DSO, and communication about new generation capacities and network topology changes. This

requires a new business process and tools for forecasting and communication, primarily addressed in this report through the TSO-DSO communication platform.

- **IRIS Module11 (TSO-DSO planning coordination suites)** is primary aiming to optimize and identify multi-energy system capacity portfolios for a resilient, low-carbon, cost-effective energy system while managing fault and extreme weather risks. For DSO planning, it develops resilience-based investment criteria for microgrids (MEMG) and their grid services under extreme conditions. TSO planning considers DER services, optimal transmission designs, and system reliability. Both aspects analyse resilience, cost-effectiveness, and flexibility resources.

Lastly, the **T4.4: Integration and UI**, will support the other tasks in providing a common integration framework across various components and tools within the context, ensuring that all elements of the system can seamlessly communicate and work together. This includes software applications, data sources, and other relevant components.

3.2 STATE OF THE ART

3.2.1 Background

Coordinating between Transmission System Operators (TSOs) and Distribution System Operators (DSOs) in the management of the electricity system poses several significant challenges due to the evolving energy landscape and the need for a more integrated and flexible grid.

These challenges are especially related to the development of Increased Distributed Energy Resources (DERs), the implementation in the EPES of more and more Intermittent Renewable Energy Sources and the grid management, involving TSO and DSO, during crisis situation.

Addressing these challenges in TSO-DSO coordination is crucial for maintaining grid reliability, improving energy efficiency, and facilitating the transition to a more sustainable and decentralized energy system. Collaboration, regulatory reforms, and technological advancements are key to overcoming these obstacles and ensuring the efficient management of the electricity system.

The IRIS product aims, through the covered use cases, at providing an innovative framework to support TSO and DSO on these challenges, leveraging in particular on processes at RSC/RCC level.

IRIS Module1 - DSO-TSO congestion and power quality coordination in application of system services

With increased share of volatile RES in the system, they will together with flexible loads participate in bigger extent in the ancillary services and balancing mechanism. The idea is, that TSO or any other actor can directly or indirectly engage ancillary service and flexibility providers also in distribution network. This network can be connected to the TSO, but according to EU regulation 2019/943, 2017/1485, 2017/2195 [3] it could be even in another country (some frequency related services are now already open to be provided anywhere inside the interconnection). Therefore, it is important for TSO to have prompt information about availability of these resources. This is valid also for responsible actors of balancing groups, which are another potential user of these services. DSO shall not interfere with this

business except in case, power supply integrity is endangered in the sense of power quality or stability (possible congestions leading to outages). Therefore, these contracts and locations of providers are not necessarily known to DSO. So, information about limitations in the network shall be distributed to all users of these services, which register for getting them. This can be TSO, aggregators or responsible for balance of balancing groups. But for sure, there are more actors, that are potentially interested in these data.

So, in R²D² we will develop tools to provide information about possible limitations in our network affecting availability of these resources (forecasts) and definite limitations (on-line measurements) in case of congestions and/or power quality issues in particular part of the network. Since we do not know exactly, which customers have contract to provide these services, we are giving information for all of them in the shape of location defined by measuring point.

IRIS Module2 – Upstream studies for TSO/DSO coordination in crisis situation

Currently, the coordination between TSO and DSO is mainly based on long term processes which usually imply exchange of knowledge about the grid state at these time horizons. The tool aims at providing a framework to get the coordination closer from the operational timeline. It is based on coordination principles that have been developed between TSOs at regional level and supported by RCC/RSCs.

IRIS Module3 – Improving of LV network observability based on billing metering system by means of secure interface with SCADA-ADMS system

To act on an optimal way in case of events, SCADA/ADMS needs to have clear picture about the network's current situation. An essential part of loads and in future also generation (DER) are connected to low voltage network (LV). In order to act properly in crisis event, one need to have reliable information about available resources and situation in the LV network. With Advances Distribution Management System (ADMS) digital twin of the network itself is achieved, but information about the actual operation state and possible overloads or voltage limits violations is not available. With close to real-time (1 minute) information from the meters used for billing purposes, SCADA can get information about the actual LV network situation.

Since the number of on-line measurements is limited, state estimator provides further information. Therefore, crisis actions on the higher level can be evaluated and ranked also according to the influence on LV loads.

IRIS Module4 – Enhancement in DER control and management systems to participate in flexibility procurement schemes for DSO and TSO to improve network operation security

Since with increasing share of DER fluctuations in the network increase and issues with power quality becoming more often, DER need to participate also in system services with fair share. Therefore, it is becoming necessary for DER to take over certain level of ancillary services (including emergency actions) However, DER are limited in their ability in their ability to provide ancillary serviced in comparison to conventional energy sources. This UC will demonstrate, how DER and flexibility can fulfil these tasks. Therefore, we need to set up the system to enable us to procure system services from DER and optimally control them. RES will be included in flexibility/system services procurement system and later provide services.

Algorithm for activation of these resources will be developed, which takes in consideration volatile generation and limitations in their abilities of proper response.

Adaptive control of the voltage profile from the transformer distribution station to the end of the power line with weighted DER participation, primarily of the PVs will be addressed. Further, local centralized control for stable participation of DER using standard communication accesses to control devices without additional investments in hardware will be set up in this UC demonstration.

Practically, RES (particularly Wind and Sun) as a most problematic option of DER can be included in provision of services for any DSO or TSO (certainly with limitations of the demo and size of this project we are talking about kW and not MW). Although schemes and mechanisms can be tested and demonstrated.

IRIS Module5 – Emergency & Restoration – Over-Frequency Protection module

Protection against the occurrence of extremely high frequency in the European Power System is based on the so-called LFSM-0 (Limited Sensitive Frequency Mode – Over frequency) controllers, which are defined by the EU network code for generator connection. However, such controllers will be applied to new generators, and during the reconstruction of existing generators, i.e. power park modules.

At the moment, TSOs can rely on a smaller number of generators equipped with this new technology, while on older generator units, over-frequency protection can be set to shut down the generator if a critical frequency value is reached.

Therefore, a TSO can assign different settings of over-frequency protection to generator units, so that in the case of extreme high frequencies, some would be out of operation and contribute to returning the frequency to the normal range.

But this solution is not sufficiently controllable for two reasons: 1) in this way, it cannot be guaranteed that the amount of production corresponding to the LFSM-0 response will be disconnected from the network; 2) Due to unequal generation disconnection by TSO control areas, unwanted flows may occur on transmission lines, which can further jeopardize the security of the interconnected system, and lead to a system split or even a total collapse and blackout.

In order to avoid these risks, it is necessary to design a tool that could manage the reduction of active power on generators in accordance with the situation in the network. Precisely, this is the idea behind the IRIS Module5

IRIS Module6 – Phasor angles monitoring and prevention of instability

PMUs are increasingly used in transmission network control, because only they can provide measurements with the highest resolution. In addition, they are characterized by high accuracy.

Conventional SCADA measurements are not sufficient to detect risks due to loss of stability. In principle, the European network is dense and well meshed, which prevents the occurrence of frequent dynamic problems.

However, the network is not equally developed everywhere and there are corridors that do not have sufficient capacity to prevent instability.

Due to all of the above, most dynamic problems are presently detected based on off-line studies, and based on them, it is possible to determine measures to reduce the risk of unstable system operation.

However, even when something has been studied, it is desirable to monitor the potentially unstable sites in real time. It is this tool that proposes one possible solution for monitoring the risk of instability and alarming when it is estimated that the risk requires preventive actions.

IRIS Module7 – Optimization of PMU installation points

The previous section outlined how PMUs are used to manage risks of instability. However, PMUs have wider uses, one of which is related to improving state estimation. Namely, PMUs measure voltage and current phasors, which means that phasor angles can also be included in the state estimation.

That's why recently there is a tendency to integrate measurements from PMUs into the SCADA system. Better state estimation will provide a more accurate network model, which further enables better results of advanced energy applications, such as power flow analysis and contingency analysis.

On the other hand, the installation of PMUs requires additional costs. Therefore, it is necessary to create a methodology that will optimize the installation of PMUs, so that a balance is found between the additional quality of the estimation and the costs of installing these devices. This is exactly the functionality of this tool.

IRIS Module8 – Emergency & Restoration – System Split module upgrade

EU regulations in the field of energy and ENTSO-E regulations pay special attention to system operation in emergency situations. That is why the network code on emergency and restoration was adopted, which is followed by many methodologies and procedures of ENTSO-E.

In addition, special tools have been developed, such as the pan-European Awareness System (EAS). This system is available to all TSOs and is currently being extended to RCCs as well. Also, there is a tendency for RCCs to play an increasing role in the coordination of TSOs, as well as for its functions to begin to relate to real time.

We should not forget the obligatory training of dispatchers, both on a national and regional basis, in order to prepare them as well as possible to act in future disturbances.

However, it also has its negative sides. The very number and complexity of the rules lead to the fact that they are very difficult to apply in cases of major disturbances. That's why further development of tools is needed, which is the main point of this module.

IRIS Module9 – Remedial Action Automation

In the European interconnection, it is impossible today to imagine the planning of system operation without network models, contingency analysis and remedial actions that are the result of those analyses.

All TSOs are obliged to create network models for each day and hour, which are submitted for validation and merging to RCCs.

After the completion of the merging of the models and the preparation of the aforementioned analyses, remedial actions are determined at the national and regional level.

Some of these RAs must be started before critical outages (preventive RAs), and for others (curative RAs), you can wait until the eventual trip of the network element actually occurs in real operation.

Determination and activation of RAs is a very important activity of TSOs and RCCs, because they are the best barrier to the occurrence of major disturbances. On the other hand, most RAs carry large costs and should be avoided when they are not necessary.

However, this mechanism still has its weaknesses, namely the certain inaccuracy of network models. This inaccuracy stems from errors in the forecast of consumption, RES producers (especially wind power plants and solar power plants), subsequent transactions on intraday markets and the like.

Therefore, this mechanism needs to be properly coupled with the real-time situation that is detected through the SCADA system, which is the purpose of this tool.

IRIS Module10 – TSO-DSO cooperation in Individual Grid Model creation

Network models are created by TSOs, where the interaction with DSOs is generally weak. When creating models, forecasting software or services are used to estimate the consumption and production of certain RES. The total consumption is often forecasted, and then it is distributed according to the key to individual points of consumption (the so-called load tree).

In the past period, the Serbian TSO introduced quality control of individual network models, based on the comparison of values from the network model and values realized in practice.

In doing so, it was observed that the biggest errors occur in areas where there are RES production capacities at the distribution level. Other errors occur when DSO changes the normal topology in its system due to planned network work.

All this points to the need to improve the process of creating an individual network model based on the inclusion of DSO in this process, which is the idea of the use case from which this tool originates.

IRIS Module11 – TSO-DSO planning coordination suite

The tool is designed to bolster the grid's ability to withstand and recover from disruptions, whether they result from faults in the system or extreme weather conditions. This is crucial for ensuring a consistent energy supply, even in the face of storms, cyberattacks, or equipment failures. The DSO planning suit will support distribution planners in identifying an optimal portfolio of microgrid technologies that can improve system resilience. However, as extreme events are rare, those distributed resources should also be used optimally to support the daily operation of TSO and DSO to maximise their asset values. In this context, the TSO can consider the services provided by those distributed technologies as an alternative to transmission assets. Integrating distributed flexibility technologies in the planning distribution and transmission will radically change the traditional network planning approach, which relies solely upon network redundancy to improve security or resilience. Throughout the planning process, the tool maintains a careful balance between cost-effectiveness and resource flexibility, ensuring that decisions are economically sound while also allowing for adaptability in the face of evolving energy demands and conditions.

3.2.2 Innovation provided

These tools IRIS modules aim at managing preventively crises by sharing crisis info, analyzing data, and coordinating efforts. Stakeholders exchange details, evaluate strategies, analyze data, coordinate findings, and validate solutions. The focus is on consensus-driven

crisis resolution through collaboration and informed decision-making. In following paragraphs, overall overview of innovation per each IRIS tool is provided.

IRIS Module1 – DSO-TSO congestion and power quality coordination in application of system services

DSO will supervise situation in the distribution network regarding voltage limits and possible congestions, which can affect availability of flexibility resources used for ancillary services for TSO. DSO informs TSO about these limitations, which was not the case before. The tool enables the use of flexibility resources for ancillary services for any TSO in any distribution network.

IRIS Module2 – Upstream studies to validate the use of TSO/DSO means during crisis

Currently, TSO and DSO do not share models and do not exchange on computation results in close to real time horizons. The Use case and the related product aims at leveraging on existing practices between TSOs to support the enhancement of the data exchange and the creation of common studies that could support TSO/DSO operation and cooperation during crisis scenarios.

IRIS Module3 – DSO Flexibility system: Improving of LV network observability based on billing metering system by means of secure interface with SCADA-ADMS system

DSO Flexibility system will increase the LV network observability with the use of measurements from meters (used for billing purpose) installed in LV network. If DSO Flexibility system detects voltage violations or overloading control actions will be sent to consumers/DER to increase/decrease the voltage or reduce the load/generation.

With the Flexibility system DSO will perform control actions for DER/consumers on LV level. Small changes on the local level have the influence as all together on a wider level.

IRIS Module4 – DSO Flexibility system: Enhancement in DER control and management systems to participate in flexibility procurement schemes for DSO and TSO to improve network operation security

DSO will perform control actions for DER/ consumers on LV level which will with their small changes on local level have the influence as all together on a wider level.

IRIS Module5 – Emergency & Restoration – Over-Frequency Protection module

This tool is designed as a centralized system that replaces LFSM-0. Instead of having an LFSM-0 controller on each generator, a centralized system is introduced that can mimic the response of the entire power system, as if each generator were equipped with this device. This design is based on Art. 16 of the Commission Regulation (EU) 2017/2196 (network code on emergency and restoration).

In this way, the TSO can immediately provide effective over-frequency protection, without waiting for all generators to be modernized. This system can be based on a combination of solutions, depending on the equipment available to the generators and their connection facilities.

One possibility is the remote reduction of production by sending a base power set, the second is the remote shutdown of the generator, and the third is the remote resetting of over-frequency protection devices in real time.

In earlier H2020 projects (CROSSBOW [10]), the basics of the solution for the national and regional over-frequency protection mechanism were elaborated. Although this project will focus on the creation of a national mechanism on the Serbian pilot site, it is useful to note that the regional mechanism can prevent the occurrence of unwanted flows during the operation of over-frequency protection and thus preserve the integrity of the system, which individual non-integrated LFSM-O controllers on generators cannot achieve.

IRIS Module6 – Phasor angles monitoring and prevention of instability

The innovation of this use-case refers to the use of PMUs to detect possible instability in parts of the network that connect the energy source to the energy sink, which lack the appropriate transmission capacity that would ensure stability in all operating modes.

Potential instability can be detected by comparing the phasor angles of two PMUs, one installed at the energy source point (generation) and the other at the sink point (consumption).

In off-line analysis, the critical value of the difference between the angles of these two phasors can be calculated, so if it is exceeded in real time, operators in the control centre are alerted to act.

IRIS Module7 – Optimization of PMU installation points

Although there is a trend to install PMUs in the transmission system, there are no software solutions that would optimize the required functionality of PMUs (which can be quite diverse) and installation costs.

In this case, the goal is to install PMUs so that the system is fully observable through these devices as well. In the previous part, it was explained that in this way the phasor angles are introduced as an additional parameter that increases the accuracy of state estimation, which is further used in advanced energy applications of great importance (contingency analysis for example).

So, the innovation of this tool is an algorithm that is able to calculate all optimal solutions for different cases: normal state (all PMUs are available), N-1 state, state with zero injections buses, limited number of channels... It is also possible to include PMUs already installed in the transmission system in the optimization.

IRIS Module8 – Emergency & Restoration – System Split module upgrade

The basic innovation of this tool is to translate complex rules related to disturbances into a list of proceedings for predefined types of disturbances, through a suitable communication tool.

The tool itself should be installed in the RCC and associated TSOs. The tool should be coupled with the SCADA system so that it can detect the disturbance and its characteristics and automatically initiate the appropriate sequence of guided proceedings.

Work on this tool was started in one of the previous H2020 projects (TRINITY [4]) and before the big disturbance of January 8, 2021. What happened during the solving of the disturbance, and some subsequent disturbances, only confirmed the necessity of such a coordination

mechanism/tool. The results of the project were communicated to ENTSO-E, which then developed a special procedure for the split system.

In this project, it is necessary to adapt this tool to comply with the newly adopted ENTSO-E system split procedure. In this way, the task of the RCCs to coordinate the affected TSOs in the event of a large disturbances can be realized by using this tool.

IRIS Module9 – Remedial Action Automation

This tool is based on the existing ROSC methodology with the aim of improving system operator responsiveness.

The idea is to automate the implementation process of predefined RAs as much as possible. The innovation is the additional verification of predefined RAs in the operational planning process, which are now being verified in real time based on the real situation in the system, through additional calculation of power flows and voltages and taking into account the contingency list.

If the situation in the network is significantly different from the planned, this procedure can determine new RAs, which the operator of the control centre confirms before RA implementation.

IRIS Module10 – TSO-DSO cooperation in Individual Grid Model creation:

In this case, the innovation is on a smaller scale and concerns the separation of the current TSO-DSO interface power exchange forecast into two forecasts: 1) distribution end load forecast (including grid losses) and 2) distributed generation forecast (mainly RES), in the process of creating the Individual Grid Models.

With the increase in RES production in the distribution system, which is not evenly distributed, there are increasing errors, if traditional forecasting is applied (for example, the total consumption is forecasted, and it is divided according to fixed parameters to individual points of connection of the distribution system to the transmission system – so called load tree parameters).

Errors are particularly large where production in the distribution system exceeds consumption, so inverse flows occur through the transformers that connect the transmission and distribution system.

Therefore, TSO and DSO must cooperate in order to jointly forecast final consumption and production in the distribution system. Also, this cooperation must include information about the change in topology in the distribution system, which affects the redistribution of flows through the mentioned transformers. Only in this or a similar way sufficiently accurate individual network models can be provided in the future.

IRIS Module11 – TSO-DSO planning coordination suite

The innovation in the IRIS Module 11 lies in its unique approach in considering the reliability contribution of different microgrid technologies in distribution and transmission system planning. It optimizes multi-energy systems, prioritizes resilience in the face of disruptions, integrates renewable energy sources, designs efficient transmission grids, and maintains cost-effectiveness and flexibility. The assets proposed to boost the resilience of the distribution grid will also provide services to transmission and will be integrated in the evaluation of transmission planning network configurations. These innovations collectively contribute to the development of a robust, low-carbon, and cost-effective energy system that

can withstand the challenges of the future, including extreme weather events and system faults.

3.3 RELEVANT USE CASES AND ACTORS

The Use Cases covered by the IRIS product are described below, together with the relevant actors, and mapping UCs and actors per each tool in the Product. These elements are further explained in D2.1 document.

