Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

Beyond SmartGrids: Making the electric grid secure, stable, reliable and resilient

08th of April of 2021

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Institute for Energy Research of Catalonia, IREC:

Began its R+D+I activities in January 2009.

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IREC is a reference institution for Energy Research in Catalonia, Spain and EU.

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RESEARCH AND TECHNOLOGICAL AREAS

- **Advanced Materials**
  - Functional Nanomaterials
  - Catalysis
  - Materials for Solar Systems
  - Nanoionics and Fuel Cells
  - Energy Storage and Harvesting
- **Bioenergy and Biofuels**
  - Thermochemical Conversion
  - Biorefinery

4 groups within this unit

Research Units

- **Energy Efficiency: Systems, Buildings and Communities**
  - NZEB (Net Zero Energy Buildings and Communities)
  - Integration of Renewables.
  - Smart Grids and Microgrids
  - Green IT
  - Electric Mobility
  - Energy Analytics

3 groups within this unit

Technological Development Units

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POWER SYSTEMS GROUP – RESEARCH Objectives and keywords

Power Systems Group Strategy aims to provide solutions for the challenges of the future power systems in order to ensure the proper advent and implementation of the Digital Grid.

The global objective for the group **is to set the path of future electrical network by the development of innovative solutions for the challenging task of ensuring resilient, stable, secure, digital and RES-based electrical network as the future of Power Systems**.

- ✓ Renewable Energy Sources
- ✓ Energy Storage Systems
- ✓ Power Electronics
- ✓ Grid Integration
- ✓ Smart Grids & Microgrids
- ✓ IoT for Energy
- ✓ Grid Digitalization
- ✓ Resilience
- ✓ Cyber-Security
- ✓ Electric Vehicle

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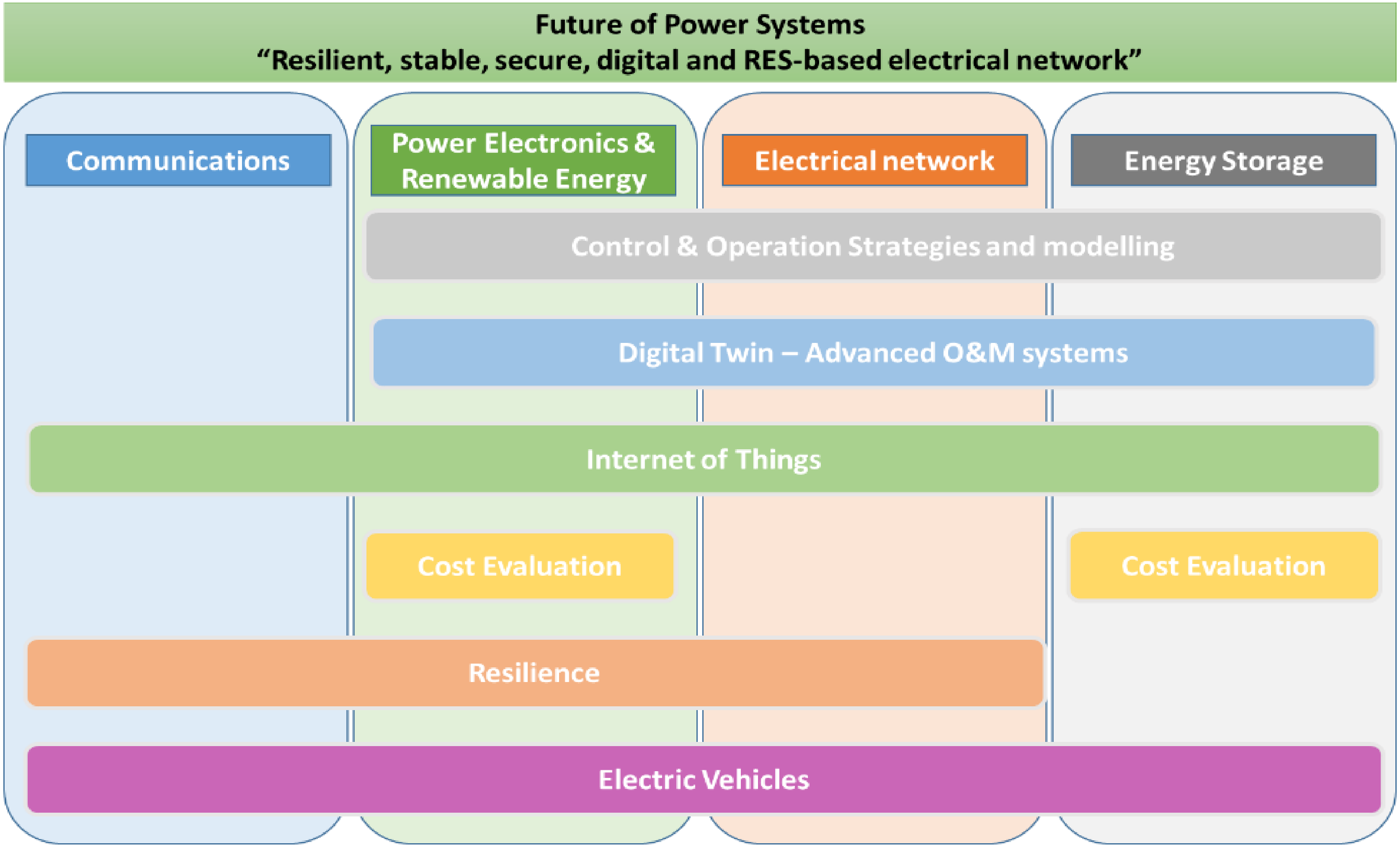
POWER SYSTEMS GROUP - RESEARCH LINES



POWER SYSTEMS GROUP - Activities

Future of Power Systems
“Resilient, stable, secure, digital and RES-based electrical network”

Communications
- IoT-based comms.
- Standards
- CyberSecurity
- Gateway development
- SCADA & HMI

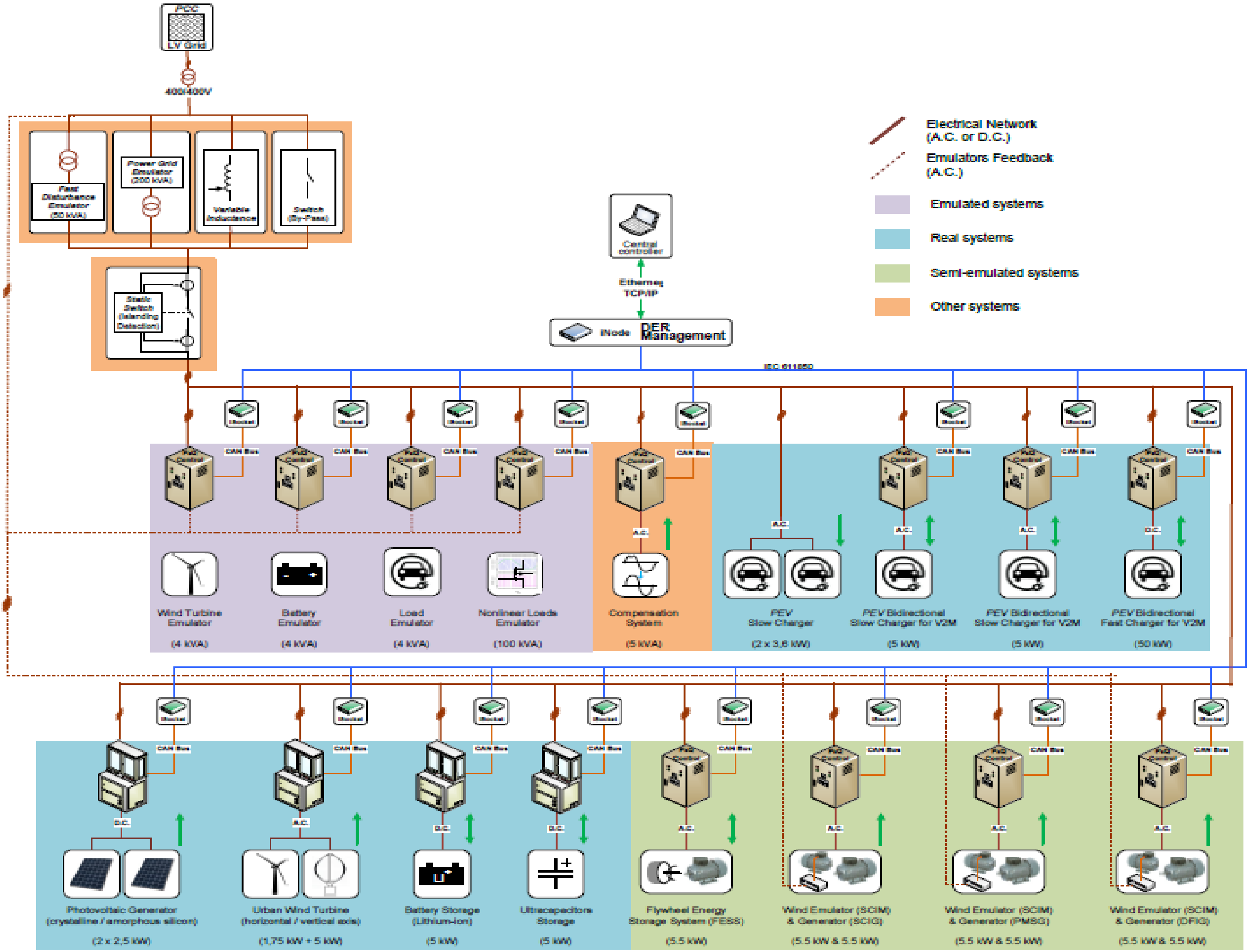
Power Electronics & Renewable Energy
- PE design & control
- Power Quality, Stability & Coordination
- RES Grid Integration
- Digital Twin

Electrical network
- State Estimation & Fault-Location
- Resilience
- Grid operation & Grid Edge
- Grid concepts: AC, DC and Hybrid

Energy Storage
- Hybrid concepts
- Advanced BMS
- EV applications
- State Estimation
- Grid support

