INDUSTRIAL RESEARCH INTO THE RELIABLE OPERATION OF DIGITAL SUBSTATIONS

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KU LEUVEN

Energy Ville

2023 EUROPEAN RTDS TECHNOLOGIES INC. USER'S GROUP MEETING 2023

2023 EUROPEAN USER'S GROUP MEETING

RTDS Technologies AMETEK

TELLING A FAMILIAR STORY

The energy transition and digitalization

- A main pillar in decarbonizing the EU is electrification
- The system must become more intelligent and flexible in order to integrate different energy sources, each with their own behaviour and technical characteristics
- Digitalization enables bidirectional communication between all the players in the energy field
- The infrastructure must cater to the communication needs of prosumers, operators, aggregators and of the devices participating in the system

TELLING A FAMILIAR STORY

Building on a legacy

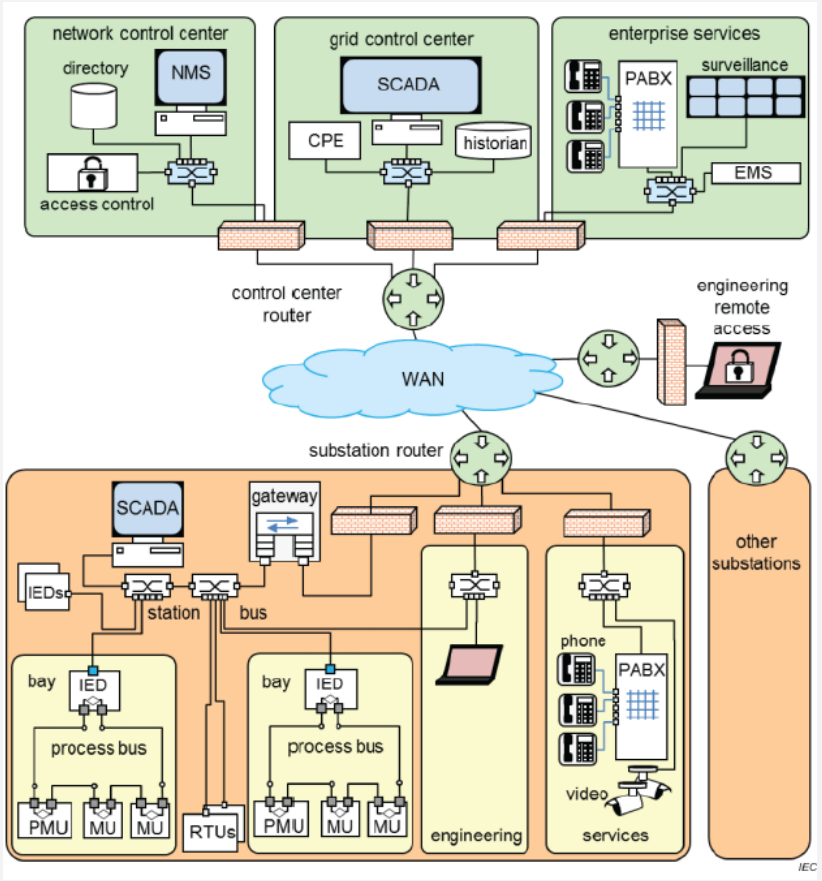
- Integration requires (industrial) processes and energy installations to momentarily stop, with huge costs. Maintenance, and the time between the discovery of a vulnerability and its mitigation might not be negligible.
- Different technologies were added on existing layers throughout the years. Modern devices should coexist with legacy devices.
- Digital grids are more a “system of systems”. Installations are complex, requiring knowledge in diverse fields of engineering
- Failures can cause cascading effects and digital systems are prone to cyber-attacks

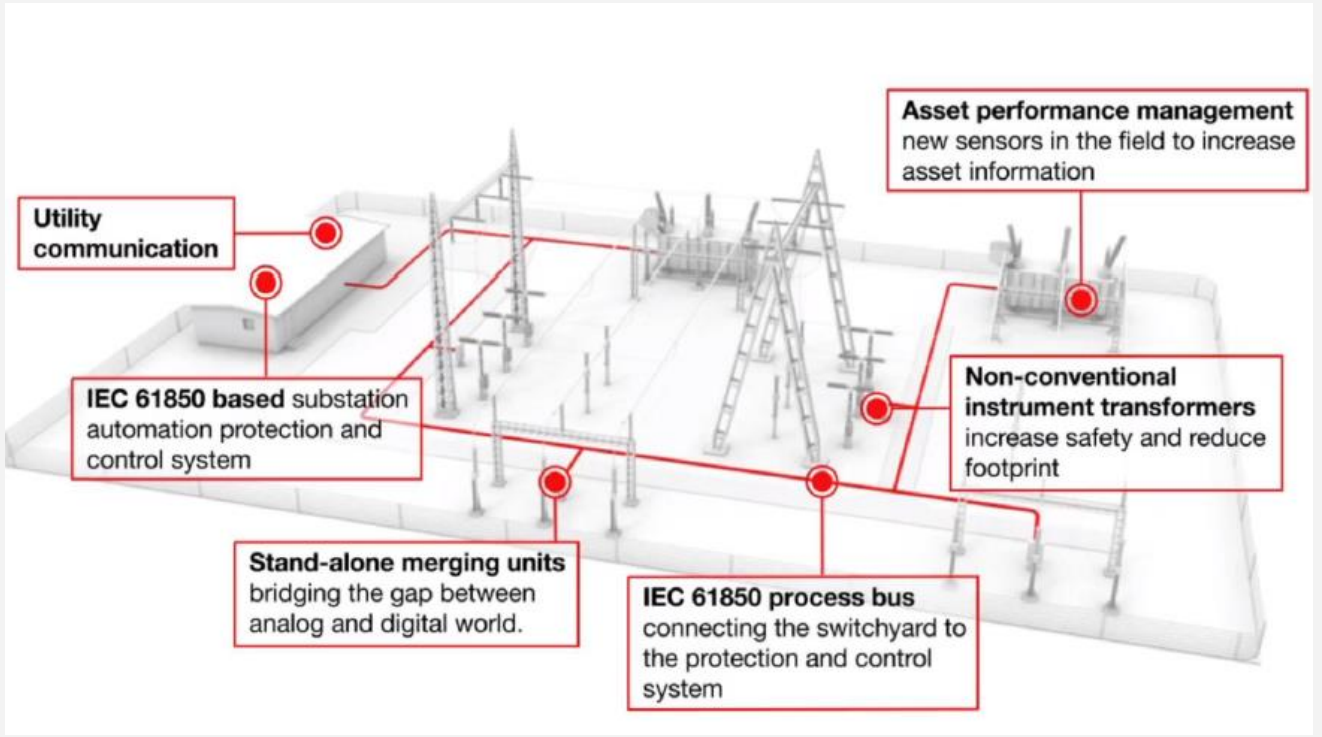
WHAT ARE DIGITAL SUBSTATIONS?