Table 2 – IRIS Resilience Suite Use Cases and related actors

ID	Title	Task	Actors
UC11	DSO-TSO congestion and power quality coordination in application of system services	T4.1	Flexibility procurement system (Flex server), SCADA/ADMS system, RTUs, Meters, TSO, DSO, Aggregator, Balance group responsible party
UC35	Upstream studies to validate the use of TSO/DSO means during crisis situations	T4.1	DSO, TSO, Power flow software, IRIS Communication platform
UC10	Improving of LV network observability based on billing metering system by means of secure interface with SCADA-ADMS system	T4.2	SCADA/ADMS system (DSO), active consumer, DER, Flexibility system, communication gateway, RTUs, smart meters
UC7	Enhancement in DER control and management systems to participate in ancillary services procurement schemes for DSO and TSO to improve network operation security	T4.2	SCADA / ADMS system (DSO), SCADA system (DER, RES), Flexibility procurement system (Flex server), RTUs, Meters
UC12	Emergency & Restoration – Over-frequency protection module	T4.2	TSO, Producer, over-frequency protection module (OFPM), SCADA/EMS system, Protection device
UC16	Phasor angles monitoring and prevention of instability	T4.2	TSO, SCADA/EMS, PMU
UC18	Optimization of PMU installation points	T4.2	TSO, IRIS OPP (Optimal PMU Placement) Application
UC19	Emergency & Restoration – System Split module	T4.2	Micro grid central controller, Multi-energy micro grid, Mobile power source, Mobile energy storage system, Mobile emergency generator, Electric vehicle, Repair crew, Distributed energy resources, Transportation operator
UC 21	Remedial Actions Automation	T4.2	TSO, Producer, SCADA/EMS system, Power Flows tool, Remedial Action tool

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

UC 15	TSO-DSO cooperation in Individual Grid Model creation	T4.3	TSO, DSO, TSO-DSO communication platform, Distributed Generation (DG) Database, Load and RES forecasting tool
UC 36	TSO-DSO planning coordination suites	T4.3	Optimize and identify multi-energy system capacity portfolios for a resilient, low-carbon, cost-effective energy system

Hereunder are the requirements defined for the application as a whole and for the different modules of the IRIS platform.

Table 3 – WP6 requirements

ID	Title	Tool/Task
GEN_001	All products GUIs should present results in English language	General requirements
GEN_001	All products GUIs should present results in English language	General requirements
GEN_001	All products GUIs should present results in English language	General requirements
GEN_002	EMMA should consider the legislative constraints regarding the limited presence of drones near critical infrastructure	General requirements
GEN_004	"Bidirectional communication between DSO	General requirements
GEN_005	Adequate measuring equipment is installed for proper monitoring of the grid	General requirements
GEN_006	Historical data from smart meters, sensors, metering devices etc. should be available.	General requirements
GEN_007	Metering data by all involved metering devices (AMI, SCADA, storage systems, etc.) should be anonymised	General requirements
GEN_008	The tools developed should be compatible with different operating systems (Windows, Linux, MacOS, etc.).	General requirements
GEN_009	"Server/virtual	General requirements
GEN_010	R2D2 will represent alerts from different products	General requirements
GEN_011	A communication channel between DSO - TSO must be existent	General requirements
IRI_001	IRIS application should be available and accessible to end-users	All
IRI_002	When the user log into IRIS application, IRIS application should get the information who is connected and his affected organization/company and roles in the application to apply the correct rights to functionalities	All
IRI_003	The ICL tools shall list conditions when electricity load cannot be met by supply	Tool 11IRIS Module11
IRI_004	IRIS solution shall use standards in the different components (CIM models, OPC format, etc.)	IRIS Module2, IRIS Module10
IRI_007	IRIS should ensure interoperability between shared / redundant components	All
IRI_008	IRIS DSO "Flexibility system" should operate as protocol communication	IRIS Module4

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

	gateway supporting different standard communication protocols like IEC 60870-5-104, MQTT, IEC61850	
IRI_009	IRIS DSO "Flexibility system" must be able to receive data from multiple source types	IRIS Module4
IRI_010	IRIS DSO "Flexibility system" should contain a database to store the received and processed data	IRIS Module4
IRI_011	IRIS DSO "Flexibility system" database should be scalable	IRIS Module4
IRI_012	IRIS DSO "Flexibility system" should automatically trigger commands/alerts based on rules/algorithms	IRIS Module4
IRI_013	IRIS DSO "Flexibility system" system should send identified commands/alerts to different destinations based on a configuration	IRIS Module4
IRI_014	IRIS DSO "Flexibility system" should have the Web GUI	IRIS Module4
IRI_015	IRIS DSO "Flexibility system" GUI access should be secure.	IRIS Module4
IRI_016	IRIS must provide phasors angle difference monitoring	IRIS Module6, IRIS Module7
IRI_017	The IRIS product must contain Emergency and Restoration Over-frequency protection module (OFPM)	IRIS Module5
IRI_018	The IRIS product must contain Emergency and Restoration System Split module (ER-SSM)	IRIS Module8
IRI_019	The IRIS product must include RES and end-load forecasting tool	IRIS Module10
IRI_020	IRIS product must contain a communication platform	All
IRI_021	IRIS product must contain Remedial Action tool	IRIS Module9
IRI_022	IRIS product must contain an application to optimize PMU installation points in the transmission network	IRIS Module7
IRI_023	IRIS DSO "Flexibility system» should contain service for voltage profile and loading calculation	IRIS Module4
IRI_024	IRIS DSO "Flexibility system» should detect if voltages and/or loadings are outside the expected limits	IRIS Module4
IRI_025	IRIS DSO "Flexibility system» should enable checking of execution of control actions	IRIS Module4
IRI_026	IRIS DSO "Flexibility system» should contain DER operation optimization for ancillary services, taking into account voltage profile and loadings	IRIS Module4
IRI_027	IRIS DSO "Flexibility system» should contain state estimation functionality	IRIS Module4
IRI_028	IRIS DSO "Flexibility system» should contain service for defining restrictions in ancillary service control actions to prevent voltage and loadings outside the expected limits	IRIS Module4



D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

IRI_029	IRIS DSO "Flexibility system» should be able to send restriction to all service providers (TSO, Aggregator, Balancing responsible, Consumer, DER)	IRIS Module4
---------	---	--------------

4 Product Description

The IRIS Resilience Suite for TSO & DSO is a comprehensive product with the primary objective of enhancing coordination among system operators in the energy industry, particularly in situations involving security concerns. This suite of tools and resources is designed to empower Transmission System Operators (TSOs), Distribution System Operators (DSOs), and coordination centres to collaborate effectively and make well-informed decisions during critical events or emergencies in the Electrical Power and Energy Systems (EPES). The project encompasses various tools and functionalities aimed at improving grid resilience and dependability.

The IRIS platform encloses 4 technical tasks, 11 tools and 11 Use Cases. Most of the Use Cases are engaged to the Serbian pilot site of the R²D² project. The high-level architecture of the IRIS Suite is described below.

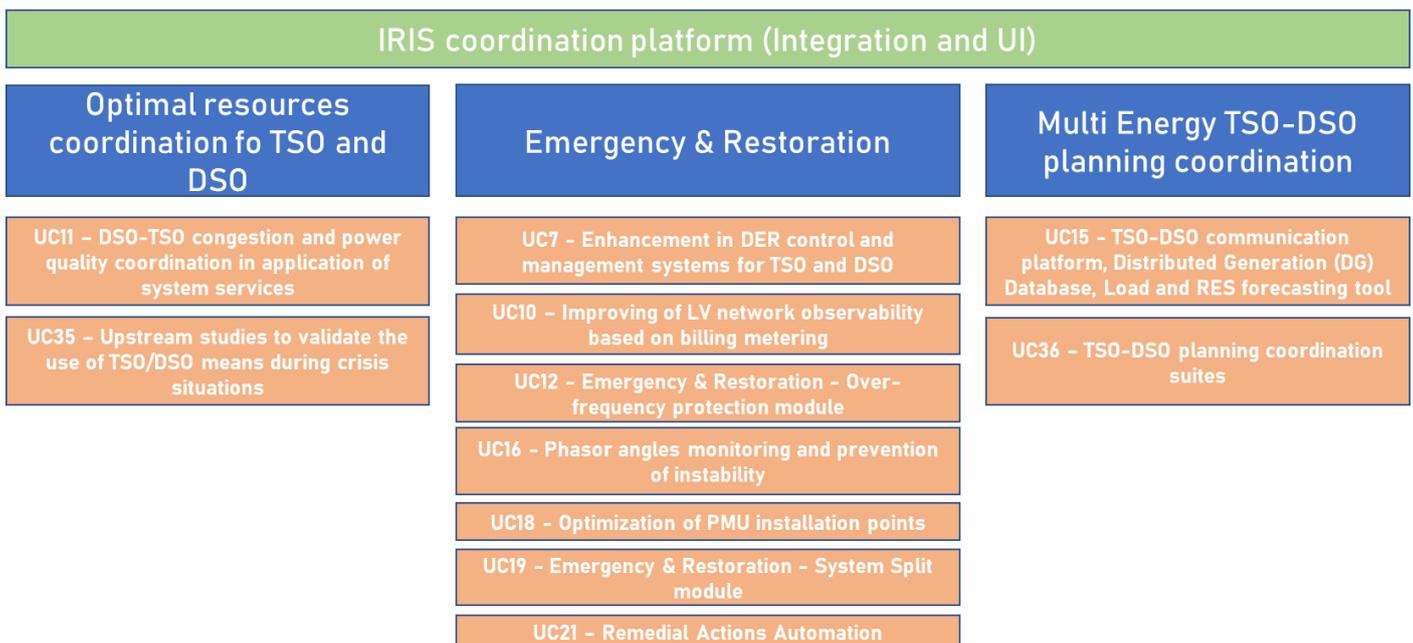


Figure 1 - IRIS high level coordination platform

4.1 TASK 4.1 – OPTIMAL RESOURCES COORDINATION MANAGEMENT FOR TSOS AND DSOS DURING CRISIS

4.1.1 IRIS Module1 – DSO – TSO congestion and power quality coordination in application of system services

Internal Architecture of the IRIS Module1

- Aim of the module

This module will provide DSO-TSO coordination in case of congestion or power quality issues in the distribution network and consequently imposed limitations in ancillary service availability in distribution network.

In case of congestion or voltage problems in distribution network, DSO sends restriction message to the TSO. TSO or any other aggregator could engage ancillary service of flexibility providers in distribution network and can worsen network condition, so this is the module to prevent it.

- Detailed architecture of the module
- Architecture of this module is given in Figure 2.

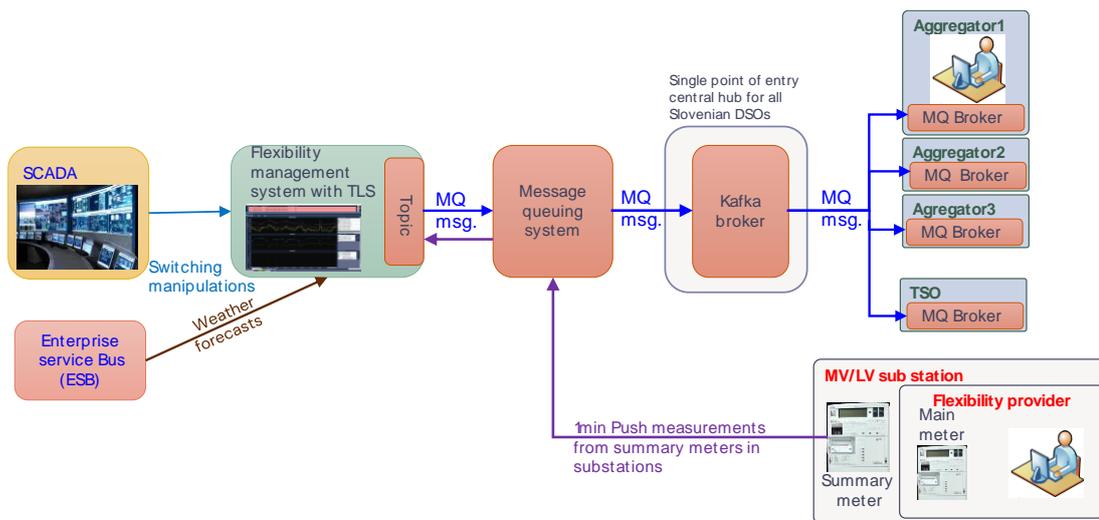


Figure 2 - tool architecture – Architecture of IRIS Module1

- Description of the components of the module,

Components of the module are given in Figure 2 and includes:

- Smart meters providing measurements of active power (P), reactive power (Q) and voltage profile (V).
- Measurement data center collecting measurements from smart meters
- SCADA/AMS system providing information about the P,Q, V and statuses
- Flexibility management system with Traffic Light System (TLS) based on UniFusion platform to run algorithms for congestion overvoltage detection.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- Techniques, algorithms and mathematical models, to be used for the module development
Algorithm in flexibility management system calculates thermal limit power of transformer which depends on temperature and predicted load of transformer. If current power of transformer exceeds thermal limit for certain duration, a Message Queue (MQ) message is send to TSO.
- Data exchanges, communication with other modules and/or products (data flows and protocols):
- Data exchange will be provided from:
 - DER (P,Q,V)
 - SCADA (P,Q,V)
- Protocols used for data exchange:
 - IEC 60870-5-104
 - MQTT
 - IEC 60870-5-104
- The data flow is between:
 - SCADA center (ELEK): Communication protocol: IEC 60870-5-104
 - Measurement data centre (ELEK): Communication protocol: MQTT
 - Flexibility system (ELEK): Communication protocols: IEC 60870-5-104, MQTT

User Interface

User interface will be implemented on UniFusion platform as Web SCADA system. Visualization will present monitoring voltages and loadings in each measurement point. Visualization also includes alarms when limits are exceeded. Data can be presented in tabular formats, charts, organised as customised dashboards.

Resources

SW resource for tool development (app, solver, optimizers, libraries, etc.)

- Software resources:
 - Standard .NET libraries
 - UniFusion platform
 - Windows/Linux operation system
 - UniFusion databases.

4.1.2 IRIS Module2 – Upstream studies to validate the use of TSO/DSO means during crisis situations

Internal Architecture of the IRIS Module2

- Upstream studies to validate the use of TSO/DSO means during crisis situation
- Detailed architecture of the module

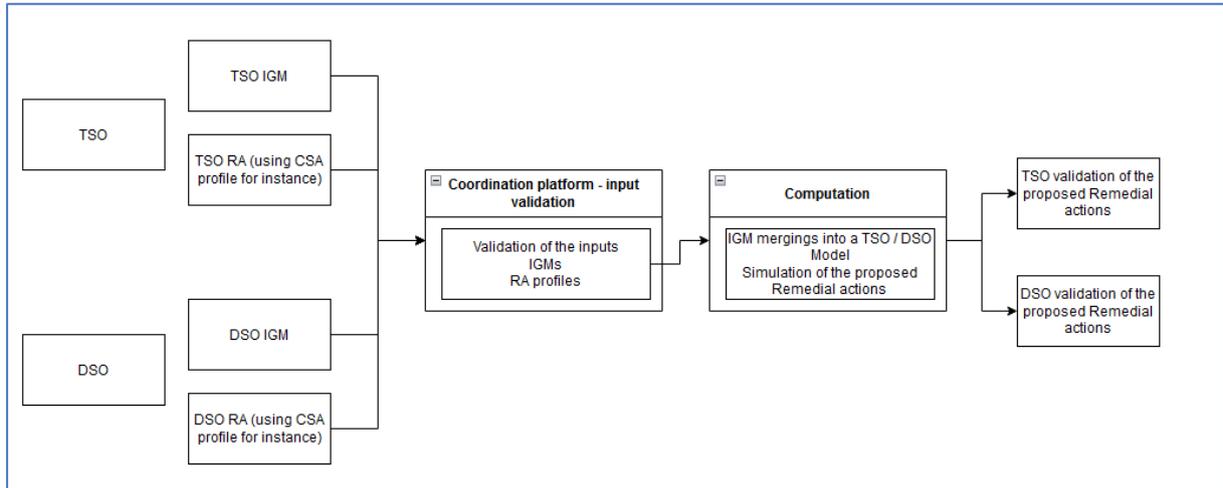


Figure 3 - Simplified description of the process

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

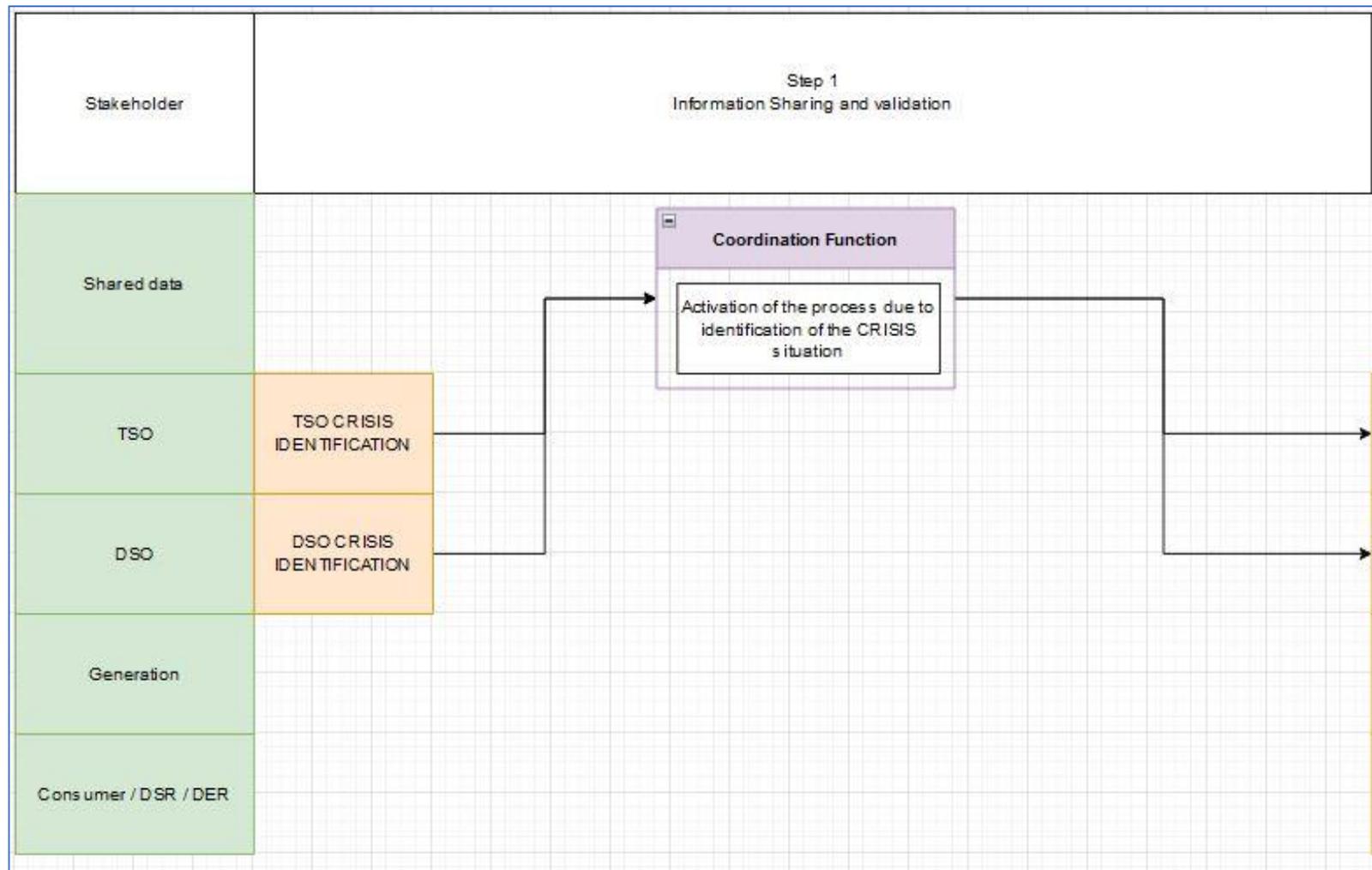
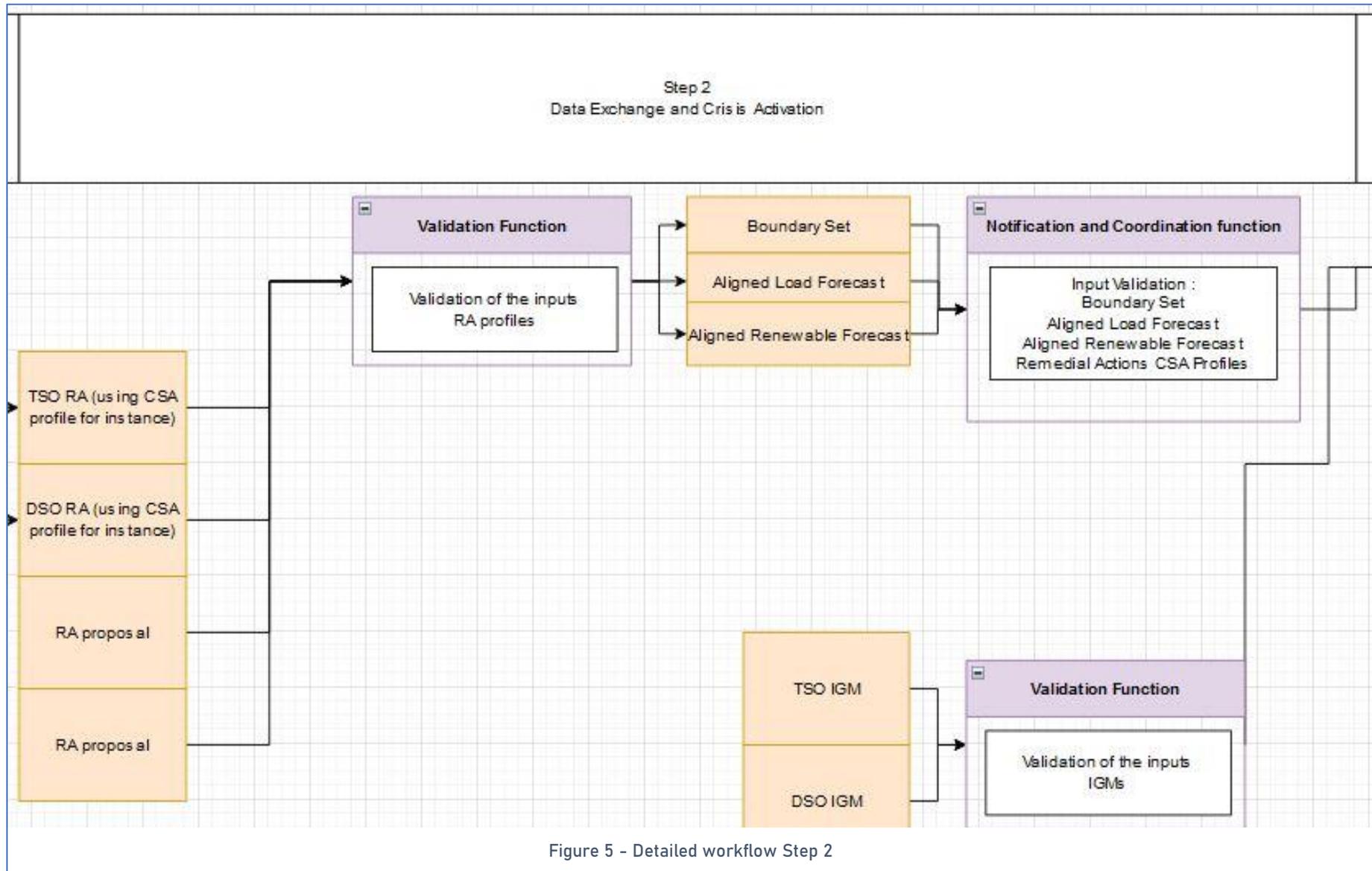