IREC Energy SmartLab

https://youtu.be/VgWzPUcAVAk



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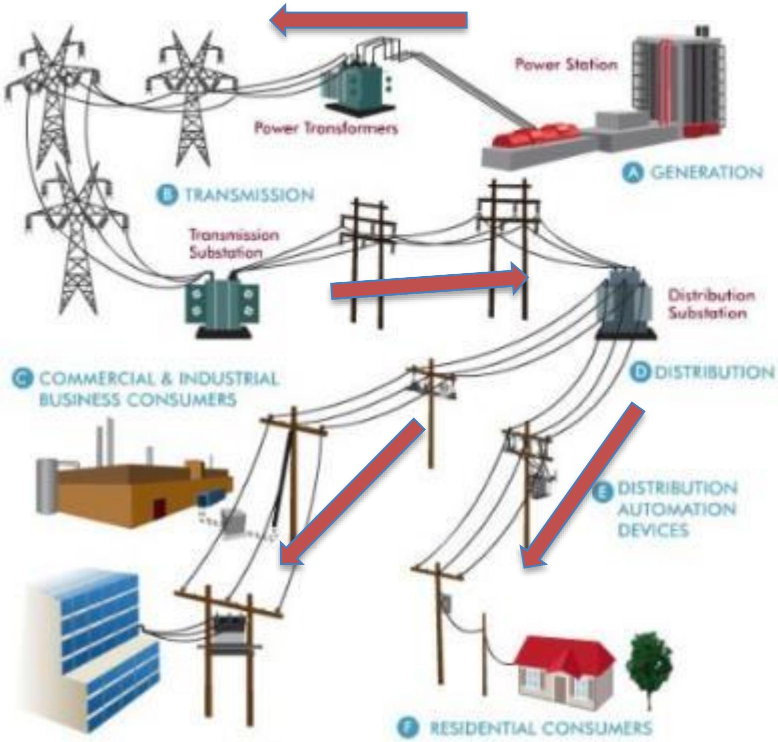
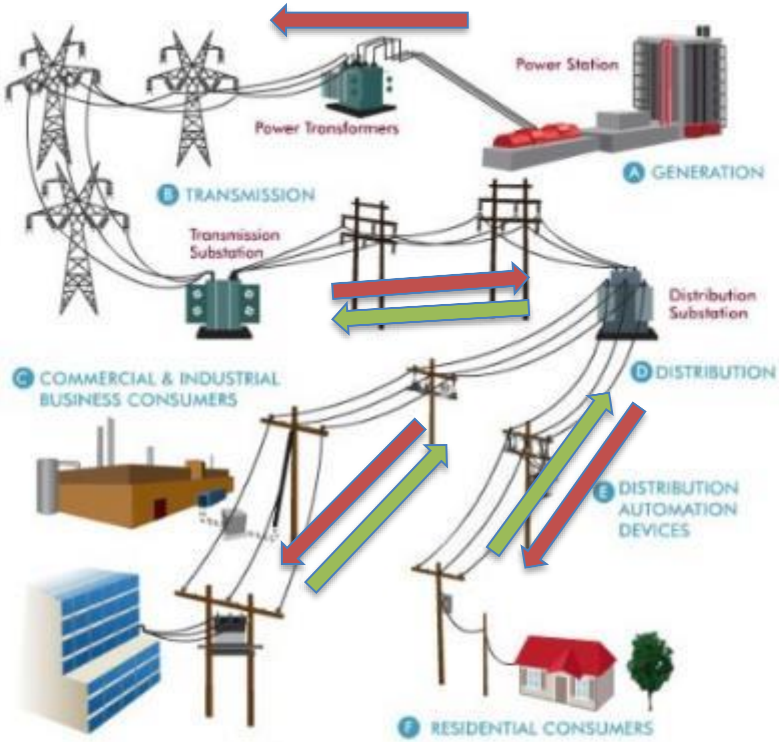
Conventional Grid



Smart Grid



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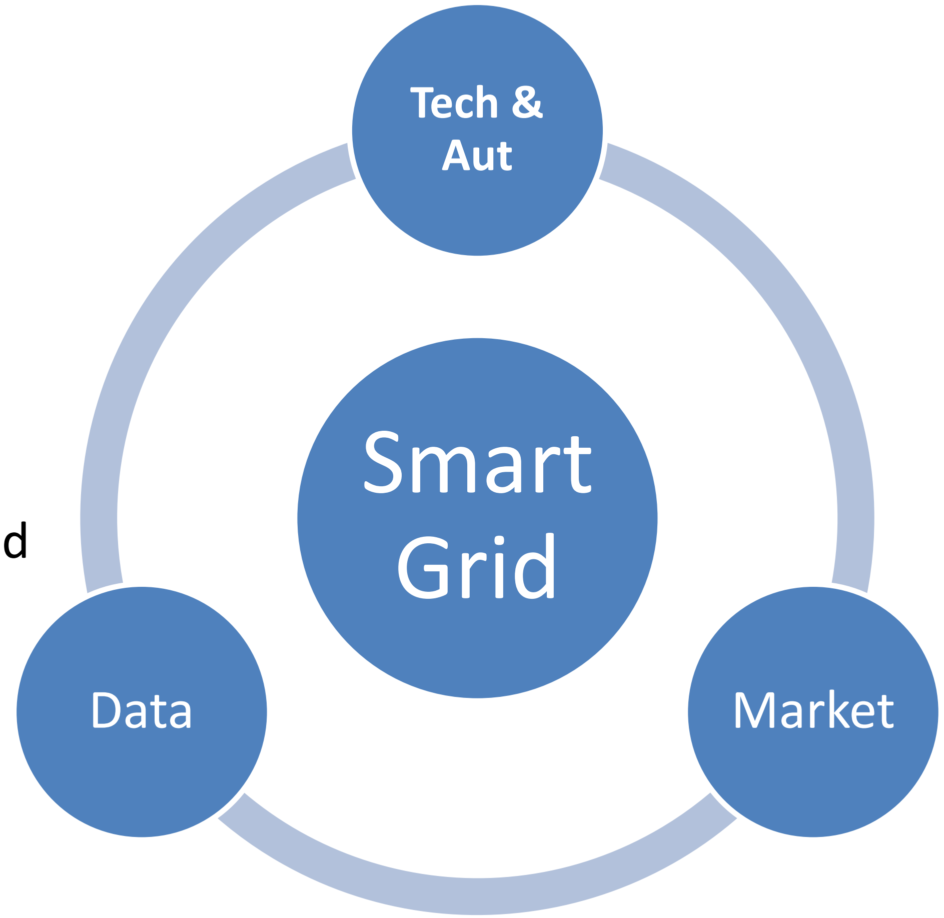
New electrical grid paradigm: SMART GRID CONCEPT

- Remote control and automation.
- Comprises everything from generation to consumption.
- The grid becomes
  - more flexible,
  - interactive
- Advanced management of the grid
  - sustainable, reliable and economic manner,
  - built on advanced infrastructure
- DER integration



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Introduction

Although, historically the electrical grid already made use of IT systems (as well-known **SCADAs**).

The **paradigm change** carried out by the increase of **RES, ESS, comms and IoT**, is opening novel opportunities for real-time monitoring and operation, wide-area information sharing, system interconnection, among others.

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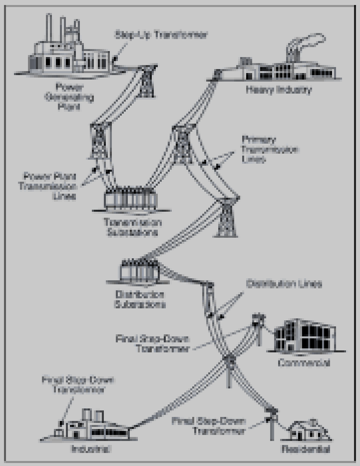
CURRENT DISTRIBUTION GRID

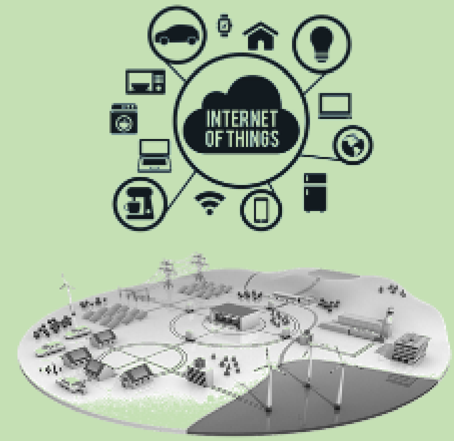


Large installation of

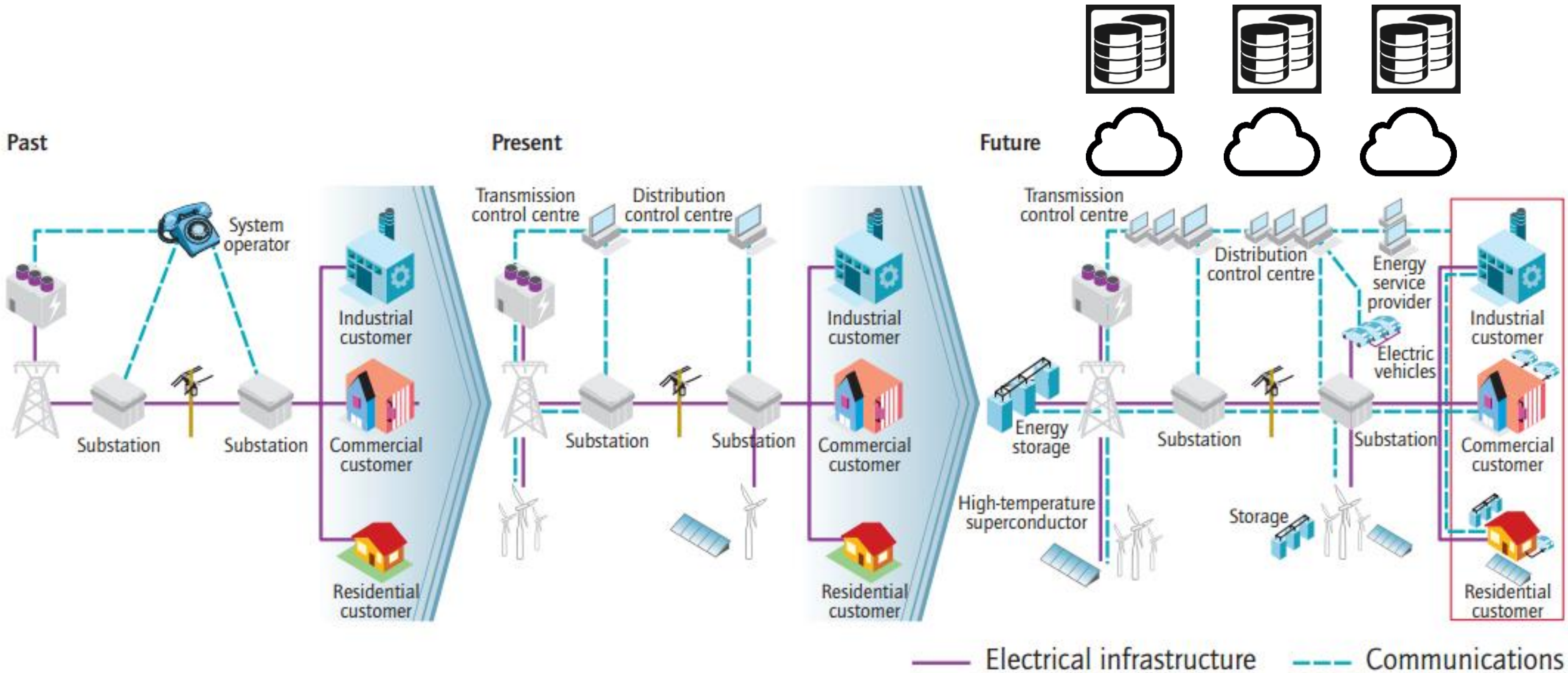
- IoT
- IT systems
- DER & ESS
- Automation
- Power Electronics

