Institute for Automation of Complex Power Systems

RWTH Aachen University

ACS Divisions

HYPERRIDE
THE FUTURE OF POWER DISTRIBUTION

Applications

Smart Cities
Flexible Electrical Networks
Center for Wind Power Drives
5G Energy Hub

Grid Dynamics

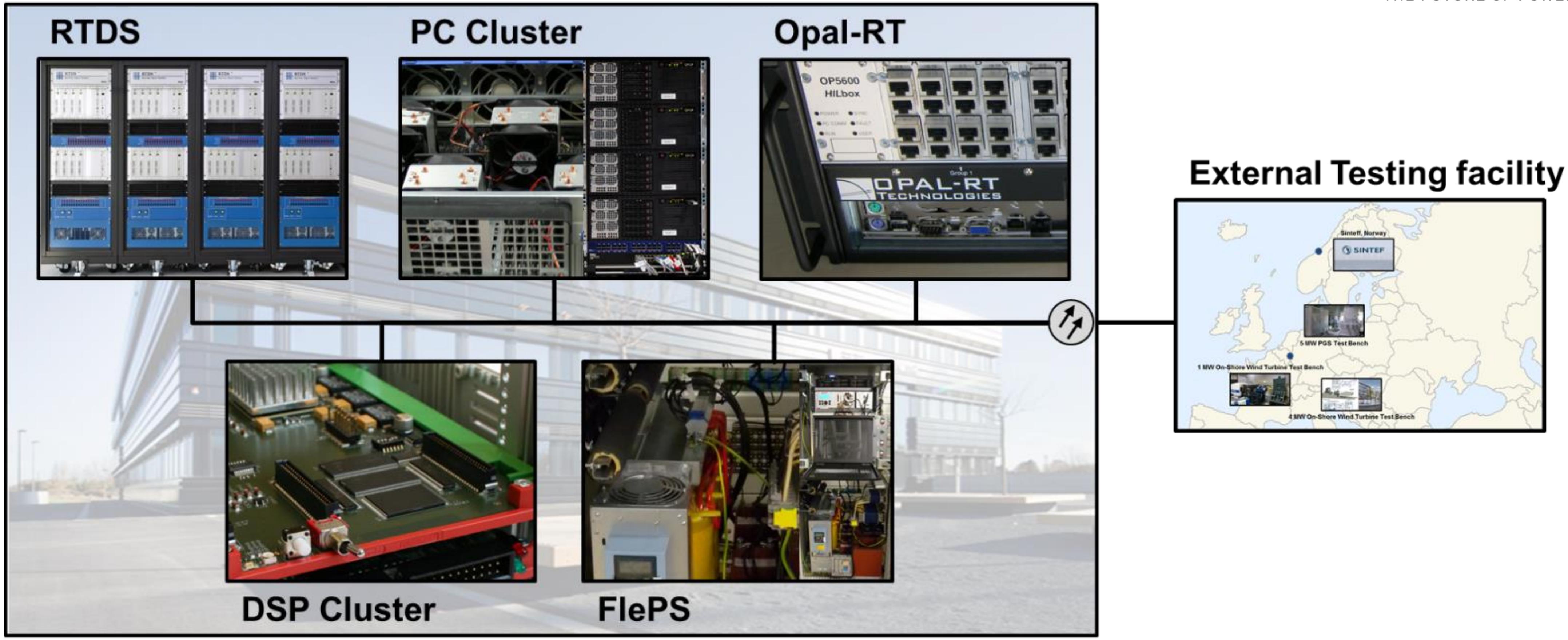
Fundamentals of Grid Dynamics
Network Stability
Hybrid DC/AC Networks
Integration of Renewables
Grid Monitoring
Grid Automation
Advanced Control Solutions

ICT 4 Energy

Energy as Data-Driven Systems
HPC
Special Operating Systems
Cloud
Real-Time Systems