Figure 4 - Detailed workflow Step 1

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)



D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

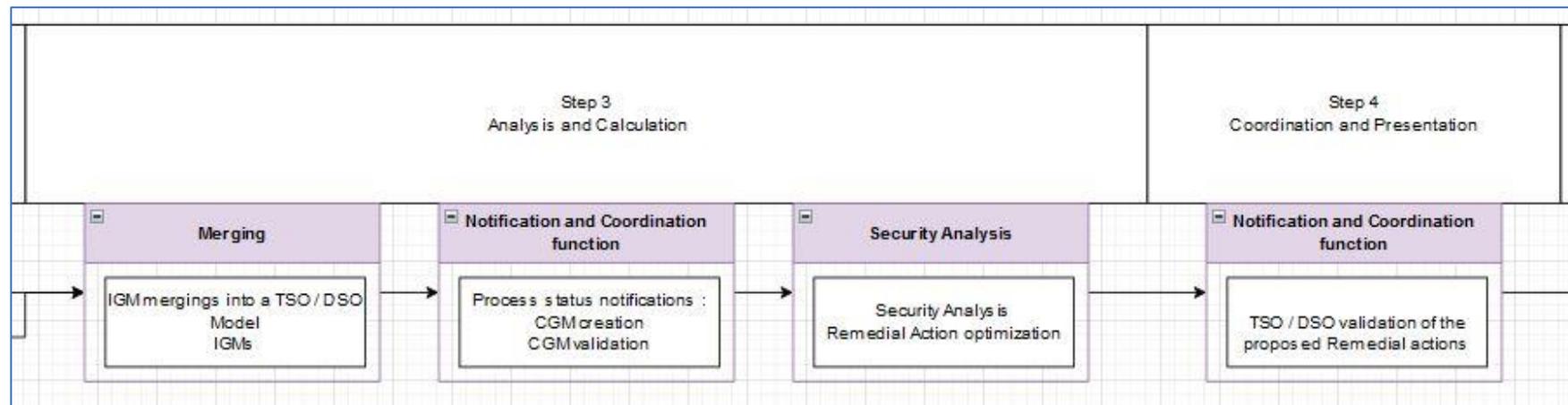


Figure 6 - Detailed workflow Steps 3 & 4

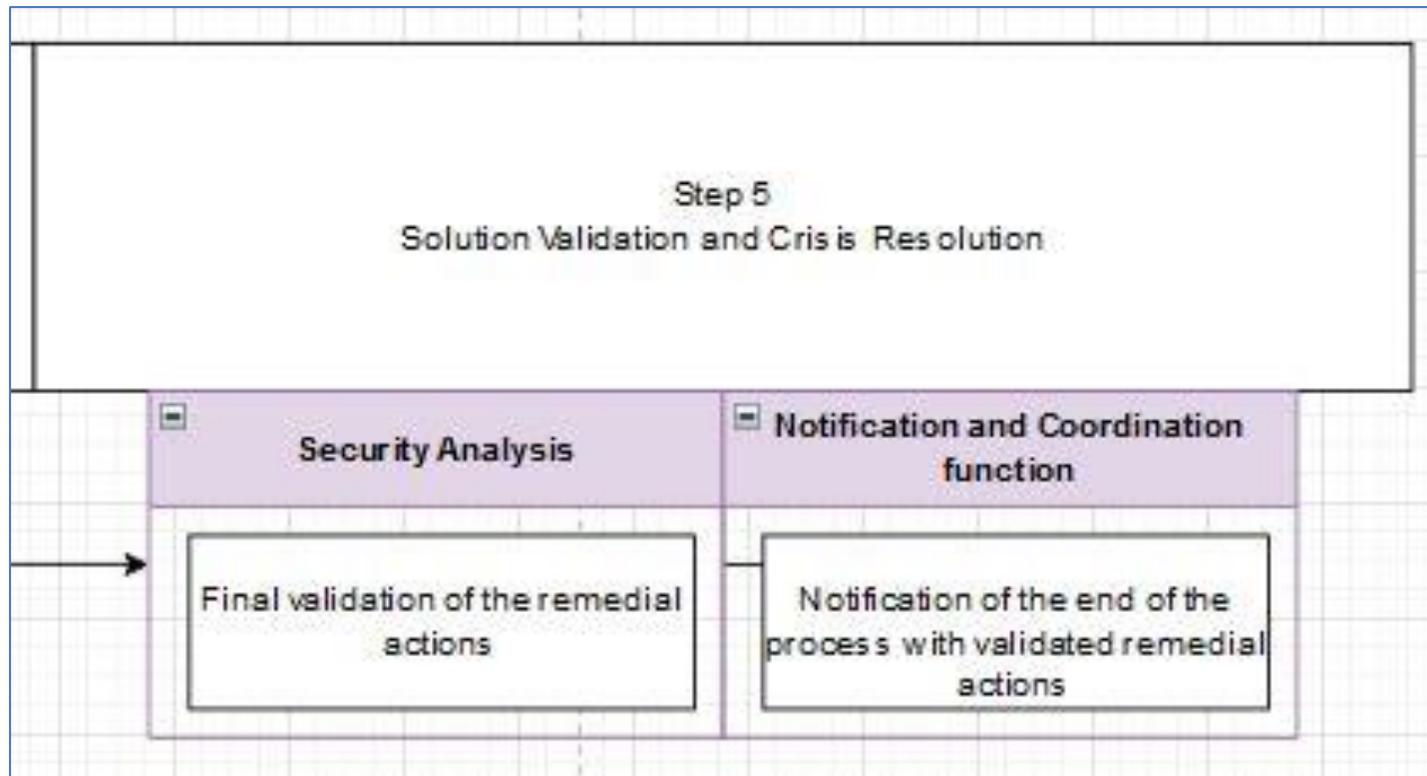


Figure 7 - Detailed workflow Step 5

- Description of the components of the module

The tool will rely on the following components:

- A coordination function, based on OperatorFabric
- A validation function to ensure the quality of the entry files
- An analysis function to perform the needed security computations
- The following algorithms and mathematical models will be used for the development of the module:
 - The analysis function will be using some power flow computations (PowSyBl or other)
 - The data exchange with leverage on common standards for network modelling and electrotechnical computations (CGMES standard, UCTUCTE standard)
- Data exchanges, communication with other modules and/or products (data flows and protocols)
 - Related business cases: BC1, BC4, BC5
 - Short description: The aim of this UC is to enhance the TSO/DSO coordination by allowing the validation of remedial actions from both sides that could be implemented then within real time operations. The expected outcome is a common platform where TSO and DSO can exchange network models and related inputs (for instance, remedial actions proposal) and validate them in this platform for real time use.
 - Demonstration pilot site: Serbia
 - Actors: DSO, TSO, Power flow software, IRIS Communication platform

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

User Interface

LET'S COORDINATE Cards management Coordination/validation
Card Feed Archives Monitoring Logging RSC KPI report

17/05/21 12:00

Potential crisis situation detected – Coordination request

CRISIS SITUATION Coming Coordination requested
04/09/2023 – 13h30 – 17h30
Stakeholders concerned: EMS / EPS

Potential crisis detected – 04/09/2023 13h30 – 04/09/2023 17h30
Received 11/05/2020 at 11:00
Coordination Status : **In progress**
Answers : EMS | EPS

Description : potential crisis detected – means to be validated by upstream studies

Period	Trigger	Description	Confirm	Reject	Explanation	Comment
04/09/2023 13h30 – 04/09/2023 17h30	EPS detected strong variation of PV inflow at DSO level	Solar infeed is beyond forecast leading to possible overflow in the TSO/DSO feeders. Study is requested to assess if disconnection of solar farms is a feasible option for the relevant timeframe				Edit comment

Comment :

Figure 8 - First screen of the coordination process

LET'S COORDINATE Cards management Coordination/validation
Card Feed Archives Monitoring Logging RSC KPI report

17/05/21 12:00

Potential crisis situation detected – Coordination request

CRISIS SITUATION Coming Coordination requested
04/09/2023 – 13h30 – 17h30
Stakeholders concerned: EMS / EPS

CRISIS SITUATION Coming Coordination requested
04/09/2023 – 13h30 – 17h30
Stakeholders concerned: EMS / EPS

Potential crisis detected – 04/09/2023 13h30 – 04/09/2023 17h30
Received 11/05/2020 at 11:00
Coordination Status : **In progress**
Answers : EMS | EPS

Description : datasets to be exchanged

Name	Element type	From	To	Validation status	Cause of request	Comment
DSO model	Model	04/09/2023 13h30	04/09/2023 17h30	6/6	Upstream study : PV infeed to high	The model is just provided for 15h30 TS
TSO model	Model	04/09/2023 13h30	04/09/2023 17h30	5/6	Upstream study : PV infeed to high	The model is just provided for 15h30 TS
DSO Remedial action	Remedial Action	04/09/2023 13h30	04/09/2023 17h30	3/3	Upstream study : PV infeed to high	Remedial action is disconnection of PV farms in substation X
TSO remedial action	Remedial Action	04/09/2023 13h30	04/09/2023 17h30	3/3	Upstream study : PV infeed to high	Remedial action is opening lines

Comment :

Received 31/08/2023 at 13:00

Acknowledge and close

Figure 9 - Second screen of the coordination process

Resources

SW resource for tool development: models for power flow studies, PowSyBl framework (or other open-source framework), OpFab/Let's Co.

The data exchanged will be based on existing standard of the business, including CGMES standard and other NC profiles (or part of it) and the related technological stack.

4.2 TASK 4.2 – EMERGENCY & RESTORATION

4.2.1 IRIS Module3 - Improving of LV network observability based on billing metering system by means of secure interface with SCADA-ADMS system

Internal Architecture of the module

- Aim of the module

The aim of the DSO flexibility system is the improvement of LV network observability and consequently system security and quality of supply based on billing metering data used in SCADA/EMS system. Based on metering data and SCADA data will be performed algorithms for automatic actions like generation/load control on LV level.

- Detailed architecture of the module

The system architecture is given in Figure 10. DSO Flexibility system is based on ELPROS UniFusion platform. Its architecture is presented in Figure 11.

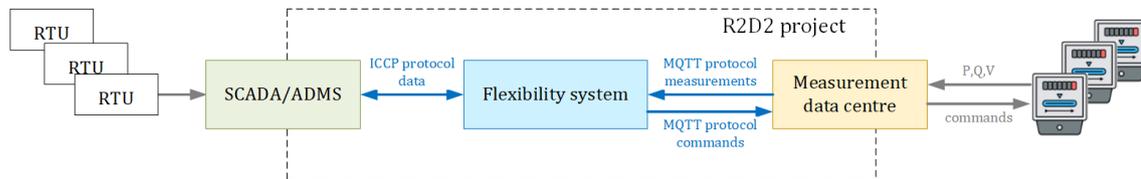


Figure 10 - Architecture of IRIS Module3

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

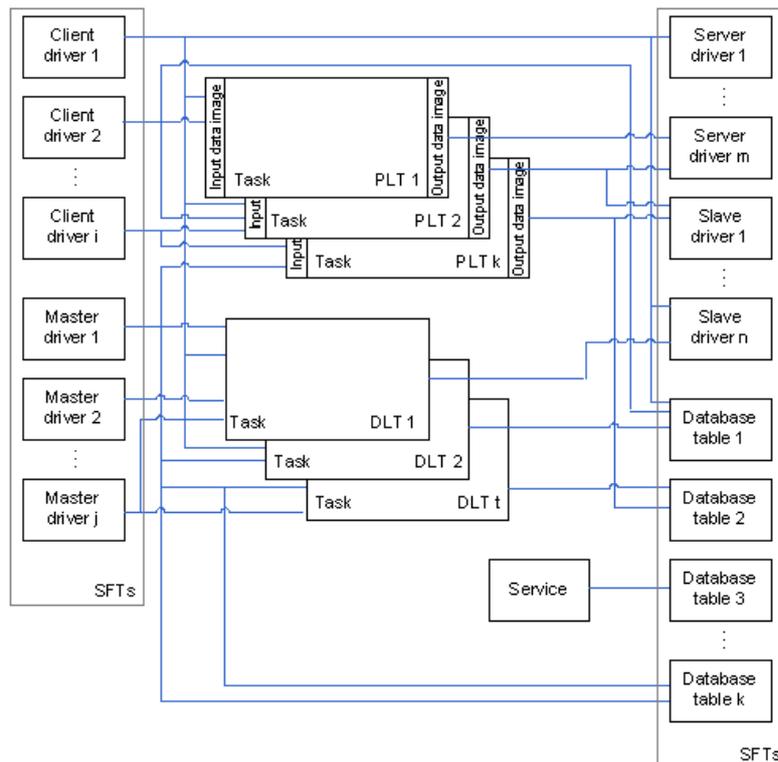


Figure 11 - UniFusion platform concept

- Description of the components of the module,

Components of the module are given in Figure 10 and includes:

- Smart meters providing measurements of active power (P), reactive power (Q) and voltage profile (V).
- Measurement data center collecting measurements from smart meters
- SCADA/AMS system providing information about the P, Q, V and statuses
- Flexibility system based on UniFusion platform to run algorithms for automatic control.

In Figure 11 is presented architecture of the UniFusion platform with input communication drivers on the left side, programmable tasks in the middle and output communication drivers on the right side. In programmable tasks the algorithms for automatic control will be implemented.

Parallel with real time processing is database and human machine interface (HMI) support. UniFusion platform is developed on .NET technology and can operate on Windows or Linux operating system. Software is developed for parallel processing. For data exchange inside the power systems are implemented communication drivers by standard communication protocols.

- Techniques, algorithms and mathematical models, to be used for the module development

This module is based on two algorithms, one for detection if voltage magnitude is within specified limits and the second for overloading detection.

Detection for voltage limits.

$$V_{min} \leq V_i \leq V_{max}$$

If voltage magnitude is higher than V_{max} or lower than V_{min} , control action is taken to mitigate voltage issues. V_{min} and V_{max} are user configurable values.

Detection for overloading.

$$P_i \geq P_{max}$$

If loading is higher than P_{max} control action is taken to mitigate overloading. P_{max} is user configurable value.

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

Data exchange will be provided from:

- SCADA (P,Q,V)
- Consumers (P,Q,V)
- DER (P,Q,V)

Protocols used for data exchange:

- IEC 60870-5-104
- MQTT
- ICCP/TASE.2

Data flow is given in Figure 10 between:

- SCADA centre (ELEK) : Communication protocol: ICCP,
- Measurement data centre (ELEK): Communication protocol: MQTT
- Flexibility system (ELEK): Communication protocols: ICCP, MQTP

User Interface

User interface will be implemented on UniFusion platform as Web SCADA system. Visualization will present monitoring voltages and loadings in each measurement point. Visualization also includes alarms when limits are exceeded. Data can be presented in tabular formats, charts, organised as customised dashboards. **Resources**

SW resource for tool development (app, solver, optimizers, libraries, etc.)

Software resources:

- Standard .NET libraries
- UniFusion platform
- Windows/Linux operation system
- UniFusion databases.

4.2.2 IRIS Module4 - Enhancement in DER control and management systems to participate in flexibility procurement schemes for DSO and TSO to improve network operation security

Internal Architecture of the module

- Aim of the module
- Increasing share of DER in the network increase fluctuations and issues with power quality. DER need to participate also in system services with fair share.

Therefore, it is becoming necessary for DER to take over certain level of ancillary services (including emergency actions) However, DER are limited in their ability when comparing them with conventional energy sources.

- This module will demonstrate, how DER and flexibility can participate in system services for DSO Detailed architecture of the module

The architecture of this module is given in Figure 12.

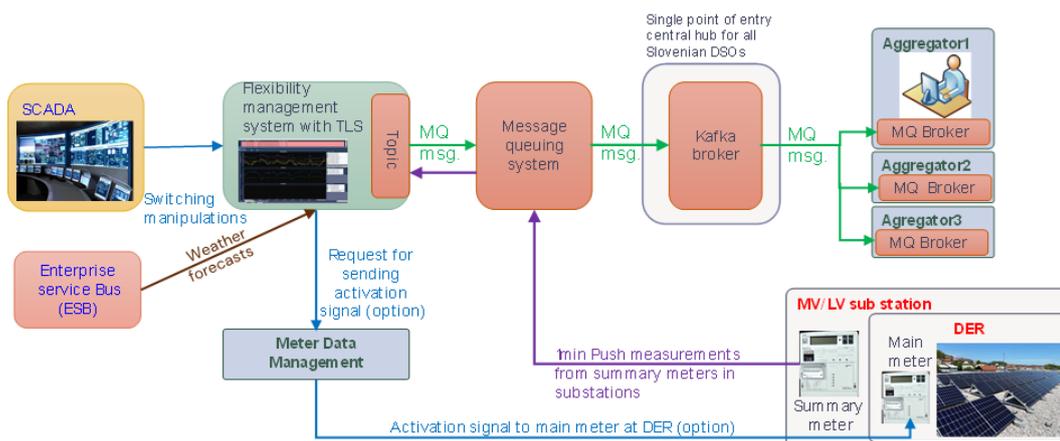


Figure 12 - Architecture of IRIS Module4

- Description of the components of the module,

Flexibility management system receives 1min close-to-real time data from summary meter in secondary substation. Based on weather forecasts and switching manipulations from the SCADA it calculates forecast of consumption/production in LV grid. When problems with overvoltage arise, the flexibility management system sends request to Meter data management for sending activation signal to DER's main meter or RTU. In case aggregators offers DER, the flexibility management system creates an activation MQ message (XML) and sends it to appropriate aggregator, which then sends a response message to DSO.