- Substations are energy nodes in the power system, where electricity is distributed, transformed and controlled
- **Digital substations** are nodes on the smart grid, using communication bus to perform its main functions [1]
- A **IEC 61850**-based digital substation: Standardized exchange of information between multiple Intelligent Electronic Devices (IEDs), utilizing the full capacity of its station and process bus for its Protection, Automation and Control (PAC).

[1] R. Loenders, G. Chaffey, D. V. Hertem et al., "Laboratory demonstration of testing digital substation reliability", IET DPSP, 2020

WHAT ARE DIGITAL SUBSTATIONS?





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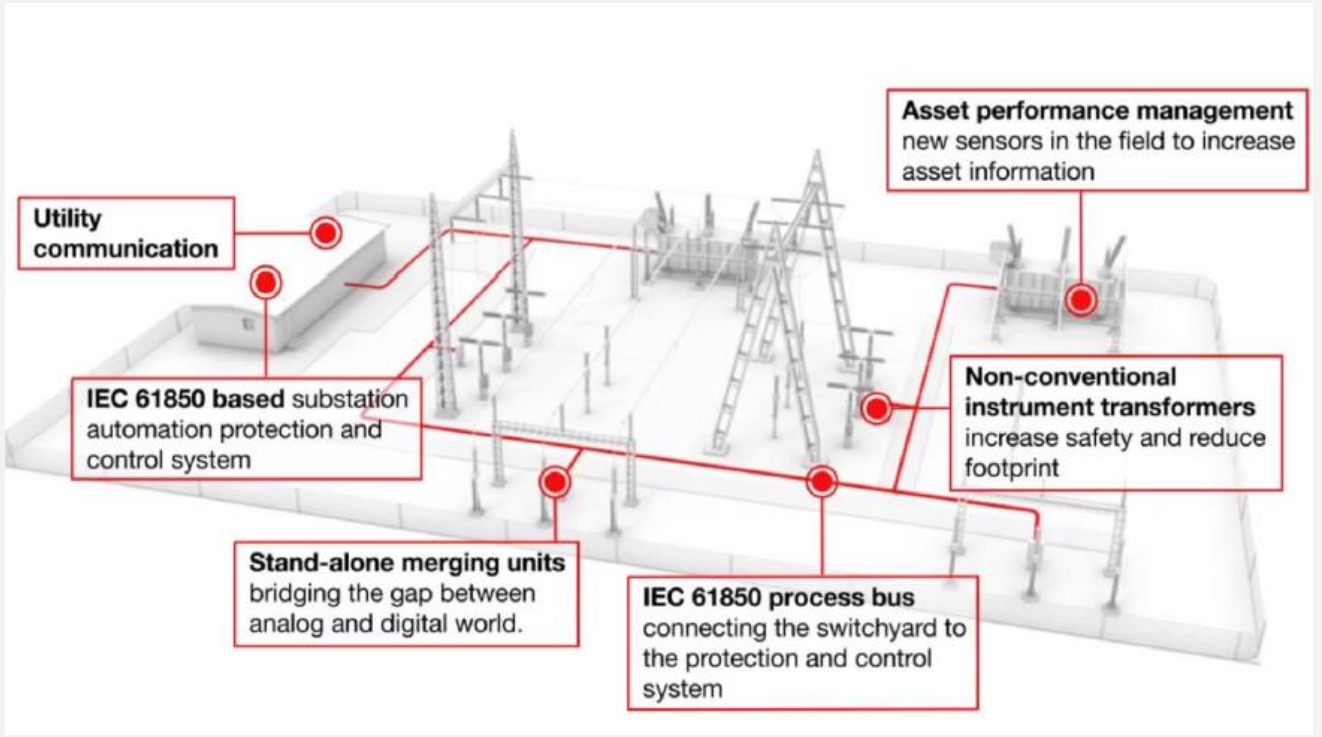


WHY? SOME EXPERIENCES AND PROJECTS

DIGSUB - TOWARDS INDUSTRY ALIGNED SOLUTIONS

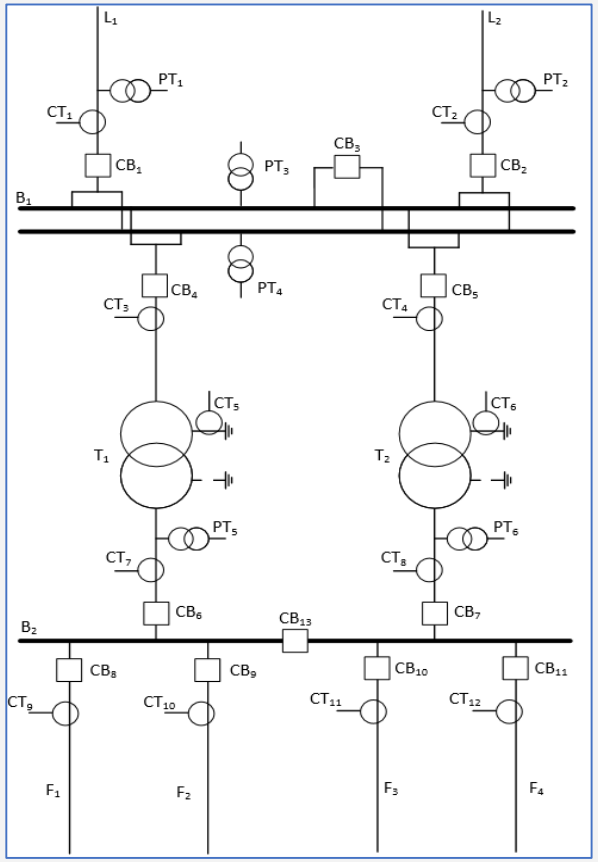
TRACTEBEL ENGIE
SIEMENS
vito
Hitachi Energy
ABB
KU LEUVEN
Laborelec
BASF
We create chemistry