EU H2020 Programme GA No. 957788

Real Time Laboratory



External Connections

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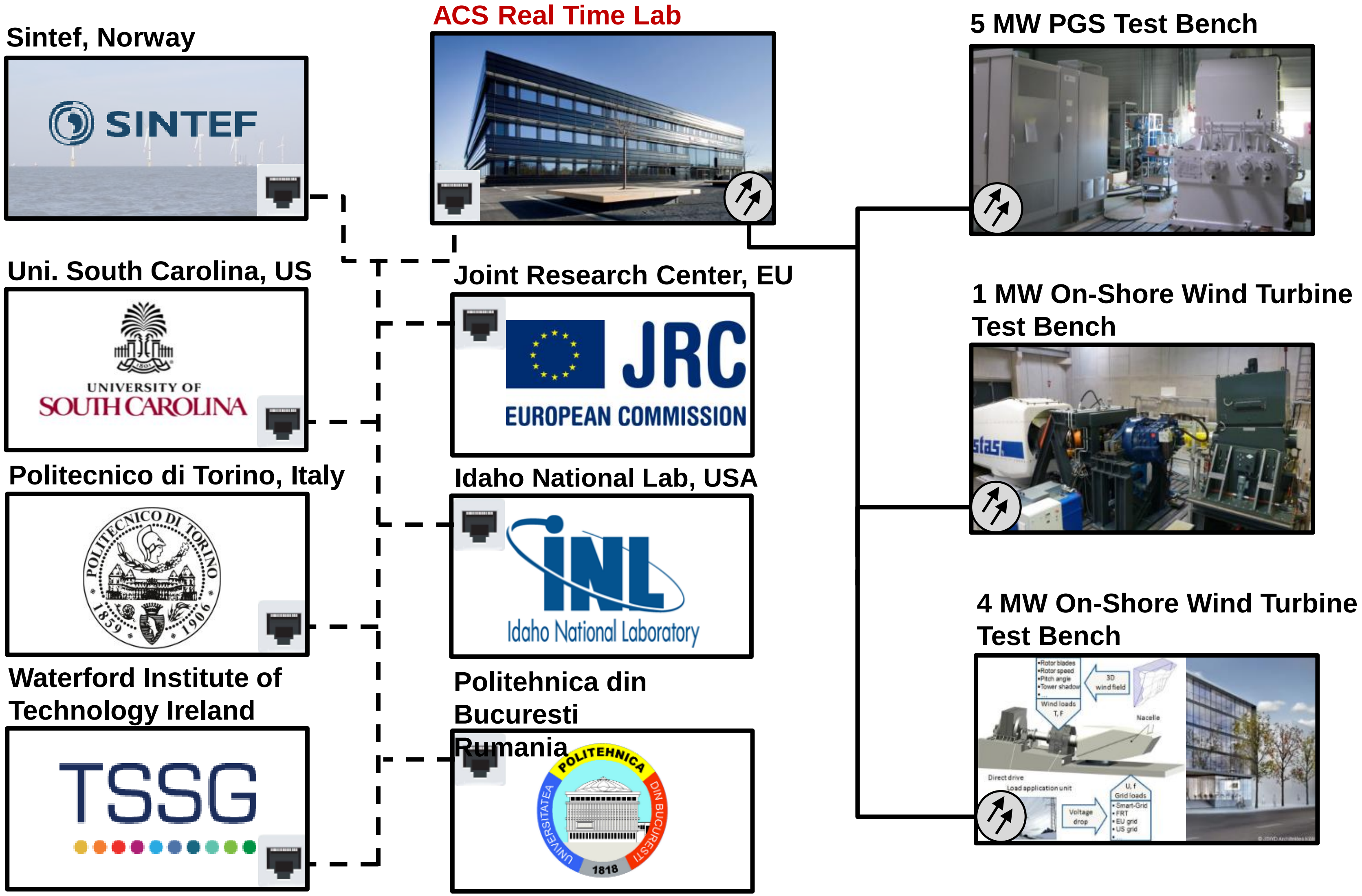

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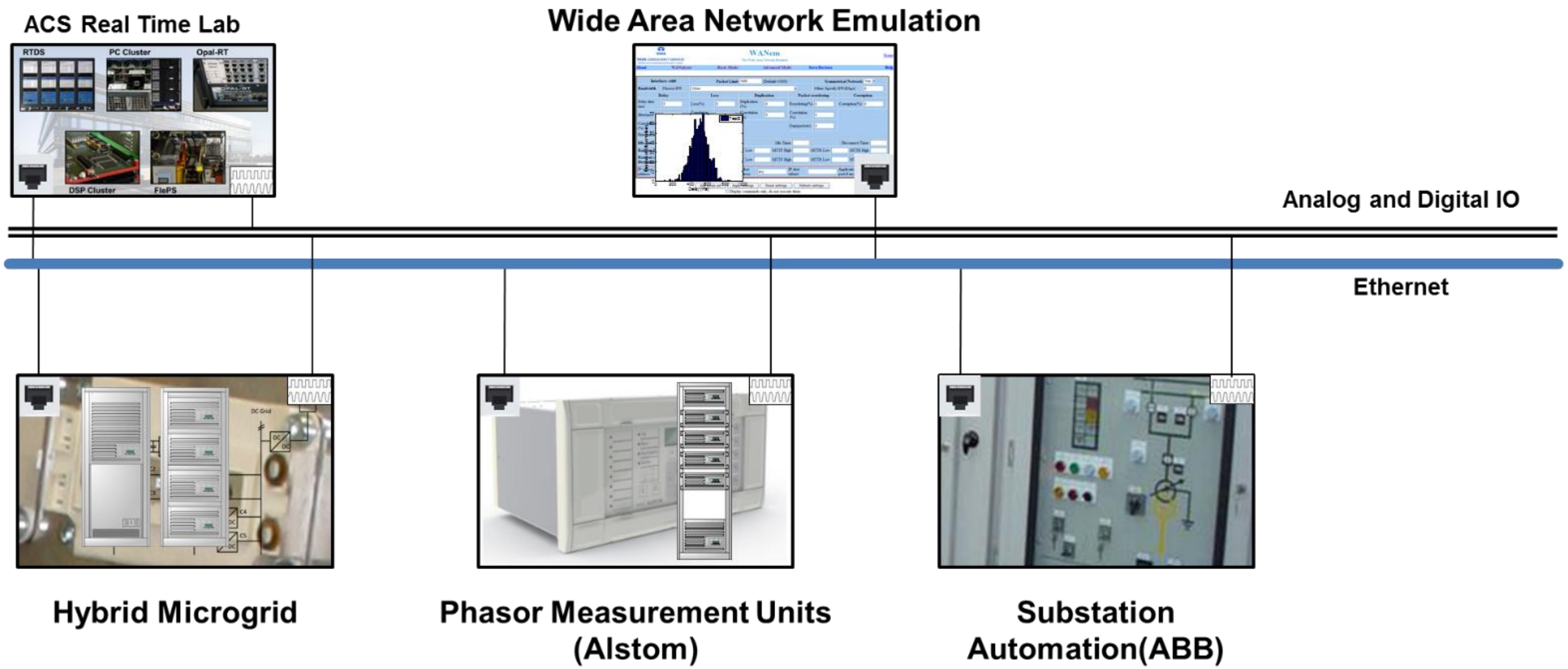
Internal Structure



Examples of SW projects

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VILLASframework

Toolset for distributed real-time simulation and HIL testbed interconnection

Pintura

Graphical CIM XML-RDF editor based on new web technologies

CIM++

Deserialiser library for C++ objects from XML/RDF documents based on CIM standards