- Techniques, algorithms and mathematical models, to be used for the module development.
- Algorithm in flexibility management system receives measurements of the voltage in the most critical point of LV feeder. If voltage exceeds limitations, then flexibility management system sends activation signal to mitigate voltage issues.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

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

Data exchange will be provided from:

- DER (P,Q,V)
- SCADA (P,Q,V)

Protocols used for data exchange:

- IEC/TASE.2
- MQTT
- IEC 60870-5-104

The data flow is between:

- SCADA center (ELEK) : Communication protocol: IEC,
- Flexibility system (ELEK): Communication protocols: IEC, MQTT
- Measurement data centre (ELEK): Communication protocol: MQTT
- Flexibility management system uses: -MQ message for activating aggregators
- Web service is used for sending request to Meter data management. Meter data management is sending activation signal to DER's main meter by DLMS protocol.

User Interface

Description of the user interface to be developed, including preliminary mock up, dashboards, charts, etc.

User interface will be implemented on UniFusion platform as Web SCADA system. Visualization will present monitoring voltages and loadings in each measurement point. Visualization also includes alarms when limits are exceeded. Data can be presented in tabular formats, charts, organised as customised dashboards.

Resources

Software resources:

- Standard .NET libraries
- UniFusion platform
- Windows/Linux operation system
- UniFusion databases.

4.2.3 IRIS Module5 - Emergency & Restoration - Over-Frequency Protection module

Internal Architecture of the module

- Aim of the module:

The Emergency & Restoration - Over-frequency protection module (OFPM) will be designed as a replacement for the missing or insufficient controllers on generating units in the power system which can operate in limited frequency sensitivity mode -

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

over-frequency (LFSM-0), as defined by EU Network Code on requirements for connection of generators.

This solution is based on Article 16 of the EU Network Code on Emergency and Restoration.

This type of over-frequency protection system will have the role of reducing the total production in the system as closely as possible when impermissibly high frequencies occur, as if each generator is equipped with an LFSM-0 controller. In addition, this system will ensure that there are no local violations of the security criteria in the network.

- Detailed architecture of the module:

The system architecture is shown in the figure below.

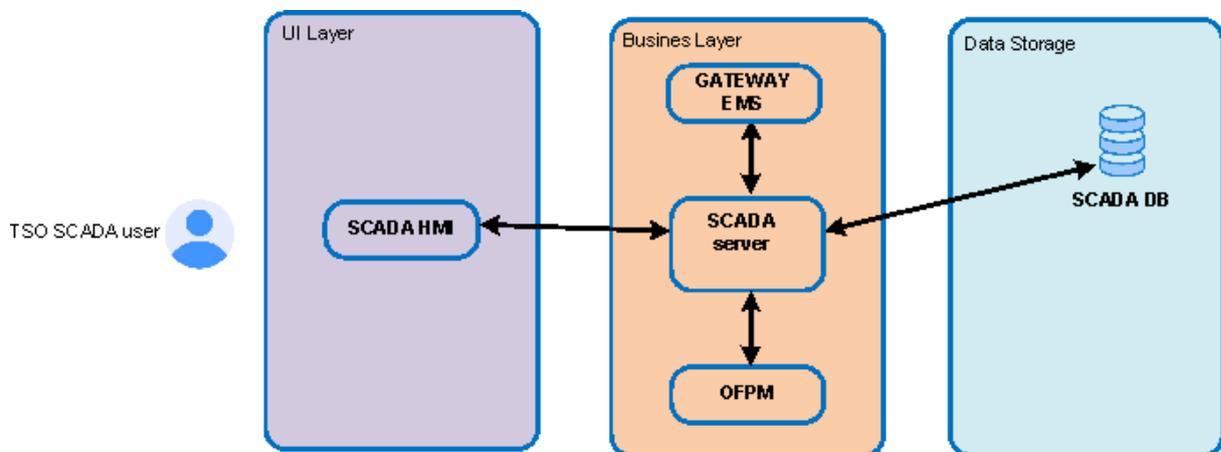


Figure 13 - Architecture of the OFPM tool

- Description of the components of the module:

OFPM is a component that contains algorithms which calculate operations for over-frequency control.

SCADA server serves as the core component of a Supervisory Control and Data Acquisition (SCADA) system, enabling remote monitoring and control of industrial processes and infrastructure.

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.

SCADA DB is a database which contains all relevant data for the SCADA system.

A gateway is a network device or software component that serves as an intermediary or bridge between two different communication networks, protocols, or systems.

- Techniques, algorithms and mathematical models, to be used for the module development:

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

As not all generators are equipped to carry out the above given technical solution for the Emergency & Restoration - Over-frequency protection module (OFPM), they will be divided into several groups as follows:

1. The first group of generators are equipped with LFSM-0 and they do not participate in the OFPM.
2. The second group of generators will be assigned fixed over-frequency protection settings (where there are no technical possibilities for remote signal sending neither LFSM-0 controllers are installed)
3. To the third group (where there are technical possibilities for sending signals remotely), the OFPM sends appropriate signals, which can be related to:
 - a) Reduction of active power production on generators
 - b) Remote disconnection of the generators from the transmission grid
 - c) OFP resetting on protection devices on generators' connection lines to the transmission grid

Reduction of active power production on generators

This OFPM mechanism is primarily intended to be applied to power plants that are capable of quick response to a power reduction signal, which in the case of the Serbian pilot site are Hydro Power Plants (HPP), Gas Power plants (GPP) and Wind Parks (WP). As WPs are on the feed-in tariff, they have priority in accessing the system, so power reduction goes according to priorities: 1) HPP 2) GPP 3) WP.

The formula for determining power reduction (P_{pr}) is:

$$P_{pr}\% = 40 \cdot f - 2008 \text{ (corresponds to recommended LFSM-0 droop of 5\%)},$$

Where f stands for frequency in Hz.

For each synchronous generator / power plant, it is known how much active power it can reduce, based on SCADA measurements and technical characteristics for aFRR/mFRR control.

This reduction is carried out in proportion to the available downward aFRR/mFRR reserve for a particular group of generators.

For each generator is calculated:

$$P_{di} = P_i - P_{mini} \text{ where:}$$

- P_{di} – available downward active power for generator 'i'
- P_i – current active power for generator 'i'
- P_{mini} – minimum active power to which the generator can be reduced

The sum of P_{di} for all generators is also calculated - $SUM(P_{di})$, as well as by generator type $SUM(P_{HPPdi})$, $SUM(P_{GPPdi})$, $SUM(P_{WPPdi})$.

1) If $P_{pr} < SUM(P_{HPPdi})$ then:

- For each hydro-generator, a new base power is determined according to the formula:

$$P_{bi} = P_i - P_{pr} \cdot P_{di} / SUM(P_{HPPdi}) \text{ where:}$$

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- P_{bi} – new base power for the hydro-generator 'i'

2) If $\text{SUM}(P_{HPPdi}) < P_{pr} < \text{SUM}(P_{HPPdi}) + \text{SUM}(P_{GPPdi})$ then:

- For each hydro-generator, a new base power equal to its minimum active power in mFRR control is determined
- For each gas fired generator, a new base power is determined according to the formula:

$$P_{bi} = P_i - [P_{pr} - \text{SUM}(P_{HPPdi})] \cdot P_{di} / \text{SUM}(P_{GPPdi})$$

3) If $\text{SUM}(P_{HPPdi}) + \text{SUM}(P_{GPPdi}) < P_{pr} < \text{SUM}(P_{HPPdi}) + \text{SUM}(P_{GPPdi}) + \text{SUM}(P_{WPdi})$ then:

- For each hydro-generator and gas fired generator, a new base power equal to its minimum active power in mFRR control is determined
- For each Wind Park, a new base power is determined according to the formula:

$$P_{bi} = P_i - [P_{pr} - \text{SUM}(P_{HPPdi}) - \text{SUM}(P_{GPPdi})] \cdot P_{di} / \text{SUM}(P_{WPdi})$$

Within the R²D² project, it is calculated that the demonstration of this OFPM mechanism will be applicable to:

- HPP Đerdap 1
- HPP Bajina Bašta
- Reversible HPP Bajina Bašta
- HPP Bistrica
- GPP Pančevo
- All WPs that are connected to the transmission system

As the OFPM is planned to activate above 50.2 Hz, this will coincide with the automatic freeze of the secondary regulation. This is based on the assumption that the behavior of the turbine regulators will not interfere with the operation of the NFZ module.

Remote disconnection of the generators from the transmission grid

This OFPM mechanism should be applied to HPPs and GPPs as a secondary mechanism (WPs can reduce power to zero through the first mechanism, while HPPs and GPPs can only reduce power to the technical minimum).

According to the predefined priority, the generators are placed in a array - for each generator, the disconnection frequency is determined according to the following formula:

$$f_{disci} [\text{Hz}] = (2008 + 0,5 \cdot P_{geni} + \sum P_{gen(1 \rightarrow i-1)} + \sum P_{T_{di}}) / 40, \text{ where:}$$

- f_{disci} – disconnection frequency for the generator in the i-th place in the array;
- P_{geni} – active power of the generator at the i-th position in the array;
- $\sum P_{gen(1 \rightarrow i-1)}$ – the sum of the active powers of the generator at the first to i-1 place in the array

For this OFPM mechanism, the following generators will be included in the project:

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- HPPs and GPPs that are also used for the reduction of active power production, with this mechanism acting when the control range is exhausted (the generators are brought to the technical minimum or if the frequency deviation is very large, so this mechanism is immediately activated)
- HPP Đerdap 2

OFPM resetting on protection devices on generators' connection lines to the transmission grid

At the time of writing this report, the methodology for calculating OFPM resetting on protective devices has not been finalized. In order to do this, it is necessary to carry out an analysis of the first two OFPM mechanisms on an annual basis - this activity is ongoing.

Also, this analyses must define rules for defining the fixed OFPM settings (the second group of generators).

It is quite certain that part of the methodology will be based on the preliminary work done within the Crossbow project. This methodology will include generators whose OFPM can be adjusted remotely (group 3) as they are equipped with modern protection and tele-communication devices, but also those that cannot (group 2).

Also, it is possible that there will be a certain addition of the methodology that would be used for the first two mechanisms of the OFPM.

- Data exchanges, communication with other modules and/or products (data flows and protocols):

Reduction of active power production on generators

As a technical solution for this OFPM mechanism, the connection between the EMS gateway and the GRAS device at the HPPs will be used, i.e. the set-point for the power base will be sent to selected Power plants. Therefore, within the project, alternative ways will not be used through EPS's (Generation Company in Serbia) infrastructure because EPS is not a project participant. Figure 14 shows the relevant EMS and EPS infrastructure that can be used for this OFPM mechanism.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

* This path will not be used in the R²D² project, but could be used after the project, if the technical solution is accepted by the EMS management and stakeholders (EPS, Regulatory Agency) - in that case this solution shall be described in the National Grid Code

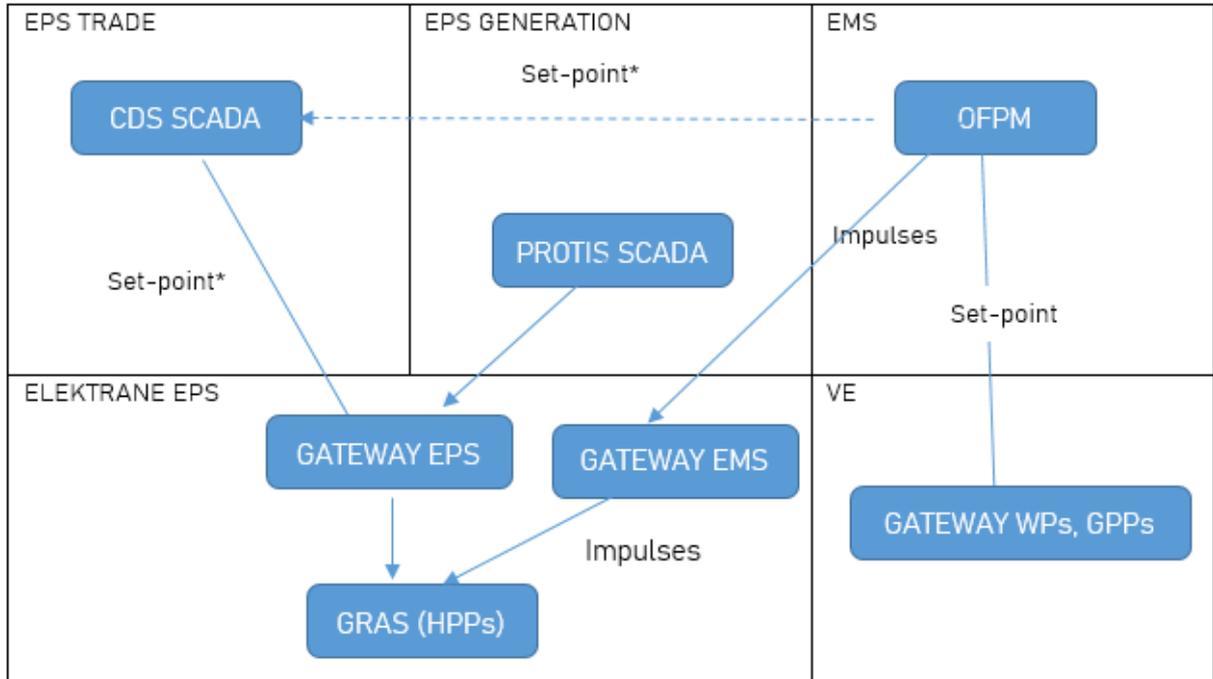


Figure 14 - Control scheme for the reduction of active power production on generators

Therefore, in this technical solution, the OFPM module must receive the frequency and active power on the generators from the SCADA system as input data. On the other hand, as output data from the OFP process, the OFPM will send the SCADA system impulses for power regulation, that is, base power, which the SCADA system will further transmit to the generators.

IPC protocol will be used for both directions of data exchange between SCADA system and OFPM, while IEC 6087058101 is used for communication between SCADA system and Power plants.

Remote disconnection of the generators from the transmission grid

Within this mechanism OFPM will act on circuit breakers in substations, not on generator circuit breakers. The reason for this is again that generation companies in Serbia are not in the R²D² project. This is shown in Figure 15.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

In this technical solution, the OFPM module must receive the frequency and active power on the generators from the SCADA system as input data. On the other hand, as output data from the OFP process, the OFPM will send the SCADA system disconnection signal, which the SCADA system will further transmit to the RTUs in the connection substation (circuit breaker in the high voltage bay of the generator's step-up transformer).

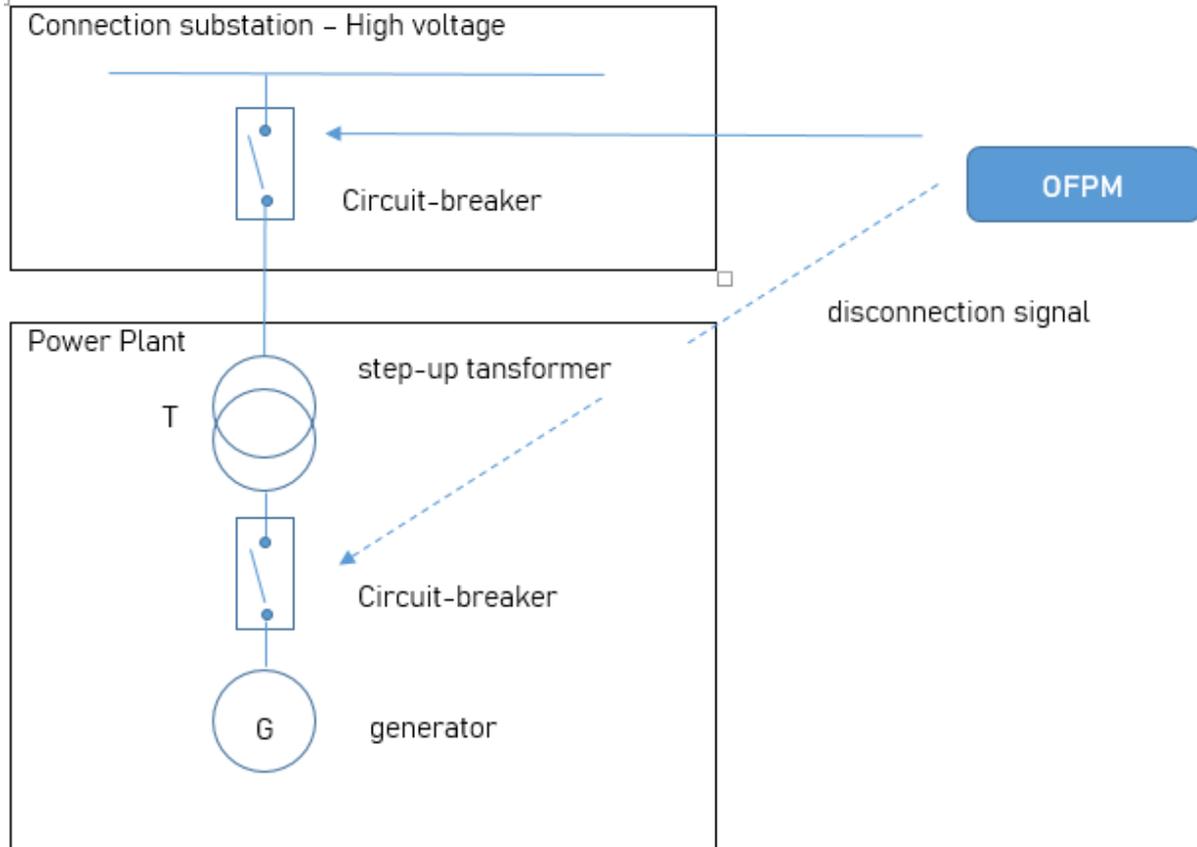


Figure 15 - Control scheme for remote disconnection of the generator

IPC protocol will be used for both directions of data exchange between SCADA system and OFPM, while IEC 6087058101 is used for communication between SCADA system and RTUs in connection substations.

OFPM resetting on protection devices on generators' connection lines to the transmission grid

In this technical solution, the OFPM module must receive the frequency and active power on the generators from the SCADA system as input data.

On the other hand, as output data from the OFP process, the OFPM will send the Control Centre (CC) SCADA system resetting values for OFP on protection devices. More precisely, several levels of OFP are set on the protection device, and then one of them is remotely activated, while the others are deactivated. This is shown in Figure 16.

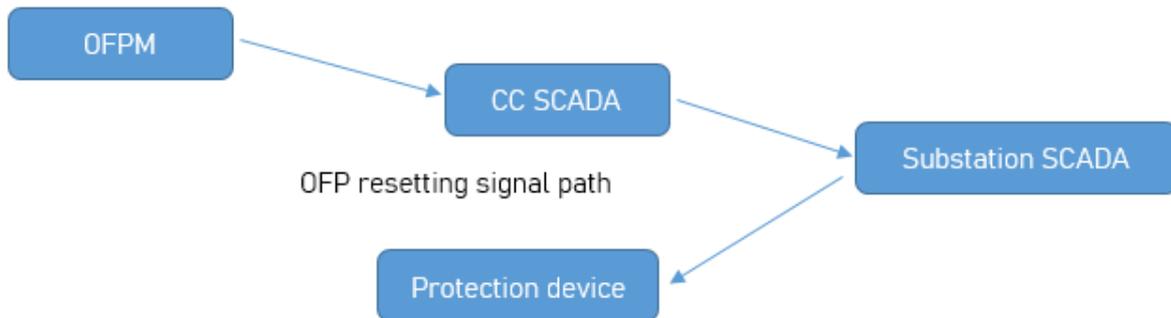


Figure 16 - Control scheme of OFP resetting on protection devices

Next, CC SCADA will send this information to substation SCADA, and finally this information is passed to selected protection device in the substation (generators' connection line).

