Paris Session 2022

# System Integrity Protection Schemes in the Context of Evolving Power Grids

*SC B5: Protection & Automation*


| | |
|---|---|
| SC B5 Chair | Rannveig S. J. Loken |
| SC B5 Secretary | Richard Adams |
| Tutorial Advisor | Klaus-Peter Brand |
| Tutorial speaker | Cedric Moors |
| | Vladimir Terzija |
| | Alex Apostolov |

# Mission of SC B5

The mission of SC B5 is to facilitate and promote the progress of engineering and the international exchange of information and knowledge in the field

**Protection and Automation** focused on

- **Protection**
- **Control**
- **Monitoring**
- **Metering**

with the aim to cover the whole power system end-to-end

# SC B5 Tutorial Agenda

**Tuesday 30th of August, 08.30 – 10.20, SC B5 Tutorial**

- System Integrity Protection Schemes in the Context of Evolving Power Grids

08.30 Introduction SC B5 Chair Rannveig S. J. Loken (Klaus-Peter Brand)

08:35 Introduction to System Integrity Protection Schemes (SIPS)
- o Cedric Moors

09:00 Smart technologies for advanced System Integrity Protection Schemes
- o Vladimir Terzija

09:25 Introduction to the typical architecture of System Integrity Protection Schemes
- o Alex Apostolov

09:50 Questions

10:15 Closing by SC B5 Chair







cigre
For power system expertise

Interactivity - Sparkup:
https://cigre.eu.sparkup.live/connect/MAILL

Please type your questions for response later in the tutorial.

# Part 1 - Introduction to System Integrity Protection Schemes

Cedric Moors

# System Integrity Protection Schemes (SIPS) - Definition

- According to IEEE C37.250-2020:

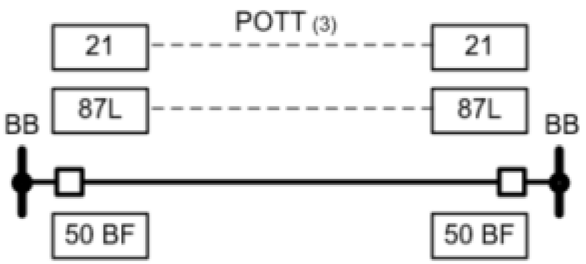
*“Serves* ***to enhance security*** *and prevent propagation of disturbances for severe emergencies caused by unacceptable operating conditions and is used* ***to stabilize the power system*** *by taking control action to mitigate those system conditions”*

- According to Cigre TF 38.02.19:

*“A System Protection Scheme (SPS) or Remedial Action Scheme (RAS) is designed to detect abnormal system conditions and take predetermined, corrective action (other than the isolation of faulted elements)* ***to preserve system integrity*** *and provide acceptable system performance.”*

# SIPS vs Grid Element Protections

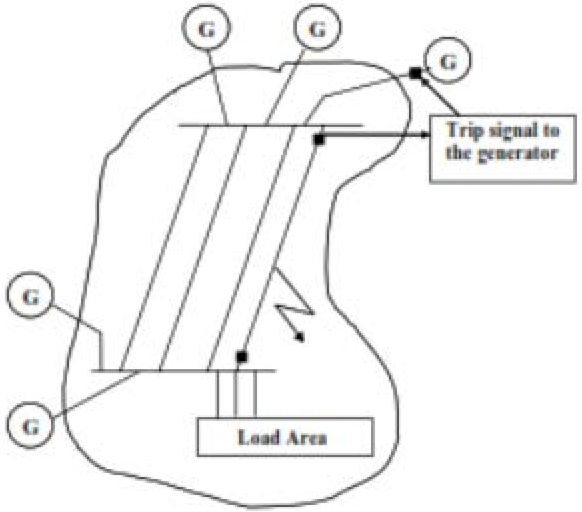
## Grid element protection




Main goals:

- To protect grid elements against consequences of “usual” faults
- To trip the fault as fast as possible in order to limit disturbances