leads to

COMING DIGITAL DISTRIBUTION GRID



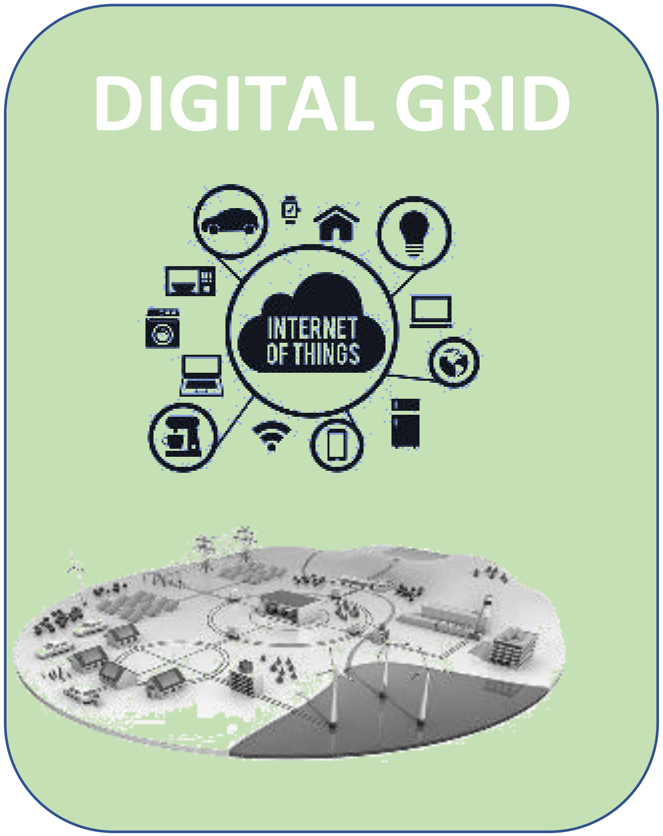
Introduction



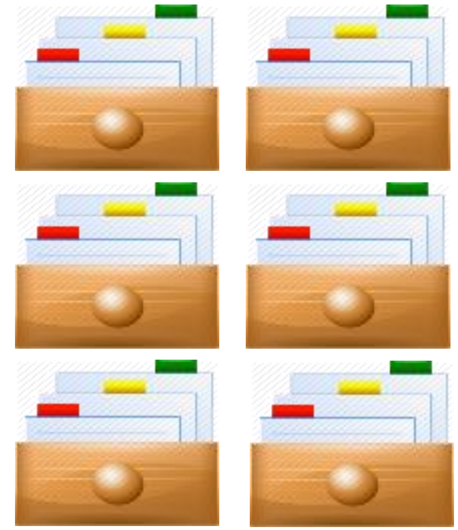
SMARTGRID

DIGITALGRID

Digital Grid



Sensors / Meters

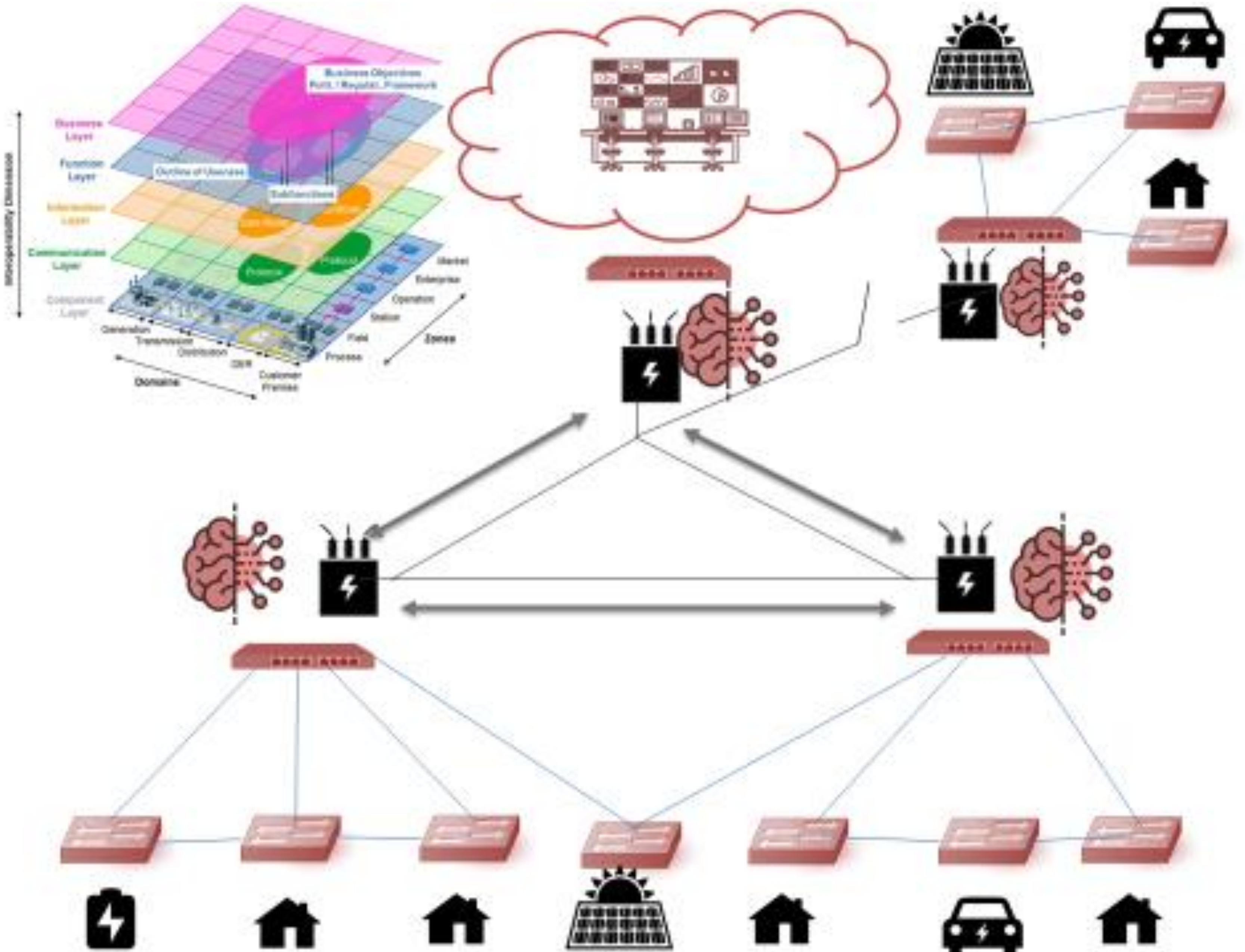


Lots of DATA

- Optimize actions
- Take better decisions
- Increase knowledge

Actuators / controllers

Digital Grid



Digitalization

How can we do it?

Transport layer protocols

NB-IOT
ZigBee
RFID
LoRa
Lte Advanced Pro
Wi Fi
Bluetooth SMART
6LoWPAN
SIGFOX One network A billion dreams

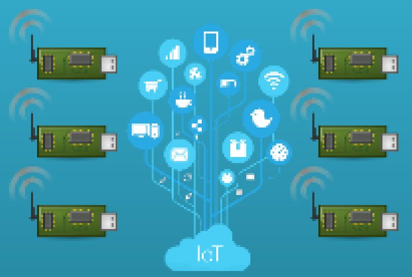
Wireless

PLC

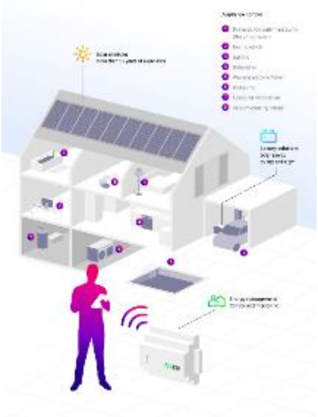
Cable based

Smart Inverters

IoT Sensors & Actuators



Internet of Things

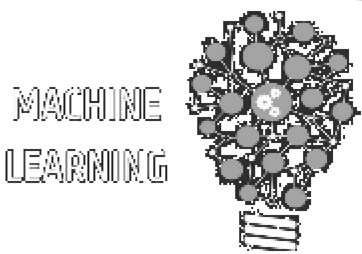


EnergyBox

SmartMeters

Challenges

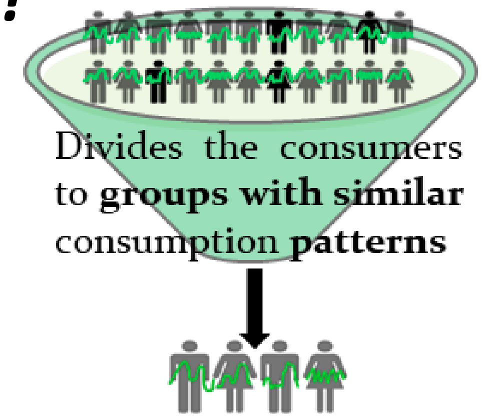
What can we do with data and automation?



Big Data

Forecasting

- Consumption
- Weather
- Climate
- Generation



Segmentation

Optimization

Control

Opportunities & Challenges of the Digitalization of the Electrical Distribution Grid

