R2D2

Reliability, Resilience and Defense technology for the grid

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R2D2 Pilot Workshop

08/07/2025

R2D2

Greek Pilot –Xanthi

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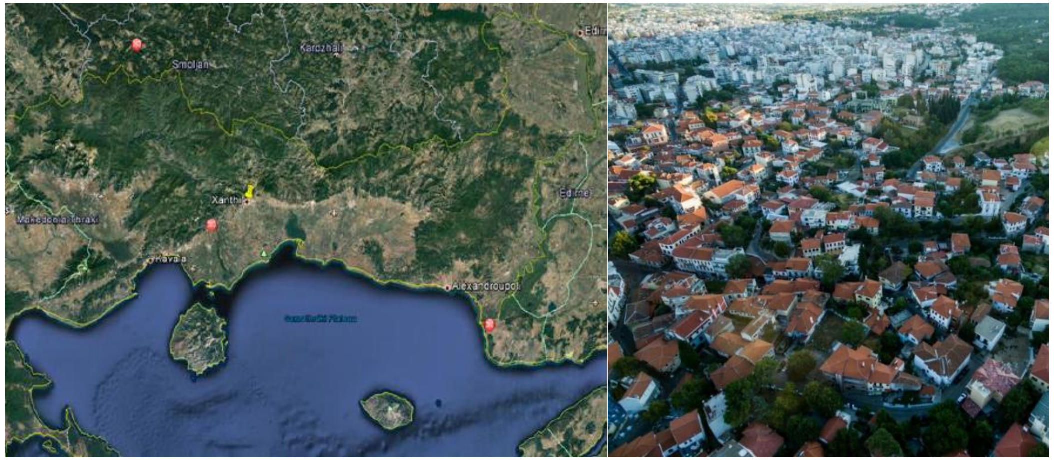
Reliability, Resilience and Defense technology for the grid

Xanthi Pilot @ glance

- HEDNO – Demo leader / end-user (C3PO/EMMA/PRECOG)
- ETRA – R2D2 coordinator / technology provider (EMMA)
- ICCS – Research & Academic - technical developer (C3PO)
- UCY - Research & Academic - technical developer (C3PO)
- CYBER - technology provider (C3PO)
- GUARD - technology provider (PRECOG)
- ICL - Research & Academic - technical developer (C3PO)

Overall Pilot Needs and Objectives

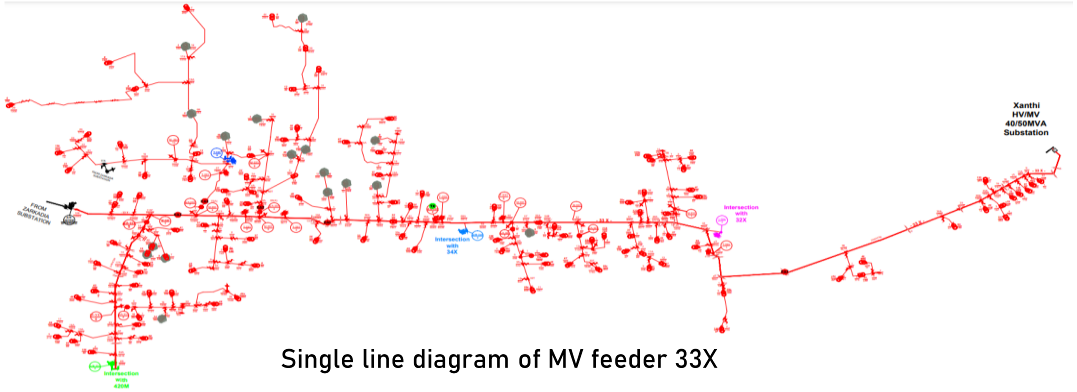
- Physical substation security enhancement
- Predictive approach on asset management
- Mitigation of extreme weather events impact on the network
- Cyber security enhancement



Xanthi region

Xanthi Pilot assets & infrastructure

- 3 MV lines from 2 HV/MV substations feeding around 247 MV/LV substations
  - Pilot MV lines: 33X, 39X, 42M
  - Primary supply: 2 HV/MV S/S (Xanthi, Magiko)
- AMI system and smart metering infrastructure on MV and major LV consumers and producers
  - Approximately 58 MV and major LV (between 55 kVA and 3800 kVA) telemetered consumers
- MV and LV RES producers
  - 39 telemetered PVs of approx. 16 MWp total installed power
  - 2 biogas units
  - Associated AMI infrastructure
- Equipment integration from previous X-FLEX project
  - Monitoring equipment in 5 MV/LV substations
  - SLAM meters in customers



Single line diagram of MV feeder 33X

MV line	Rated Power
MV line 1 (39X)	~16 MVA installed power at the line
MV line 2 (33X)	~30 MVA installed power at the line
MV line 3 (42M)	~19 MVA installed power at the line