CIMpy

Python package for import, modification and export of CIM grid data

Distribution System State Estimator

Matlab code of a voltage and current state estimator for distribution systems

DPsim

Real-time power system simulator

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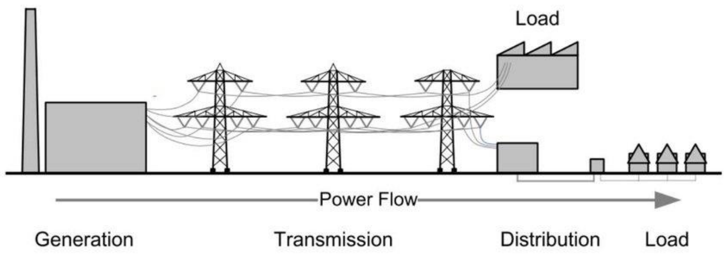
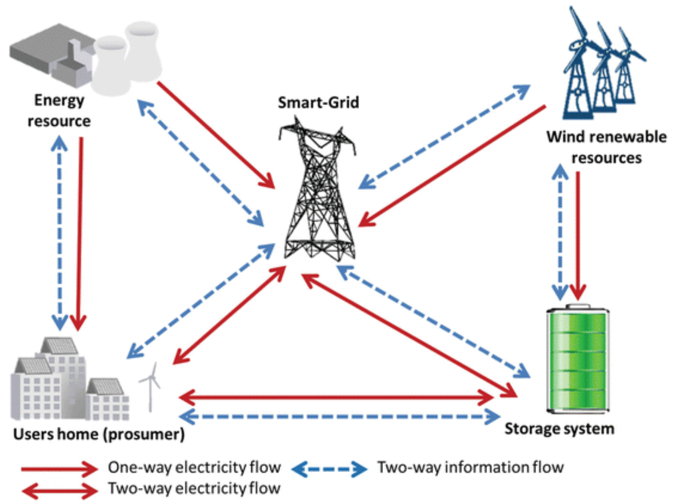
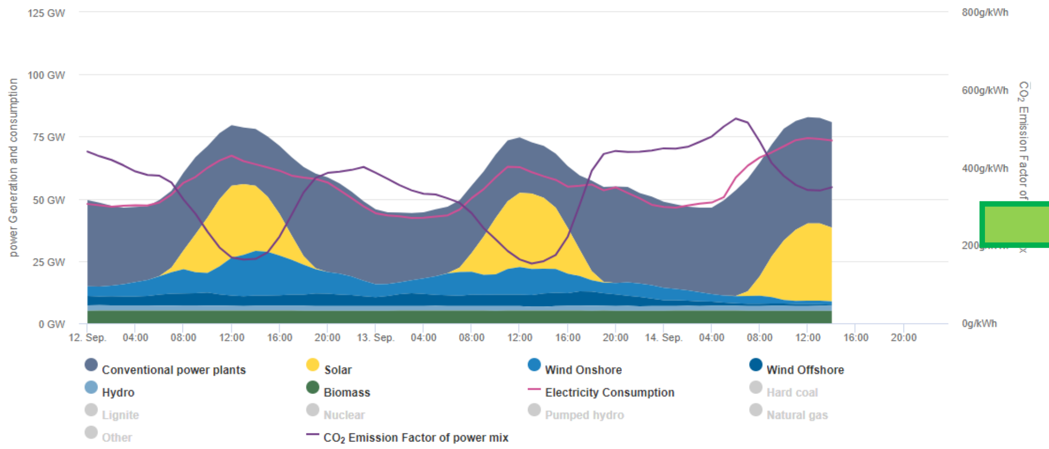
Motivation 1: new power flows

The increasing presence of Distributed Energy Resources (DERs) is transforming the traditional schemes of power flow in the electric distribution grids





Power Generation and Consumption



New use cases for
<u>Network Reconfiguration</u>

Motivation 2: Service Restoration Platform

Transformation of Electrical Power Systems: IoT devices and new grid actors

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Smart Grid Automation

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Continuous monitoring and analysis of vast amount of collected data