RELIABILITY

PRICING

SUPPLY-DEMAND INTEGRATION

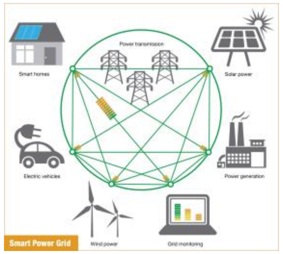
CYBERSECURITY

GRID STABILITY

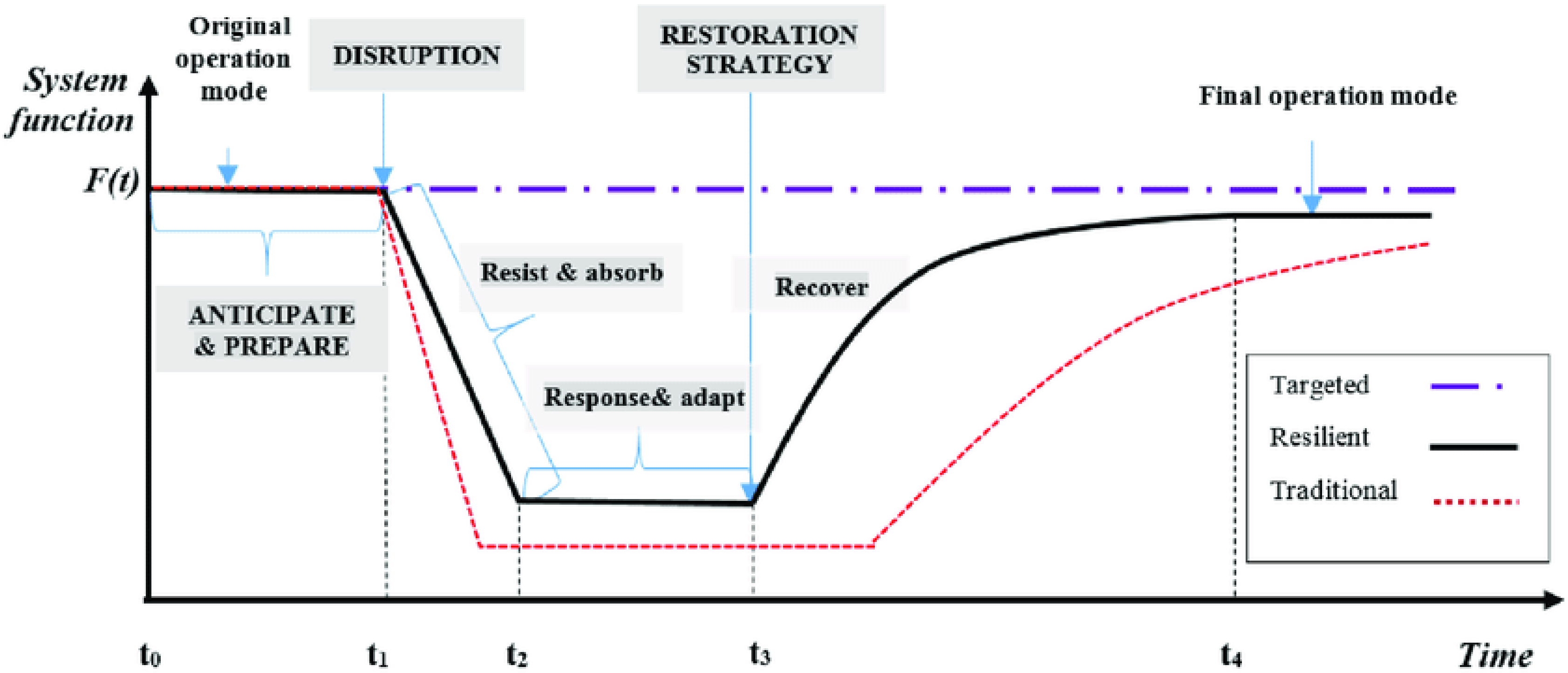
RESILIENCY

INTEROPERABILITY

ADAPTABILITY

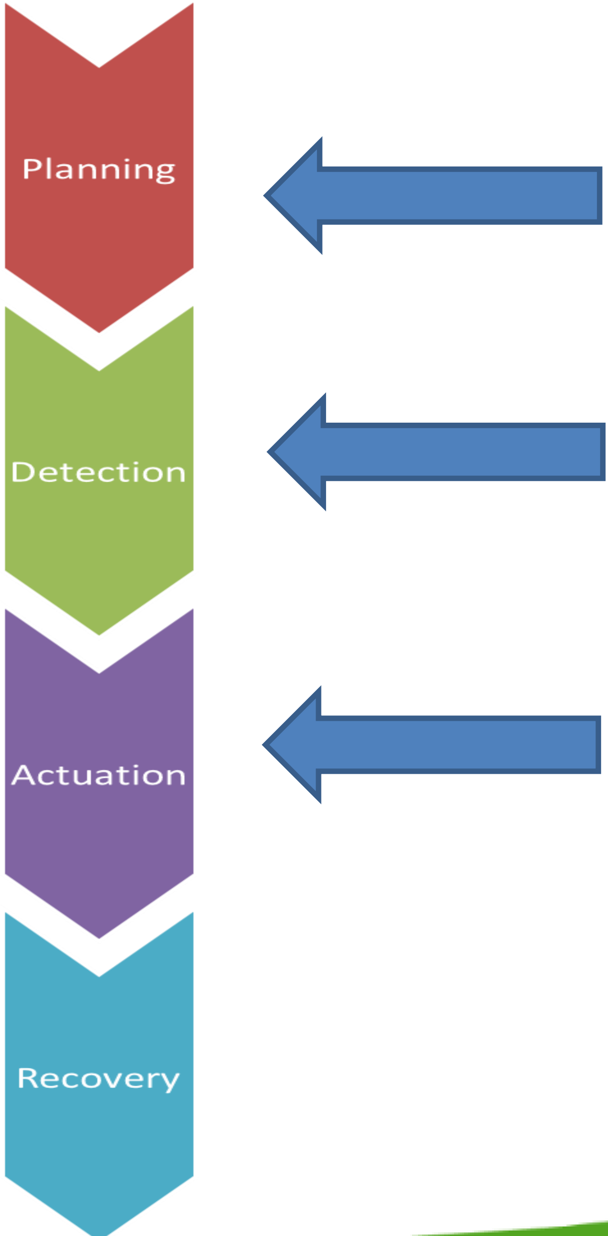


Actions for resilience, security and system reliability



Planning → Detection → Actuation → Recovery

Activities to be presented today

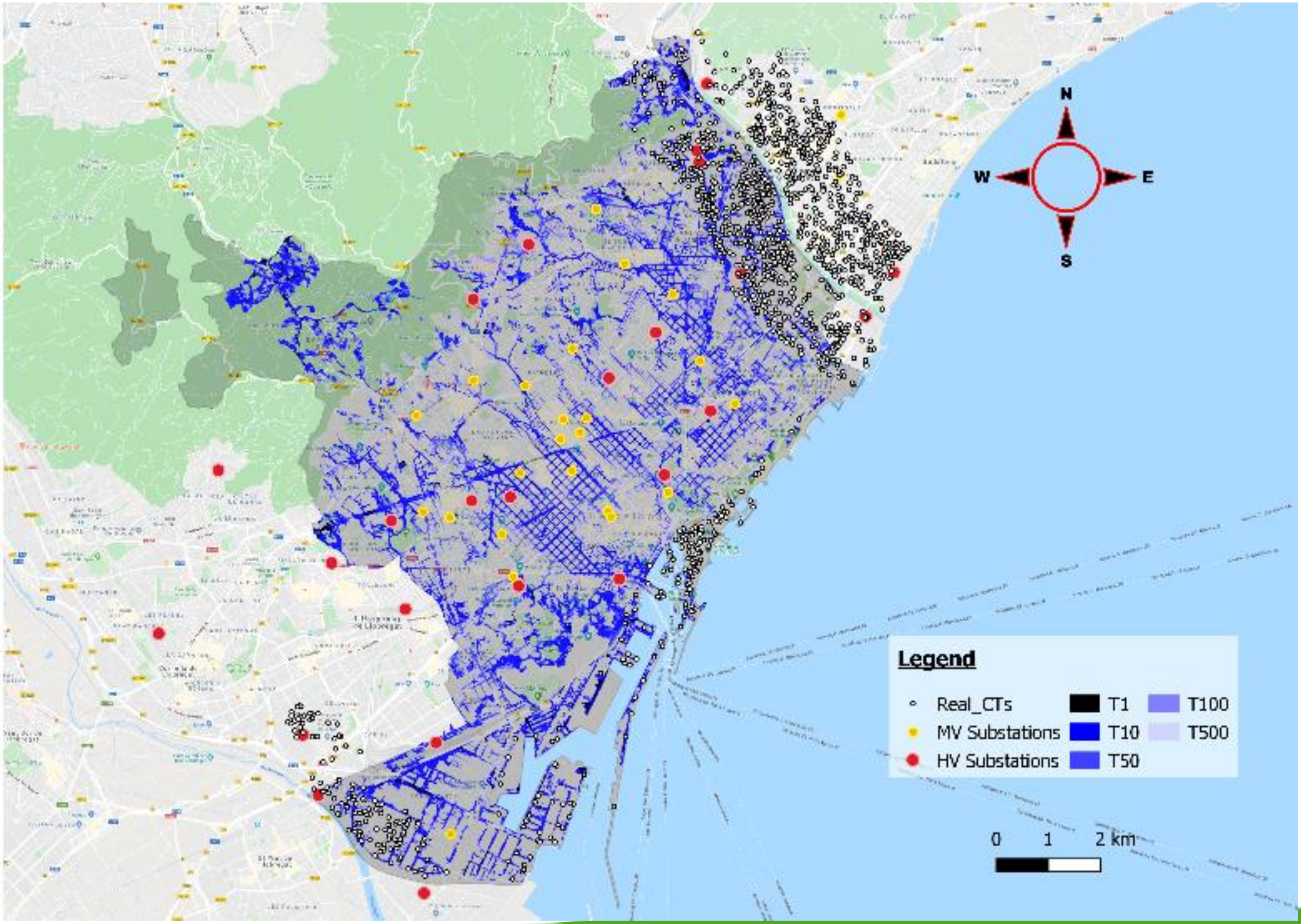


Risk Assessment tool for climate and weather events

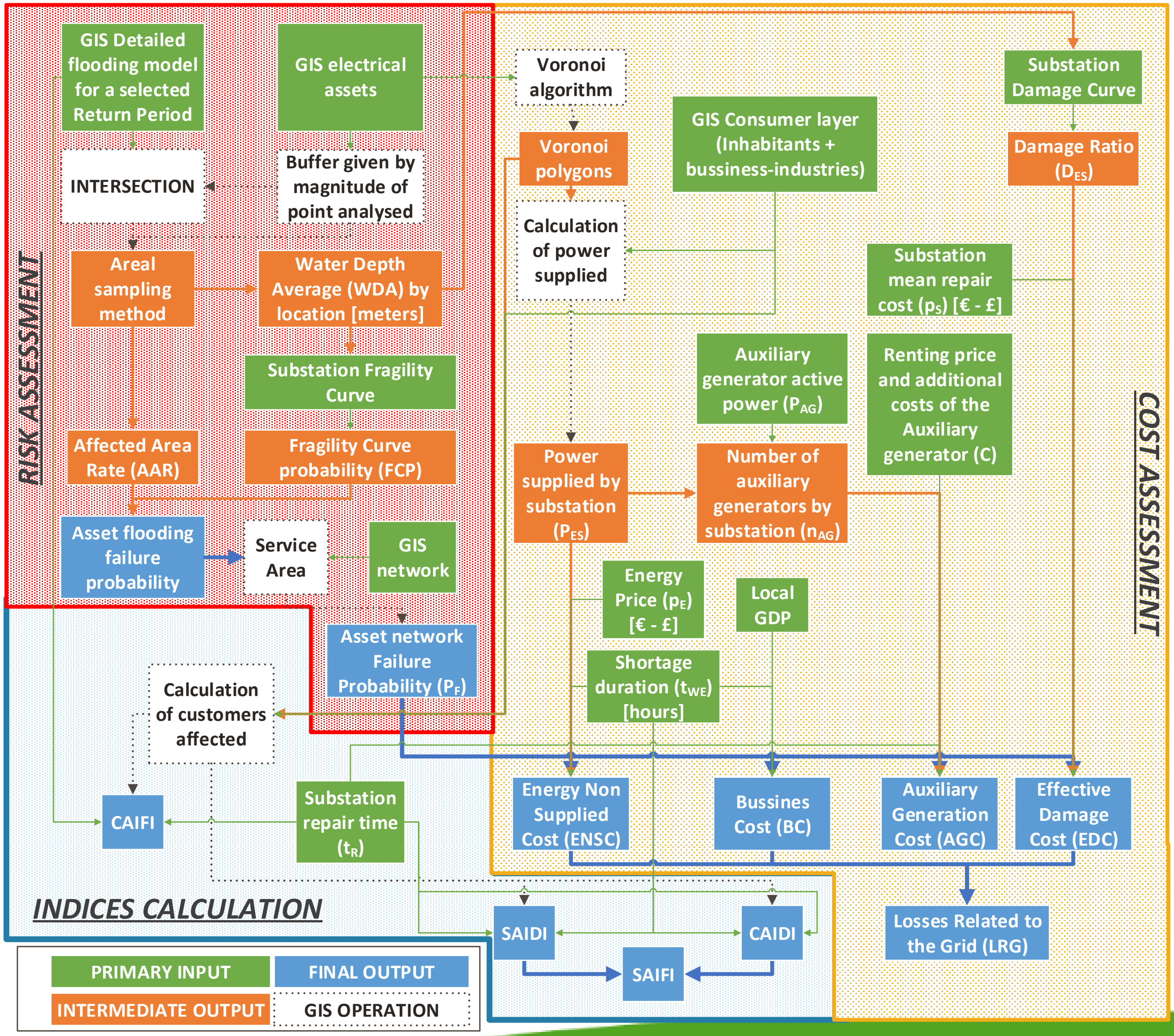
Fault identification and location algorithm