## System Integrity Protection Schemes (SIPS)

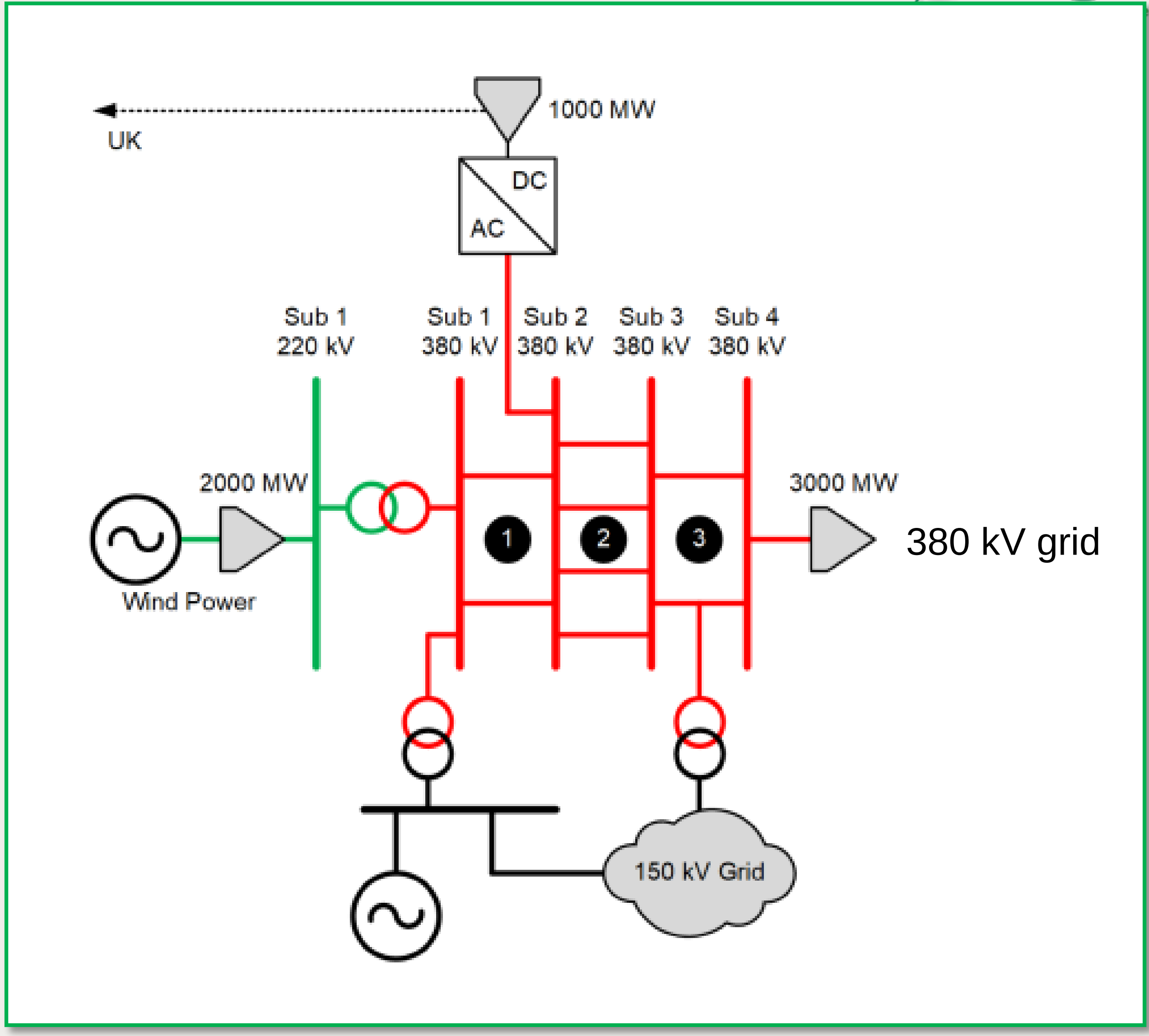



Main goals:

- To detect contingencies and to take the necessary control actions in order to preserve system integrity
- Optionally, to provide system operator with real-time information about  system status (for example: stability margin)

# Example: offshore corridor SIPS

- Context: connection of 2 GW offshore production and 1 GW HVDC to 380 kV grid through dedicated corridor
- Main goals of SIPS:
  - stop instability if 380 kV corridor completely lost at max. production (extreme contingency)
  - prevents interaction between HVDC and offshore converters
- Action to apply: tripping of offshore production and HVDC link (if needed)
- Max tripping time: 100 ms
- Needs defined from dynamic simulations, with EMT detailed model