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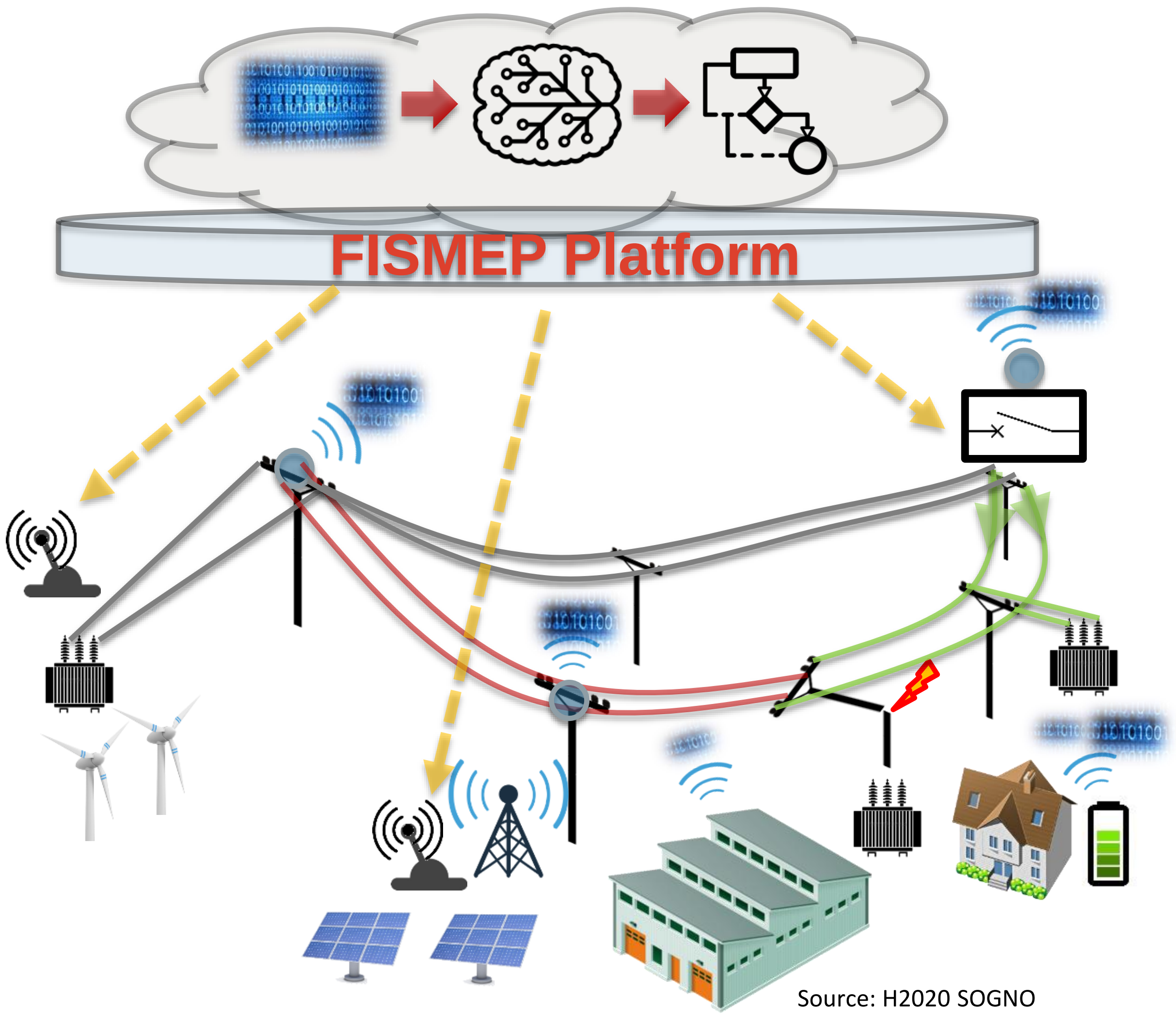
High computing power and time-consuming algorithms

Cloud architectures with distributed system services: **middleware**

- standards APIs and protocols



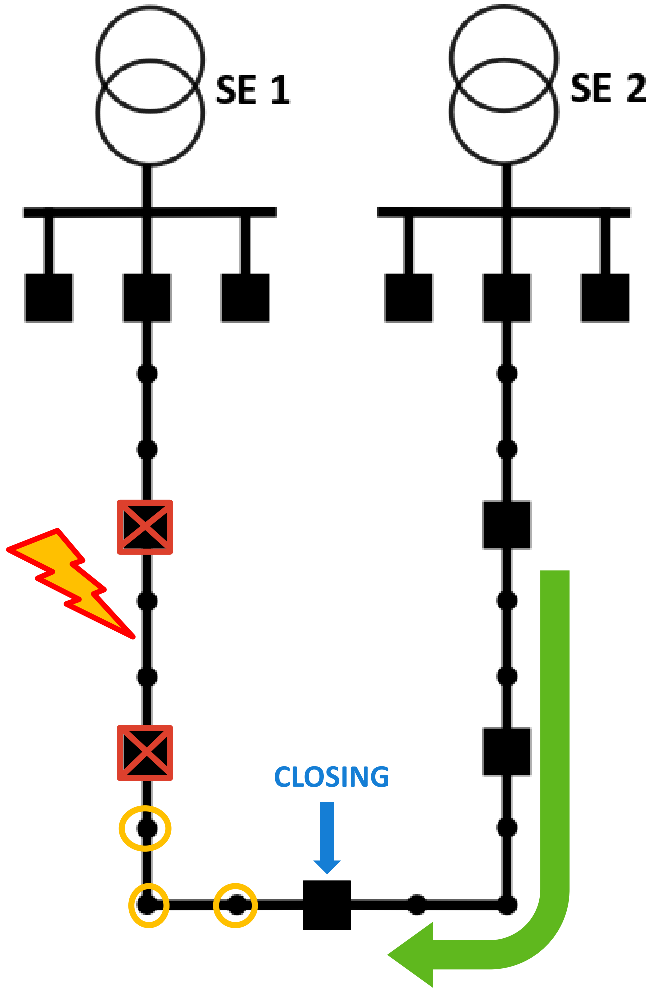
Source: H2020 SOGNO

Service Restoration Concept

- Traditionally, fault management actions are carried out by human operators
- Distribution Management Systems (DMS) deploys fully automated Fault Location, Isolation and Service Restoration (FLISR):
  - Prompt intervention of protection
  - Minimization of outage consequences
  - Recovery to healthy condition

Improvement of reliability indeces:

- SAIDI
- CAIDI



Determination of the Reconfigurable Paths

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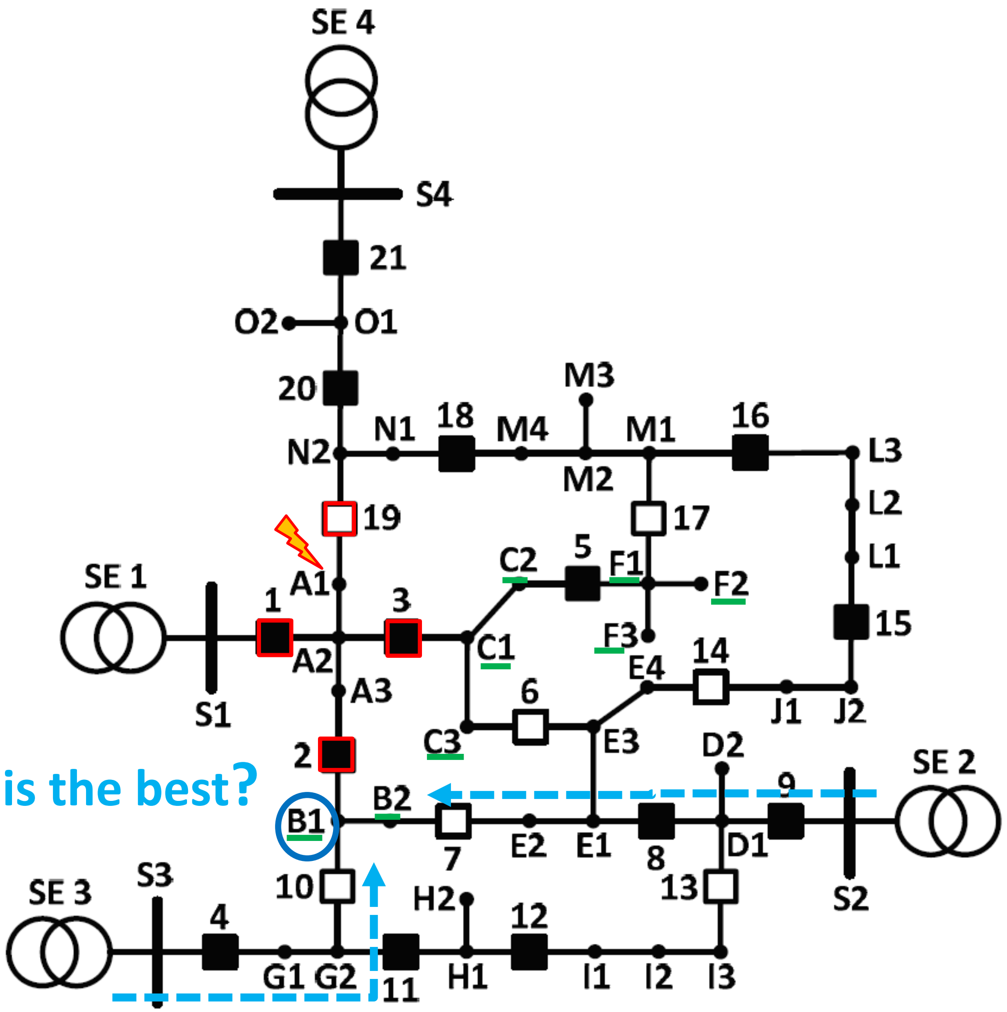
- Target restoration load according to priority index λ → hospital, transportation, communication, gas network site
- For each substation present in the network:
  - most suitable path toward the load
  - using the Dijkstra's algorithm for shortest path:

$$Z_a^b = min \sum_{x,y \in G'_{a,b}} |\overline{Z}_{x,y}|$$

- Set of candidates that include the closing of a tie-switch (normally open switch – white square)

Which is the best?



Selection of Optimal Topology

The optimal solution is identified by considering two criteria:

1. Total power losses

$$P_{x,y} = 3\Re\left[\overline{V}_x \underline{\left(\overline{V}_x \frac{G_+ + jB_+}{2}\right)} + \overline{V}_y \underline{\left(\overline{V}_y \frac{G_+ + jB_+}{2}\right)} + \left(\overline{V}_x - \overline{V}_y\right)\underline{\left(\frac{\overline{V}_x - \overline{V}_y}{R_+ + jX_+}\right)}\right]$$

2. Utilization of electric ' '·

$$\theta_{x,y} = \frac{I_{max_{x,y}} - \left|\overline{I}_{x,y}\right|}{I_{max_{x,y}}}$$

The three minimum values of $\theta_{x,y}$ are recorded: θ_1, θ_2, θ_3

Four parameters: P, θ_1, θ_2, θ_3

Multiple-Criteria Decision Analysis

1. Analytical Hierarchy Process (AHP) is implemented, to define the comparison matrix:

$$A = \begin{bmatrix} 1 & w_{P\theta_1} & w_{P\theta_2} & w_{P\theta_3} \\ \frac{1}{w_{P\theta_1}} & 1 & w_{\theta_1\theta_2} & w_{\theta_1\theta_3} \\ \frac{1}{w_{P\theta_2}} & \frac{1}{w_{\theta_1\theta_2}} & 1 & w_{\theta_2\theta_3} \\ \frac{1}{w_{P\theta_3}} & \frac{1}{w_{\theta_1\theta_3}} & \frac{1}{w_{\theta_2\theta_3}} & 1 \end{bmatrix}$$