Self-healing and clusterization of distribution grid

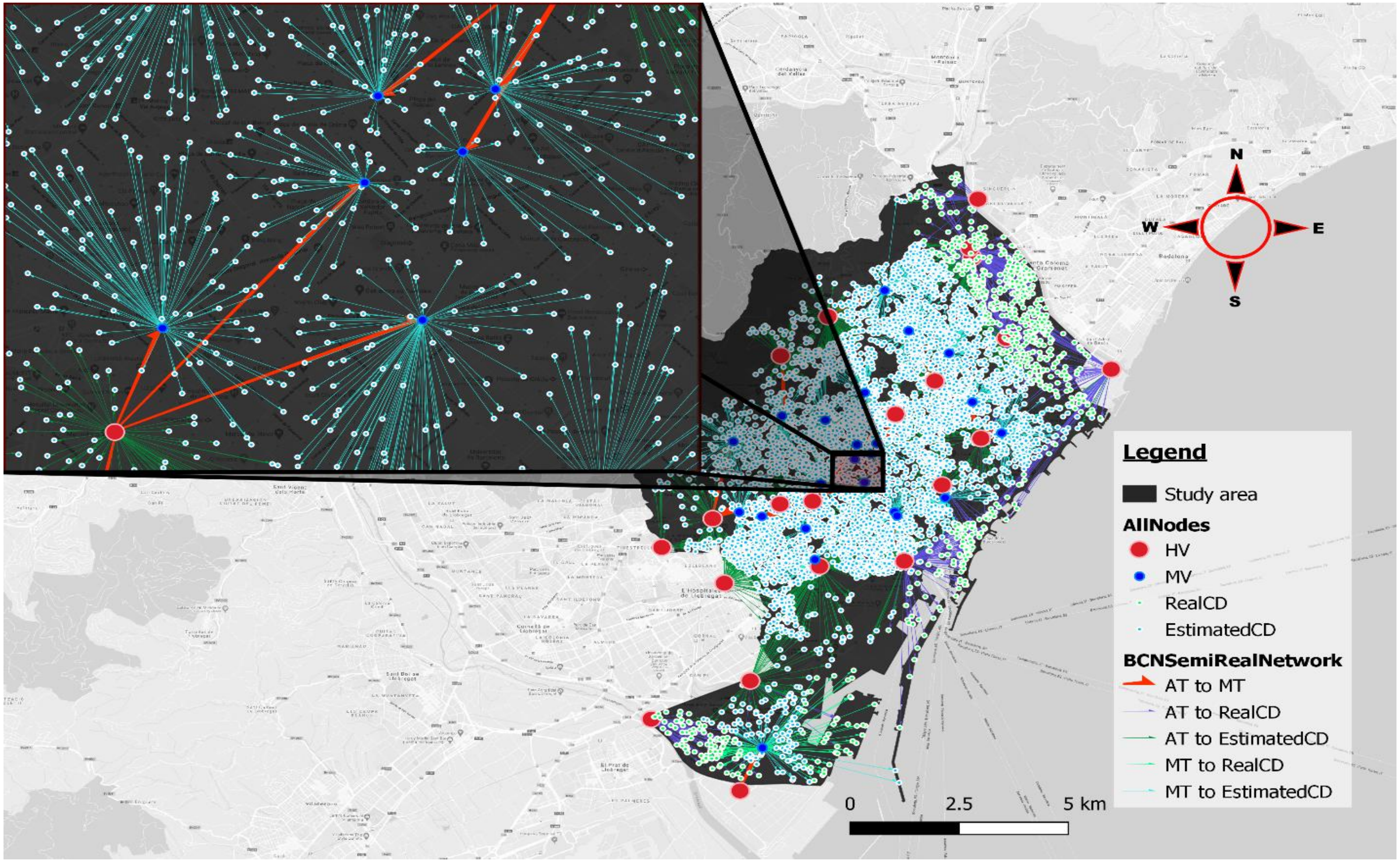
Planning: Risk Assessment tool for climate and weather events



Planning: Risk Assessment tool for climate and weather events



Planning: Risk Assessment tool for climate and weather events



By taking advantage of existing data and parameters (population density, energy consumption, mean distribution, etc), estimations for the rest of the zones can be made. Example: **GREEN** real data, **BLUE** estimated electrical distibution centers.

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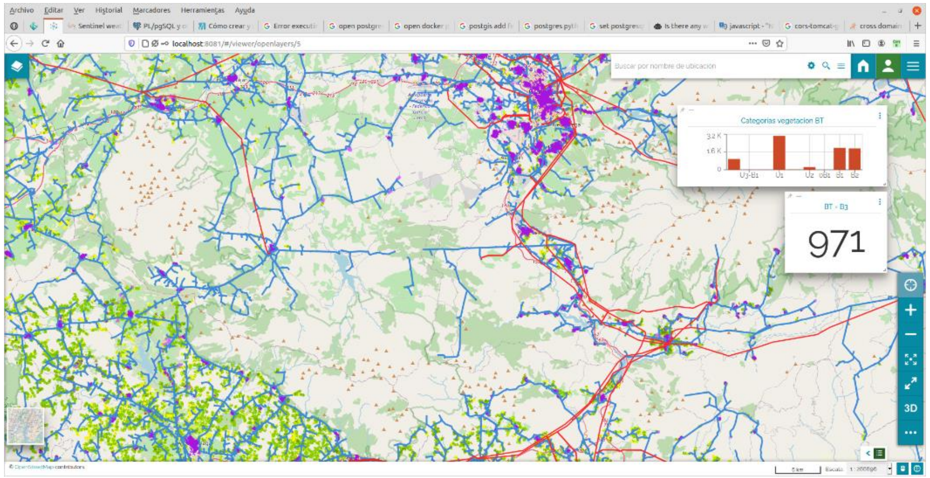
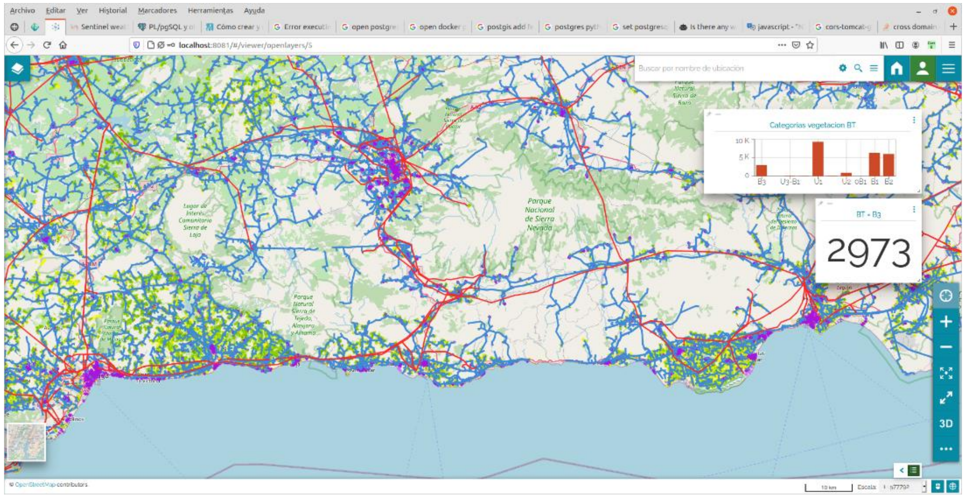
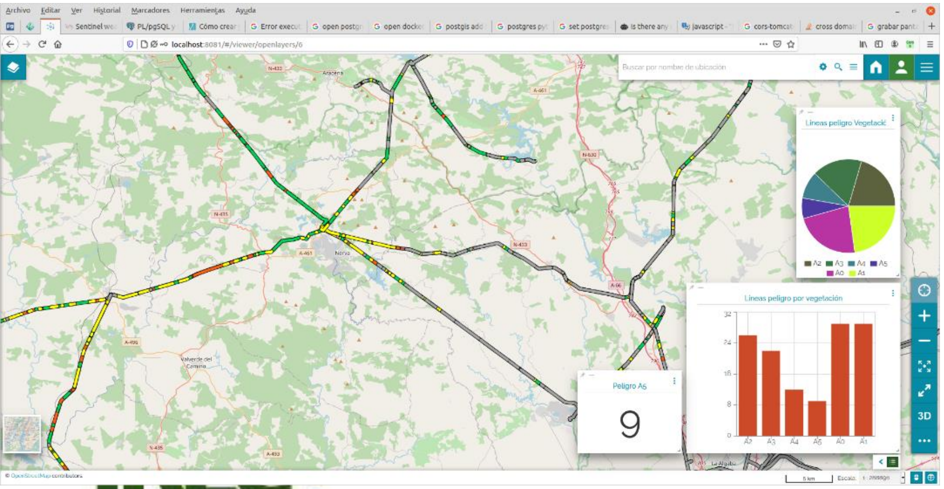
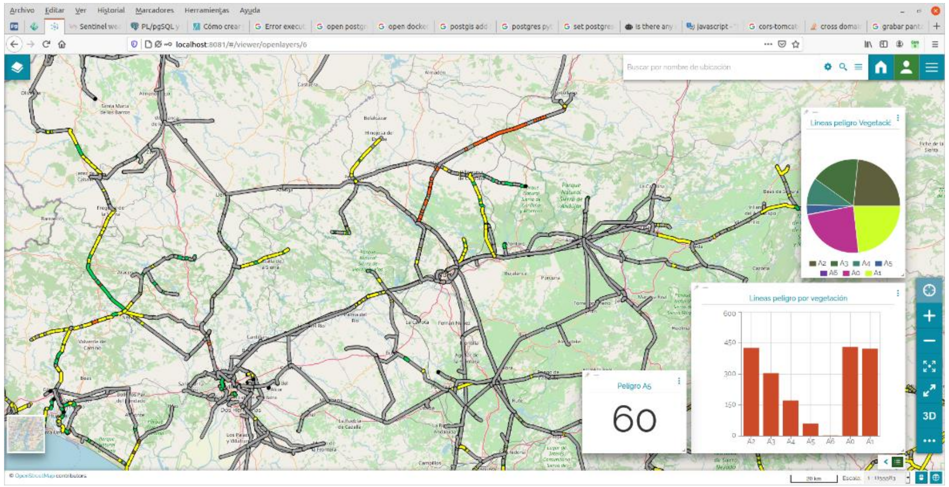
Planning: Risk Assessment tool for climate and weather events