GUIDELINES DESIGN & MONITORING	RISK ASSESSEMENT (FMEA)	TESTING PROCEDURES	DIAGNOSTIC TOOLS	CASE STUDIES	ROADMAP

HOW? SUBSTATION-IN-THE-LOOP

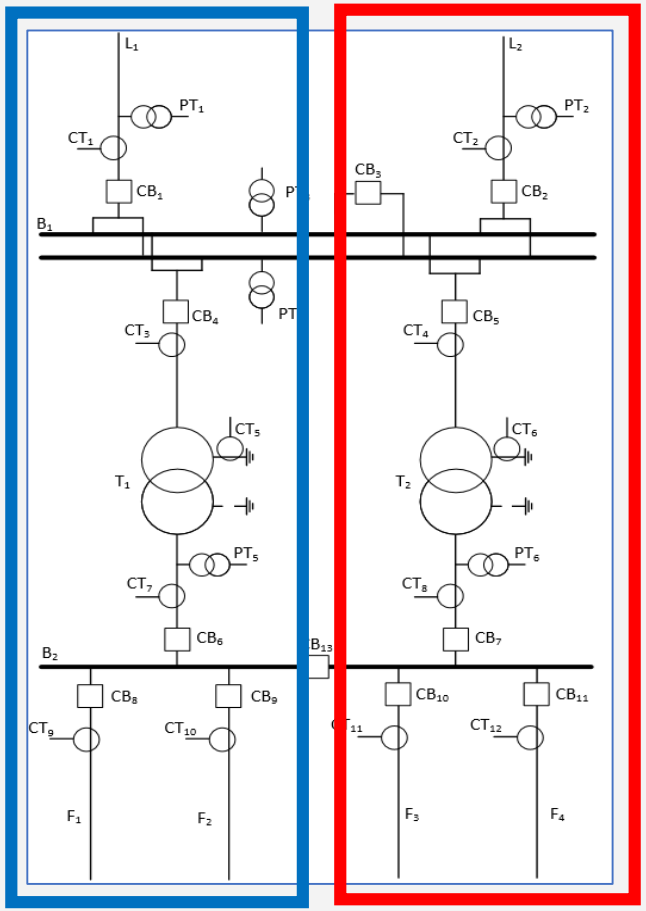
HOW? SUBSTATION-IN-THE-LOOP

RTDS Technologies



HOW? SUBSTATION-IN-THE-LOOP

RTDS Technologies



SIEMENS

Hitachi Energy

HOW? SUBSTATION-IN-THE-LOOP

RTDS Technologies

ANALOGUE

current and voltages

Binary IO

DIGITAL

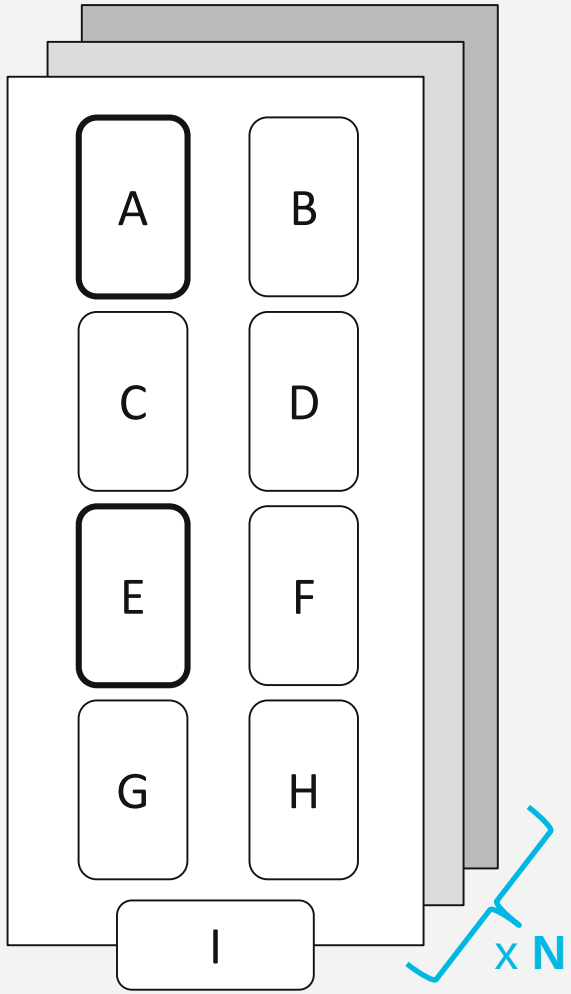
Sampled Values (SV)