Comparison of importance among P and θ_1

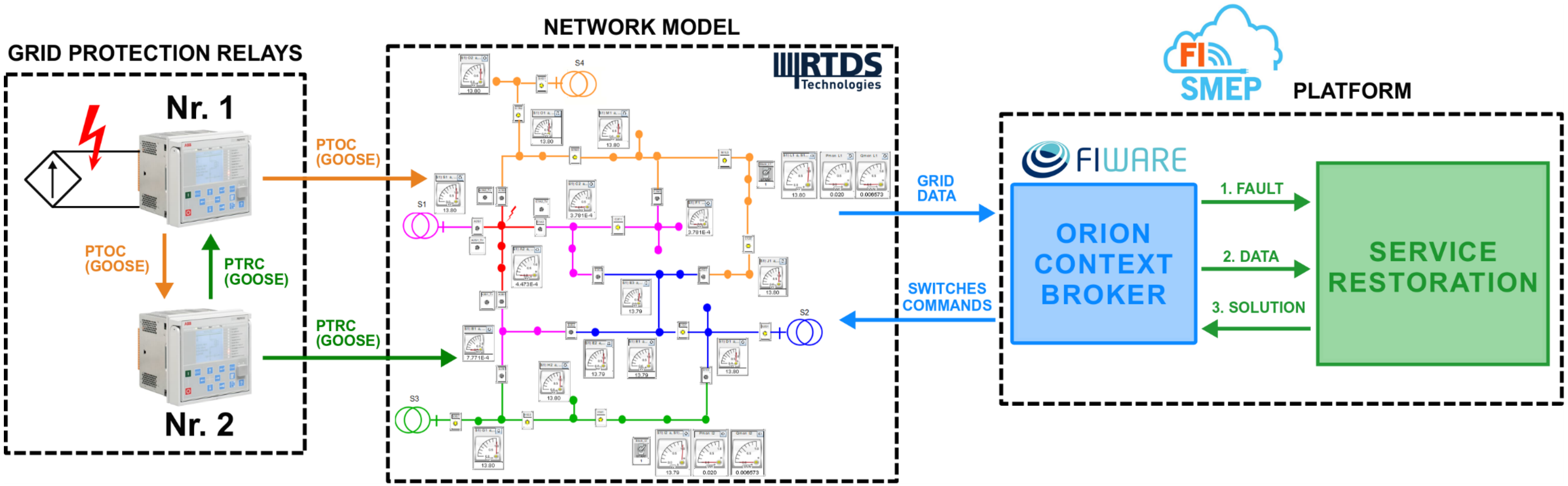
2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS): distance of each candidate solution to the positive and negative ideal ones

$$A^+ = \{v_1^+, \dots\dots\dots v_n^+\}$$
$$where\ v_j^+ = \{\max(v_{ij})\ if\ j \in B\,; \min(v_{ij})\ if\ j\ \in C\}$$

$$A^- = \{v_1^-, \dots\dots\dots v_n^-\}$$
$$where\ v_j^- = \{\min(v_{ij})\ if\ j \in B\,; \max(v_{ij})\ if\ j\ \in C\}$$

Service Restoration as Middleware: Control Flow

- Data are provided from the electrical network to the platform via HTTP
- Orion Context Broker (CB) notifies the received data about **tripped circuit breaker:**
  1. SR is activated and retrieves actual network data from CB
  2. SR computes the reconfiguration solution and communicates it to CB
  3. The closing operating command is issued to switches in the electrical network
  4. Process repeats until all possible loads are re-connected



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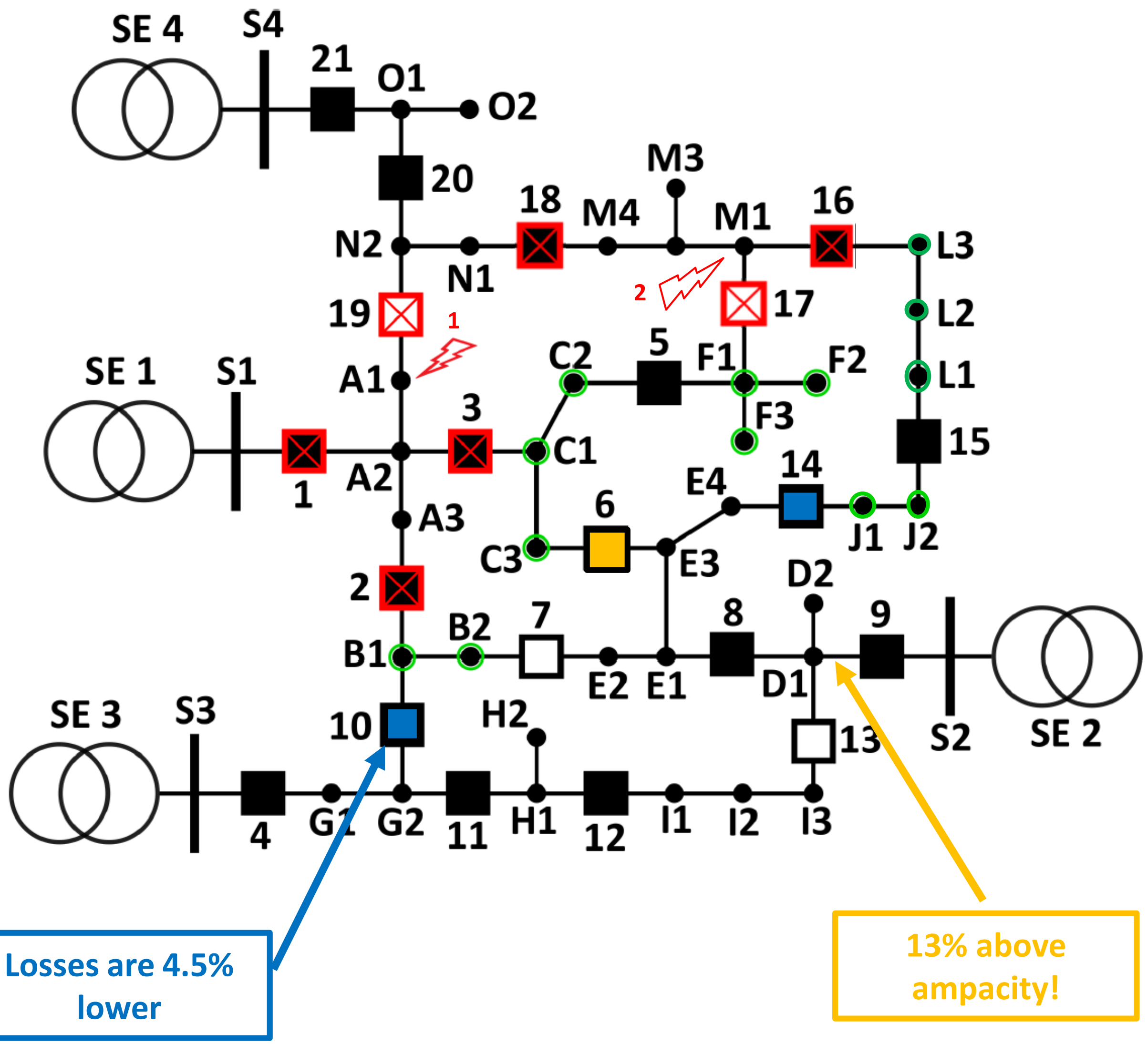
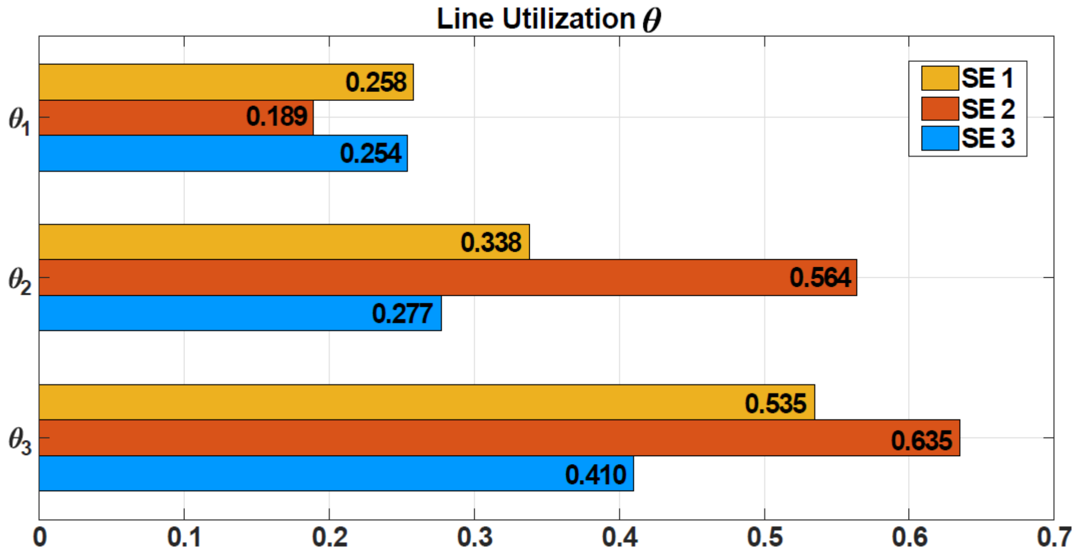
Assessment Cases I