IPC protocol will be used for both directions of data exchange between CC SCADA system and OFPM, while IEC 6087058101 is used for communication between CC SCADA system and substation SCADA. Finally, GOOSE protocol is used for communication between substation SCADA and selected protection device.

User Interface

At this stage of OFPM product development, the UI is not precisely defined. However, based on what is stated in the UC definition form and in the previous description, the following can be concluded:

- The UI interface must have separate views for each of the above 3 technical solutions for OFPM implementation
- Reduction of active power production on generators view must contain:
 - List of generators participating in this OFPM mechanism
 - Information on the current generator power and on the set base power (to which the generators should reduce their active power)
 - Summary trend diagram and active power trend diagram for each of the generators
- Remote disconnection of the generators from the transmission grid view must contain:
 - List of generators participating in this OFPM mechanism
 - Information about the frequency value at which the generators will be disconnected
- OFP resetting on protection devices on generators' connection lines to the transmission grid view must contain:
 - List of generators participating in this OFPM mechanism

- Enabled and disabled OFP protection values for each of the generators
- In addition, it is necessary to have a view in which it will be possible to see the fixed values of OFP on generators on which it is not possible to reset the OFP in real time and remotely

Resources

The software resources for the development of the tool are as follows:

- 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- a specialized software application designed to manage and configure the database components of a Supervisory Control and Data Acquisition (SCADA) system
- Backend - C++
- DB - MySQL/MariaDB
- NetBeans - IDE
- Version Control - Git

4.2.4 IRIS Module6 - Phasor angles monitoring and prevention of instability - EMSS

Internal Architecture of the module

- Aim of the module:

Sometimes the fulfilment of security criteria (for instance N-1 criterion) in the operation of the power system does not mean that the stability of the system is ensured. Such events are relatively rare in the European interconnection, but can lead to serious disturbances.

By applying PMUs, it is possible to identify the risk to the stability and act preventively to avoid unwanted consequences. This module monitors the possible occurrence of transient instability through two PMUs, where one is installed in the production centre and the other is installed in the consumption centre.

The greater the active power flow between these two observed points, the greater the angle difference measured by the PMUs which are connected to SCADA or WAMS system. When the critical angle difference is reached, the SCADA or WAMS system activates an alarm, after which the operators in the control centre should apply a re-dispatching of the active power injections into the network, until the angle difference falls below the critical value, which will preserve the stability of the system operation. The critical angle is calculated on an off-line application for simulating the dynamic state in the network.

This module can also be applied to other types of disturbances when stability of system operation is jeopardized. For example, if parts of the system are

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

interconnected by weak connections, then higher power flows can lead to oscillations on transmission lines between these two parts of the system.

- Detailed architecture of the module

This module has a simple architecture consisting of PMUs installed in the transmission system (specifically, 2 PMUs will be installed) and a central system that processes data from the PMUs and generates an alarm when needed. This central system can be a SCADA system or a WAMS system - SCADA system will be used in this project.

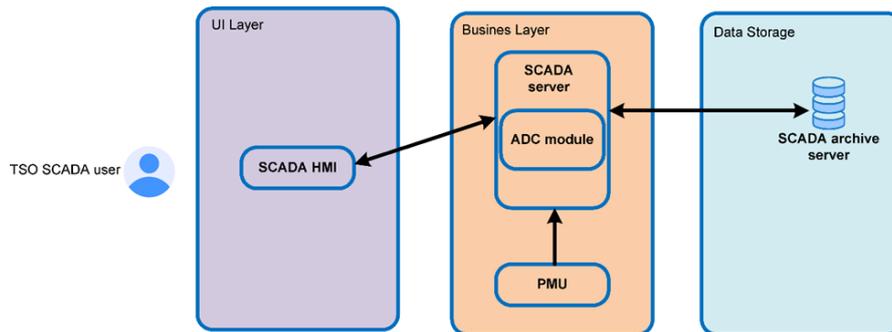


Figure 17 - UI, Business and Data Storage layer of IRIS Module⁶

Figure 17 shows user interface (UI), Business and Data Storage Layers of the module. SCADA HMI (human machine interface) represents the UI layer. Business layer consists of SCADA server and PMUs. Inside the SCADA server is ADC (angle difference calculation). And finally, Data Storage layer is composed of SCADA archive server.

The SCADA system and the PMU will communicate through the TSO's telecommunication network.

- Description of the components of the module: This module consists of PMUs connected directly to the SCADA system and SCADA system. Parts of the SCADA system relevant for this module are already mentioned such as SCADA HMI, SCADA archive server and SCADA server. SCADA systems and PMUs are well known so we will not describe them in this report. The calculation of the phase angle difference between two PMU devices is performed within the ADC (Angle difference calculation) module. This module essentially derives its data from SCADA calculations that represents the phase angle difference between two PMU devices.
- Techniques, algorithms and mathematical models, to be used for the module development: This module is based on the equal area criterion. The equal area criterion is a simple graphical method for concluding the transient stability.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

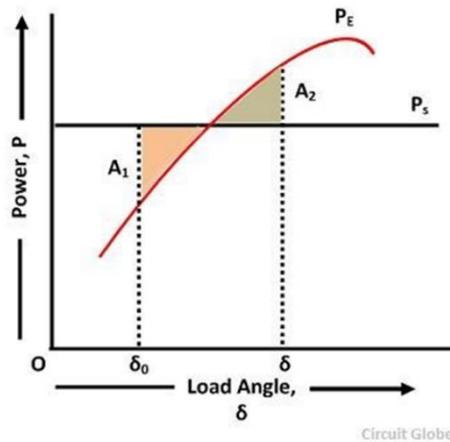


Figure 18 - Equal area criterion

Figure 18 depicts area criterion. P_E stands for electrical power, P_S for mechanical power and δ load angle. δ_0 is the torque angle at which the machine is operating while running at synchronous speed under normal conditions. The area A_1 represents the kinetic energy stored by the rotor during acceleration, and the A_2 represents the kinetic energy given up by the rotor to the system, and when it is all given up, the machine returns to its original speed. The area under the curve should be zero, which is possible only when electrical power has both accelerating and decelerating powers, i.e., for a part of the curve $P_S > P_E$ and for the other $P_E > P_S$. Hence the name equal area criterion. The equal area criterion is also used for determining the maximum limit on the load that the system can take without exceeding the stability limit. This can happen only when the area between the P_S line and the P_E curve is equal to the area between the initial torque angle δ_0 and the line P_S . In this case, the area A_2 is less than the area A_1 ; the system will become unstable. The problems associated with the transient stability of the system is because of the following reasons. These are as follows:

- Sudden change in load
- Switching off one of the lines which cause a change in the reactance of the system and hence a change in load conditions.
- Sudden fault on the system which causes the reduction in output, requiring an arrangement for clearance for the clearance of the fault rapidly, and study of after fault condition which may cause part of the system outage.

In each case, the procedure will be to determine the power angle curve for the initial conditions of the system, for the conditions under fault, and for the after fault condition and plot the curve in per unit value. Then locate the points for the load initial conditions finding out δ_0 . Then, using equal area criterion, determine the new angle of displacement δ . The maximum angle δ_{max} which may be allowed and the corresponding maximum permissible load can also be determined. The value of angle between two observed PMUs that would trigger alarming of the module is to be calculated as:

$$\delta_{Alarm} = \delta_{max} - \delta_{SecurityMargin}$$

The security margin is to be estimated based on TSO's operational security risk management. All this calculation are done off line in a software for stability calculations. Only the result δ_{Alarm} is used to set alarming in the module.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- Data exchanges, communication with other modules and/or products (data flows and protocols): PMUs measure voltages and currents at selected locations (critical substations) on a power grid and send as an output accurately time-stamped voltage and current phasors with very high resolution.

Therefore, the data exchanged between PMUs and SCADA are:

- Voltage
- Current
- Frequency
- Time stamp of measured value

Typically, PMUs deployed have direct connection to central PDCs in which case the latest IEEE C37.118 standards.

However, it is also possible to integrate the PMU data stream directly in SCADA system via IEC 60870-5-104 protocol. Particularly, this technical solution and this protocol will be used in the R²D² project for this module.

User Interface

The UI for this module is not precisely defined at the moment. What is absolutely necessary is to enable the following:

- Entering the critical value of the angular difference between observed two phasors (grid nodes where two PMUs are installed)
- Displaying of the current value and angular phasor difference
- Trend diagram of angular phasor difference
- Alarm setting in case the measured value of the angular difference between the observed two phasors exceeds the critical value

Resources

The following SW resources will be used to develop this module:

- SCADA Configuration Tool is software application used in the field of industrial automation and control systems. Its primary function is to facilitate the setup, design, and configuration of SCADA systems.
- SCADA HMI Configuration Tool allows users to create customized graphical interfaces to 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 is a specialized software application designed to manage and configure the database components of a Supervisory Control and Data Acquisition (SCADA) system.

4.2.5 IRIS Module7 – Optimization of PMU installation points – EMSS

Internal Architecture of the module

- Aim of the module: The aim of Optimal PMU Placement Application (OPPA) is to optimize the installation of Phasor Measurement Units (PMUs) in a power system to achieve full observability while minimizing the number of PMUs required. Full observability refers to the ability to accurately estimate the state variables (voltage magnitudes and phase angles) at all critical buses in the power system.
- Detailed architecture of the module: The architecture of the OPPA is presented in the Figure 19:



Figure 19 – Architecture of the IRIS Module7

Description of the components of the module: The OPPA aims to provide power system operators and planners with cost-effective solutions for enhancing system monitoring and control through PMU deployments.

The module consists of the following key components:

- User Interface: Provides a user-friendly interface for specifying the power system topology, defining constraints, selecting optimization mode, and viewing results.
- Data Input Module: Allows users to input information about the power system topology, including bus locations, transmission lines, and existing PMU locations.
- Optimization Engine: The core of the OPPA, it employs various optimization algorithms to determine the optimal PMU placement. This component is responsible for running the chosen optimization process (basic, N-1, or with existing PMUs) and generating results.
- Visualization Module: Visualizes the power system topology, proposed PMU placements, and observability results, aiding users in understanding the recommendations.
- Reporting and Export: Allows users to generate reports summarizing the OPPA results and export data for further analysis or integration with other power system tools.
- Techniques, algorithms and mathematical models, to be used for the module development: This optimization module offers three different modes:

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- **Basic Calculation:** Determine the minimum number of PMUs required for full observability without considering any contingencies or existing PMUs in the system.
- **N-1 Calculation:** Evaluate the minimum PMU requirements while considering potential single-component failures (N-1 contingencies) in the power system.
- **Incorporating Existing PMUs:** Optimize PMU installations by taking into account the presence of pre-installed PMUs, thereby minimizing additional installations while ensuring full observability.

The development of the OPPA involves the utilization of advanced techniques, algorithms and mathematical models: Optimization Algorithms implement optimization algorithms such as Linear Programming (LP), Mixed-Integer Linear Programming (MILP). The OPPA algorithm is shown on the Figure 20.

By combining these techniques and models, the OPPA will provide actionable recommendations for optimizing PMU installation points, ensuring efficient power system monitoring and control.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

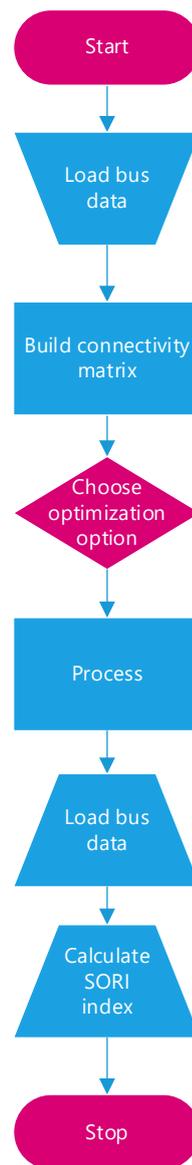


Figure 20 – The OPPA optimisation algorithm

- **Data exchanges, communication with other modules and/or products (data flows and protocols):** The OPPA exchanges the following data:
 - **Input data:** User gives the input in the user interface application in two ways: by importing of an excel file, which contains information about nodes and lines (beginning node and ending node) of the observed power system, or drawing the graph of the power system. Next, the application will build the binary connectivity matrix. Users can choose optimization option to be solved. Since the result could consist of several optimal solutions, the SORI index will be calculated to describe the quality of the optimization.
 - **Output data:** Users should have the capability to export the results and recommendations in multiple formats for further analysis and integration, for example in csv format.

User Interface

The user interface for this PMU installation optimization module presents a comprehensive approach that caters to both user convenience and advanced functionality:

- **User-Friendly Data Input:** The inclusion of two distinct methods for data input, i.e., importing data from an Excel file and allowing users to draw the power system graph directly, is a commendable choice. This dual-input approach ensures flexibility and accommodates users with varying preferences and data availability. Importing data from Excel streamlines the process for users who already have structured data, while the option to draw the graph empowers users to create a visual representation of their power system, fostering engagement and understanding.
- **Binary Connectivity Matrix Generation:** The automated generation of a binary connectivity matrix based on the user's input is a crucial feature. This matrix forms the foundation for subsequent optimization calculations and observability analysis. By automating this step, the module simplifies the process and reduces the risk of errors that can arise from manual matrix creation.
- **Optimization Options Selection:** The ability for users to select different optimization options (e.g., basic calculation, N-1 calculation, or considering existing PMUs) directly through the user interface is a thoughtful design choice. It grants users the flexibility to tailor the optimization process to their specific needs and requirements. Providing clear and intuitive options within the interface ensures that users can easily navigate and make informed selections.
- **SORI Index for Optimization Quality:** The inclusion of the SORI index as a metric to assess the quality of optimization results adds significant value to the module. It provides users with a quantitative measure of optimization quality, aiding in the evaluation and comparison of multiple optimal solutions. This metric enhances the module's usability for decision-making and planning processes, as users can prioritize solutions with higher SORI values.
- **Feedback Loop and Iterative Design:** Lastly, consider incorporating a feedback loop into the development process. Regularly gather input from potential users or stakeholders to refine the interface. This iterative approach ensures that the final user interface aligns closely with users' needs and expectations.

Resources

The application will be developed in programming languages that are well-suited for mathematical modelling and optimization tasks i.e. Python and MATLAB.

4.2.6 IRIS Module8 - Emergency & Restoration - System Split module upgrade - EMSS

Internal Architecture of the module

- **Aim of the module:** ENTSO-E rules determine procedures in case of major disturbances (Continental Europe Synchronous Area Framework Agreement - Emergency & Restoration Policy rules). However, their implementation during disturbances is difficult, as there are many complex rules.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

In addition, new European regulation 2019/943 envisages responsibility for Regional Control Centres (RCCs) in the event of major disturbances, such as supporting the coordination and optimization of regional restoration as requested by transmission system operator.

To make it easier for dispatchers to apply the Emergency & Restoration (ER) rules and to give the RCC an appropriate role in coordinating major disturbances, a use case was developed in the TRINITY project provided for the following:

- Detection of major disturbances and their characteristics (system split, system blackout, frequency deviation)
- Communication and coordination module that guides TSO operators through a step-by-step ER process while allowing a RCC to oversee and steer the entire process.

The results of the TRINITY project have been communicated to the ENTSO-E and they have been used to create a procedure in case of system split. The purpose of this use case is to align the communication procedure developed in the TRINITY coordination tool with the mentioned ENTSO-E procedure and to further test and improve this coordination process. In addition, the necessary algorithms for the entire implementation of the ENTSO-E procedure will be designed.

To facilitate implementation of ENTSO-E ER procedure in a real environment as well as to allow for its testing and further enhancements, the ER module developed in TRINITY project and deployed within SCC infrastructure will be updated and complemented with a real-time data acquisition system and a historical database.

With the implementation of mentioned SCADA system, ER module will have a possibility to inform in real-time TSO dispatchers and RCC operators about ongoing power system crisis. Moreover, the ER module will be implemented and validated in real conditions (not in study mode as done in TRINITY project), by improving methodologies and algorithms for frequency leader and frequency islands determination, and by introducing more complex coordination problems thus further improving business process for emergency and restoration.

- Detailed architecture of the module: The system architecture is shown in the Figure 21.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

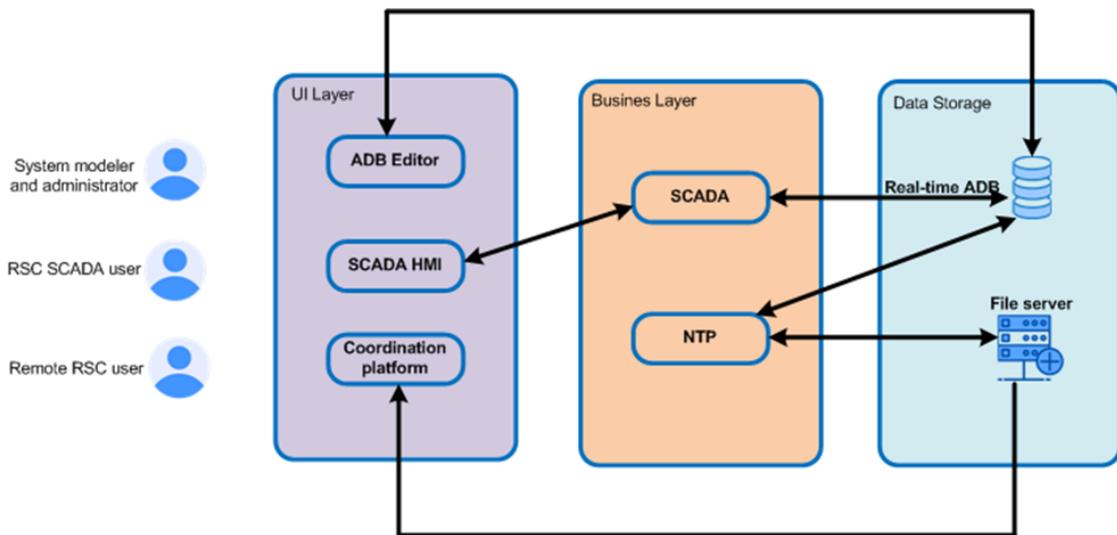


Figure 21 - ER tool architecture - Architecture of IRIS Module8 'ER'

- Description of the components of the module: NTP (Network Topology Processor) determines network topology and identifies electrical islands Based on static equipment connectivity and switching equipment statuses. The NTP generates a bus-branch equivalent network model with branch parameters determined from actual equipment parameters. Measurements from the SCADA system are further associated to this bus-branch model.

Real-time ADB application database ADB is implemented as a relational database and serves as a central repository of data on the power system elements (generators, transmission lines, transformers, loads), as well as all necessary data for determining the static topology of the network (element connectivity, bus structure, busbar field descriptions, circuit breaker descriptions...). The static connectivity of the power system elements is described by their terminal connections to the nodes. Apart from static, relatively unchanging data, the application database contains dynamic data on analog measurement values and the status of switchgear obtained from the SCADA system. The application database also contains system parameters necessary for the operation of network applications, as well as corresponding data required for the connection with the SCADA system.

- The ADB Editor is a tool for viewing and editing ADB content. The network model is visually represented in the form of a hierarchical tree. The hierarchical levels are: company, area, substation, and voltage level.
 - 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 dialogs directly from dynamic pictures.
 - Coordination platform serves as tools for communication between participants in the process and for coordinating their actions. Based on the results of the system split and blackout detection application, reports are created on the coordination platform.
- Techniques, algorithms and mathematical models, to be used for the module development: Topology is processed in two stages: 1) identification of the buses and

2) identification of the islands. First stage identifies buses through processing of switching equipment statuses. Determination of energized electrical islands is performed after measurements allocation. An electrical island is energized if there is at least one voltage measurement above a certain threshold.