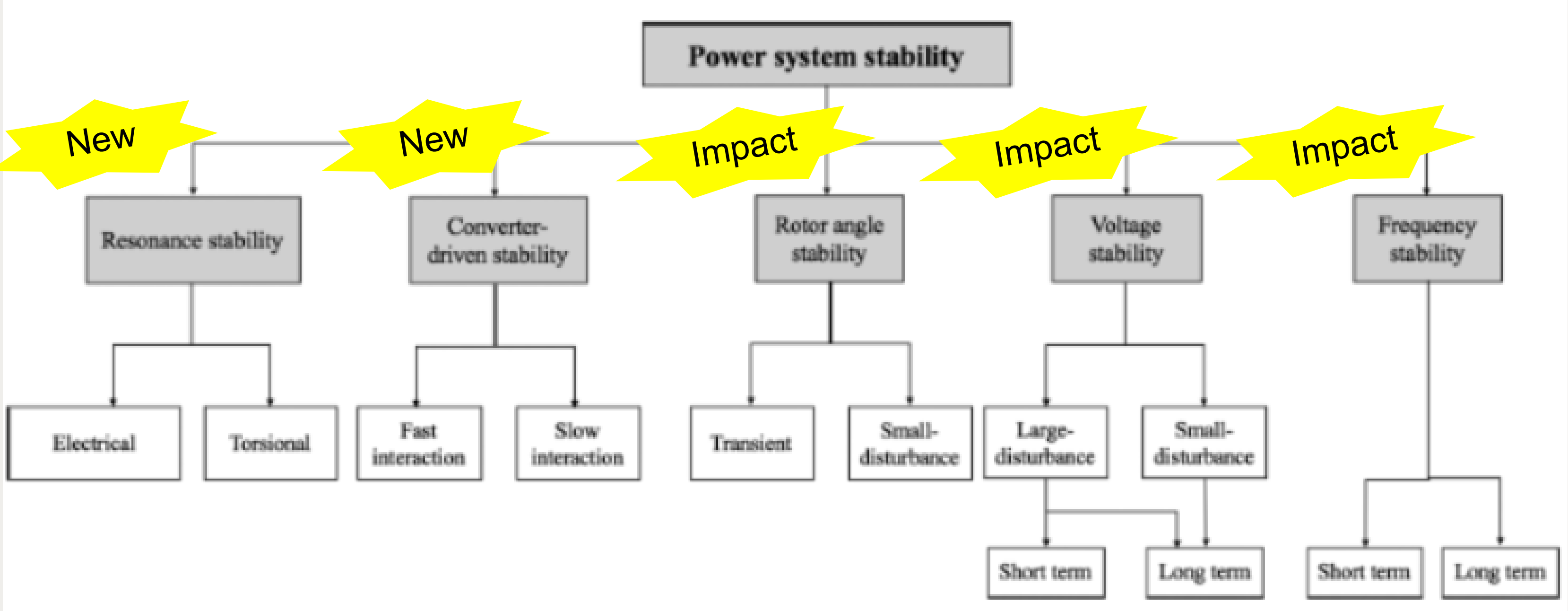


# More SIPS will be probably deployed in the near future

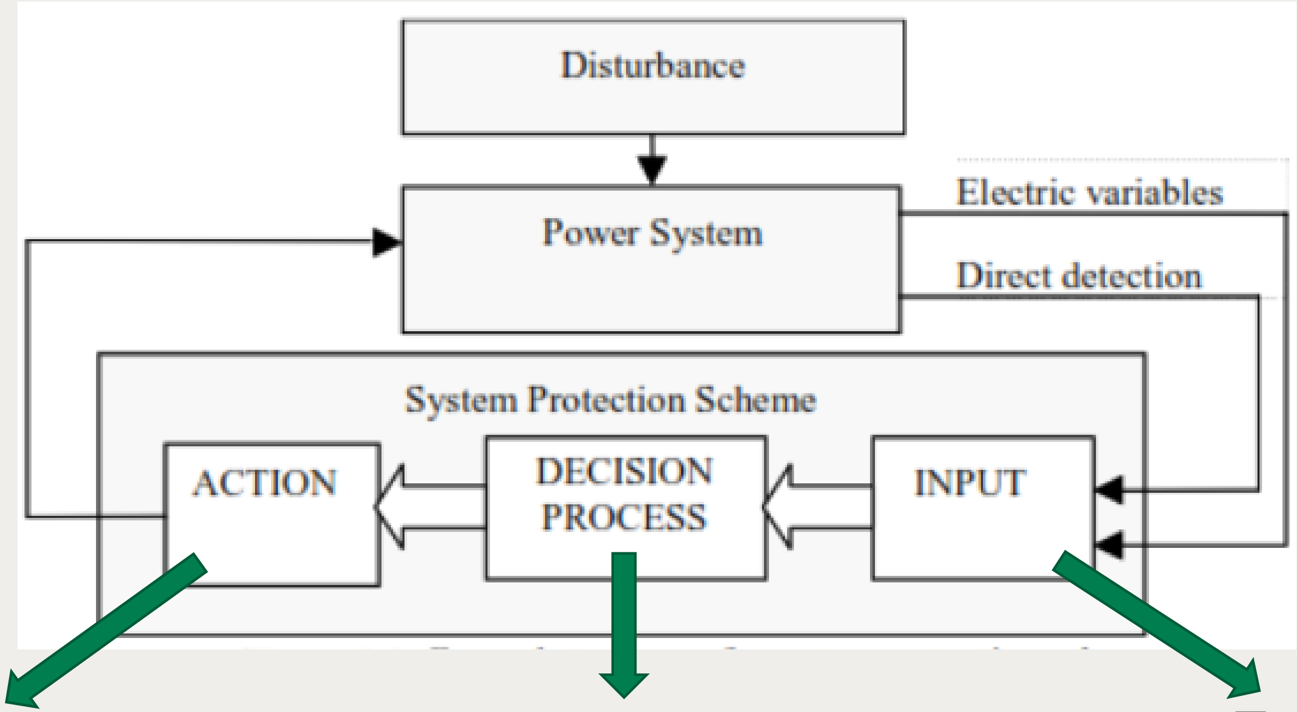
- Strong (r)evolution at generation and transmission levels (more offshore, more decentralized production, more Inverter Based Generation, less “classical” generation, more HVDC), in the context of decarbonization
- Strong increase of load consumption and deep changes in load behavior (electric vehicles)
- Challenge to build new infrastructure on time (“Nimby” effect)
- Power system dynamics deeply impacted (see below)
- SIPS = cost-effective solution wrt investments in primary infrastructure

*The fossil fuel economy has reached its limits. We want to leave the next generation a healthy planet as well as good jobs and growth that does not hurt our nature.”*

*- Ursula von der Leyen, July 2021*



# SIPS general structure and classification




*Local action vs wide area action*

*Centralized vs Decentralized*

*Event-based vs response-based*

# Event-based vs response-based SIPS

- Response-based: based on measured electric variables, such as voltage, frequency, etc
- Event-based: operates upon recognition of a particular combination of events, such as loss of several lines in a substation

| SIPS type | Benefits | Drawbacks |
|---|---|---|
| Event-based | • Faster | • Can only take actions for designed events<br>• Typically rely on binary information such as equipment position |
| Response-based | • Covers a wider range of events | • Slower, not applicable against fast phenomena |

# Centralized vs decentralized SIPS

- Centralized: the action to take is decided in one location, from remote information
- Decentralized: the action to take is decided at several locations, from local information

| SIPS type | Benefits | Drawbacks |
| --- | --- | --- |
| Centralized | • Action better adapted to current grid situation | • Relies on telecommunication system, so slower and less reliable<br>• Potential single point of failure |
| Decentralized | • Faster<br>• Natural redundancy | • Need for good synchronization of all SIPS actions for all possible contingencies (during design) |

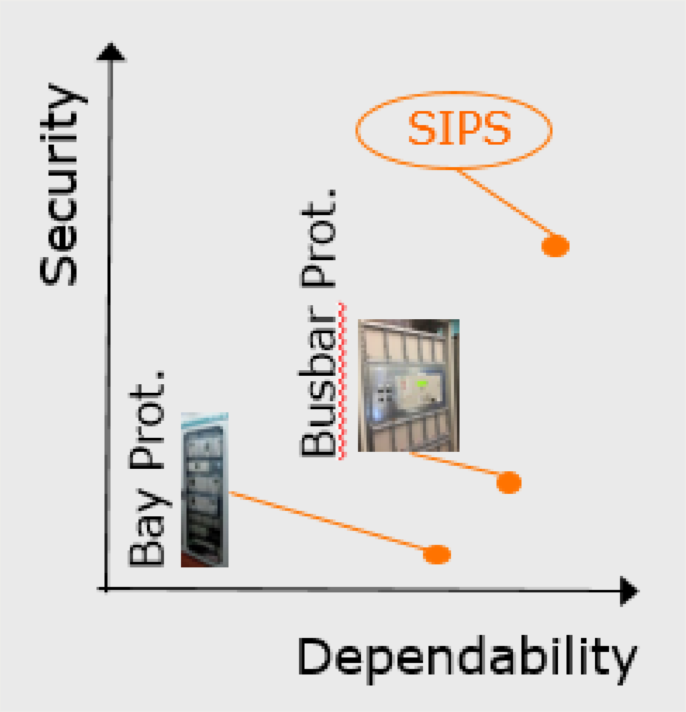
# *Local vs wide area action*

- Local action: the action to take is applied in one location, typically where the action has been decided
- Wide area action: the action to take is applied in various locations, sometimes far from each others

| SIPS type | Benefits | Drawbacks |
|---|---|---|
| Local action | • Faster | • Only applicable for specific contingencies, when local actions are sufficient |
| Wide area action | • Covers wider ranges of actions | • Relies on telecommunication system, so slower and less reliable |