GOOSE

AMPLIFIERS

PAC CUBICLES

EMULATION OF PAC

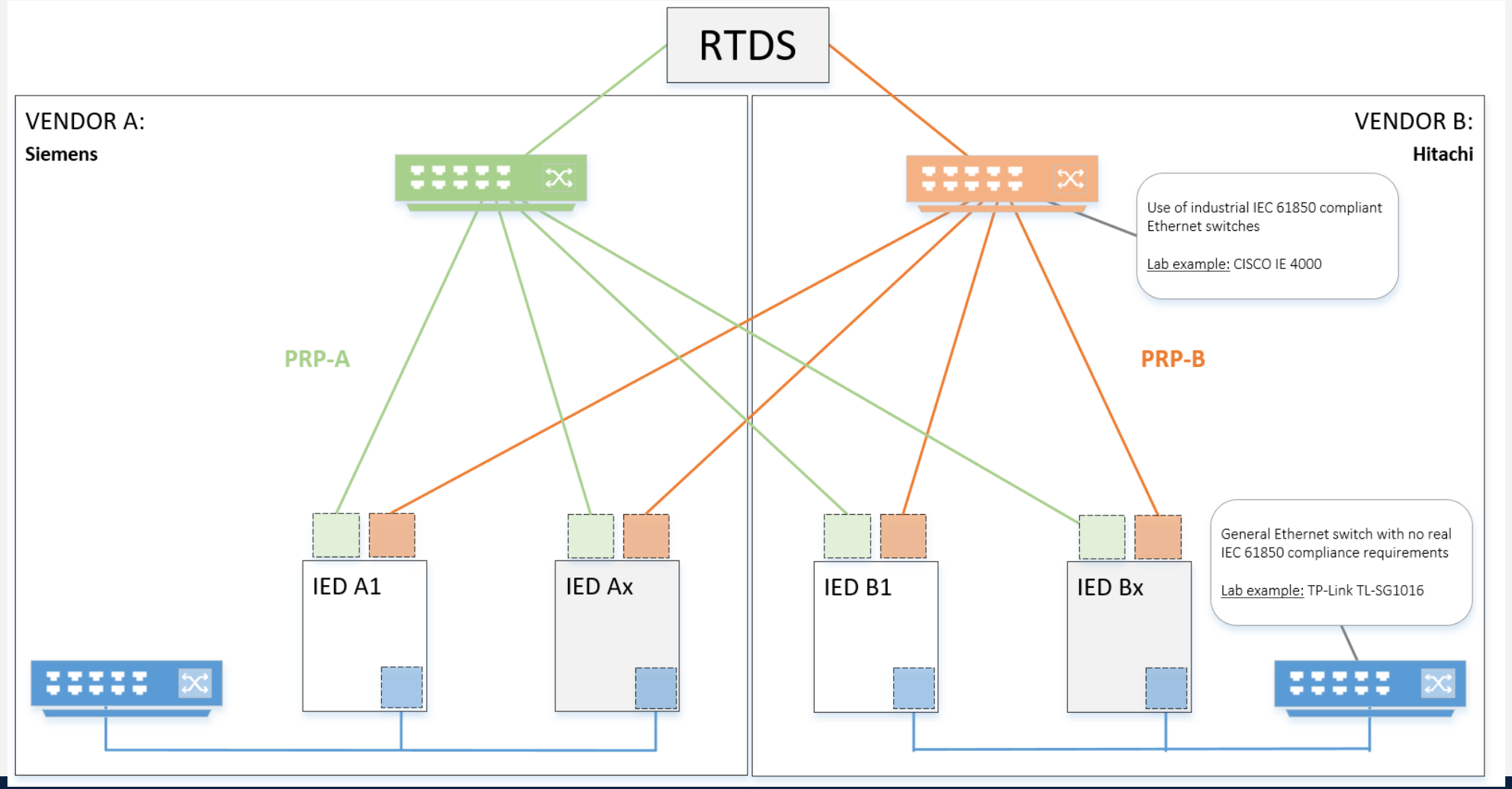


Outlook on single-protection requirements

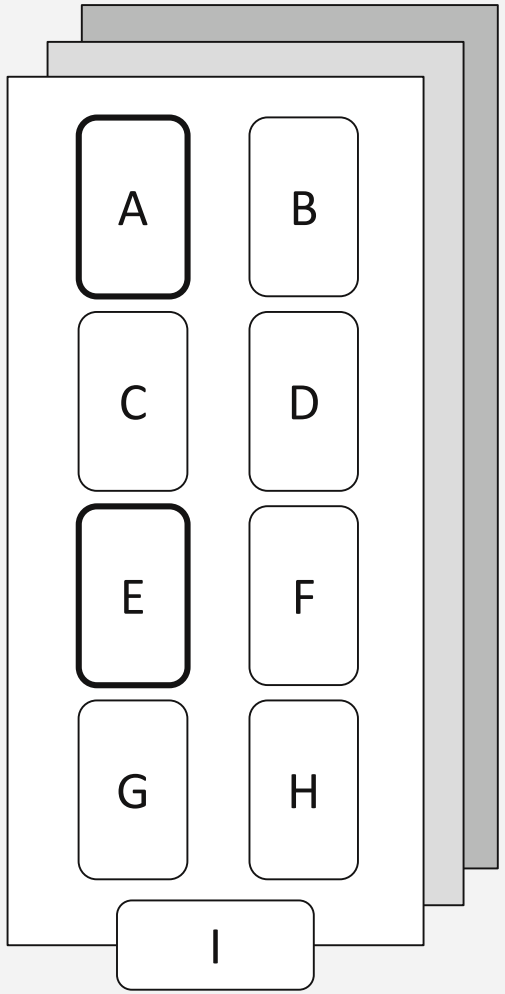
A	:	Primary Protection
B	:	Redundant protection
C	:	Back-up protection
D	:	Bay-controller
E-H	:	Merging Unit
I	:	Remote Terminal Unit (RTU)

Interoperable protection applications (**N**)

- Multiple protection zones
- Multi-vendor, Multi-generation,…
- Inter-substation protection
- …


RTDS
VENDOR A:
Siemens
VENDOR B:
Hitachi
Use of industrial IEC 61850 compliant Ethernet switches
Lab example: CISCO IE 4000
PRP-A
PRP-B
IED A1
IED Ax
IED B1
IED Bx
General Ethernet switch with no real IEC 61850 compliance requirements
Lab example: TP-Link TL-SG1016

EMULATION OF PAC



ANALOGUE

DIGITAL

e.g. per (general) IED has:

- (3) voltage and (3) current inputs
- (4) binary input and (8) output

- (2) redundant process bus
- (2) redundant station bus
- (1) general communication port

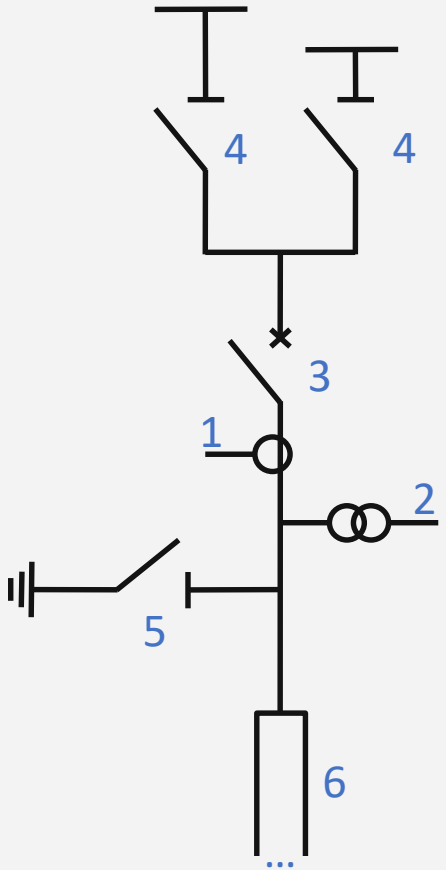
requiring:

- (1) GTNETx2 with (2) SMV & (2) GOOSE
- (1) GTNETx2 with (2) GOOSE & (2) IEC104

e.g. per substation:

- (1) GTSYNC - no redundancy

EMULATION OF PAC



Instrument transformers

1. (4) Currents
2. (4) Voltages

- Modelling saturation, resonances…

Switch-gear

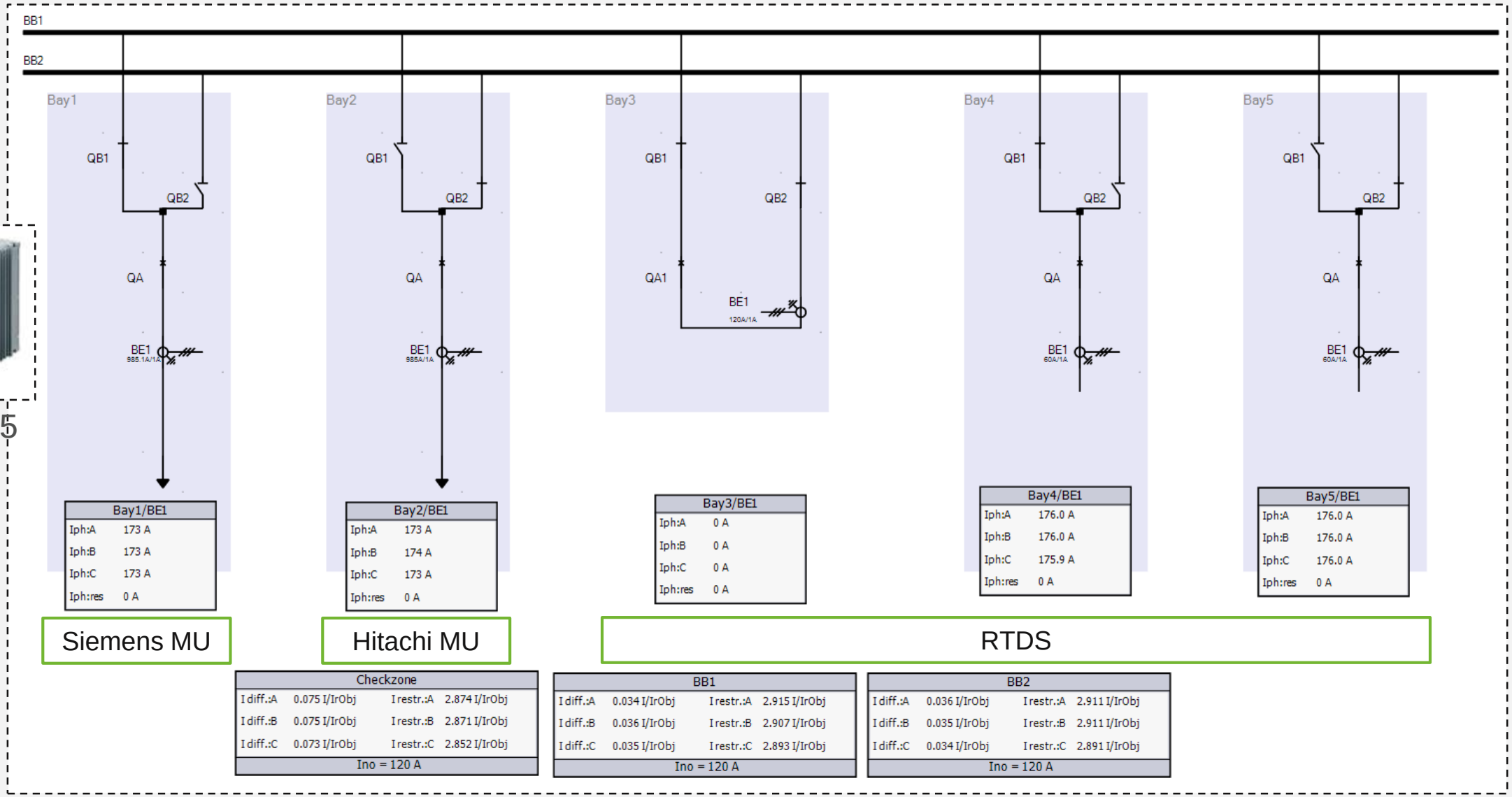
3. Circuit breaker
4. Disconnector
5. Earth Switch

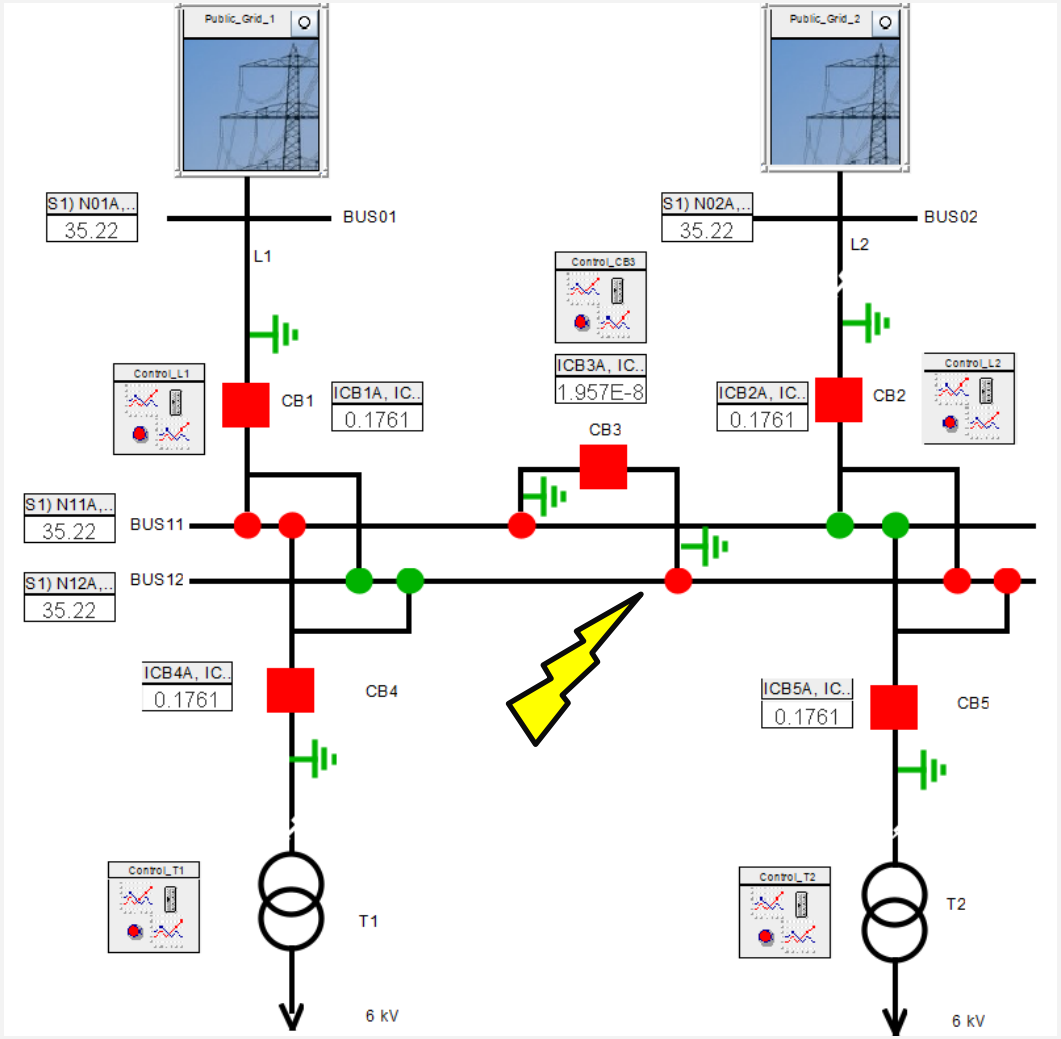
- position feed-back and control
- Interlock logic
- Health state and alarms
- Physics (arcing, short-circuit capabilities…)