Active data and KPIs control









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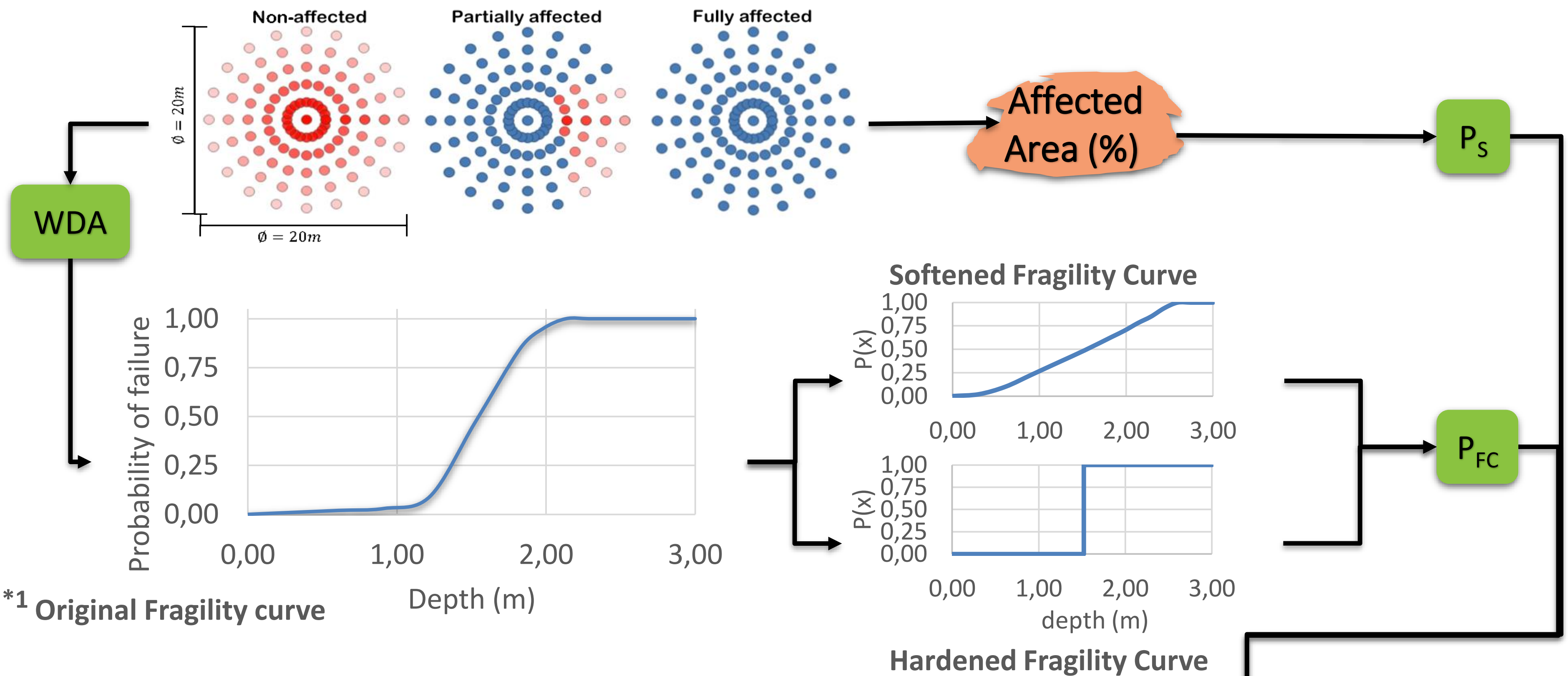
Planning: Risk Assessment tool for climate and weather events



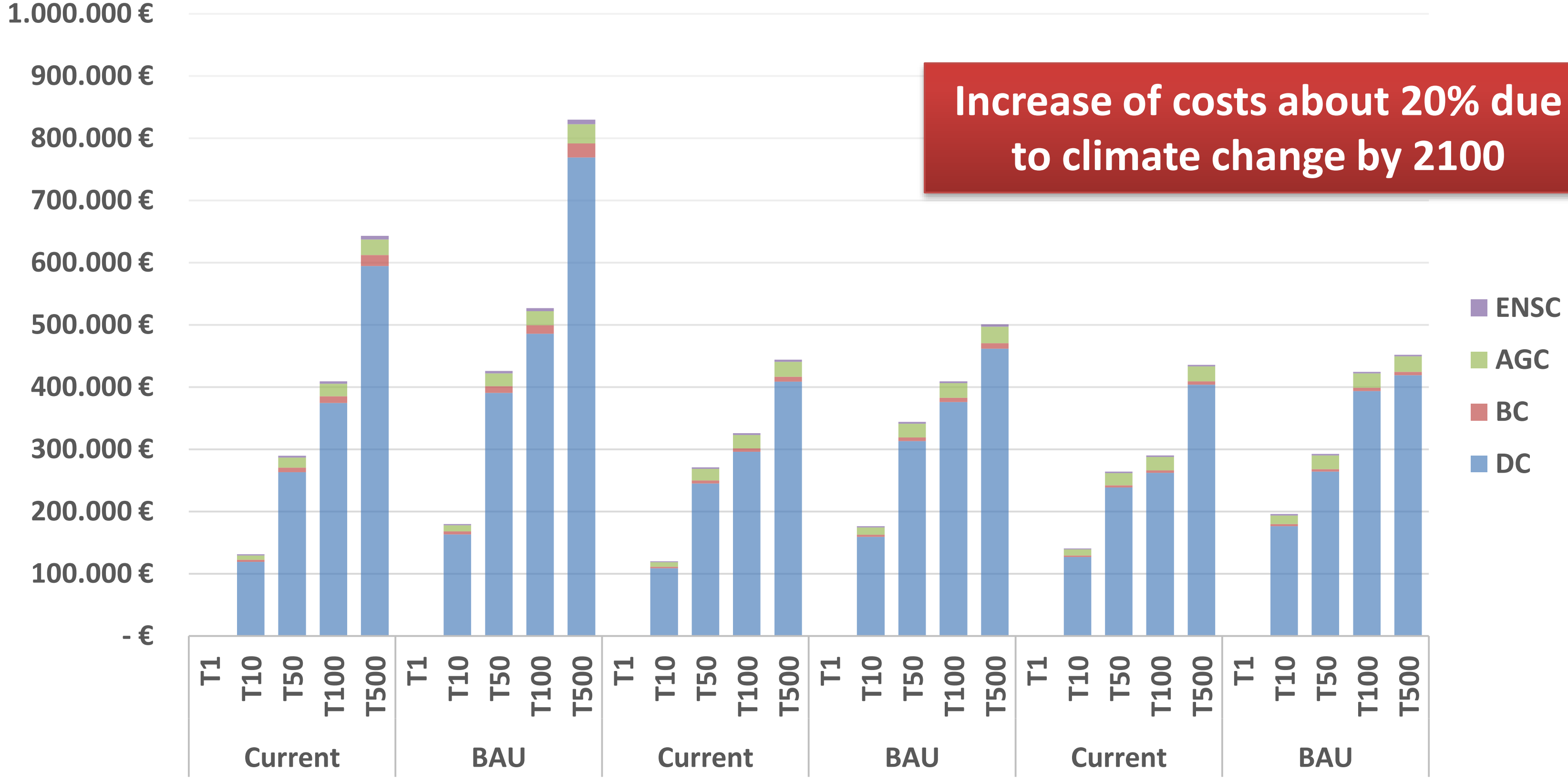
Probability Range	Named category
$P_F < 1\%$	Low Failure Probability (LFP)
$1\% < P_F <= 10\%$	Moderate Failure Probability (MFP)
$10\% < P_F <= 50\%$	High Failure Probability (HFP)
$P_F > 50\%$	Non-Acceptable Failure Probability (NAFP)

$$P_F = P_S \times P_{FC}$$

*1 Original fragility curve obtained from: FEMA (2009) Federal Emergency Management Agency (US government)

Planning: Risk Assessment tool for climate and weather events

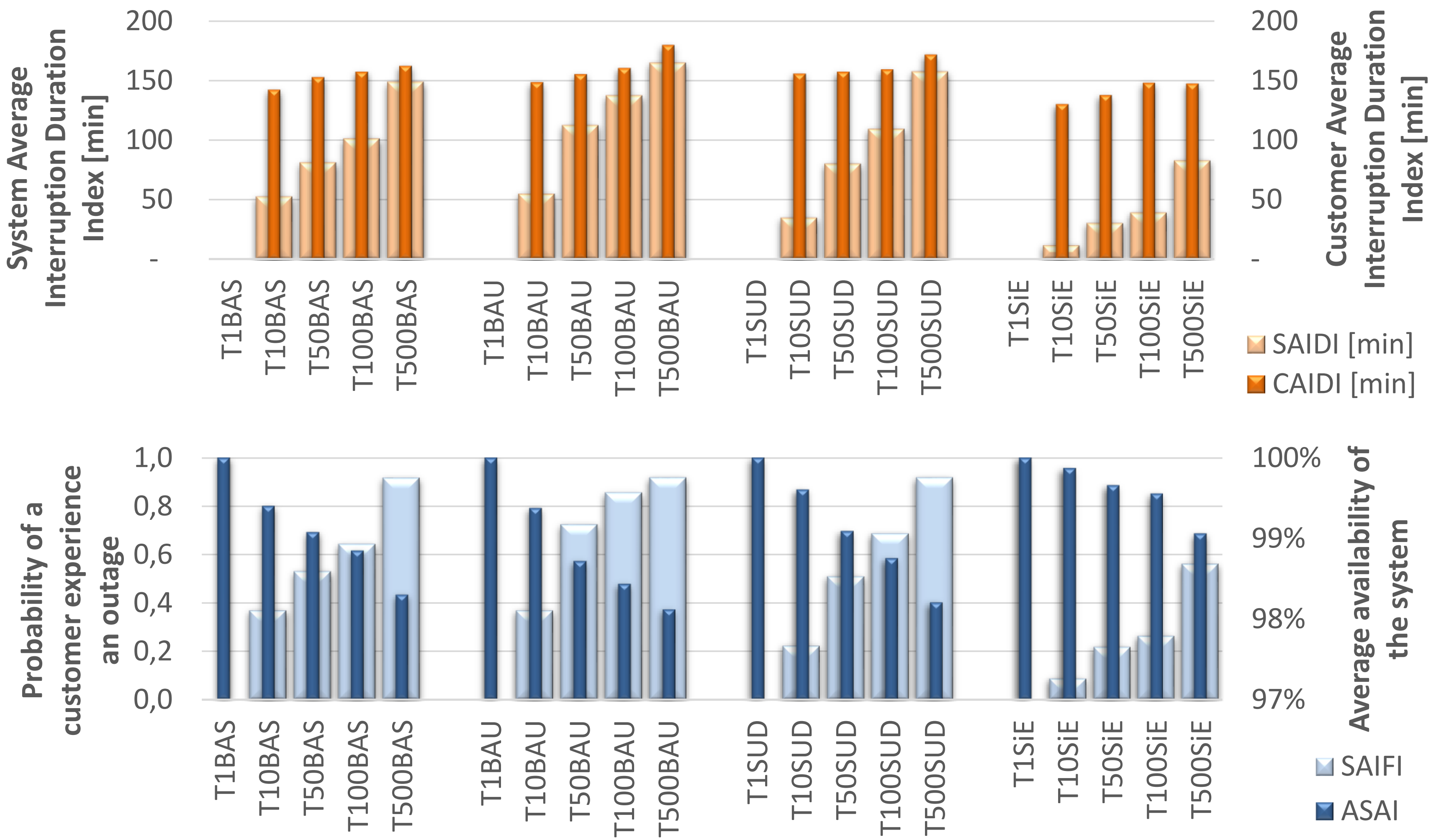
Cost assessment – Results when analyzing CTs