# SIPS requirements regarding PAC philosophy

- Dependability: very high
- Security: high / very high. In some cases unwanted tripping can have similar consequences as tripping refusal
- Speed of actions: depends on type of phenomena. Typical range: 70 ms – a few minutes
- Availability: usually high, depends on risk (probability and impact) in case of fail dangerous




**SIPS design usually differs from “classical” PAC solutions (specific logics, increased redundancy)**

# Back to our example: offshore corridor SIPS implementation

- 100 ms tripping time needed, detection of all possible corridor openings needs complex logic:
  - Event-based
  - Centralized
  - Local actions (limited to 3 substations)
- Dedicated telecommunication system for information exchange between substations
- Complete redundancy to maximize availability and allow hot maintenance
- Specific logics (opening detection validated by various criteria) to increase security
- Test completely performed in RTDS environment, with detailed grid model

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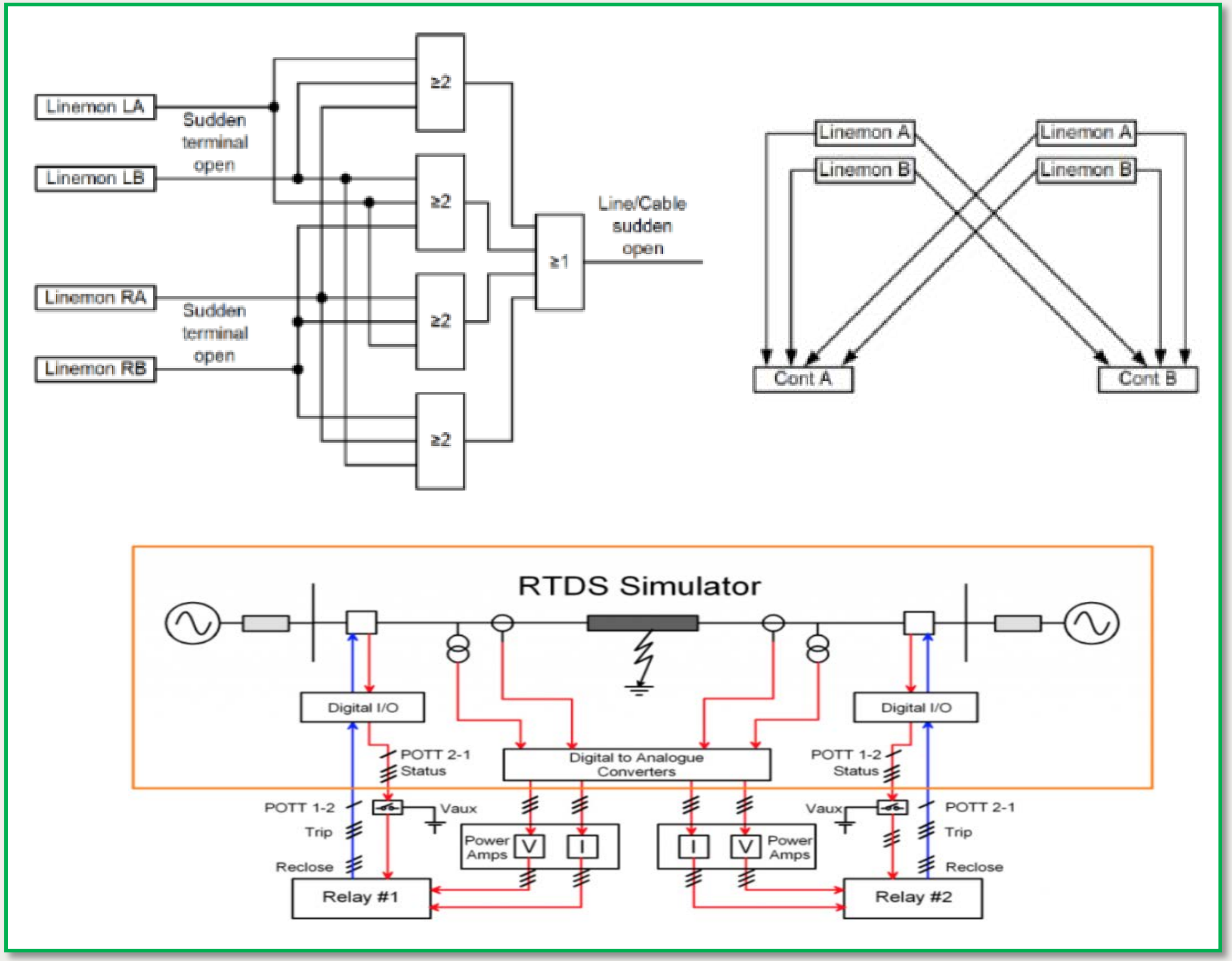

# SIPS vs WAMPACS

- WAMPACS = Wide Area Monitoring, Protection And Control Schemes
- Used for
  - Monitoring
  - Wide area protection, to prevent/stop instabilities
  - Wide area control, to prevent/stop instabilities
  - Post-fault analysis
- WAMPACS make use of Phasor Measurement Units (PMUs)