Magiko Primary S/S & MV feeders

AMI in aerial MV/LV T/S

Xanthi Pilot Description: Software involved

Network monitoring SW

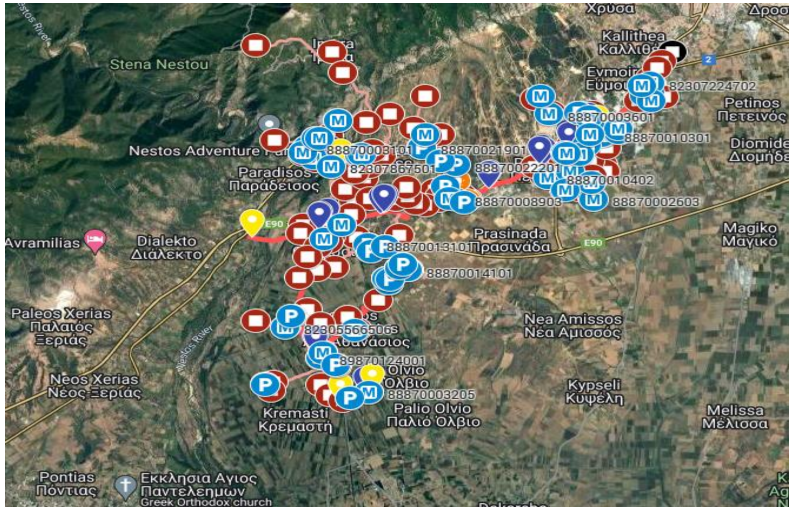
- SCADA system monitoring the 3 MV lines feeders SCADA/DMS and connected RTUs

Network Topology SW

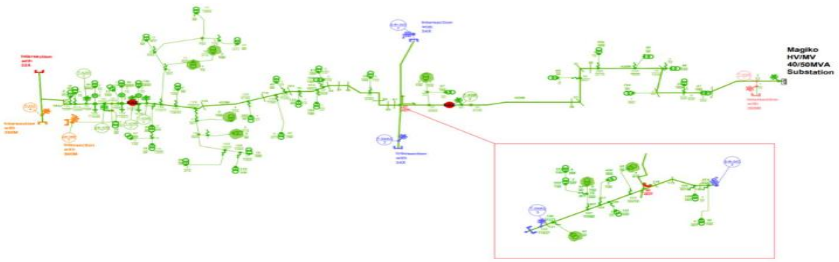
- KML files available for each MV line
- Outages Monitoring and Reporting System

DSO Data Server

- Isolated environment, hosting DSO data (SCADA data and AMI data) mostly for analytics and research purposes



.kml geographical representation in Google maps



Single line diagram of MV feeder 42M

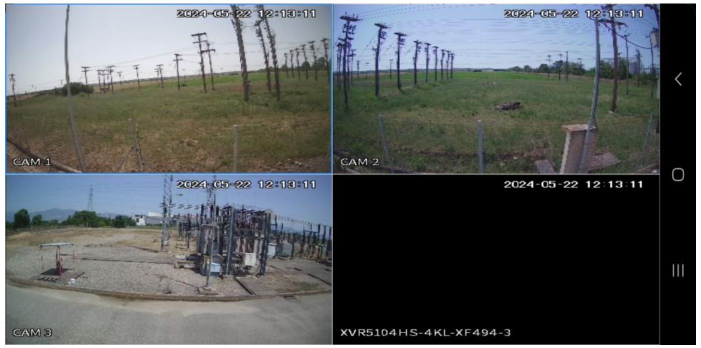
MV feeder 33X topology in MS Visio (left)

Xanthi pilot: Needs & Benefits

Physical substation security enhancement	Predictive approach on asset management
I. **Cause:** Physical attack (Primary/secondary S/S) or natural event may cause damage to infrastructure II. **Need:** Additional equipment to inspect & monitor the grid and its assets III. **Benefit: Improved Grid resilience** • Faster reaction and intervention of the DSO	I. **Cause:** Inaccessible and remote equipment inspection II. **Need:** efficient predictive approach on asset management III. **Benefit: Predictive asset management** • Decrease of costs, unplanned interruptions and technical losses
Extreme weather events impact mitigation	**Cyber security enhancement**
I. **Fact:** 2021, EWE - heavy snowfall in Greece: severe outage: 250.000 households without electricity II. **Need:** exploration of new resilience-informed planning and operational strategies III. **Benefits: Extreme events impact mitigation** • Enhanced Network reliability • Reduction in power interruption and component damage	I. **Cause:** installation / upgrade of new IT systems II. **Need:** cyber-vulnerability testing and cyber-security III. **Benefits: Evaluation mechanisms exploration of IT/OT security practices** • AMI: Dynamic threat detection & data integrity testing / prevention of possible data leak caused by misconfiguration

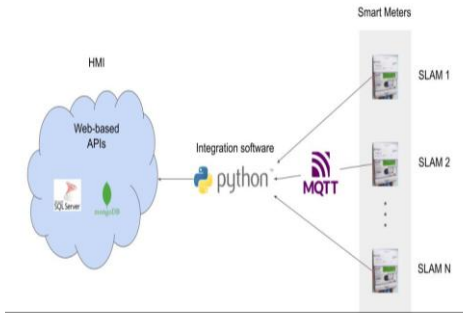
Xanthi Pilot equipment installation

- **Surveillance cameras** at HV/MV Magiko substation: *successful installation - data integration*
  - Equipment security against physical threats
  - Equipment safety due to unplanned equipment failures
- **Thermal camera**: *Successful procurement and testing*
  - Inspection on primary HV/MV Magiko S/S and Overhead local network Infrastructure (Overhead MV/LV T/S)
- **Sensor device** procurement planning
  - MV/LV T/S Physical security enhancement (e.g. alarm notification)
- **Staging Environment**
  - Testing infrastructure: emulation of Supervisory Control and Data Acquisition (SCADA) system / AMI system functionality