Feeder

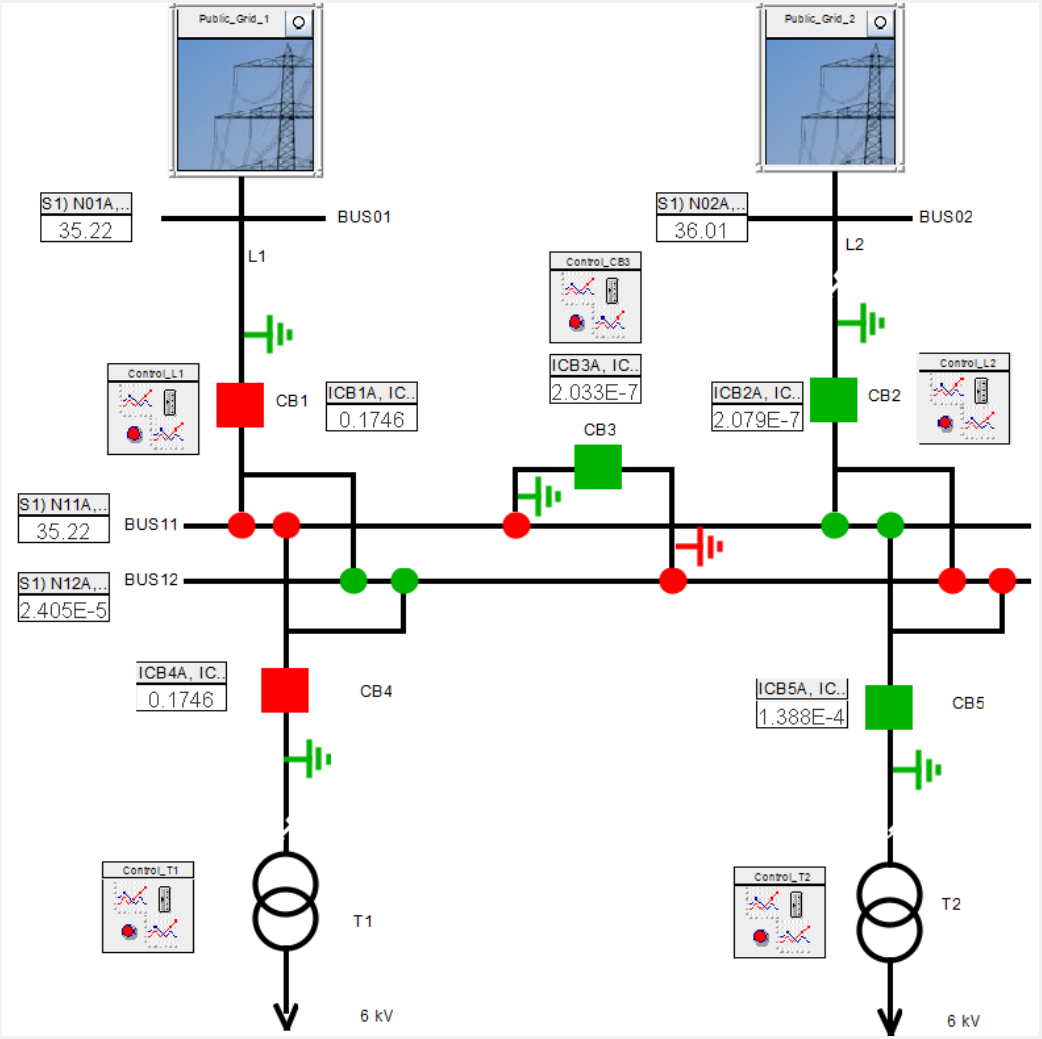
6. Cable, transformer, load…

7SS85


BB1
BB2
Bay1
Bay2
Bay3
Bay4
Bay5
QB1
QB2
QA
QA1
BE1
Bay1/BE1
Iph:A 173 A
Iph:B 173 A
Iph:C 173 A
Iph:res 0 A
Bay2/BE1
Iph:A 173 A
Iph:B 174 A
Iph:C 173 A
Iph:res 0 A
Bay3/BE1
Iph:A 0 A
Iph:B 0 A
Iph:C 0 A
Iph:res 0 A
Bay4/BE1
Iph:A 176.0 A
Iph:B 176.0 A
Iph:C 175.9 A
Iph:res 0 A
Bay5/BE1
Iph:A 176.0 A
Iph:B 176.0 A
Iph:C 176.0 A
Iph:res 0 A
Siemens MU
Hitachi MU
RTDS
Checkzone
Idiff.:A 0.075 I/IrObj Irestr.:A 2.874 I/IrObj
Idiff.:B 0.075 I/IrObj Irestr.:B 2.871 I/IrObj
Idiff.:C 0.073 I/IrObj Irestr.:C 2.852 I/IrObj
Ino = 120 A
BB1
Idiff.:A 0.034 I/IrObj Irestr.:A 2.915 I/IrObj
Idiff.:B 0.036 I/IrObj Irestr.:B 2.907 I/IrObj
Idiff.:C 0.035 I/IrObj Irestr.:C 2.893 I/IrObj
Ino = 120 A
BB2
Idiff.:A 0.036 I/IrObj Irestr.:A 2.911 I/IrObj
Idiff.:B 0.035 I/IrObj Irestr.:B 2.911 I/IrObj
Idiff.:C 0.034 I/IrObj Irestr.:C 2.891 I/IrObj
Ino = 120 A