- Accordingly:
  - WAMPACS are a specific type of SIPS
  - They are response-based (PMUs)
  - They are typically centralized (use of phasors data concentrator)
  - They act typically on a wide area
  - They are not applicable for SIPS with fast action time requirement

# References


- IEEE C37.250-2020. IEEE Guide for Engineering, Implementation, and Management of System Integrity Protection Schemes. *IEEE Std C37.250-2020, pp 1-71*, 2020
- S. Stankovic & all. System Integrity Protection Schemes: Naming Conventions and the Need for Standardization. *Energies 2022, 15, 3920.*
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- N. Hatziargyriou & all. Definition and Classification of Power System Stability – Revised and Extended. *IEEE Trans. on Power Systems, Vol. 36, No 4,* 2021
- R. Hanuise & all. Ensuring the Stability of the Belgian Grid with a Special Protection Scheme. *47th Annual Western Protective Relay Conference, Virtual Format, 2020*

# Part 2 - Smart technologies for advanced System Integrity Protection Schemes

Vladimir Terzija

# Green-Agenda and Changes of the System Nature

**Key changes:**

1) reduced power system inertia
2) reduced fault level
3) increased level of harmonics
4) control interactions
5) increased level of uncertainties
6) other…

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# Low Probability High Impact Events + Severe Weather Conditions

N-x security-based operation of the system (x=1,2,3)

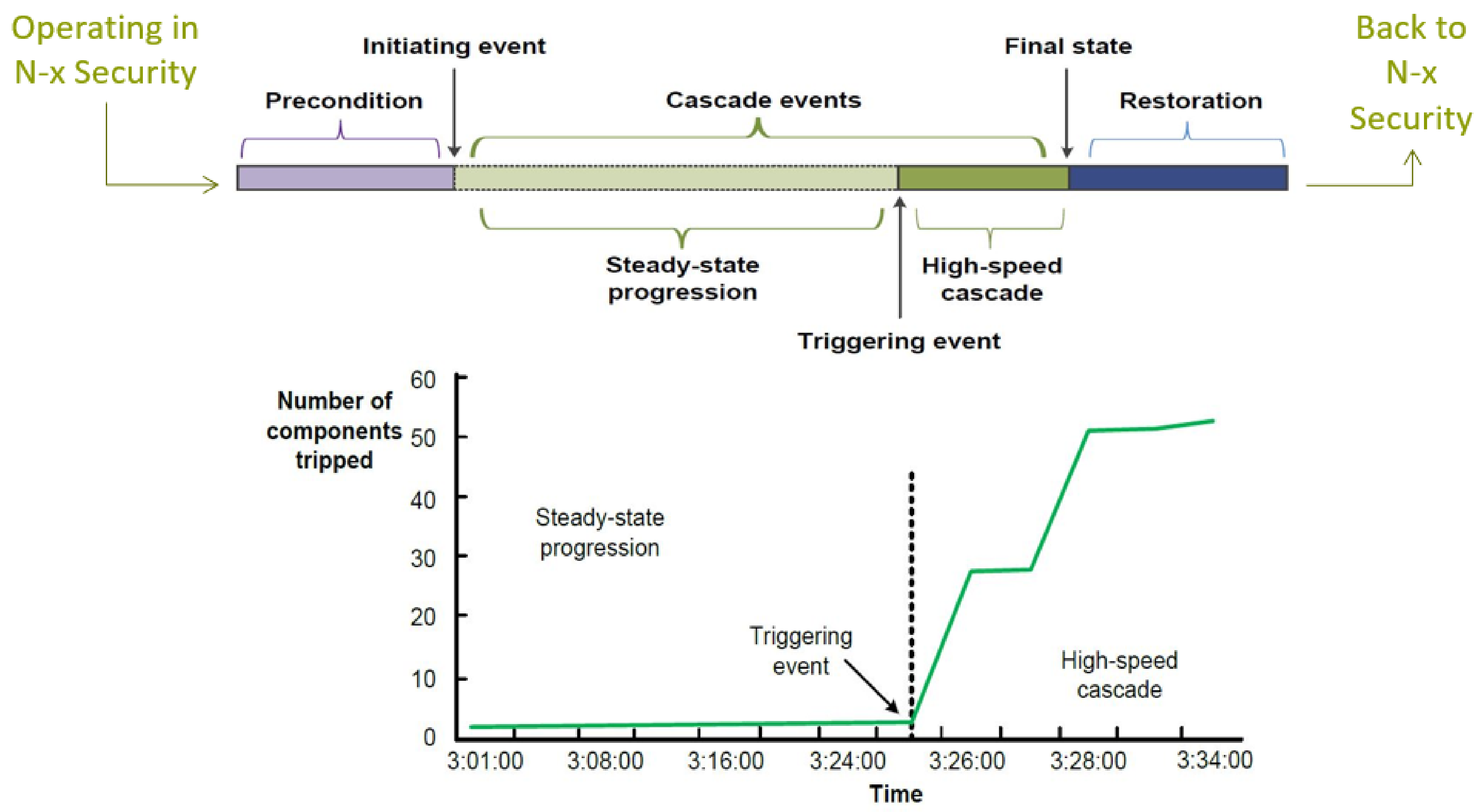
Low Probability High Impact Events are those not covered by the security assessment

They might lead to cascading events with a very complex nature

Severe natural disasters might also lead the system to a partial or a total blackout

Novel technology, e.g. sensors, high speed communication links, supercomputers, AI/Machine Learning-based solutions, must be adequately applied, respecting the nature on phenomena happening in the system

# Cascading Events Leading to Blackouts




Italy Blackout September,2003

Technology and solutions supporting SIPS must consider the **nature** of events against which SIPS are designed