Images from Magiko Substation-CCTV

Thermal Images from Secondary/Primary Substations



Staging Environment Architecture

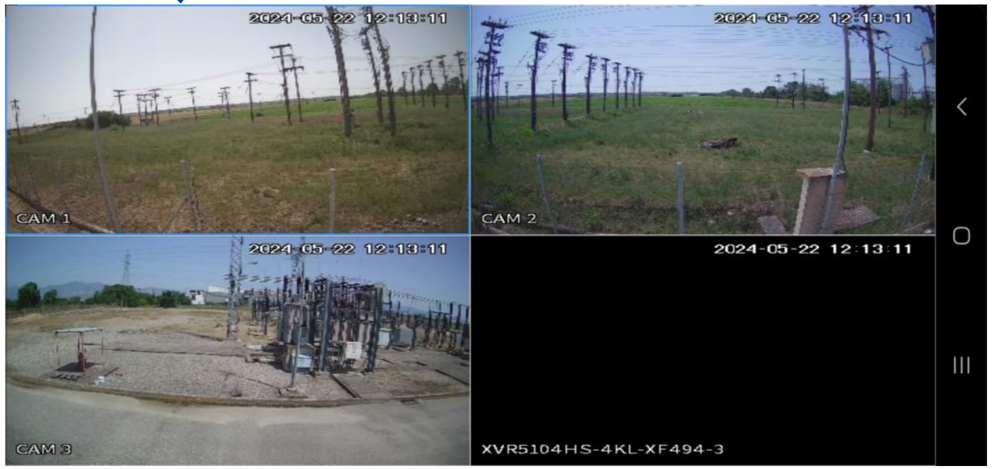
Use Case: Physical security enhancement in core network components – Primary substations (EMMA SURVEILLANCE TOOL)

Leader: ETRA

Participants: ETRA, HEDNO

Planned Functionalities

1. Installation of four (4) CCTV cameras on Magiko substation, 24-h visual inspection:
    - HV/MV T/Ss – main S/S entrance
    - MV line feeders
2. Image / video stream collection in local machine – RTSP communication with EMMA SURVEIL
3. EMMA SURVEIL: AI Trained algorithms for animals, birds, persons, fire and smoke detection
4. Classification and identification on received video stream
5. Visualization in ETER
6. Incident generation and distribution to GIMAN



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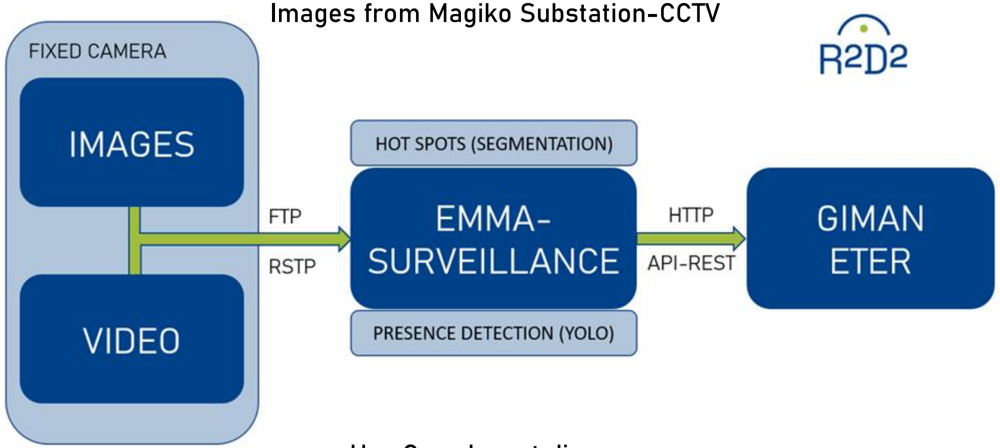
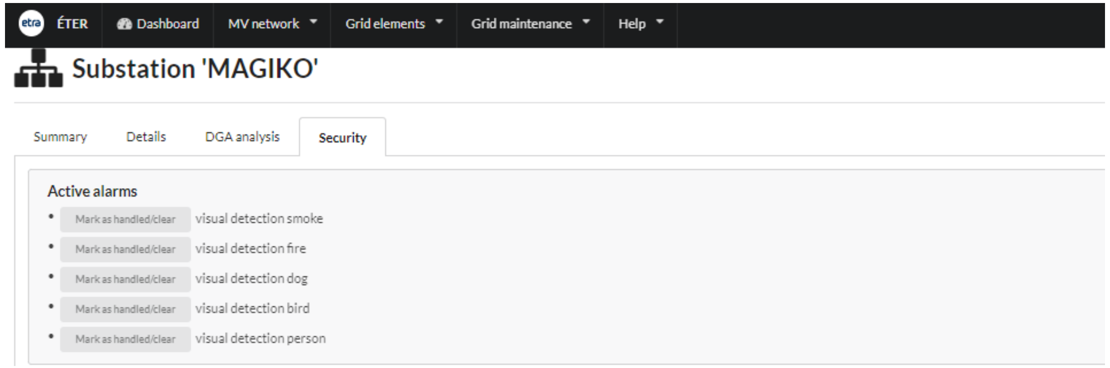