Increase of costs about 20% due to climate change by 2100

Planning: Risk Assessment tool for climate and weather events

Reliability indexes calculation - Results

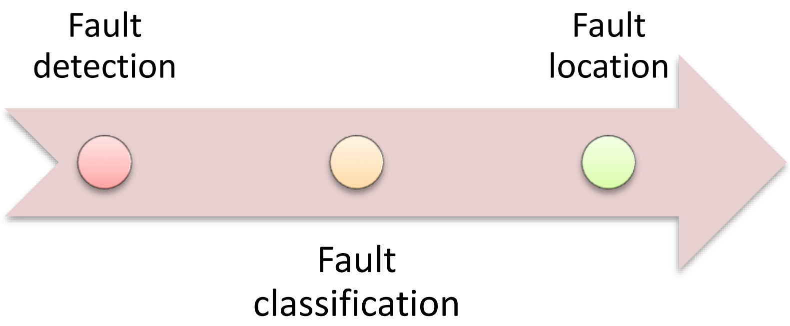


Detection: Fault identification and location algorithm

Power outages' significant ramifications
&
Increased ICT solutions

→

Demand and capability of **faster**, more **accurate** fault isolation



Fault Classification

→ Facilitates the fault location process in various methods.

→ Need for further research in the case of distribution grids.

Detection: Fault identification and location algorithm

A new criteria has been developed by modifying and merging some existing ones which are more specific for transmission systems

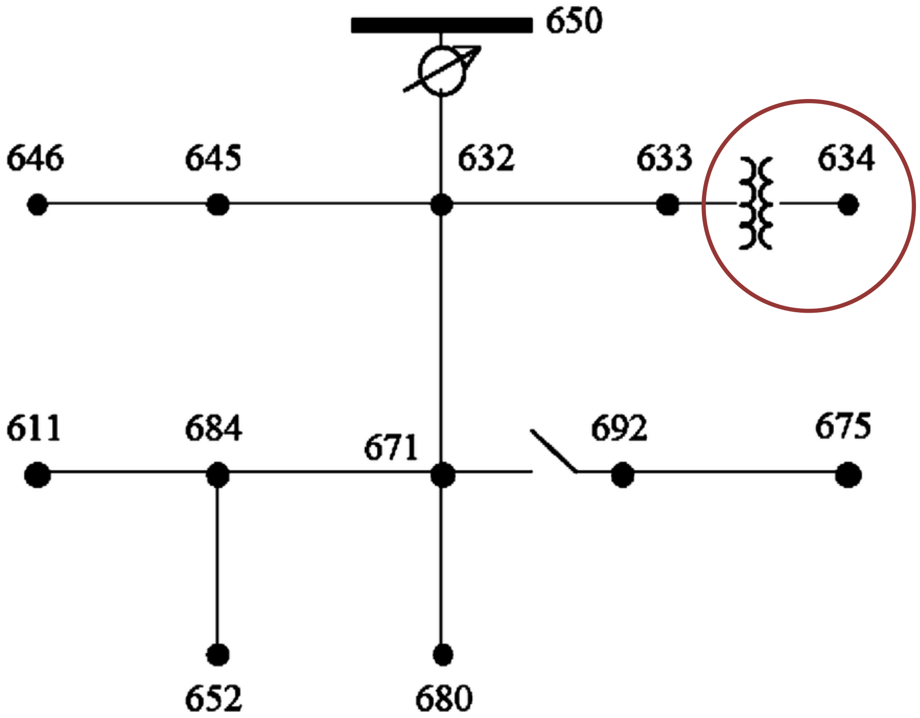
1ph & 2ph faults	3ph faults	Distinction between 2ph faults
Based on Novosel et al.	Based on Kezunovic et al. with adjustments on the criteria sets	Criterion based on the theory of the symmetrical components

Theory: 2ph faults → $I_0 = 0$

2ph-g faults→ $I_0 = (-I_1)\frac{Z_2}{Z_0+Z_2} \neq 0$

Criterion: $I_{0_{After}} - I_{0_{Before}} > I_{0_{Before}}$

Detection: Fault identification and location algorithm



IEEE 13 node test feeder

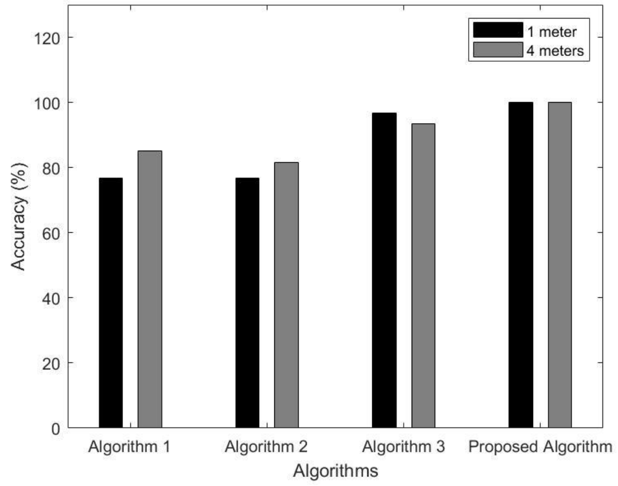
- 4 measurement points
- Highly unbalanced
- Low voltage branch

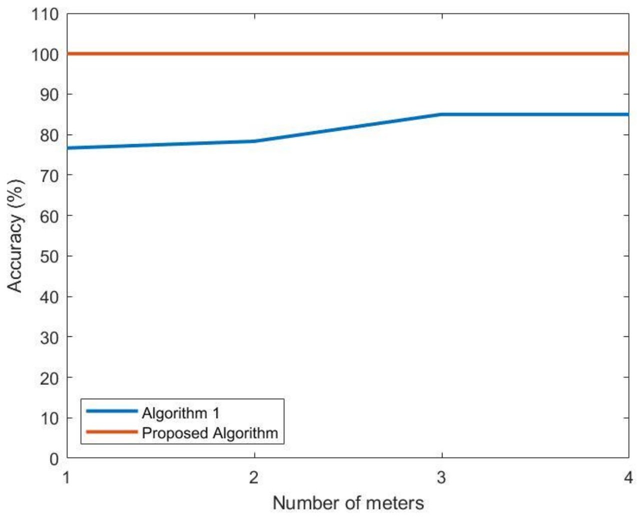
Parameters

1. Type of fault
2. Number of meters
3. Location of the fault
4. Fault resistance
5. Noise

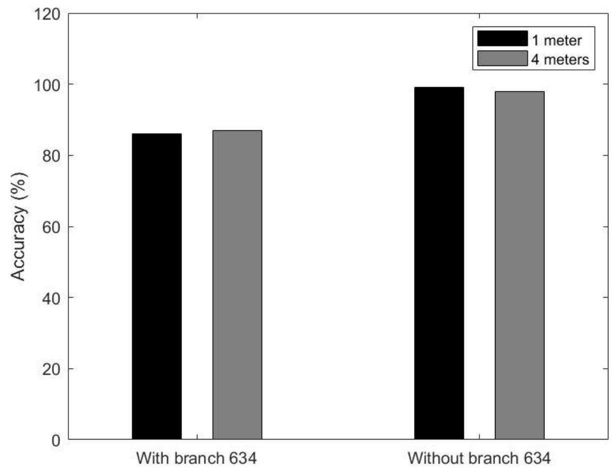
Detection: Fault identification and location algorithm

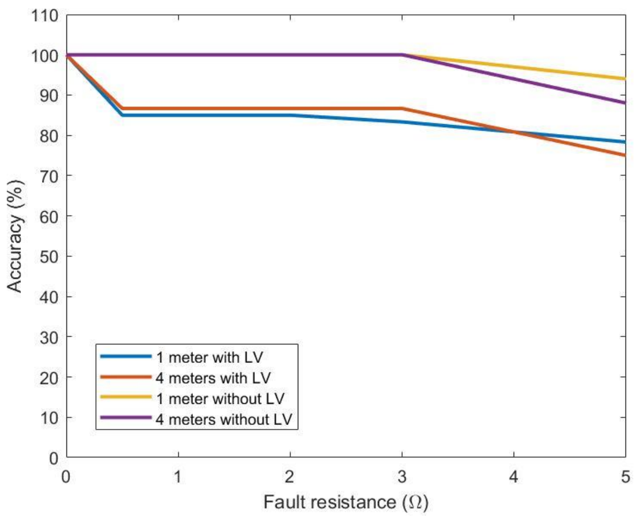
RESULTS without fault resistance or noise





RESULTS with fault resistance





Actuation: Self-healing and clusterization of distribution grid

- **The electrical grid** a critical infrastructure that **needs to be resilient**, minimizing the service disruption to ensure minimum impact on end users.

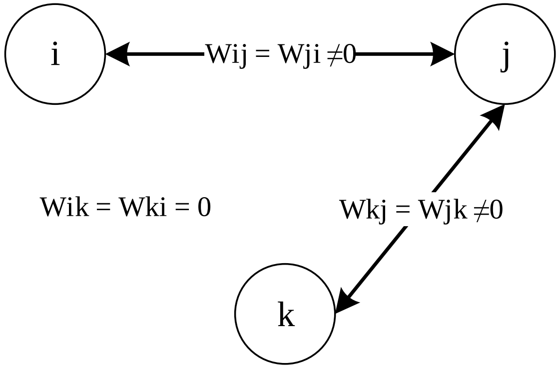
- This can be achieved through **two main methods** **network reconfiguration** or allowing **islanded/disconnected operation**.

- <u>**Objective:**</u> Provide a self-healing and islanding method for the electric grid while minimizing the unsupplied loads and increasing network resilience.