# Key Aspects to be Considered

Monitoring

Protection

Control

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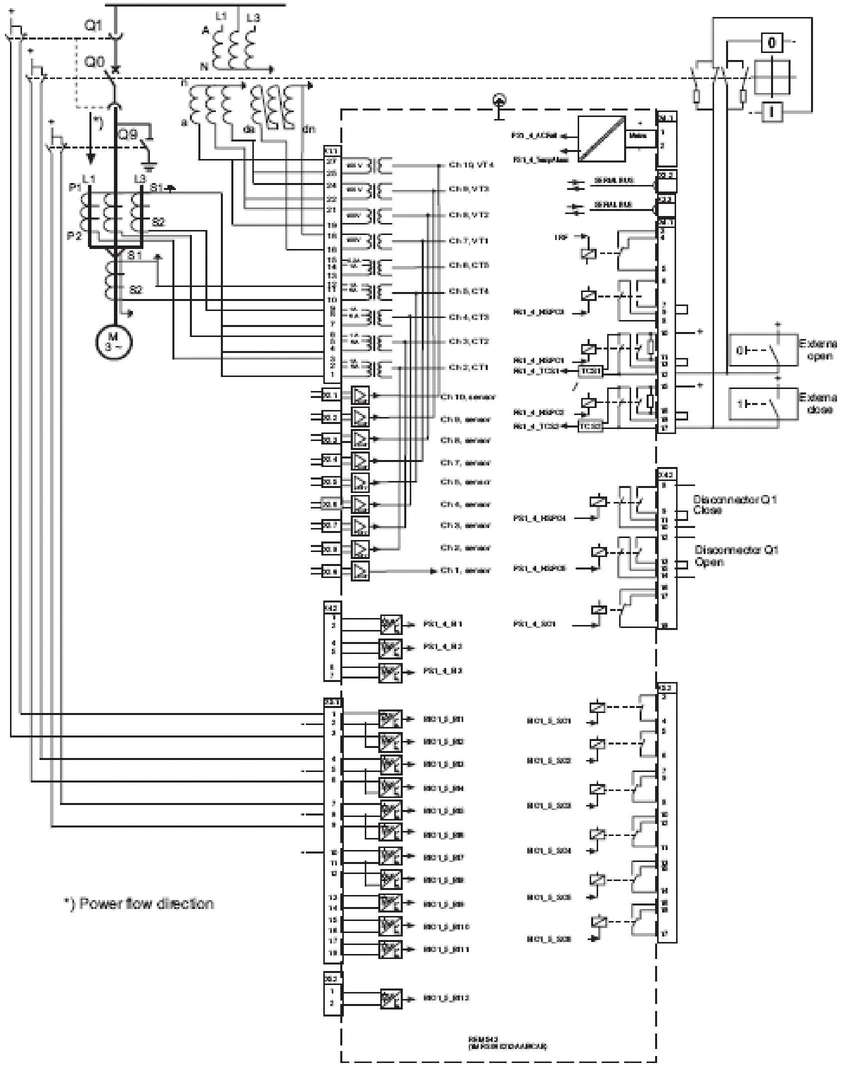
# Intelligent Electronic Devices - IEDs

The core of data acquisition, processing and transfer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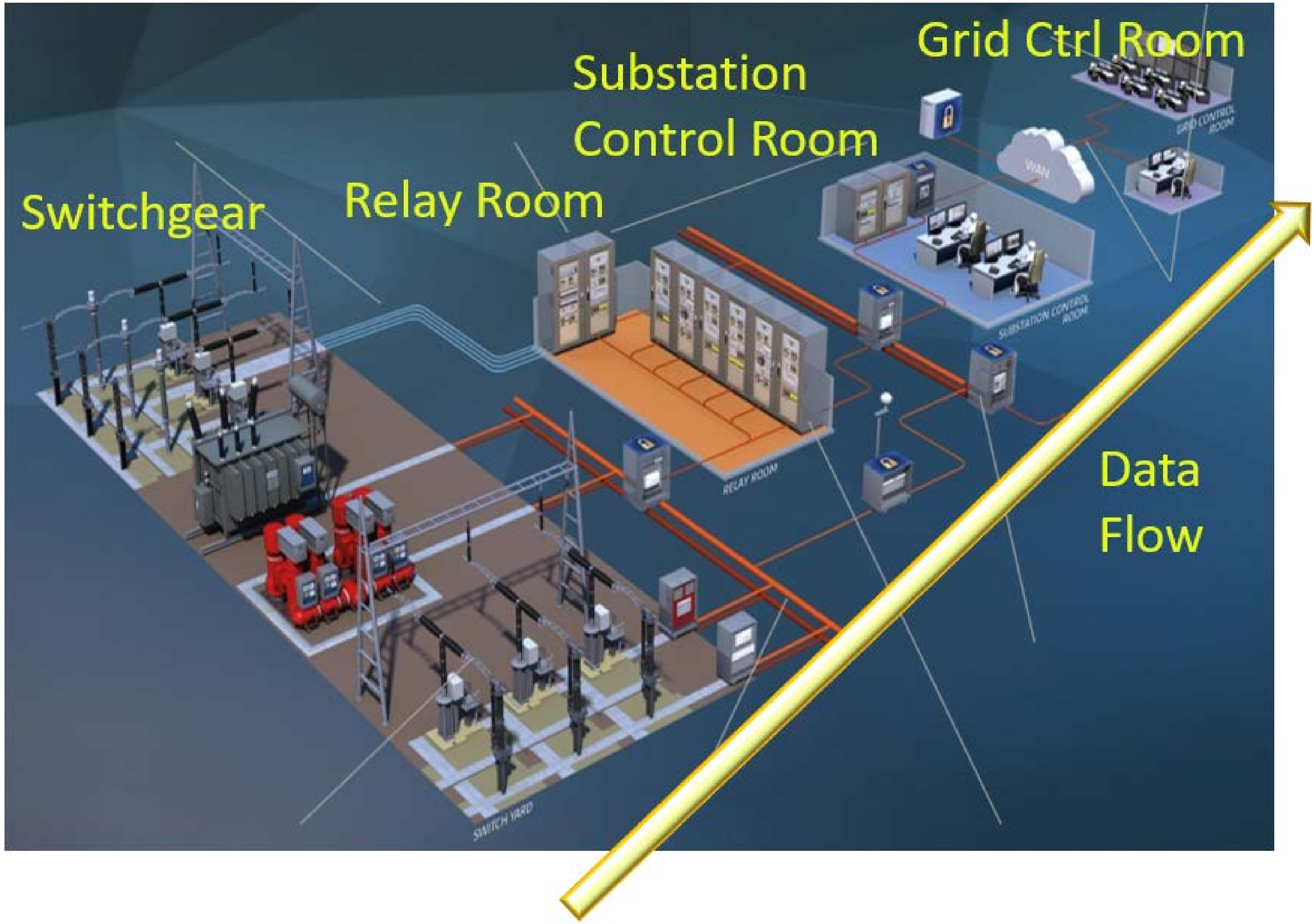
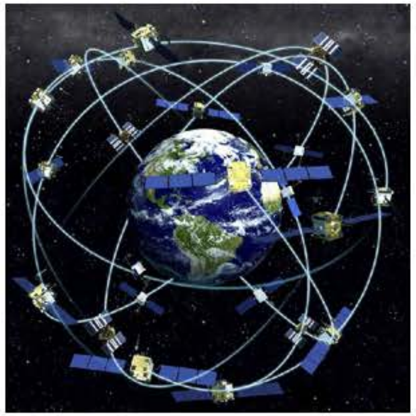
# Digital Substation and the Entire Process Digitalization