Use Case layout diagram

Preliminary demonstration

1. Testing the correct identification of physical security threats of different types:
   - Unauthorised access
   - presence of small animals or birds that might endanger the electrical components
   - presence of smoke and presence of fire
2. Triggering alarms upon the identification of every threat



Alarms, based on incidents in Magiko Substation

EMMA: Example of incident, classified as human

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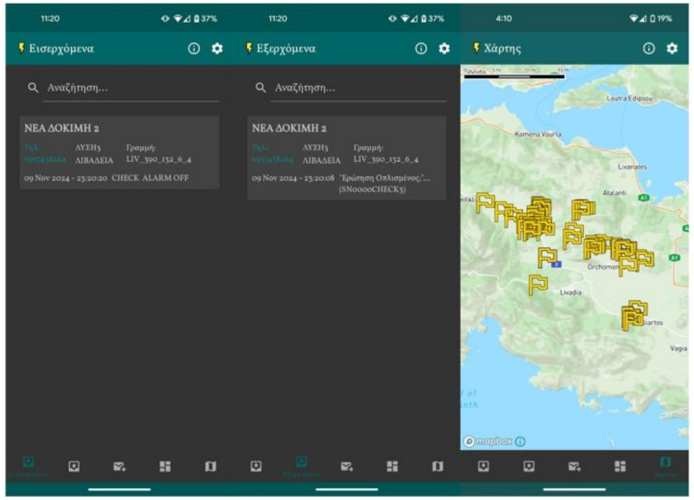
Use Case: Physical security enhancement in core network components – secondary substations

Leader: HEDNO

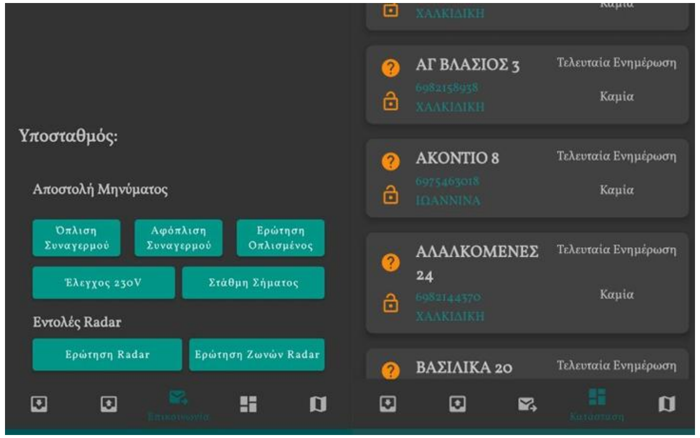
Participants: HEDNO

- Identification of aerial MV/LV substations for sensor device installation (MV lines 33X, 39X, 42M), based on theft vulnerability and risk analysis performed by HEDNO Xanthi Region

- Procurement and installation of 3 sensor devices (Jul. 25)



Installation points of similar-type sensor devices in HEDNO network (application environment)



Status of secondary transformers (application environment)

Use Case: Prevention and mitigation of cascading effects in case of extreme weather events

Leader: UCY

Participants: HEDNO, ICCS, ICL, CYBER

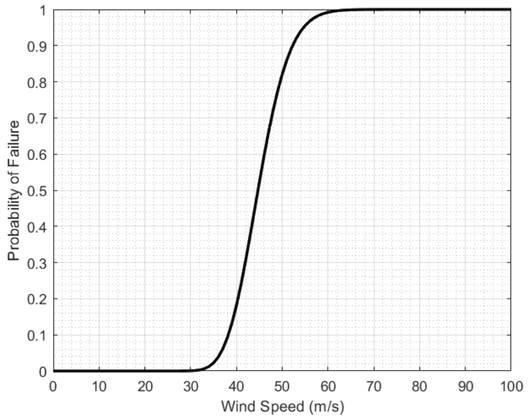
OBJECTIVES

1. **Spatial and temporal event and fragility modelling**
    - Development of flexible weather event simulators
    - Fragility-driven impact assessment
    - Evaluation of windstorm propagation and assessment of its spatiotemporal impact on distribution network
    - Stochastic framework to capture uncertainties including scenario generation and reduction algorithm based on PDFs