In every execution cycle, NTP generates an XML file with a temporary list of islands. Each island is assigned a temporary ID that corresponds only to that cycle of the topology processor. Each island has an energization status indicating whether it is energized and a list of nodes. At any given time, there may be islands in the network that have been split or have become de-energized. Any changes in the energization status of islands are detected, and some may be declared as split or in a blackout state. The algorithm considers only 220 kV and 400 kV nodes by default for input data. Users have the possibility to define voltage levels of interest for analysis.

In each processing cycle, topology processor data from the current and previous cycle are used. There are theoretically three situations:

1. Pure system split - an energized island is split into two or more smaller islands that are still energized;
2. System splitting with blackout - an energized island is split into two or more smaller islands, where some of the smaller islands are de-energized;
3. System blackout - the previously energized island becomes completely de-energized.

System split detection is performed as follows:

- A check is performed for each 400kV and 220kV nodes to see if it exists in the list of nodes from the parent island of the previous cycle. If a node did not belong to any island, for example, because it was isolated, it will not be analyzed in the next cycle.
- By comparing the IDs of the parent island in the current cycle, each node is checked to see if it remains in the same island. If a node from the list belongs to a different island, a system split is declared if the observed node that changed islands is in an island that is larger than or equal to the electric island threshold, which is user-configurable. To prevent a branch failure from being misinterpreted as a network split, this threshold is set to 3.
- The islands in which node splitting occurred in the latest cycle are marked as new split islands. These islands, as well as all nodes that belong to them, are assigned the "split" status.

The blackout detection algorithm is performed by iterating through all connected electrical islands. When an electrical island is de-energized, its list of corresponding nodes is checked to see if any were energized in the previous cycle. If the number of such nodes is greater than a user-configurable threshold, the entire island and all nodes within it are marked with a blackout status.

Islands can be classified as:

- Splitting island - all nodes of such islands have the status "split" and do not have the status "blackout";

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- Island entered a blackout state - all nodes in such islands have the status blackout and do not have the status "split";
- Splitting island entered a blackout state - all nodes of such islands have the status "split" and have the status "blackout".

Following the final classification, the system stores the following data:

- Time of the previous and current cycle;
- List of all connected islands in the current and previous cycle;
- If an island was formed by splitting, information about the original island is kept, as well as a list of all islands that were split from the same island as the current one;
- Information about the status of the island.

If there is a low-voltage part of the network that is not included in the model, the existing algorithm could, theoretically, falsely report the occurrence of an islanding event even if it does not exist (islands connected at lower voltages). Additional frequency-based verification would improve the algorithm and prevent such errors from occurring.

- Data exchanges, communication with other modules and/or products (data flows and protocols): Apart from the core application modules, there are also supplementary modules designed to facilitate the primary function of data conversion: SCADA2ADB interface, ADB2SCADA interface and ADB2NTP interface. The communication between TSOs (Transmission System Operators) and RSC SCADA Server takes place via IEC 60870-6 TASE.2 protocol. MySQL C API is used for communication with a database. The data flow is presented in the picture below (Figure 22).

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

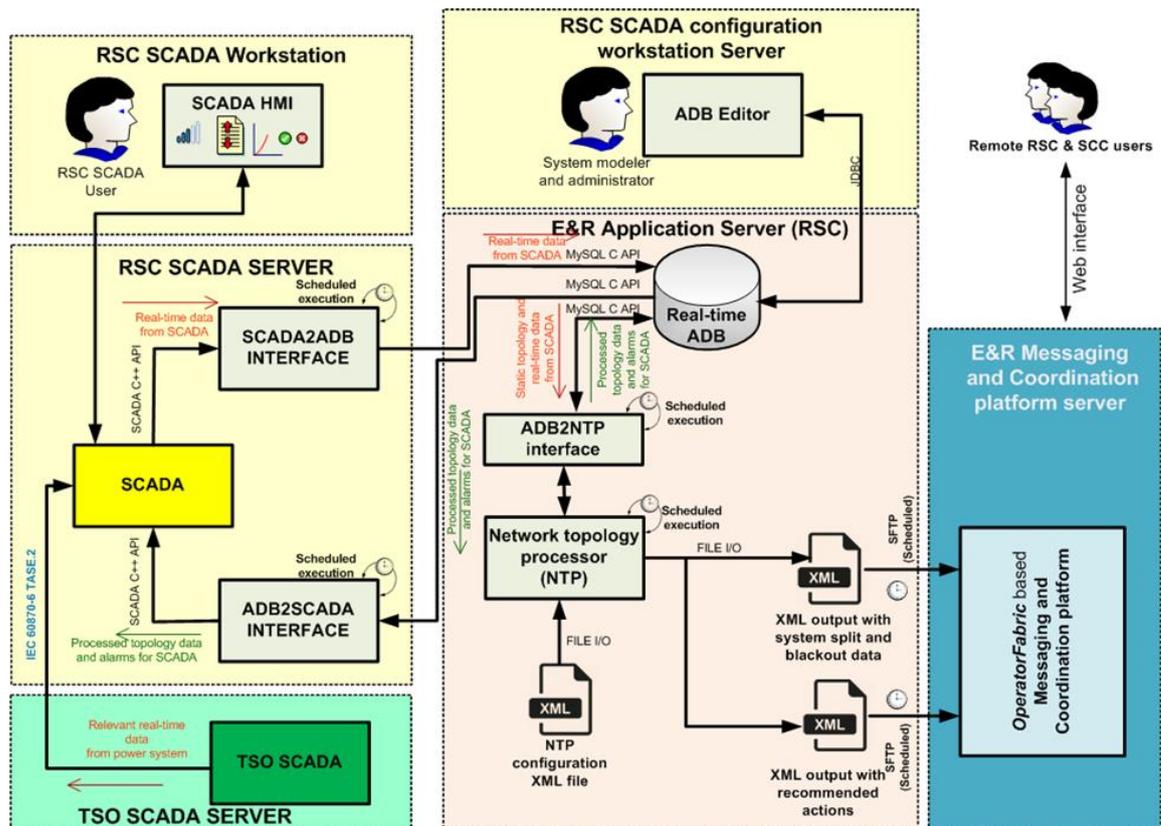


Figure 22 - Data flow in ER toll

User Interface

The ER module will have a suitable SCADA HMI interface to visualize disturbance events as well as to verify the output from the decision support tool.

Based on the results of the system split and blackout detection application, reports are to be created on the coordination platform. This platform serves as a means of communication between participants in the process and for coordinating their actions. Communication through the coordination platform is based on a notification system in the form of cards that are displayed to users. There are four types of cards:

- Informative cards notify the operator of an event or convey a message from other participants in the system, without requiring a response from the operator.
- Active notifications require some action from the operator, such as confirming or rejecting a proposed power outage plan, requesting an increase in production, and so on. Active cards are also used when coordinating multiple users to align the plan of action, such as when a part of the system fails, multiple participants in the power system need to coordinate their work to safely restore the system to a stable state.
- Alarm cards are similar to active cards, but additionally indicate that an urgent response from the operator is required.

- Alignment cards indicate that some coordination has been completed and send the results of that coordination.

Resources

The following SW resources will be used to develop this module:

- OperatorFabric platform which is a modular, extensible, industrial-strength platform for use in electricity, water, and other utility operations. This platform is developed by the Linux Foundation and with publicly available code.
- SCADA Configuration Tool is a software application used in the field of industrial automation and control systems. Its primary function is to facilitate the setup, design, and configuration of SCADA systems.
- SCADA HMI Configuration Tool 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 is a specialized software application designed to manage and configure the database components of a Supervisory Control and Data Acquisition (SCADA) system.
- Oracle Netbeans 8.1 or newer or Apache Netbeans 9.0 or newer for Java development
- Visual studio for C++ development.
- MySQL database GUI tool for editing tables.

4.2.7 IRIS Module9 – Remedial Action Automation – EMSS

Internal Architecture of the module

- Aim of the module:

Currently, in ENTSO-E Regional Operational Security Coordination (ROSC) methodology RAs are based on analysis calculated prior to the real time, on a model prepared in day ahead or intraday time frame. This implies that RAs that are agreed in day ahead or even intraday may not be applicable to the real time operation, due to unexpected changes in the system. In such cases, the agreed RAs must be reconsidered or even new RAs must be defined in a very short period of time. This is only possible if RAs determination is automated. This mechanism can also be used when defining so-called fast RAs according to the ROSC methodology (presently they are based on personal experience, i.e. qualitative criterion is used instead of numerical when defining fast RAs). With automated RAs, the resilience of the system could be greatly increased in the most demanding situations.

RAs can be:

1. Preventive (PRA) which is by the definition from ROSC methodology “a RA that is the result of an operational planning process and needs to be activated prior to the investigated timeframe for compliance with the (N-1) criterion”

2. Curative (CRA) which is by the definition from ROSC methodology “a RA that is the result of an operational planning process and is activated straight subsequent to the

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

occurrence of the respective contingency for compliance with the (N-1) criterion, taking into account transitory admissible overloads and their accepted duration”

For preventive RAs the change of flows or voltage shall be assessed on the N situation and on each of the N-1 situations resulting of the contingency list simulation. For curative RAs the change of flows or voltage shall be assessed by simulating of the post-contingency situation for which this curative RA has been designed.

Automation part of this use case doesn't only apply to the RA determination but also to RA execution. The set of the signals that contain switching commands or set-points from a certain RA can be sent to SCADA system to be executed. This will help to reduce the time needed for manual operations and RA would be applied almost instantly.

- Detailed architecture of the module:

RA tool is designed to operate in correlation with SCADA/EMS tools, namely CA (Contingency Analysis), DPF (Dispatcher Power Flow) and SCADA subsystem itself (for issuing appropriate controls).

Architecture of the module and dataflow is shown at following figure. The RA tool itself consists of two main components:

- RA tool Desktop Java application
- Set of database stored procedures and mapping tables in study network (EMS) application database.

Overview of detailed architecture and connections with SCADA EMS components is shown at Figure 23.

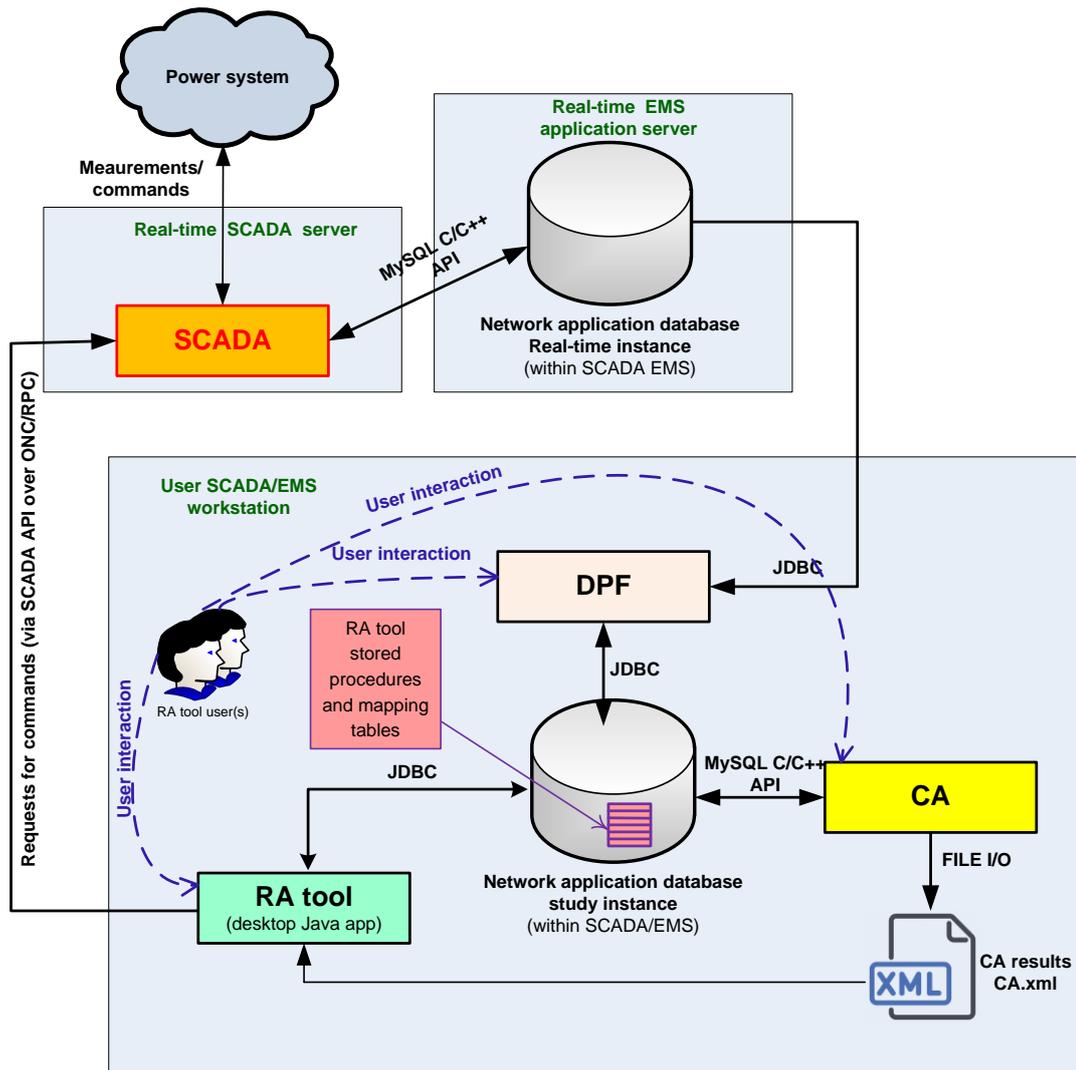


Figure 23 - Architecture of IRIS Module9 'Remedial Action Automation tool architecture Automation'

- Description of the components of the module:

RA tool desktop Java application will be Swing based Java application that will enable user to interact with other SCADA/EMS components and tools and with set of stored procedures. This means that RA determination and filtering will be done via this application. In addition, after DPF and CA tools confirm that selected RAs are valid, the module will allow user to request issuing of appropriate SCADA commands via SCADA API. This tool will be based on Java JDK 1.7 (to match existing libraries and tools within SCADA/EMS which use this version of JDK). All database communication will be performed via JDBC for MySQL. Interaction with SCADA will be done via custom Java SCADA API using ONC/RPC (Open Network Computing/Remote Procedure Call) API.

Stored procedures and mapping tables are to be used to execute RAs and to map these actions with contingencies. For each RA MySQL stored procedure will be defined in database. These procedures will be designed as standard MySQL stored procedures and/or functions and added to the study mode EMS network application databases (based on MySQL). In order to establish map of contingencies, RAs and appropriate SCADA

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

commands mapping tables will be added to EMS network applications database in study mode. These will contain following maps:

- Map of contingency with RA stored procedure
- Map of RA with appropriate SCADA commands
- Description of possible RAs

Stored procedures will be used to modify data into DPF tool tables in order to validate (by using DPF tool and CA in study mode) whether user selected (by means of RA desktop application) RA is appropriate (this is equivalent to change data manually in DPF, however via stored procedure these changes will perform instantaneously). Stored procedures will not be able to issue commands via SCADA, but RA desktop application will, on user request, send appropriate requests to SCADA.

- Techniques, algorithms and mathematical models, to be used for the module development:

Algorithm for RA tool is shown in Figure 24.

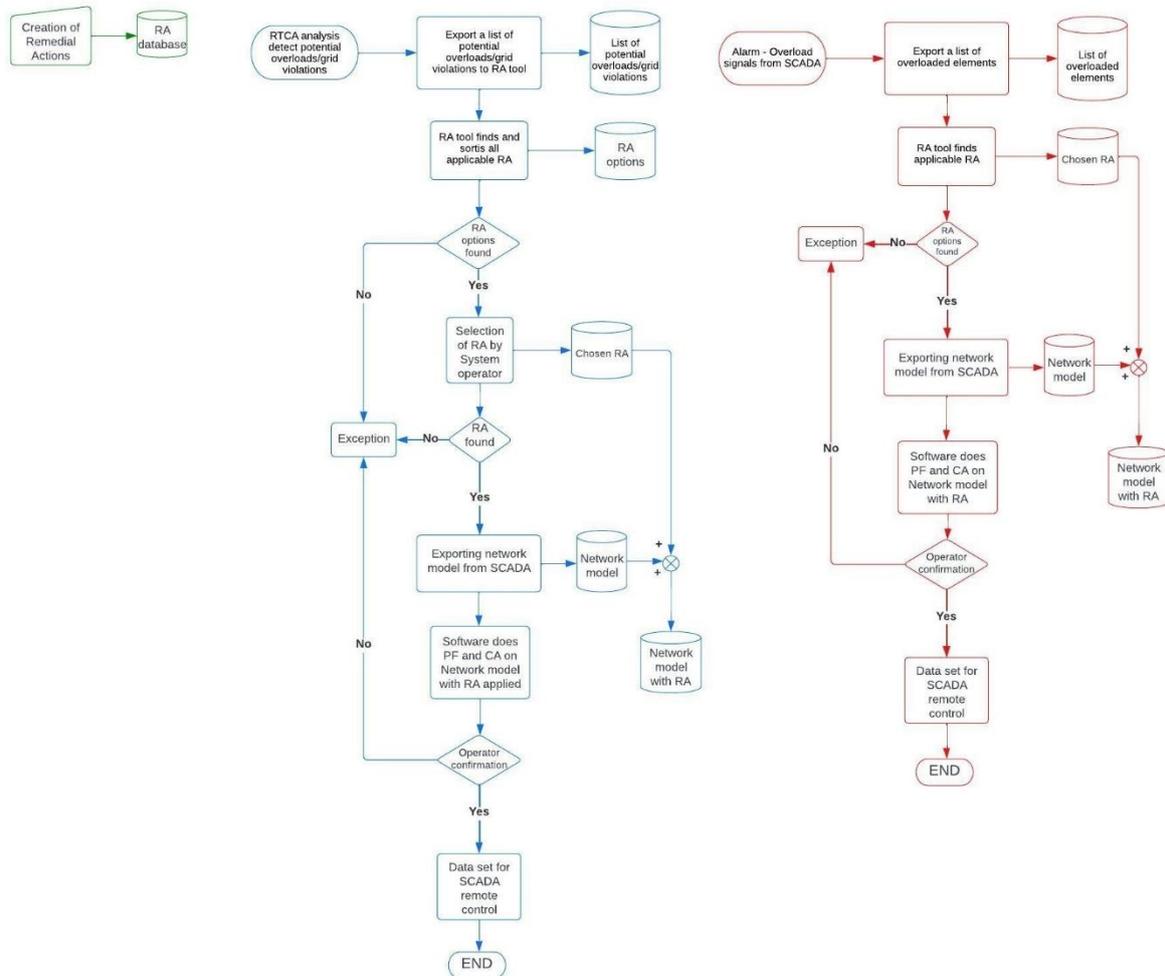


Figure 24 - Remedial Action Automation tool algorithm

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

As described, there are two separate independent loops. First, there is a loop which would be activated by results from CA, while the second loop is to be triggered by system operators (after overload alarming).

Operation regarding network model modification from RAA tool is as follows:

- After CA generates the list of contingencies in CA XML export file, RAA tool (desktop application) imports data from XML and presents user with contingency list.
- By using mapping tables RAA tool filters appropriate remedial action list and presents it to user.
- When user selects RA(s) and confirms them, RAA tool uses mapping tables to select appropriate stored procedures. These procedures change data in power flow (DPF) application tables automatically, by inserting new or scaled values (depending on procedure and type of RA) instead of values retrieved from real-time (base case). After that DPF tool operates “as usual”. All changes are transparent to DPF tool that is power flow application will operate in same manner as if data were entered manually via DPF user interface. DPF calculations are initiated from DPF tool HMI where results are presented.
- Data exchanges, communication with other modules and/or products (data flows and protocols):

Figure 25 presents data flow between RAA tool components and other tools, including SCADA/EMS workstation, EMS RT application, SCADA servers (Institute Mihajlo Pupin (IMP's) VIEW4 and General Electric (GE) SCADA/EMS system. Additional link might be provided toward ENTSO-E Awareness System.