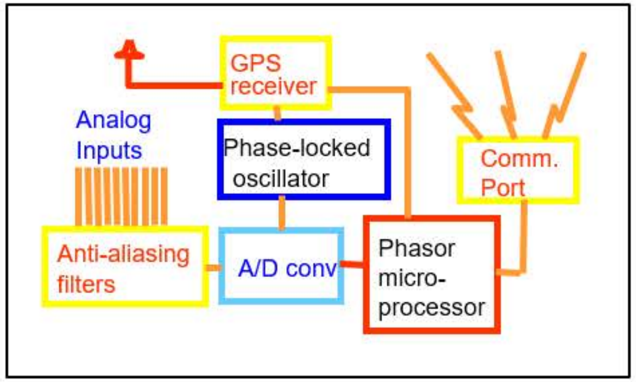
- Non-conventional instrument transformers
- Fiberoptic communication infrastructure
- IEC61850 communication protocol
- Fast data transfer to higher hierarchical levels
- Immunity to EMC-type of problems
- Simplified testing procedures
- Vertical and horizontal data-transfer
- Support of advanced EMS applications and ancillary services (e.g. f-, or v-ctrl.)
- Support of SIPS

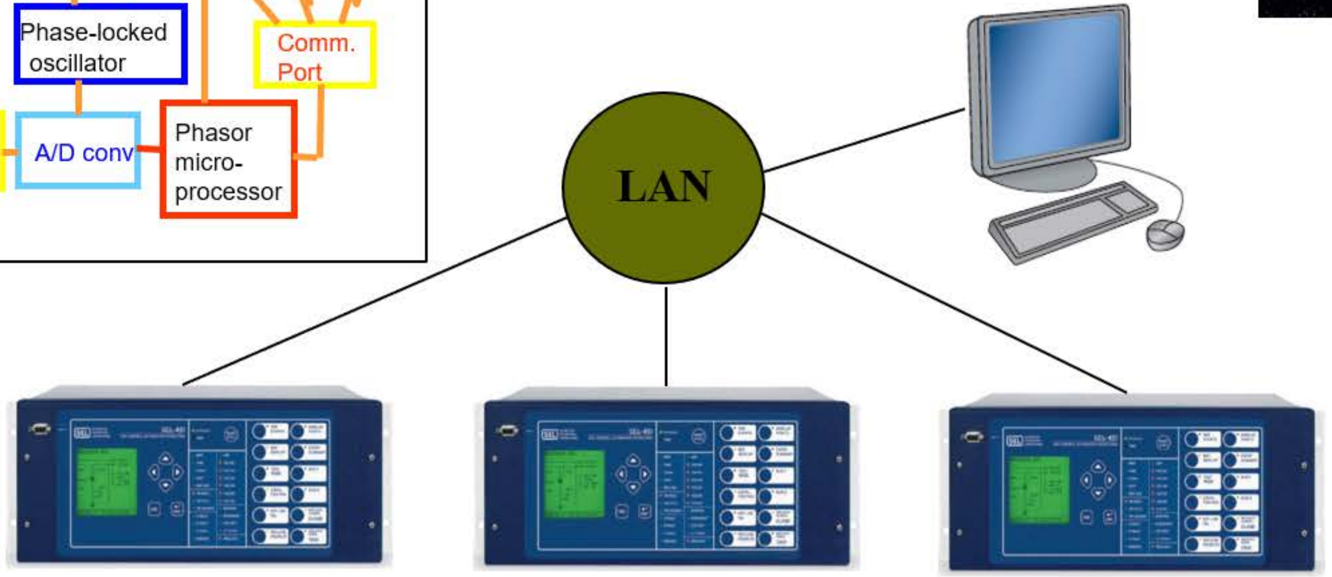


# Synchronized Measurement Technology - PMUs

Additional functionality opening doors for new monitoring, protection and control solutions, including **SIPS**.