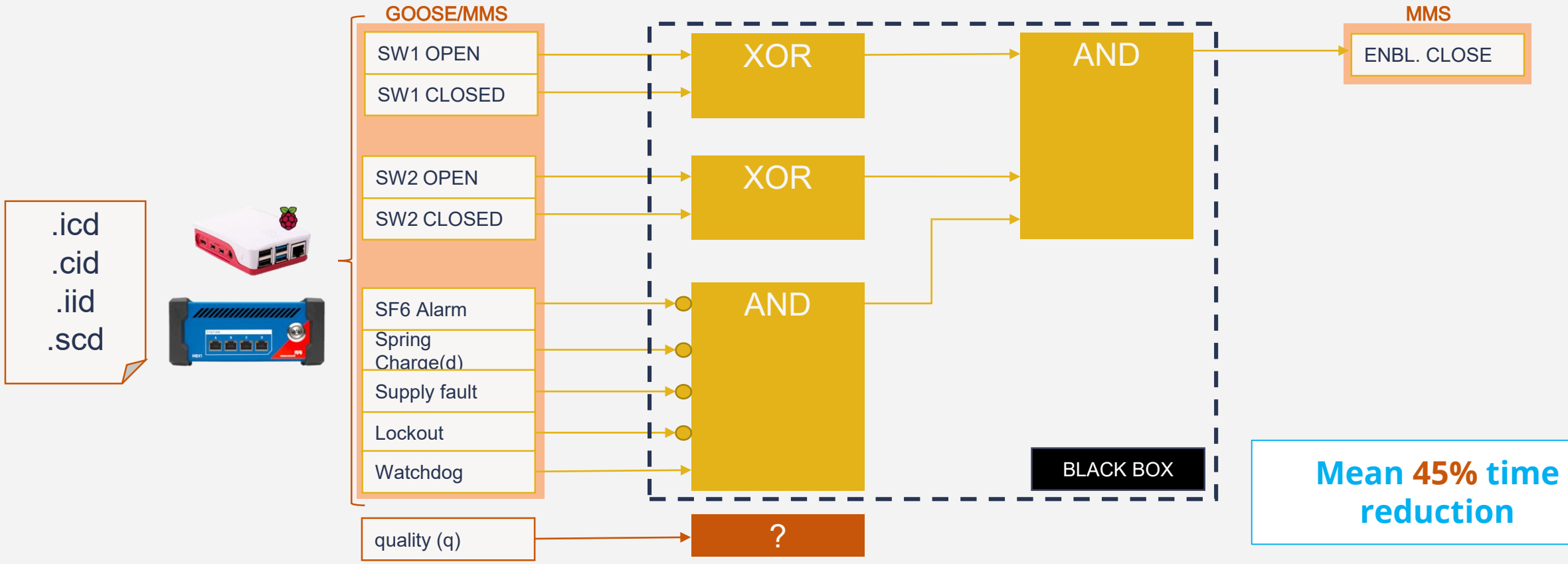
Ground fault on busbar 2



Selective and timely trip

AUTOMATED TESTING

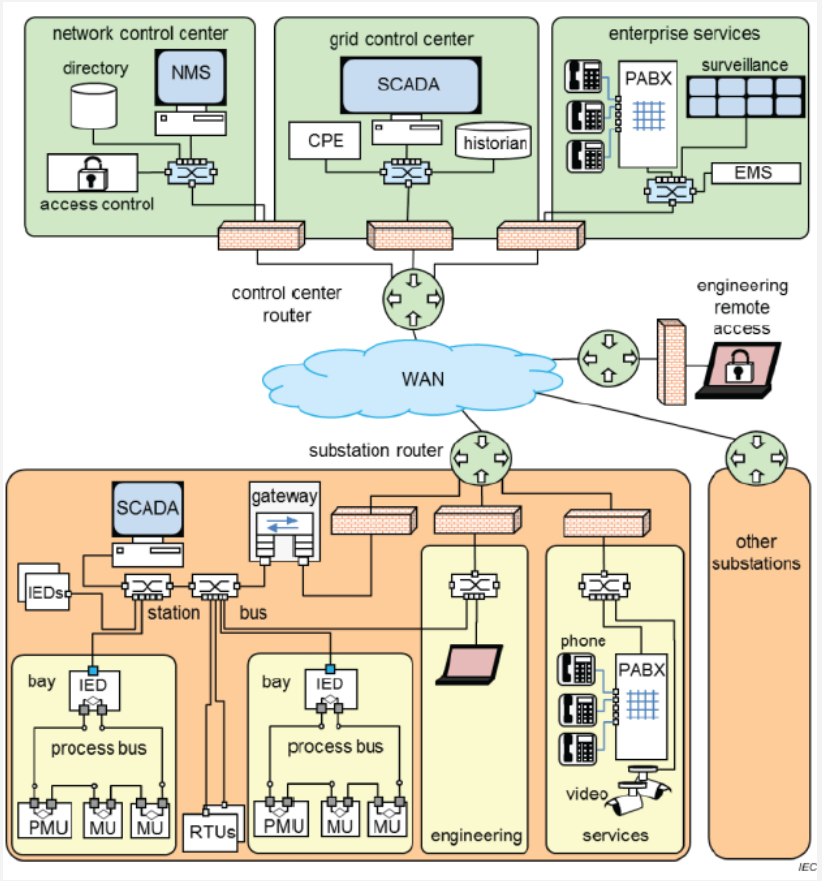
Case study for circuit breaker interlocks



Mean 45% time reduction

R. Loenders et al. Practical review and advancements in testing multi-vendor digital substations, CIRED, 2023

HOW? SUBSTATION-IN-THE-LOOP

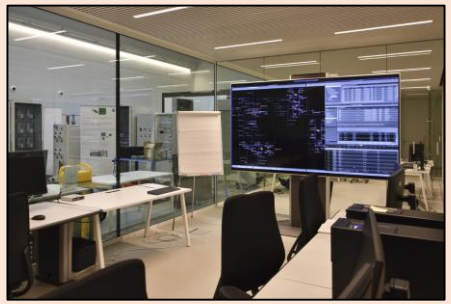


CONTROL ROOM

SCADA

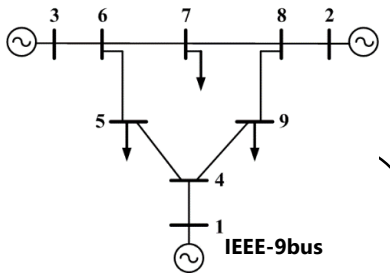
Who/what performs the control action for WAN applications?
e.g. GE PowerOn, RTU, controller, RTDS

How to interface?



RTDS

Which network topology?



IEEE-9bus

GTNETx2

Which protocols to utilize?

Enough switches acquired?

Ethernet switch

NET-SIM

SNORT/NS3

Simulated network topology, information traffic, and (end)nodes?

Run applications on server

PACS

LAN/WAN network topology?
Cyber-security measures or infrastructure (lab, field and how does these impact tests)