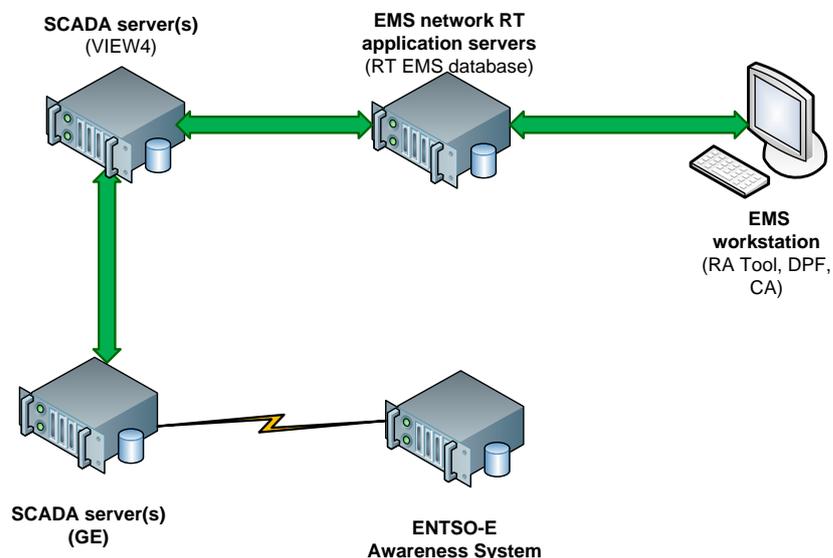


Figure 25 - Data flow between RAA tool components

Similarly, Table 4 presents data exchange protocols between RAA tool components (data source is listed in the first column, while the data destination is given in the top row).

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

Table 4 - Table 4.2.7.1: Data exchange protocols between RAA components

	SCADA (VIEW4)	IRIS RAA TOOL	(D)PF TOOL	CA TOOL	EAS	SCADA (GE)
SCADA (VIEW4)		N/A	MySQL C API	MySQL C API	N/A	ICCP/TASE.2
IRIS RAA TOOL	SCADA API (ONC/RPC)		JDBC	File I/O	N/A	N/A
(D)PF TOOL	SCADA API + MySQL C API	N/A		File I/O + JDBC	N/A	N/A
CA TOOL	SCADA API + MySQL C API	File I/O	File I/O + JDBC		N/A	N/A
EAS	N/A	N/A	N/A	N/A		ICCP/TASE.2
SCADA (GE)	ICCP/TASE.2	N/A	N/A	N/A	ICCP/TASE.2	

User Interface

Control Centre operator monitors the alarm list of the SCADA/EMS system and upon detection of grid violation(s) opens RAA tool interface. In general, RAA tool interface (RAA desktop Java application) should be consisted of two parts:

- General interface that enables:
 - Interface with EMS network application database (which will be extended with content of RAA data, mapping and stored procedures)
 - Import of CA XML data (from study and real time CA)
 - RAA HMI will present users with list of contingencies from CA XML file - user will be able to select (filter) relevant contingency
 - RAA HMI will present user with list of possible remedial actions for selected contingencies. User will be able to select (filter) appropriate from list.
 - Button for execution of stored procedures which represent selected remedial actions on DPF data in EMS network applications database.
- Command signals interface:
 - Button for sending requests for appropriate commands to SCADA (if user is satisfied with DPF and study CA results after remedial actions are applied on base case).
 - Commands will be sent to SCADA via Java SCADA API over ONC/RPC. The RAA tool HMI will receive from SCADA confirmation if command request is accepted or error occurred. Actual execution results (opening of switching equipment or base point change) have to be verified on SCADA.

Resources

The following SW resource are needed for RAA tool development:

- Java Development Kit (JDK) 1.7 - this version will be used to match one used by SCADA/EMS system and it's Java libraries
- Oracle Netbeans 8.1 or newer or Apache Netbeans 9.0 or newer for Java development.
- MySQL database GUI tool for writing procedures and editing tables. We will use Dbeaver a cross-platform tool that supports MySQL, MariaDB and other databases.
- MySQL JDBC for interfacing databases
- VIEW4 SCADA API for Java (built on JDK 1.7, communicating via ONC/RPC)
- DPF (Dispatcher Power Flow) and CA (Contingency Analysis) tools from VIEW4 SCADA system
- VIEW4 SCADA standard configuration tools

4.3 TASK 4.3 - MULTI-ENERGY TSO-DSO PLANNING COORDINATION

4.3.1 IRIS Module10 - TSO-DSO cooperation in Individual Grid Model creation via TSO-DSO communication platform

Internal Architecture of the module

- Aim of the module:

In order to create more accurate Individual Grid Models (IGMs), it is necessary to take into consideration the production at the distribution level. Therefore, instead of forecasting the power flow at the TSO-DSO interface, it is better to forecast and model the distribution load and the distributed generation separately.

This task is relatively complex and consists of several steps that include the initial forecast of consumption and production (which can be done by TSO or DSO or both entities), as well as subsequent harmonization between TSO and DSO.

In addition, DSO should periodically inform TSO about newly installed generation capacities in the distribution system (type, installed power, location), as well as about changes in topology in its network that affect the power flows through the transformers that connect the transmission and distribution system.

In order to successfully implement all this, it is necessary to establish a new business process, to use tools for forecasting, as well as tools for communication between TSO and DSO.

This is exactly the task that needs to be done through UC15. As we can see, one part of the work refers to the design of a new business process, another part will

refer to changes in forecasting methodologies, and the third to the development of tools. This report primarily deals with the TSO-DSO communication platform, which should support the business process of creating IGM on a new basis.

The idea of this platform is to send relevant notifications to TSO/DSO operators when their attention is needed and additionally, and aggregate all the notifications from these different processes into a single screen and to allow operators to act on them if needed. Specifically, the module will be adapted to communication on the TSO-DSO relation regarding the exchange of data related to producers connected at the DSO side.

- Detailed architecture of the module:

Detailed architecture of the TSO-DSO communication platform and its businesses environment is presented in Figure 26.

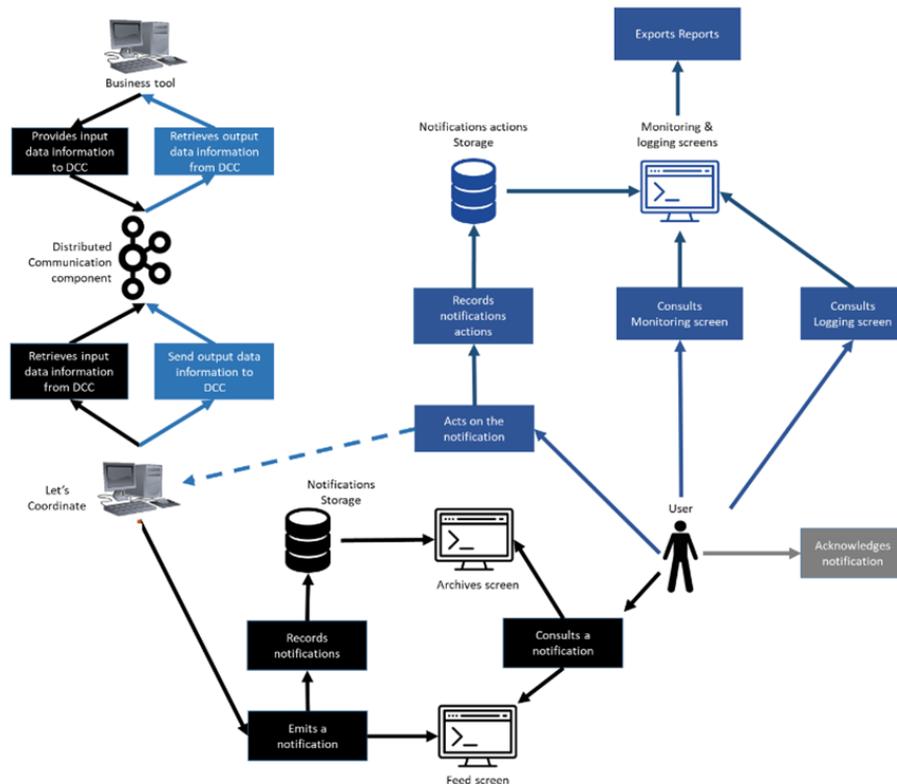


Figure 26 – Architecture of IRIS Module 'TSO-DSO Communication Platform'

- Description of the components of the module:

A common practice is to define a UI layer, Business layer and Data Storage layer for each tool or module. The UI layer is explained in detail in one of the following sections, while the next paragraph refers to the business layer.

TSO-DSO communication module should ensure the coordination of relation TSO-DSO after the implementation of the following actions:

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- TSO creates dataset with distributed load and distributed generation forecasting (for each DSO substation connected to the transmission system) nodes of interest and everyday forecasts production for these nodes.
- TSO sends to DSO notification via communication platform forecasted distributed generation and load about new production forecast.
- DSO receives notification about TSO production forecast.
- DSO checks and corrects forecasted distributed generation and load data if this data does not comply with specific operational conditions in the distribution grid.
- DSO uploads corrected forecasted distributed generation and load data or notifies TSO that forecast is accepted.
- TSO receives information on forecasted distributed generation and load data check – if DSO have corrected this data, forecasting file is attached.

This module also has data storage servers in its architecture, as a Data Storage component (notification storage, notification actions storage).

- Techniques, algorithms and mathematical models, to be used for the module development:

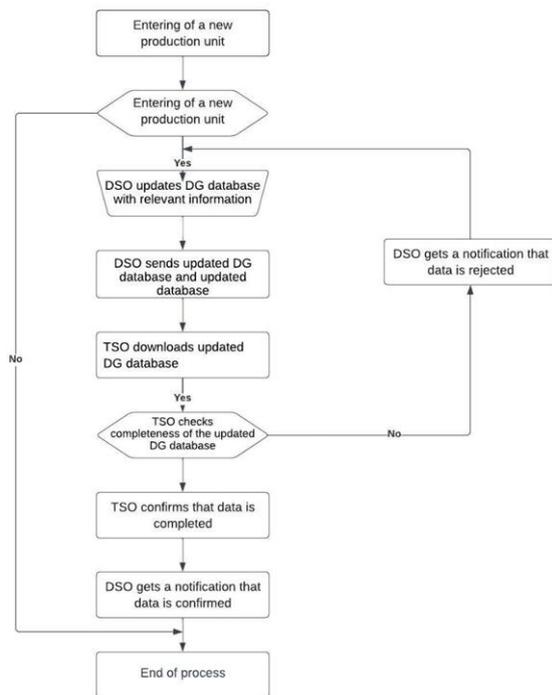


Figure 27 - TSO-DSO Production Unit Information Process Flow

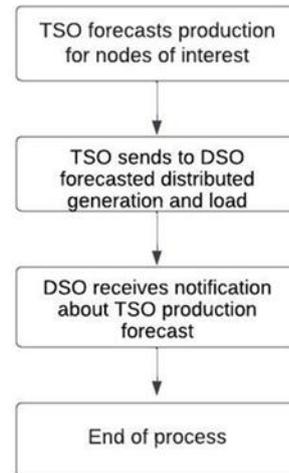


Figure 28 - TSO-DSO Forecast Process Flow

Figure 27 and Figure 28 show two business process flows. The left part refers to the periodic updating of the database on production capacities at the distribution level, and the right part to the creation of IGMs.

Forecasting:

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

The choice of forecasting model depends on the specific requirements of the forecasting task, the availability of data, and the desired forecasting horizon (e.g., short-term or long-term). Often, a combination of different models or a combined approach can provide the most accurate and reliable RES production forecasts. Additionally, forecasting model performance should be continuously monitored and updated as new data becomes available.

Forecasting of wind power plants and solar power plants is based on knowledge of the location of the production facility and meteorological conditions. On the other hand, hydro and thermal production capacities of higher power must have their own work plans, so in this case a forecast is not necessary. Probably the most difficult to forecast will be mini-hydroelectric cranes, for which a method of forecasting has yet to be devised.

TSO-DSO communication:

There will be two kinds of notifications which depends on the event:

- INFO: for an informative notification, user can just acknowledge it.
- ACTION: for an action/smart notification when user should act (accept, reject, explanation about rejection and comment).

The color of the notification depends on the status of the card:

- INFO – blue: Information is received (like results of calculation are available)
 - COMPLIANT – green: Validation has been performed successfully (like ACK is positive)
 - ACTION required – orange – Warning: Please consider this notification and act to manage the raised situation/issue
 - ALARM – red – Critical issues (like Process failed, validation failed)
- Data exchanges, communication with other modules and/or products (data flows and protocols)

Figure 29 shows data exchange and communication in the described business environment. Blue arrows present communication via SFTP protocol, while green ones represent communication via HTTPS protocol.

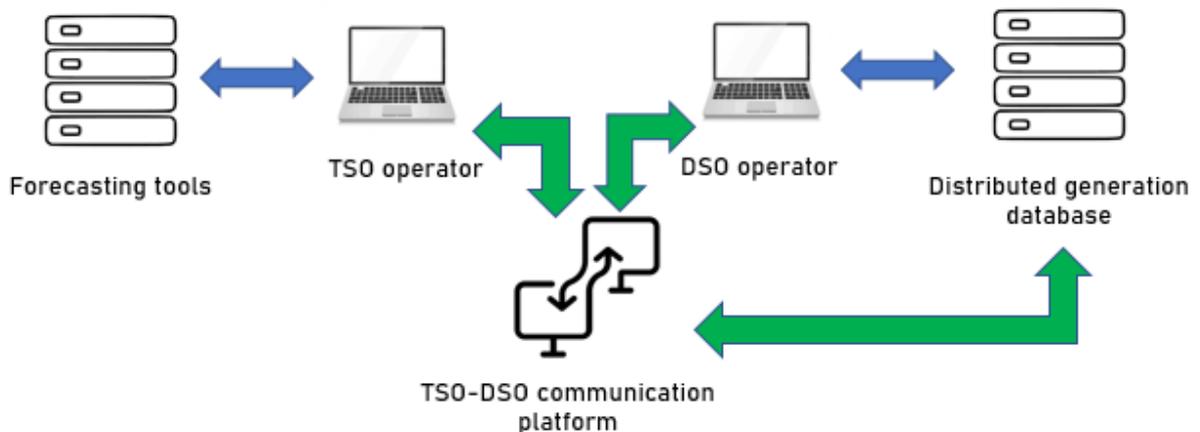


Figure 29 – TSO-DSO Data exchange and protocols

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

DSO must provide consistent database on distributed generation (location, type, installed active power, position in distribution system – consumption area of 110 kV distribution substation connected to the transmission system).

TSO operator will provide via forecasting tools load forecasts for, and RES generation forecasts. These data must be aggregated at the level of the consumption area of the 110 kV distribution substation.

All the above-mentioned data are exchanged between TSO and DSO operators through the TSO-DSO communication platform. Besides, additional data can be exchanged through this platform, such as expected load redistribution between 110 kV distribution substations, due to topology changes in the distribution system.

All these data are exchanges in order to achieve the maximum accuracy of the input files used to create IGMs.

User Interface



Figure 30 -: OpFab display

Figure 31 presents generic view of the TSO-DSO communication platform which will be based on OperatorFabric platform, an OpenSource framework dedicated to communication and coordination process.

At the top of the page is a header with a menu to access the various tool and module screens as follows:

- Card Feed screen: To receive and display the different notifications. User will have the possibilities to manage the notifications in this screen.
- Archiving screen: To access to all existing notifications which are stored in the database

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- Monitoring screen: To monitor the status of the coordination
- Logging screen: To displays logs of the relevant information about the coordination process
- Card creation link Card creation menu: To create from the GUI a notification and to send it to different users or group of users

The login information menu is used for logging in. In the top right of the page, one can enter name & company of logged user. Below to the name of the logged user, current time for selected time zone of the day is displayed.

Resources

The following SW resources will be used to develop this module:

- OperatorFabric platform which is a modular, extensible, industrial-strength platform for use in electricity, water, and other utility operations. This platform is developed by the Linux Foundation and with publicly available code.
- Vitec Aiolos forecast studio that have possibility to accurately forecasts RES production per single unit (home, industrial object, power plant ...)
- The Transmission Network Analyzer (TNA) is an application designed for the calculation of the static Load Flow, Contingency Analysis, Transmission Capacity calculations (NTC-based, flow-based), Congestion Forecast (DACF, D2CF, IDCF), validation and merging of the models, model format conversion (UCT/CIM/RAW), short circuit calculation as well as building and editing the UCT/CGMES datasets and auxiliary files and lists.

4.3.2 IRIS Module11 - TSO-DSO planning coordination suite

Internal Architecture of the module

The main aim of the module is to optimise and identify the optimal multi-energy system capacity portfolios that can deliver a resilient low-carbon energy system at the minimum cost while managing appropriate risks associated with faults and extreme weather conditions. For the DSO planning suite, criteria for resilience quantification will be developed to drive resilience-oriented investments in different types of multi-energy microgrid (MEMG)-based components and their grid services functionalities, considering the uncertainties of weather-driven stressed system conditions, loss of transmission supply and potential failures of different distributed components. Investment decisions of local networks and various MEMG resources (distributed generation, battery energy system, electric vehicles and vehicle-to-grid, demand response technologies from smart appliances and smart Heating Ventilation and Air Conditioning system (HVAC), electrolysers and hydrogen storage) are determined most cost-effectively to ensure a target resilience level. The benefits of having diversity in energy and flexibility resources to improve resiliency will be examined.

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

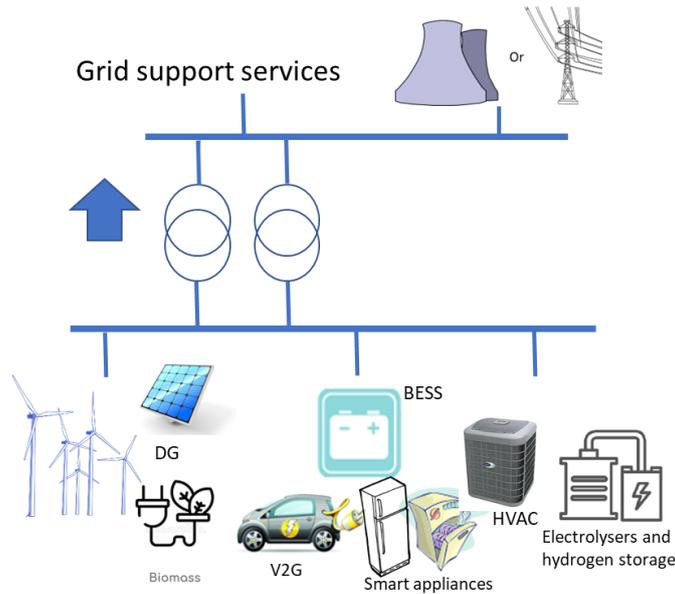


Figure 32 - MEMG resources considered for providing network services and improving energy system resilience

For the TSO planning suite, the availability of DER services will be considered to ensure the optimal transmission system designs achieve the optimal security level (e.g. N-1/N-2). The energy system portfolios will be tested under a set of High Impact Low Frequency (HILF) events to demonstrate the adequacy of the developed approaches. The interaction between TSO and DSO will be analysed as the reliability of DER services driven by a range of factors such as the number of units, temporal availability of the services, diversity profiles, and energy storage capacity will need to be considered by TSO. On the other hand, the transmission supply reliability to grid supply points will be considered by DSO.