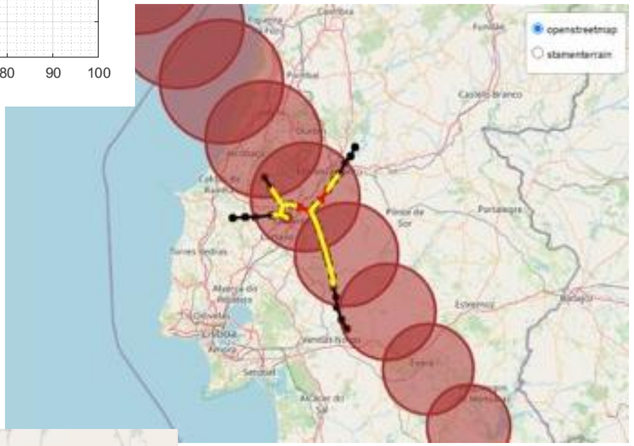
2. **Cascading modelling and quantification**
    - Cascading simulators for assessing the impact of cascading outages initiated by weather events
    - Resilience analysis of wide range of scenarios
    - Coupling of machine learning algorithms with weather event and cascading simulators for enhancing their practicality and efficiency
    - Quantification of the benefits of networked microgrids in operational flexibility and resilience

Tool Achievements: Overview

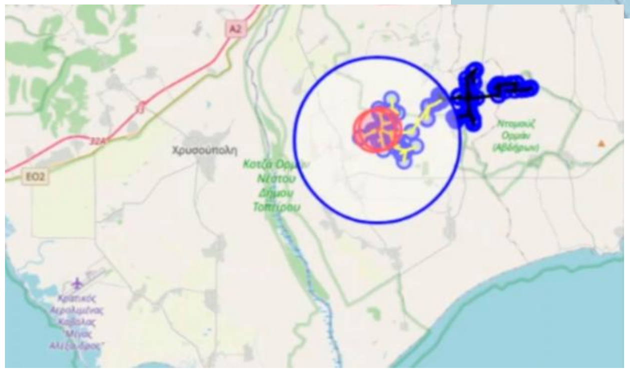
- **Advanced weather event simulator,** capable of generating historical and random wind events in a spatiotemporal manner.
- **Fragility-aware impact assessment of weather events,** coupled with **multi-temporal and multi-spatial OPF, cascading and machine learning models**.
- **Formation of networked microgrids** for enhancing operational flexibility and resilience of distribution networks
- Several **quantification metrics** can be calculated, along with many project KPIs, e.g., energy not supplied.
- Applied on **IEEE test systems and the 125-bus Xanthi pilot network**.
- **Preliminary demonstration** – currently TRL=5



Wind fragility curve of OHL



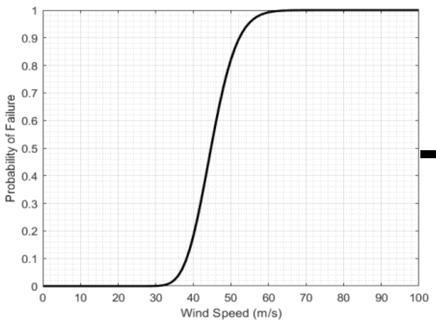
Spatiotemporal windstorm event modelling (IEEE test system)



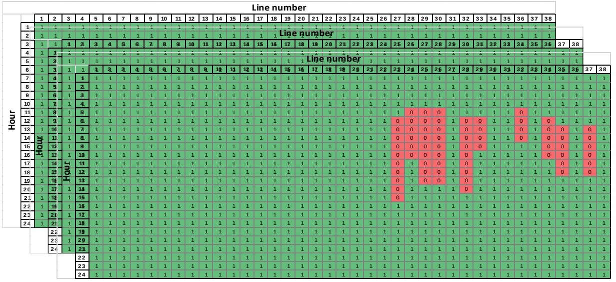
Xanthi Pilot System Application

Tool Achievements: Spatial and Temporal Weather Event Simulator and Fragility Assessment

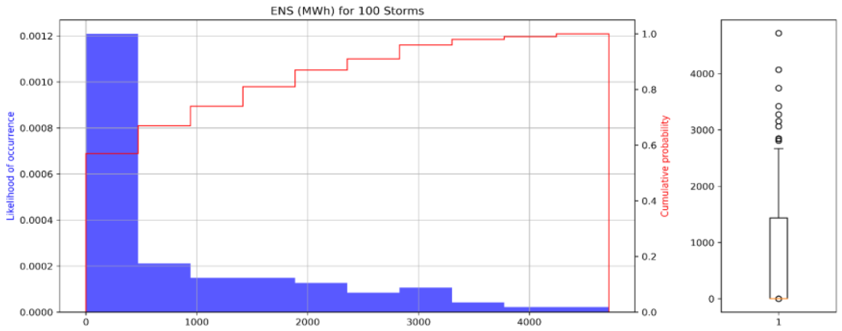
Spatial and Temporal Modelling of the Event