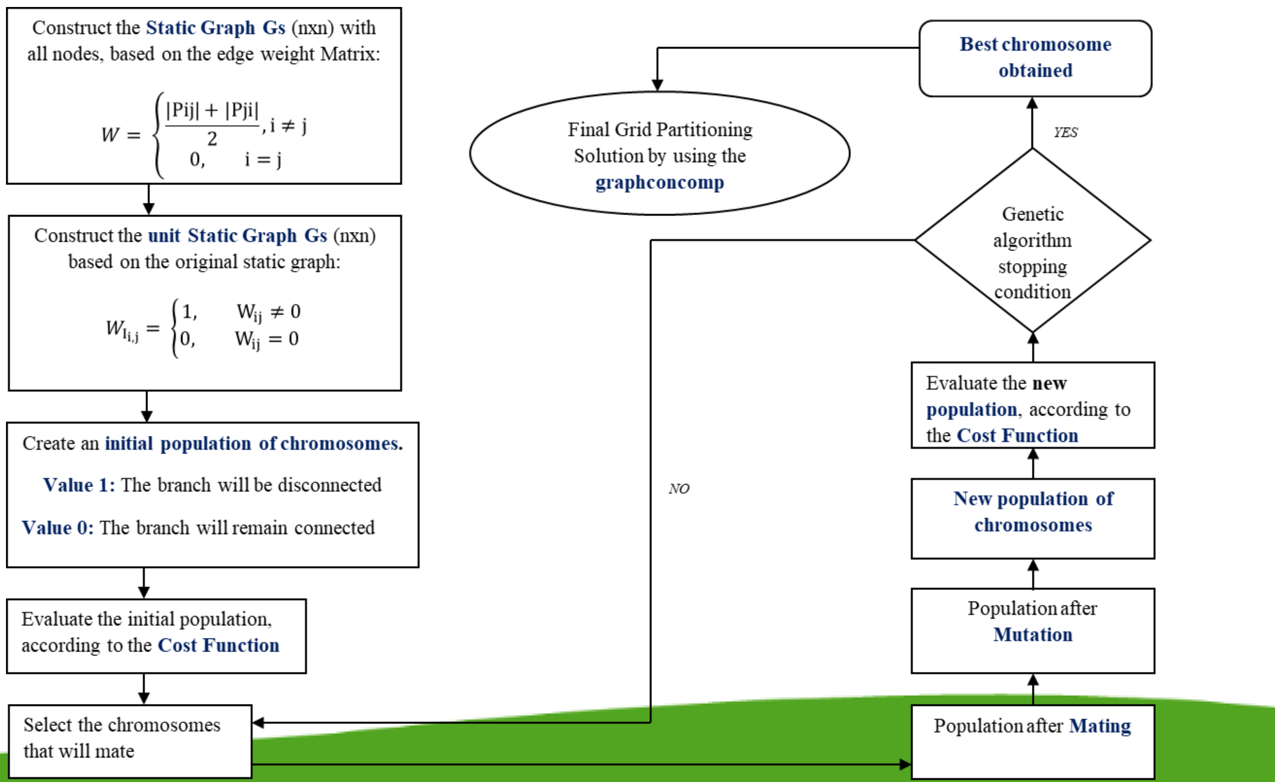
- We can take advantage of distributed RES, ESS and prosumers, to select the optimal islands (dynamic microgrids) depending on the load and generation status.

Actuation: Self-healing and clusterization of distribution grid

- **Network partitioning problem** → **Graph–cut problem**
- **Binary Genetic Algorithm for problem solving**

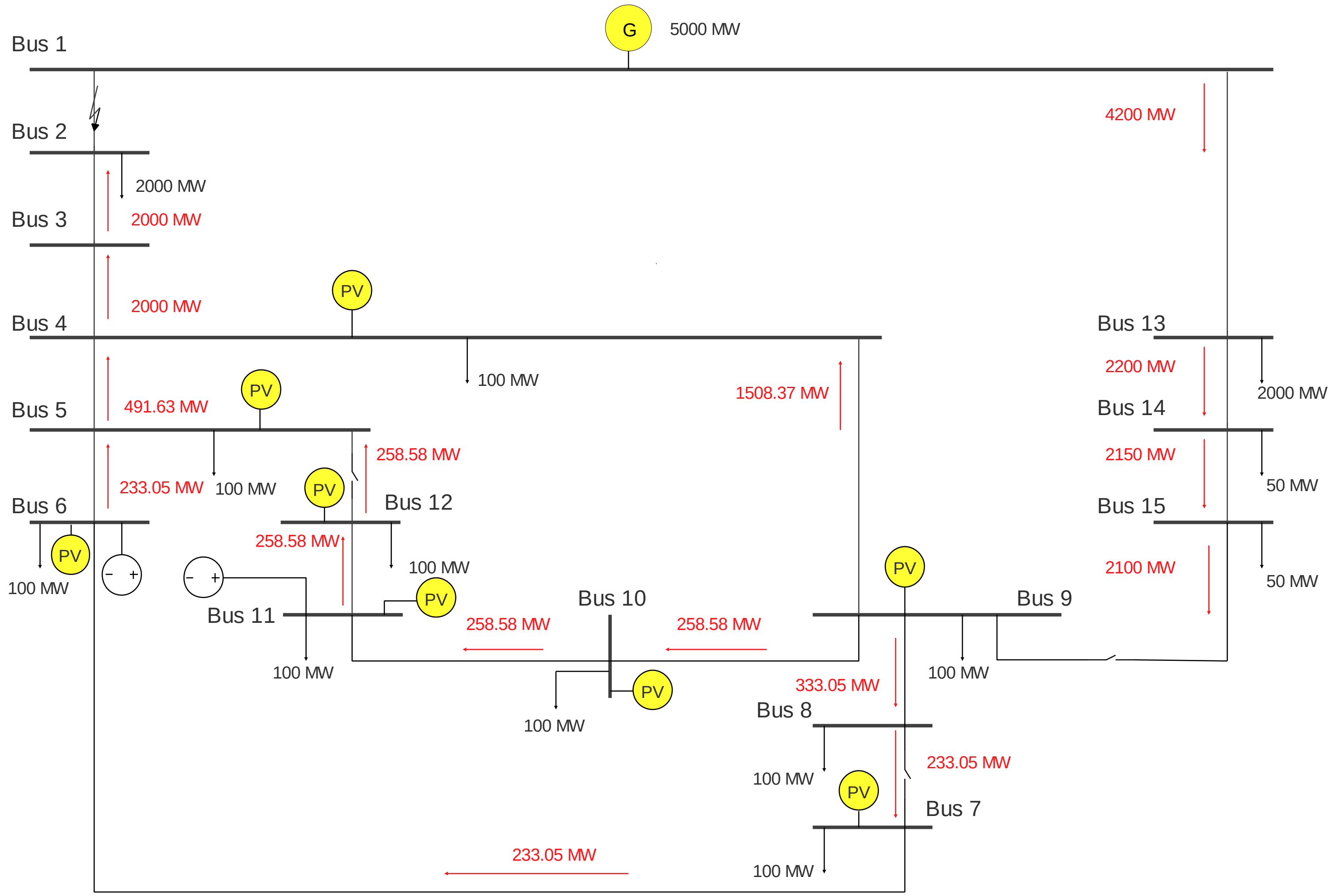


Intentional Islanding Tool Flowchart



Actuation: Self-healing and clusterization of distribution grid

Grid under testing Power Flow Results on Modified CIGRE 15 Benchmark



Actuation: Self-healing and clusterization of distribution grid

Results

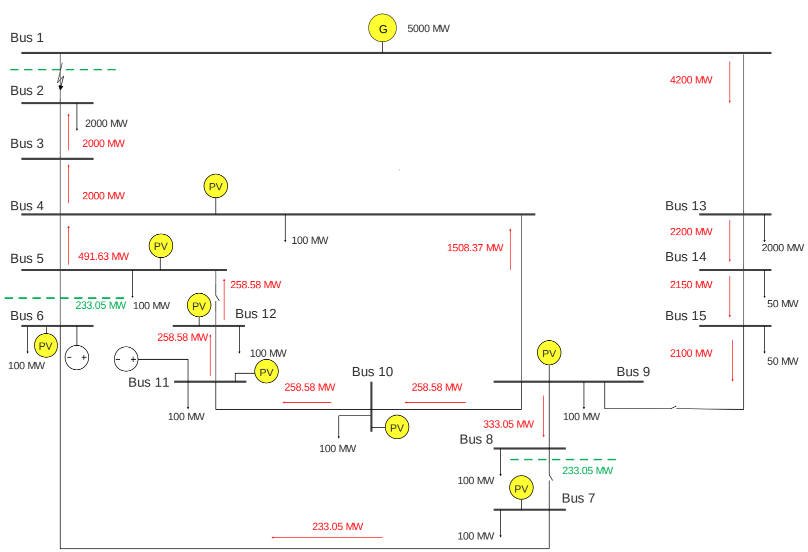
2 islands forced

Best Chromosome

1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cutset	Interrupted Flow (MW)
Lines: 1-2, 5-6, 7-8	466.09

	P_G (MW)	P_L (MW)	Difference (MW)
Island 1	4800	4800	0
Island 2	200	200	0



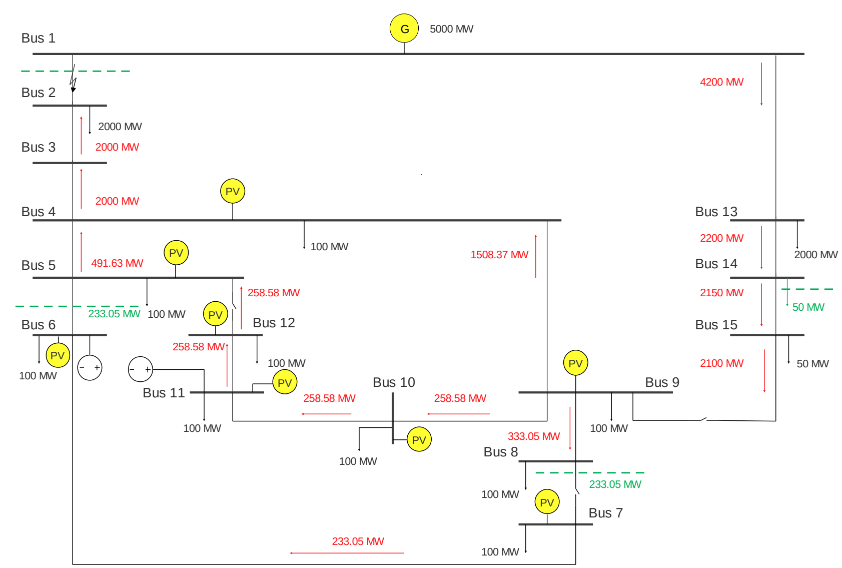
3 islands forced

Best Chromosome

1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Cutset	Interrupted Flow (MW)
Lines: 1-2, 5-6, 7-8 Load: 14	516.09

	P_G (MW)	P_L (MW)	Difference (MW)
Island 1	4800	4750	50
Island 2	200	200	0



Wrap up

The Future Digital grid, opens new opportunities and brings new challenges.

Increased Resilience and Security of supply is key since the Electrical Grid is a CRITICAL INFRASTRUCTURE

In this regard, we have been working on the different key steps towards this as PLANNING, DETECTION and ACTUATION.

Further advances and usage of Data Analytics are key for this. The integration of various methods and techniques will end up into a DIGITAL TWIN of the distribution grid.

Thank you for your attention

Questions?

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