MU – SAM600

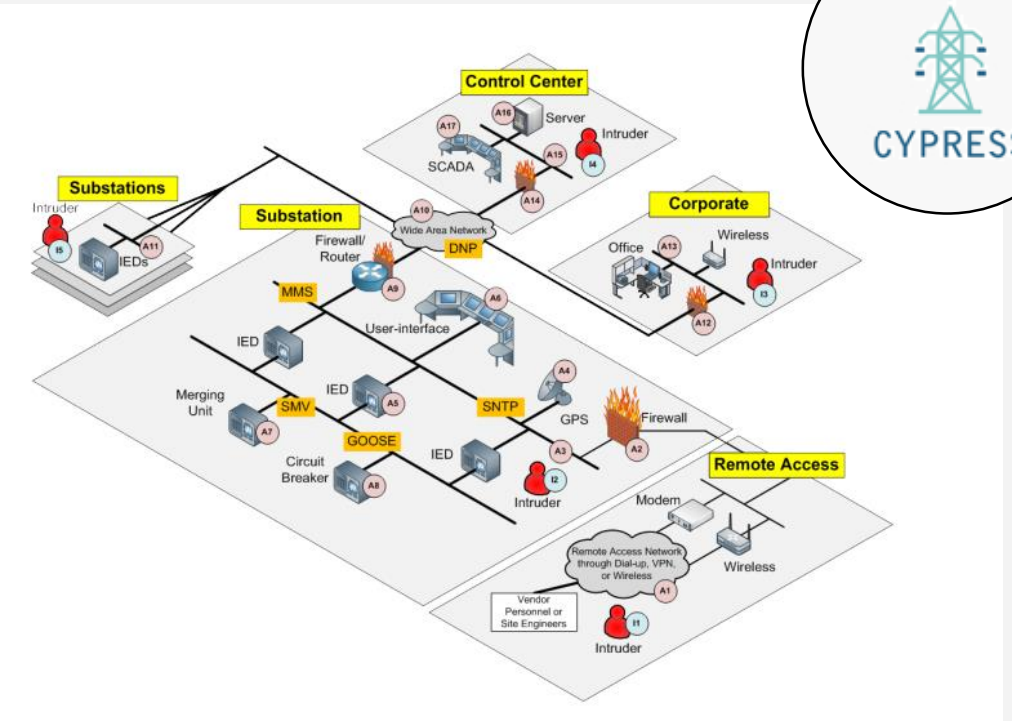
LAN

IED – REL670

WAN

RTU – 540CID01

CYPRESS - REAL-TIME CO-SIMULATION FOR CYBER SECURITY TESTING



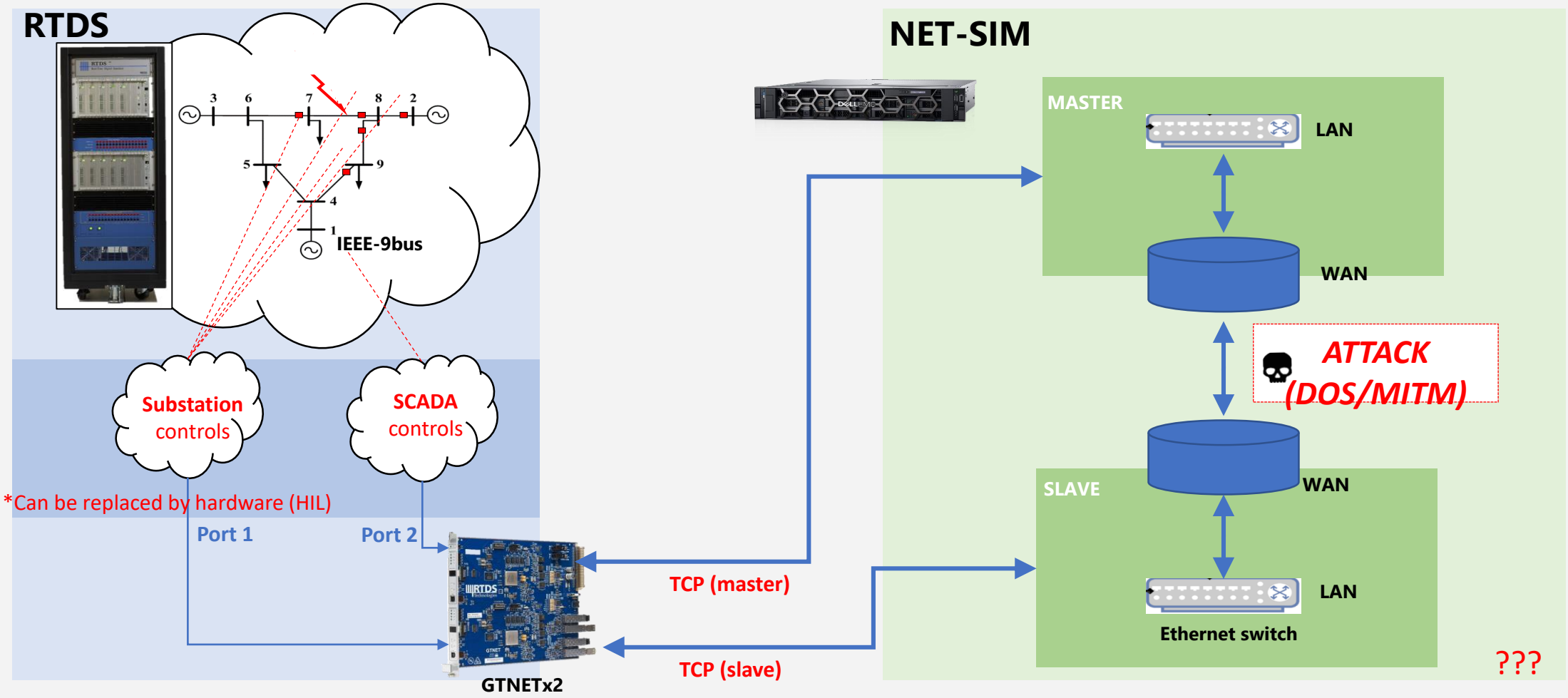
CYPRESS

Added emulation of

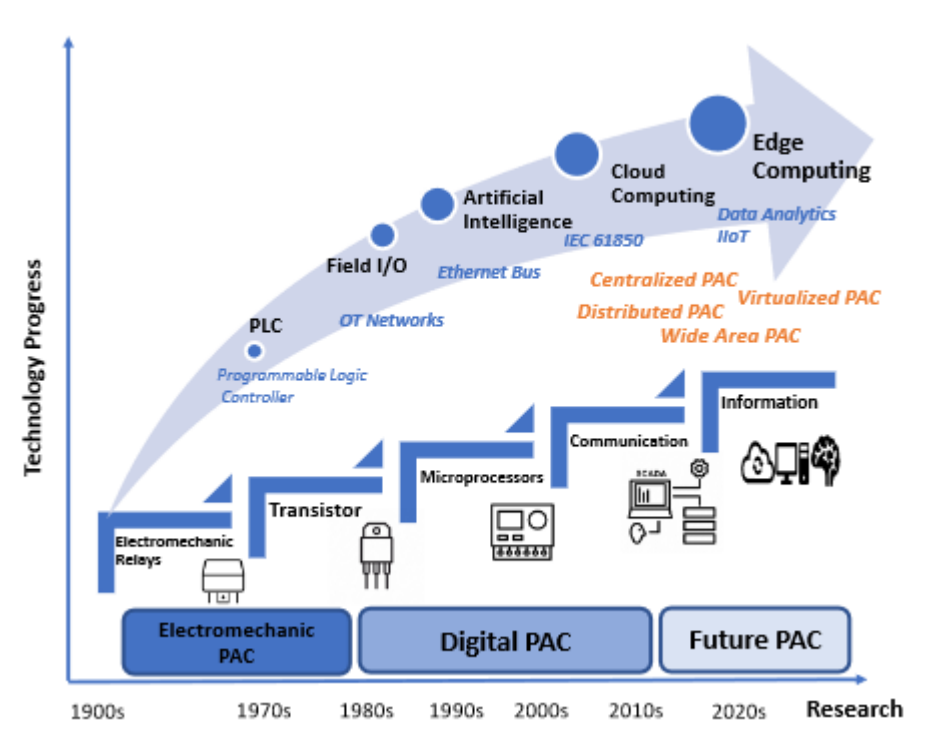
- Interdependent Architectures
- Security measures
- Encryption of data
- Data privacy and policy

T. Behdadnia & G. Deconinck, A new deep learning-based strategy for launching timely DoS attacks in PMU-based cyber-physical power systems, ISGT, 2022

CYPRESS - REAL-TIME CO-SIMULATION FOR CYBER SECURITY



FUTURE OF RESEARCH ON DIGITAL SUBSTATIONS



- Micro-grids
- Renewable power plants
- Offshore grids
- (HV)DC substations
- Mobile substations
- Cyber-security

Fig: Kabbara et al., 'Towards Software-Defined Protection, Automation, and Control in Power Systems', Energies, 2022

SOME EXPERIENCES AND PROJECTS