- As test grid, a 13.8 kV distribution network with passive and active loads (100 kW – 1MW)
- The computation process considers the minimization of power losses as target
- The Service Restoration proved the adaptability to multiple faults

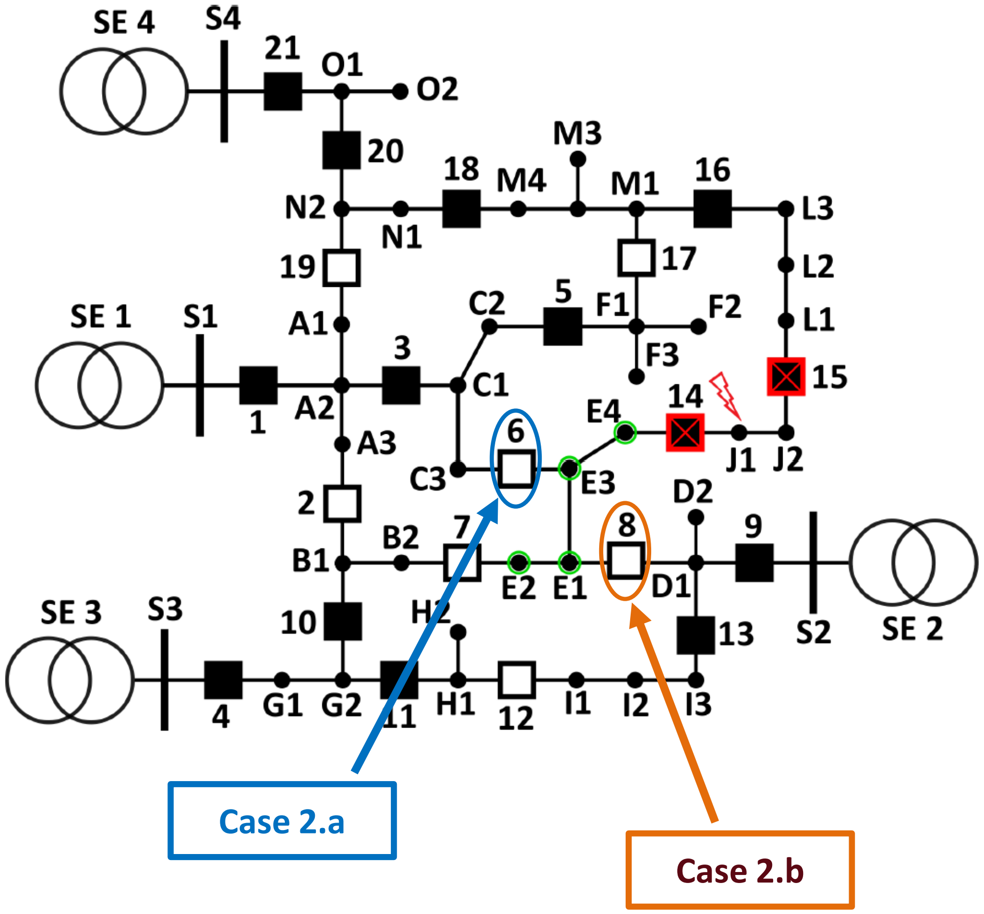


Assessment Cases II

The test evaluates the impact of MCDA inputs to the restoration process



	$w_{P\theta_1}$	$w_{P\theta_2}$	$w_{P\theta_3}$	$w_{\theta_1\theta_2}$	$w_{\theta_1\theta_3}$	$w_{\theta_2\theta_3}$
Test Case 2.a	1/9	1/9	1/9	4	4	1
Test Case 2.b	1	1	1	2	2	2