The architecture of the tool is illustrated in Figure 33.

T4.3 Tool Architecture

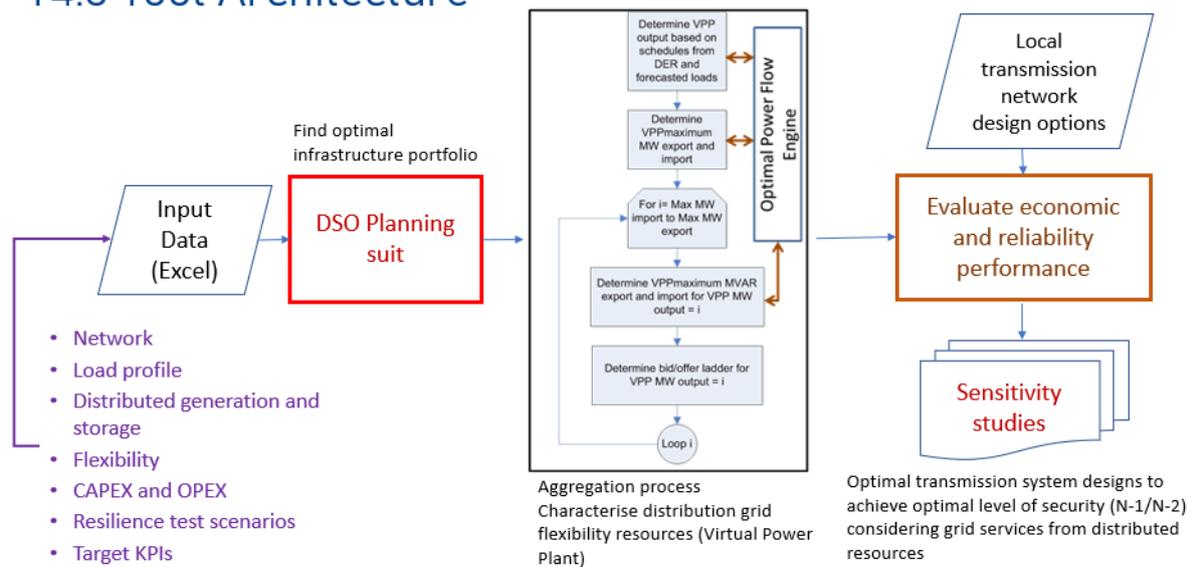


Figure 33 – Architecture of IRIS Module11 DSO Planning Suit

The tool consists of:

- An Excel spreadsheet containing the input and output data. Input data consist of:
 - Network data
 - Load data including the profile (hourly) and the category: essential and non-essential load
 - Generation and energy storage data
 - Flexibility characteristics of load, generation, and storage
 - Cost data including CAPEX and OPEX of MEMG components, value of loss load
 - Resilience test scenarios
 - Target reliability
 - Network design options
- DSO planning suit, which will optimise the system to determine the portfolio of MEMG components to meet the target reliability considering the resilience test scenarios.
- The optimal power flow (OPF) module calculating and monitoring the system states (flows, voltages) of the distribution system to optimise the network control devices (transformers, shunts), generation output and demand as well as calculating the maximum flows that can be changed at the grid supply point, i.e. the interface point between the TSO and DSO. The OPF module will provide dynamic data on the availability of distributed resources that can be used to support TSO's network congestion management. The availability is calculated such that the use of those services by TSO will not violate DSO's local network constraints.
- A set of transmission design options will be evaluated to determine the least cost design while meeting the resilience and reliability requirements considering the support from distributed flexibility resources. Different options' reliability and cost performance will be calculated, compared, and analysed using sensitivity studies.

DSO Planning Suit

The DSO planning suit is formulated as a large-scale linear optimisation problem to minimise the investment in MEMG components and networks to improve flexibility and energy system resilience against extreme system operating conditions considering the contingency or extreme weather events. The tool will analyse the extreme operating conditions and determine the resource adequacy and flexibility required to deal with those events. For example, during the supply interruption from the main grid due to outages or supply scarcity, the non-essential load will be switched off, and distributed generation and energy storage including mobile sources, can continuously supply the essential loads.

The optimisation problem is formulated as follows:

Minimise Total investment cost of MEMG components and load shedding cost

MEMG components include demand flexibility, BESS including mobile storage, back-up generation(e.g. fuel cells)

Subject to

Power balance constraints for all extreme conditions considered

Capacity adequacy constraints considering the Equivalent Service Delivering Capacity (ESDC) of the technologies

The ESDC calculation will consider a number of factors such as the temporal availability, number of sources, technologies, etc. ESDC is defined as the capacity of traditional service providers that can be replaced by the capacity of the new service providers without compromising reliability quality considering the reliability performance difference and the interface between these two technologies.

The general principle of calculating ESDC of a technology is as follows:

- Identify the reliability metric that will be used for comparing the reliability performance of different cases; for example, Loss of Load Probability (LOLP), Loss of Load Expectation (LOLE), Expected Energy Not Supply (EENS), and others;
- Calculate the reliability metric of the counterfactual system with traditional solutions – it is worth noting that the reliability of the counterfactual system depends on the reliability of the traditional service providers;
- Calculate the reliability metric of the system with the technology in question;
- Find the point where the system's reliability with the technology is equal to the reliability of the counterfactual system and determine the equivalent capacity.

Transmission planning suit

This tool will use the flexibility and resources invested at distribution to support transmission. In that context, the range of available resources that could be offered to support transmission network operation will be aggregated and presented to TSO as a Virtual Power Plant (VPP).

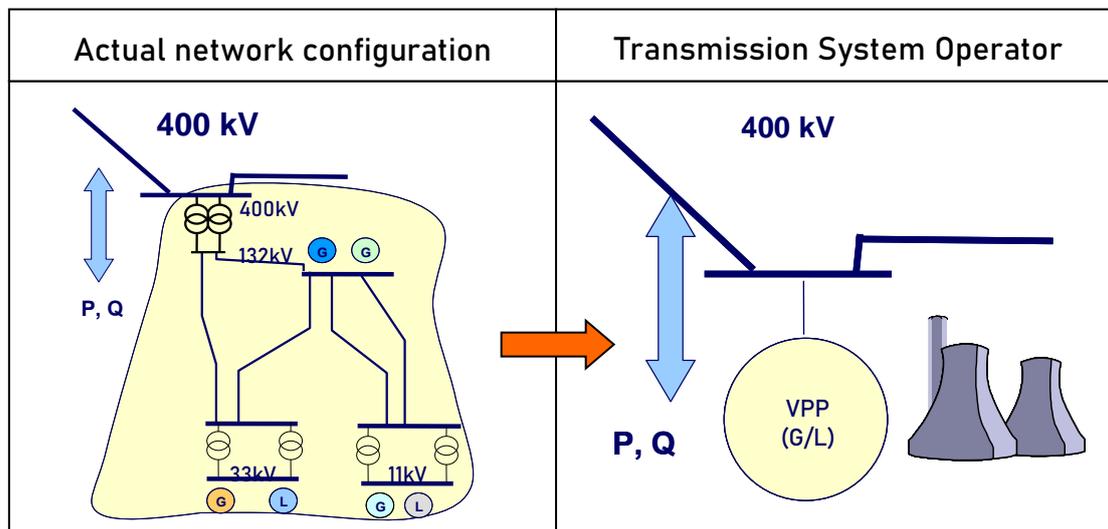


Figure 34 - Virtual Power Plant concept

A Virtual Power Plant is a flexible representation of a portfolio of DER that can be used to make contracts in the wholesale market and to offer services to the system operator – subject to the firmness of access to distribution networks. A VPP not only aggregates the capacity of many diverse DER, but it also creates a single operating profile from a composite of the parameters characterising each DER and incorporates spatial (i.e. network) constraints

into its description of the capabilities of the portfolio. The VPP can be used to facilitate the trading of DER in the wholesale energy markets (e.g. forward markets and the Power Exchange) and can provide ancillary services to support transmission system management as well as to contribute to the active management of distribution networks.

The characterisation process of the VPP is illustrated in Figure 35.

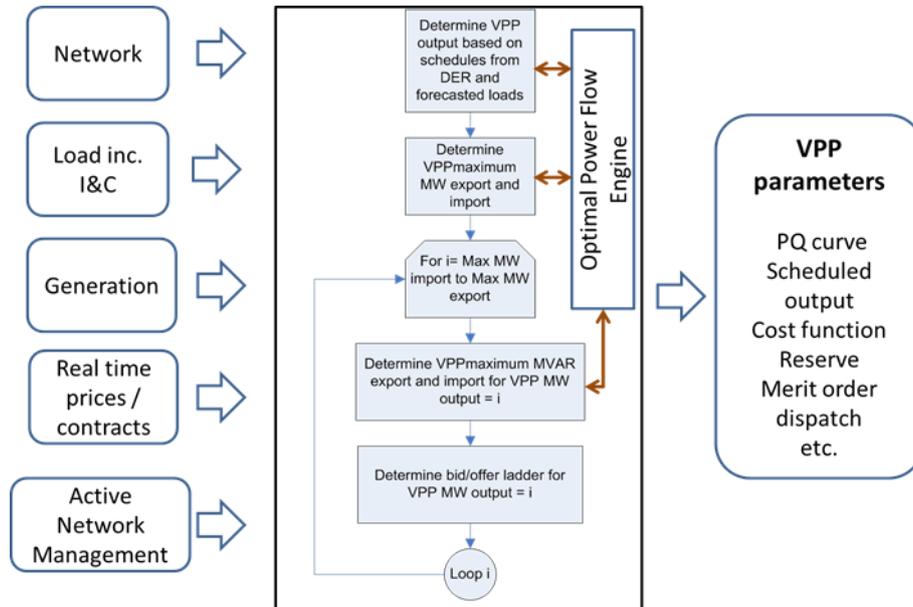


Figure 35 - Characterisation process of VPP

For this process, the input data consist of network data, load data including the flexibility of controllable loads, generation data. The scheduled generation outputs and the loads in the VPP area are then aggregated by the tool which calculates the scheduled power injection from the VPP using the Optimal Power Flow (OPF) formulation. The OPF is also used to calculate the maximum MW export and import which satisfy all the operating constraints of the local network regarding voltage and flow limits. Once the spectrum of the MW output is identified, the range of power output that can be exported or imported by the VPP area without violating operation constraints of the generators, loads and the network can be calculated. At the same time, the changes in generation cost due to the requirement to increase or decrease the output of VPP can be obtained. From those calculations, the VPP parameters can be synthesised. The parameters include the PQ technical capability curve, scheduled generation/load of the VPP, the VPP cost functions, the amount of reserve, and the merit order dispatch within the VPP.

Based on the range of VPP characteristics under different contingent conditions, the network security contribution to transmission is calculated. Their performance of the different transmission configuration (e.g. N-0, N-1, N-2) can be evaluated and the optimal solution can be obtained.

User Interface

An Excel spreadsheet is used as the user interface where the input and output data are stored. The input data consists of

D4.1 – Design of the resilience suite for TSO and DSO (IRIS)

- System data (generation, network, load, storage)
- MEMG investment options
- Cost data (investment, operation, curtailment)

Data are formatted in tabular like below:

Number of buses		37																										
Total		ALL											Total	514.910	60.340	0.000	0.000	203.470	0.000	0.000	0.000							
No	Name	Area	Zone	Type	PL (MW)	QL (Mvar)	PLS (MW)	QLS (MVar)	PG (MW)	QGS (MVar)	NPG (MW)	NQS (MVar)	Voltage (p.u.)	Angle (deg)	Rated Voltage (kV)	Set Voltage (p.u.)	Vmin Intact (p.u.)	Vmax Intact (p.u.)	Vmin Post-fault (p.u.)	Vmax Post-fault (p.u.)	Cost of Load shedding (RMV/h)							
1	BOLN4	1	1	3	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	400	1	0.9	1.1	0.9	1.1	2000							
2	BOLN3	1	1	0	18.73	1.77	0.0000	0.0000	13.7200	0.0000	0.0000	0.0000	0.9347	0.1020	33	0	0.9	1.1	0.9	1.1	2000							
3	GODG	1	1	0	45.14	5.01	0.0000	0.0000	14.6300	0.0000	0.0000	0.0000	0.9358	-2.4232	33	0	0.9	1.1	0.9	1.1	2000							
4	HORS1A	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0001	-0.1851	138	0	0.9	1.1	0.9	1.1	2000							
5	THRB1	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9333	-0.9574	132	0	0.9	1.1	0.9	1.1	2000							
6	HORS11	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	-0.1916	132	0	0.9	1.1	0.9	1.1	2000							
7	DORH1	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9309	-2.0850	132	0	0.9	1.1	0.9	1.1	2000							
8	DORM3	1	1	0	33.28	3.95	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9872	-4.4701	33	0	0.9	1.1	0.9	1.1	2000							
9	SMAL1	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9350	-0.8322	132	0	0.9	1.1	0.9	1.1	2000							
10	LEIG1A	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9346	-0.8039	132	0	0.9	1.1	0.9	1.1	2000							
11	BERK1	1	1	0	-26	-0.82	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9390	-0.5195	132	0	0.9	1.1	0.9	1.1	2000							
12	LEIG3	1	1	0	44.65	6.4	0.0000	0.0000	47.3600	0.0000	0.0000	0.0000	0.9325	-0.6581	132	0	0.9	1.1	0.9	1.1	2000							
13	SMAL31	1	1	0	39.79	-4.61	0.0000	0.0000	5.4700	0.0000	0.0000	0.0000	0.9394	-2.5322	132	0	0.9	1.1	0.9	1.1	2000							
14	STEY1A	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9384	-0.3588	132	0	0.9	1.1	0.9	1.1	2000							
15	STEY1B	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9387	-0.3740	132	0	0.9	1.1	0.9	1.1	2000							
16	STEY3	1	1	0	16.38	-4.53	0.0000	0.0000	15.7100	0.0000	0.0000	0.0000	1.0025	-0.4403	33	0	0.9	1.1	0.9	1.1	2000							
17	FISG1	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9389	-0.5202	132	0	0.9	1.1	0.9	1.1	2000							
18	BRIG1	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9382	-0.5598	132	0	0.9	1.1	0.9	1.1	2000							
19	FISG3	1	1	0	88.16	0.04	0.0000	0.0000	41.0000	0.0000	0.0000	0.0000	1.0041	-2.8451	132	0	0.9	1.1	0.9	1.1	2000							
20	BRIG3	1	1	0	63.31	17.17	0.0000	0.0000	1.3400	0.0000	0.0000	0.0000	0.9337	-3.4059	132	0	0.9	1.1	0.9	1.1	2000							
21	KENS1A	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9399	-0.0211	132	0	0.9	1.1	0.9	1.1	2000							
22	KENS1B	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9399	-0.0217	132	0	0.9	1.1	0.9	1.1	2000							
23	HORS1B	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9399	-0.1855	132	0	0.9	1.1	0.9	1.1	2000							
24	HORS12	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9398	-0.1921	132	0	0.9	1.1	0.9	1.1	2000							
25	HORS5	1	1	0	27.06	2.94	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9384	-5.9462	132	0	0.9	1.1	0.9	1.1	2000							
26	LEIG1B	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9347	-0.8065	132	0	0.9	1.1	0.9	1.1	2000							
27	MOLU1	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9383	-0.5681	132	0	0.9	1.1	0.9	1.1	2000							
28	Moulsecoomb	1	1	0	13.84	0	0.0000	0.0000	0.5600	0.0000	0.0000	0.0000	0.9376	-3.4704	33	0	0.9	1.1	0.9	1.1	2000							
29	BEED1B	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9386	-0.4034	132	0	0.9	1.1	0.9	1.1	2000							
30	WORT1B	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9386	-0.5478	132	0	0.9	1.1	0.9	1.1	2000							
31	WORT33	1	1	0	20.39	6.09	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9570	-2.4387	132	0	0.9	1.1	0.9	1.1	2000							
32	WORTHIC_D	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9365	-0.3638	132	0	0.9	1.1	0.9	1.1	2000							
33	WORTH3	1	1	0	88.84	23.21	0.0000	0.0000	46.3200	0.0000	0.0000	0.0000	0.9571	-2.4381	33	0	0.9	1.1	0.9	1.1	2000							
34	BEED1A	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9391	-0.4185	132	0	0.9	1.1	0.9	1.1	2000							
35	WORT1A	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0011	-0.6435	132	0	0.9	1.1	0.9	1.1	2000							
36	THRB3	1	1	0	81.32	3.78	0.0000	0.0000	10.0800	0.0000	0.0000	0.0000	0.9307	-4.7732	132	0	0.9	1.1	0.9	1.1	2000							
37	SMAL32	1	1	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9385	-2.5303	132	0	0.9	1.1	0.9	1.1	2000							

Figure 36 - Illustration of the input data format

A set of macros will be developed to enable the execution of distribution and transmission planning calculations. The optimisation module will be developed in Mosel, reading the input data and returning the optimisation results to the spreadsheet. The results will contain:

- MEMG investment portfolio needed and the associated costs to meet the resilience requirements
- The expected volume of essential load that needs to be curtailed if the investment is insufficient
- Transmission network optimal security configuration with and without the contribution from distributed resources

Resources

The tools are developed using the following resources:

- Excel with Visual Basic
- Mosel and FICO Xpress optimisation

4.4 IMPLEMENTATION AND DEPLOYMENT PLAN

Gantt of the development of the product - year 2

Activity 1: Basic development

Activity 2: User Interface development

Activity 3: Continuous SW quality and security dependency

Activity 4: KPIs at component level

Activity 5: Unit test

Activity 6: early SW delivery

Activity 7: SW documentation & deliverable preparation

Activity 8: Final SW delivery

Table 5 - Implementation and Deployment Plan of IRIS Resilience Suite

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	[Shaded]																																																			
Activity 2	[Shaded]																																																			
Activity 3	[Shaded]																																																			
Activity 4	[Shaded]																																																			
Activity 5	[Shaded]																																																			
Activity 6	[Shaded]																																																			
Activity 7	[Shaded]																																																			
Activity 8	[Shaded]																																																			

5 Conclusions and next steps

The design of WP4 has allowed to develop the Use Cases and the overall structure of the IRIS product.

With the proliferation of renewable energy sources (RES) and greater grid interconnection, resources for Electric Power and Energy System (EPES) management are becoming increasingly distributed across various levels, including Transmission System Operators (TSOs), Distribution System Operators (DSOs), and Regional Security and Coordination Centres (RCCs). This shift necessitates tools capable of supporting these new communication and coordination channels.

The IRIS modules developed within the IRIS Resilience Suite will help system operators to handle these new challenges to improve the resilience of the EPES.

The next steps will be focused on engaging the development of the proposed UCs and their integration and testing.

By following these steps, these modules can transition from the design phase to practical implementation, ultimately enhancing the resilience and security of the energy grid through improved communication, monitoring, and coordination.

6 References

- [1] “R²D² Description of Action,” in Annex I to the Grant Agreement. EC, 2022.
- [2] “R²D² Grant Agreement. EC, 2022”.
- [3] EU regulation 2019/943, 2017/1485, 2017/2195
- [4] TRINITY Project: <https://trinityh2020.eu/>
- [5] COORDINET Project: <https://coordinet-project.eu/>
- [6] OpFabOperatorFabric : <https://opfab.github.io/>
- [7] PowSyBl : <https://www.powsybl.org/>
- [8] CGMES Standard: <https://www.entsoe.eu/data/cim/cim-for-grid-models-exchange/>
- [9] UCTE Format: <https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/ce/otherreports/UCTE-format.pdf>
- [10] CROSSBOW project : <https://cordis.europa.eu/project/id/773430>
- [11] ENTSO-E Regional Operational Security Coordination (ROSC) methodology RAs <https://documents.acer.europa.eu/en/Electricity/OPERATION-CODES/SYSTEM-OPERATION>



**Funded by
the European Union**

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them. Horizon Europe Grant agreement N° 101075714.