Asset Fragility Assessment



Time-series of network status

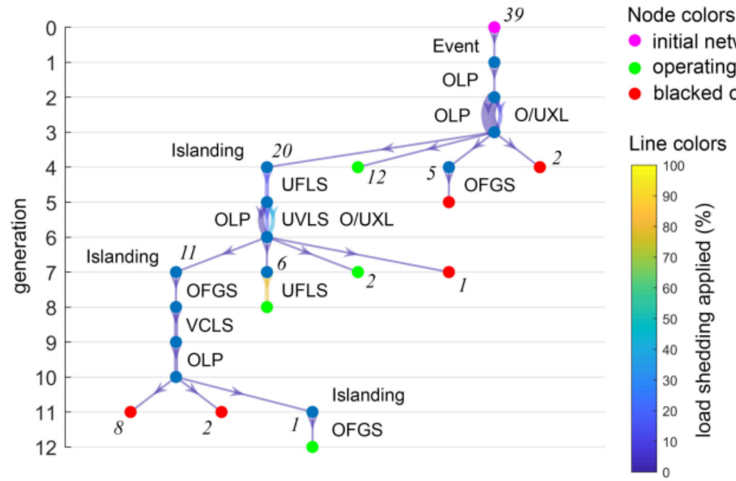


Impact Assessment - ENS

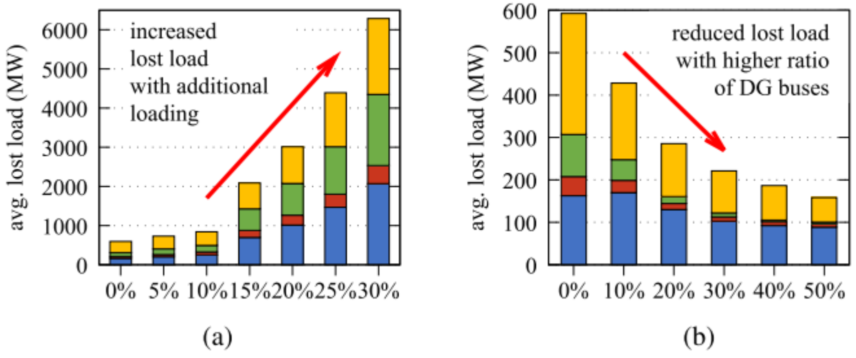
Tool Achievements: AC Cascading Simulator

- Coupled with windstorm event simulator for simulating **wind-induced cascading outages**
- Capable of modelling the **spatial propagation of cascading outages** across the system, including **various protection mechanisms**
- Capable of **quantifying various cascading metrics**, e.g., islands formed, number of protection operations, load shedding, etc.

Visualization of a cascade in the IEEE 39-bus network



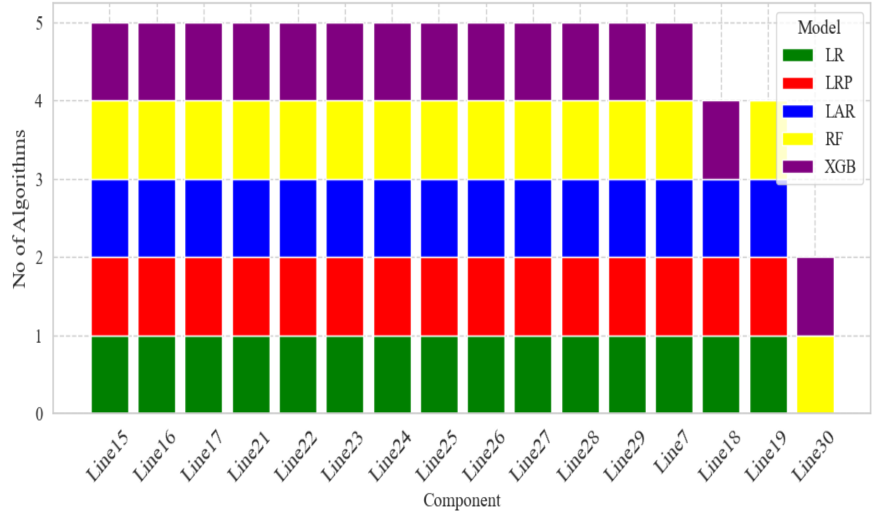
Causes of lost load: UFLS (blue), UVLS (red), VCLS (green), and tripped buses (yellow). (a) Additional loading. (b) Ratio of DG buses



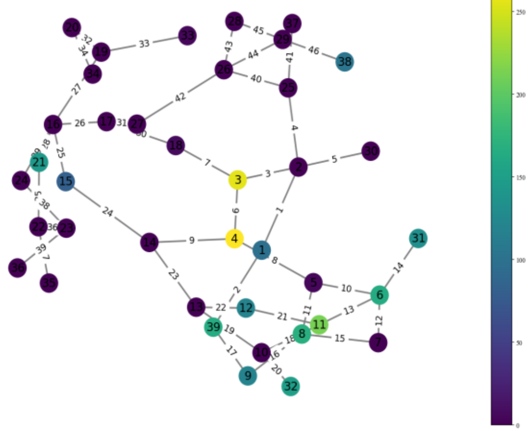
Tool Achievements: ML Applications

- **Identification of critical power system components** in means of contribution to load shedding as a result of cascade propagation
- **Accurate prediction of bus load shedding** as a result of cascade propagation using solely the line status along machine learning models.
- Investigate whether machine learning systems deployed to monitor the operation of power systems are susceptibles to **malicious machine unlearning**.