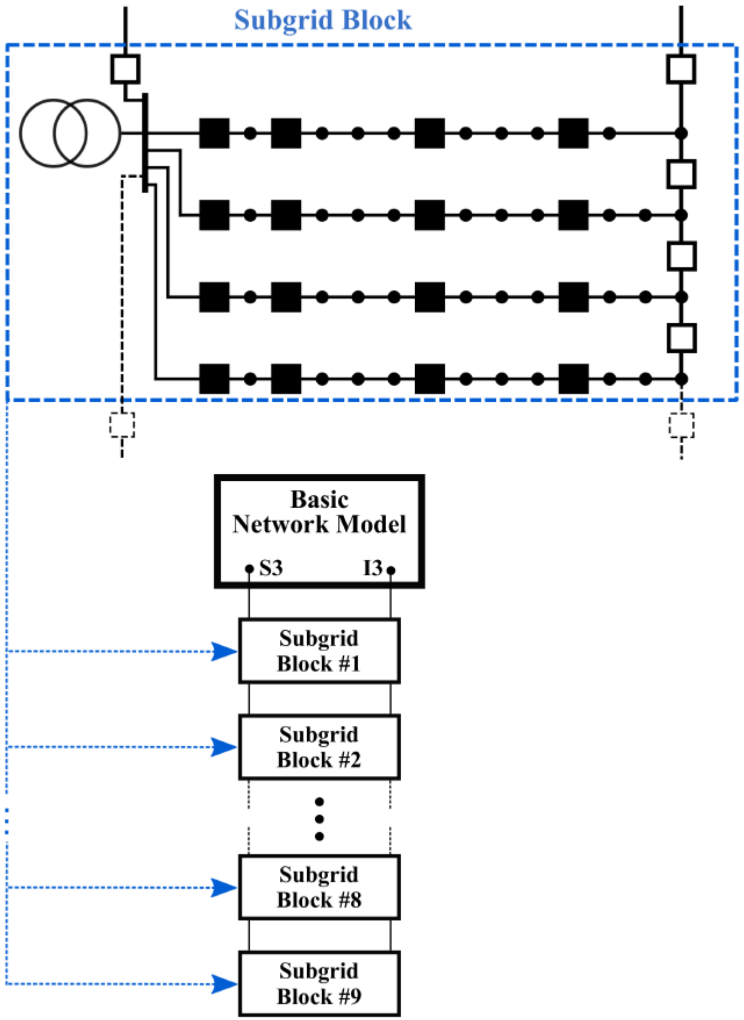
Assessment Cases III

- Test case with 400 nodes grid, to evaluate:
  - The performance of deployed platform
  - The communication latency of the setup
- Each test is repeated 50 times
- Apart from communication with field devices, main delay is due to internal platfrom process

NETWORK LATENCY TO ACTIVATE SR

Number of Nodes	Min	Max	Average	STDEV
40	0.136s	0.192s	0.157s	0.015s
400	1.145s	1.481s	1.319s	0.101s

- The results are in line with update rates between RTU and control center of DSO

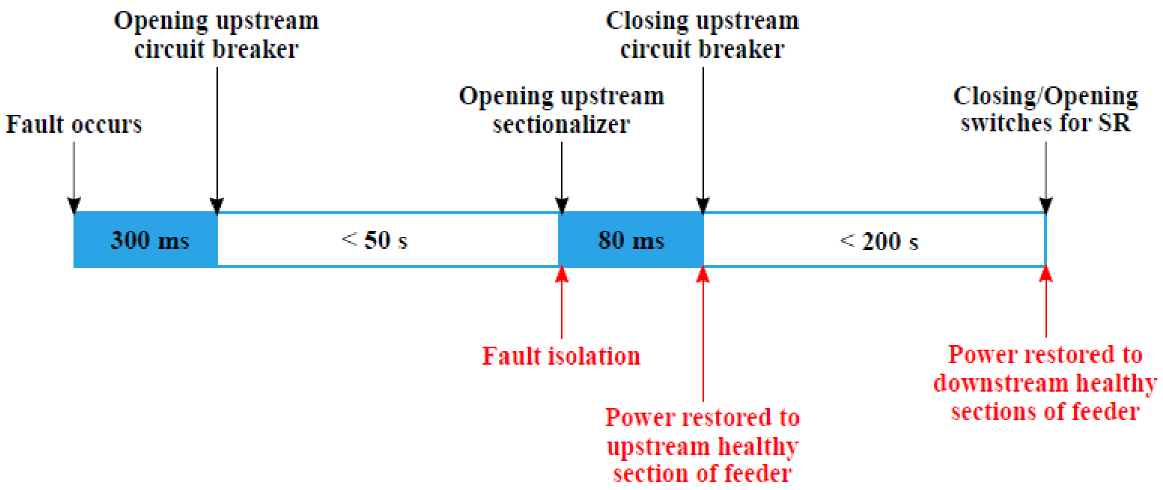


Platform Evaluation

- The computed time starts from the SR activation until the implementation of closing commands for switches

COMPUTATION TIME OF SR IN DIFFERENT TEST CASES

Number of Nodes	Min	Max	Average	STDEV
40	4.846s	5.574s	5.21s	0.013s
400	84.121s	88.78s	86.45s	0.123s



- Operating times are in line with self-healing FLISR solutions (≈ 3 min.) and satisfactory with respect to CAIDI values of European networks (= 40 min., 2016 in Germany)