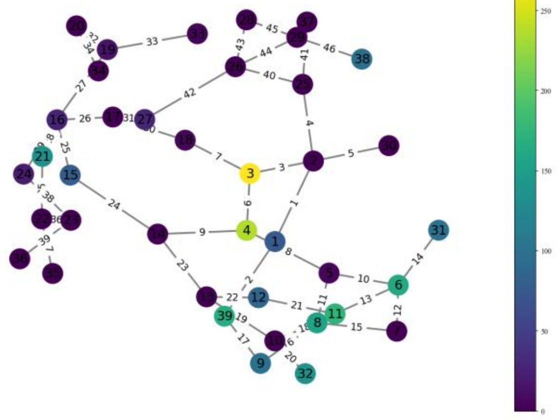
Identification of critical components and ML comparison



Actual Load Shedding



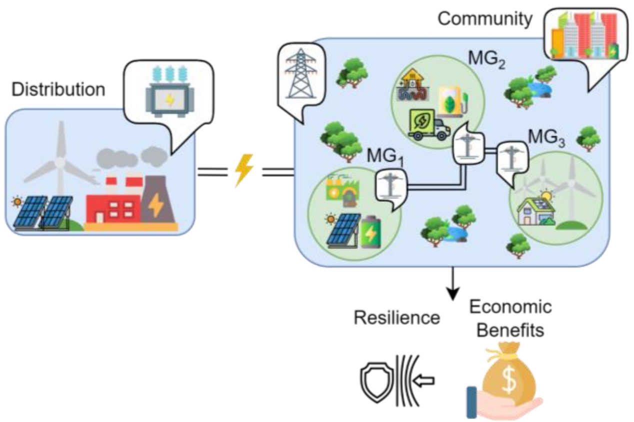
ML-predicted Load Shedding



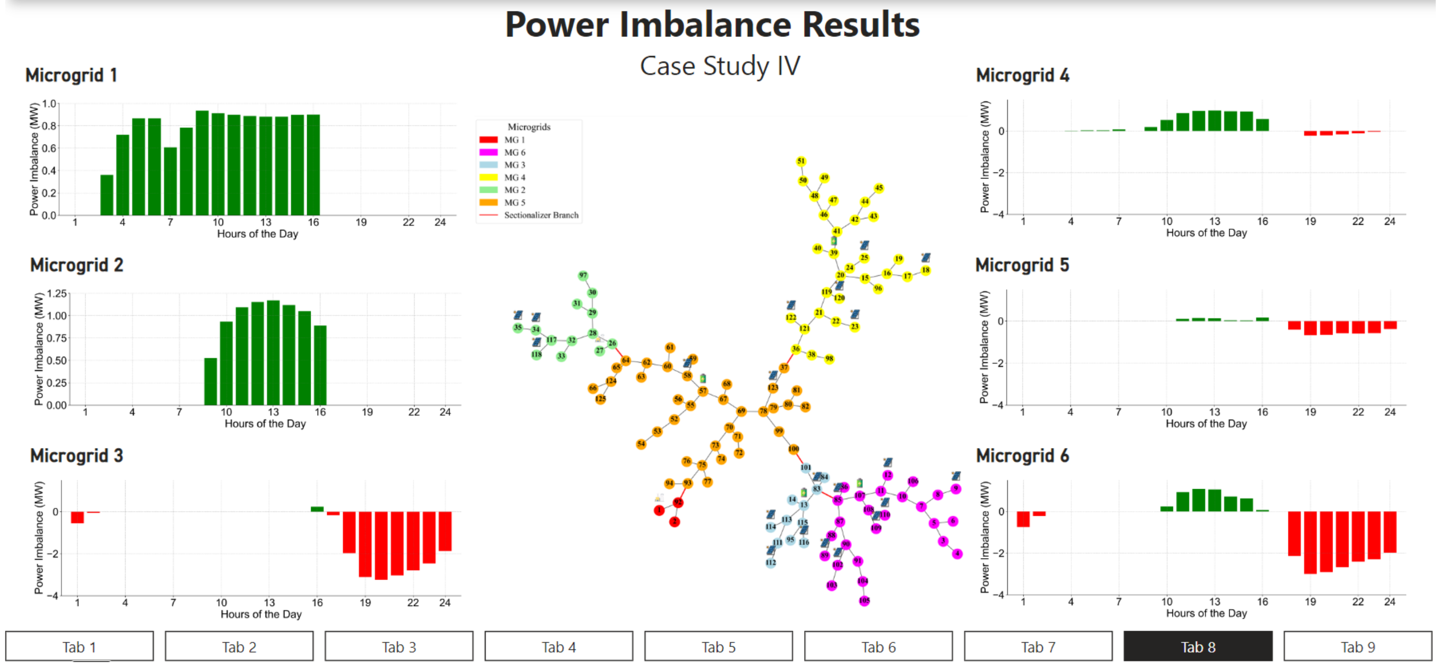
Tool Achievements: Networked Microgrids for Resilience Enhancement

NMGs can provide:

- Resilience enhancement
- Operational flexibility
- Reduced load shedding
- Coordinated energy management
- Economic benefits



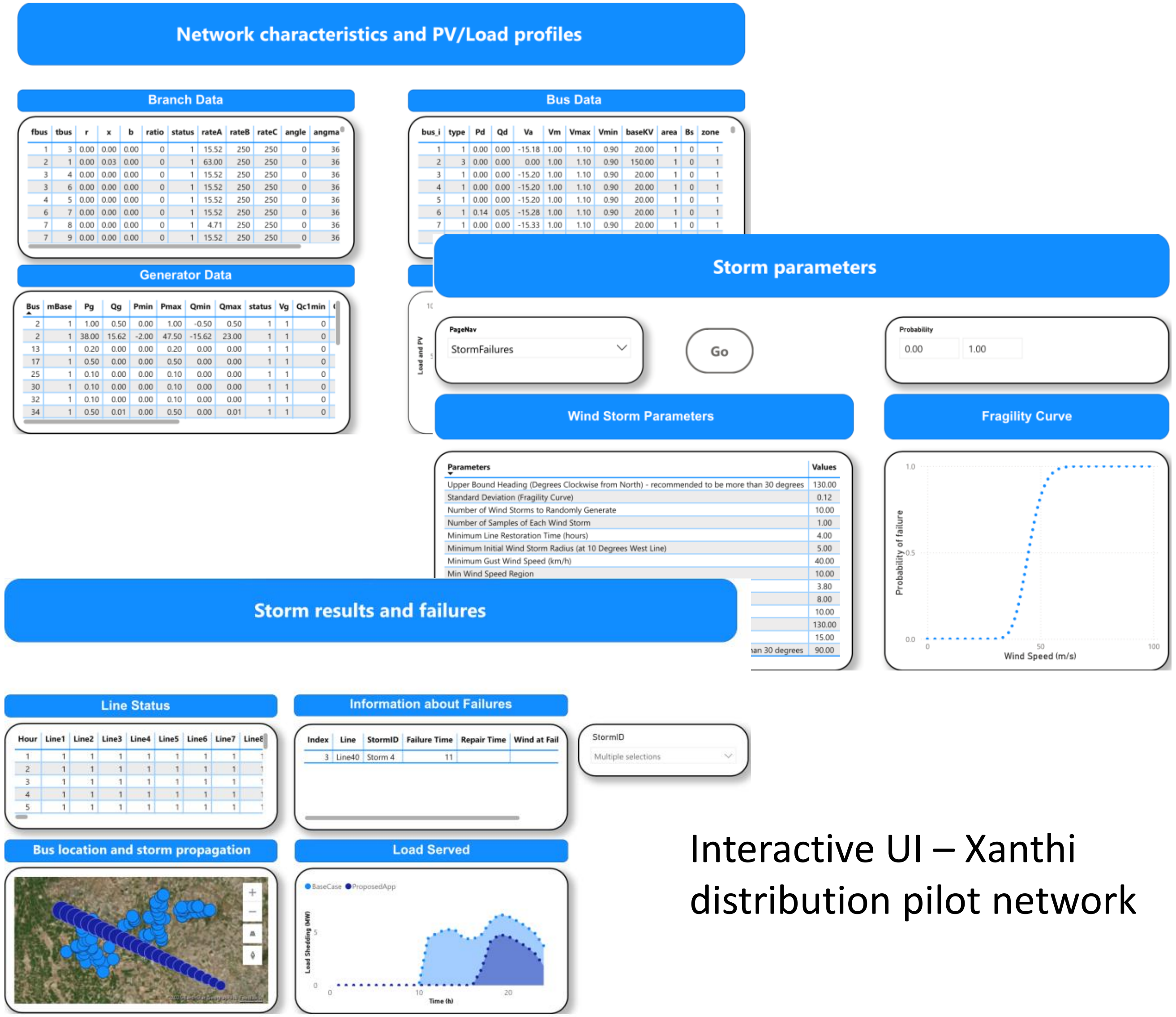
Formation of Networked Microgrids under Emergency Operation with Power Exchanges



Application on Xanthi demo distribution network: impact assessment and resilience enhancement against windstorm events

Demonstration activities

- Targets of preliminary demonstration:
  1. Parametrization of wind-storm event, via input by the DSO/weather provider.
  2. Assessment of wind-storm's impact in the local grid (MV line 42M)
     - Fragility-driven impact assessment by deploying wind-related fragility curves for overhead lines
     - Energy not served (ENS) calculation
  3. Investigation of benefits of microgrid formulation scenarios: power losses reduction potential
- Preliminary demonstration conclusions:
  1. Weather event simulator, fragility impact assessment and resilience enhancement via NMGs achieved.
  2. Interactive user interface developed, enabling the end-user to insert network, fragility and event characteristics.
  3. Preliminary results show approximately 40% and 25% reduction respectively in energy not served and operational costs during an extreme wind event via the formation of networked microgrids.



Interactive UI – Xanthi distribution pilot network

Key Outcomes

- ✓ *Network data sharing with **advanced state estimator systems** and experience with **AI tools***
- ✓ *Exploration of **network flexibility scenarios***
- ✓ ***Enhanced supervisory capabilities** in critical infrastructure of the network (High Voltage/Medium Voltage substations)*

Focus for Future Research

- ❖ Digitization and Monitoring of the Network & Low Voltage (LV) Monitoring
- ❖ Exploration of Broader Flexibility Sources (Battery Energy Storage Systems - BESS, Black-Start Capabilities)

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