# Satellite-based Time-Synchronization


**Examples:**

**Global Positioning System – GPS**

**Glonass**

**Galileo**

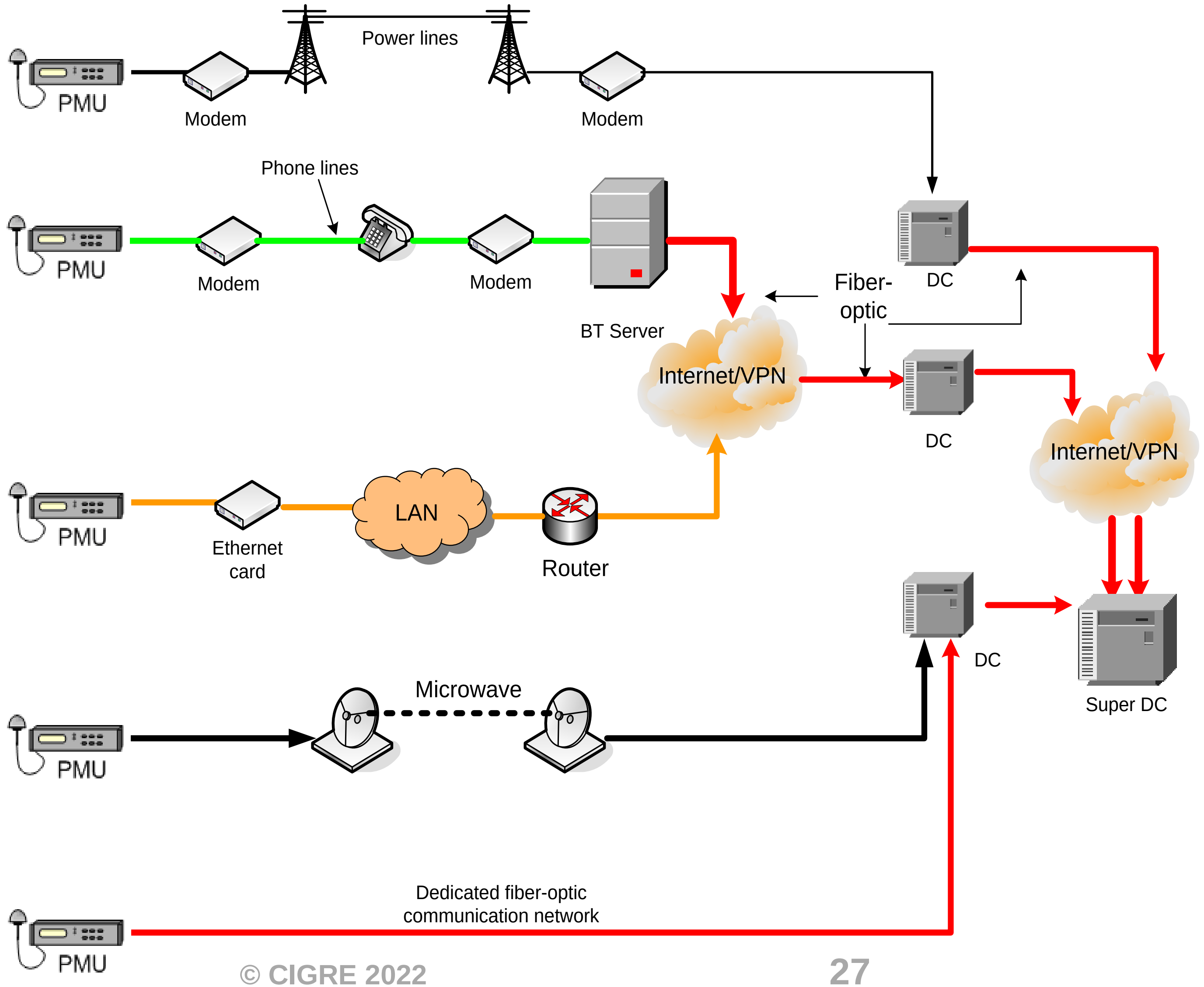
**Beidou**

Different systems are capable of operating together, e.g. by combining satellites belonging to different systems

# WAMPAC Architecture

Different communication media
Different latency/bandwidth

A single communication protocol (IEEE C37.118, "IEEE Standard for Synchrophasor Measurements for Power Systems"

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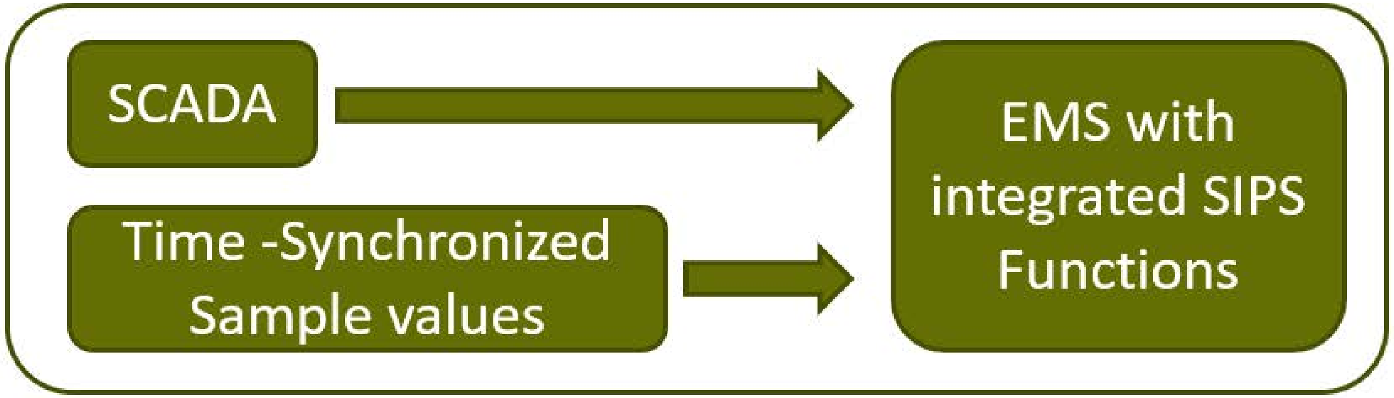
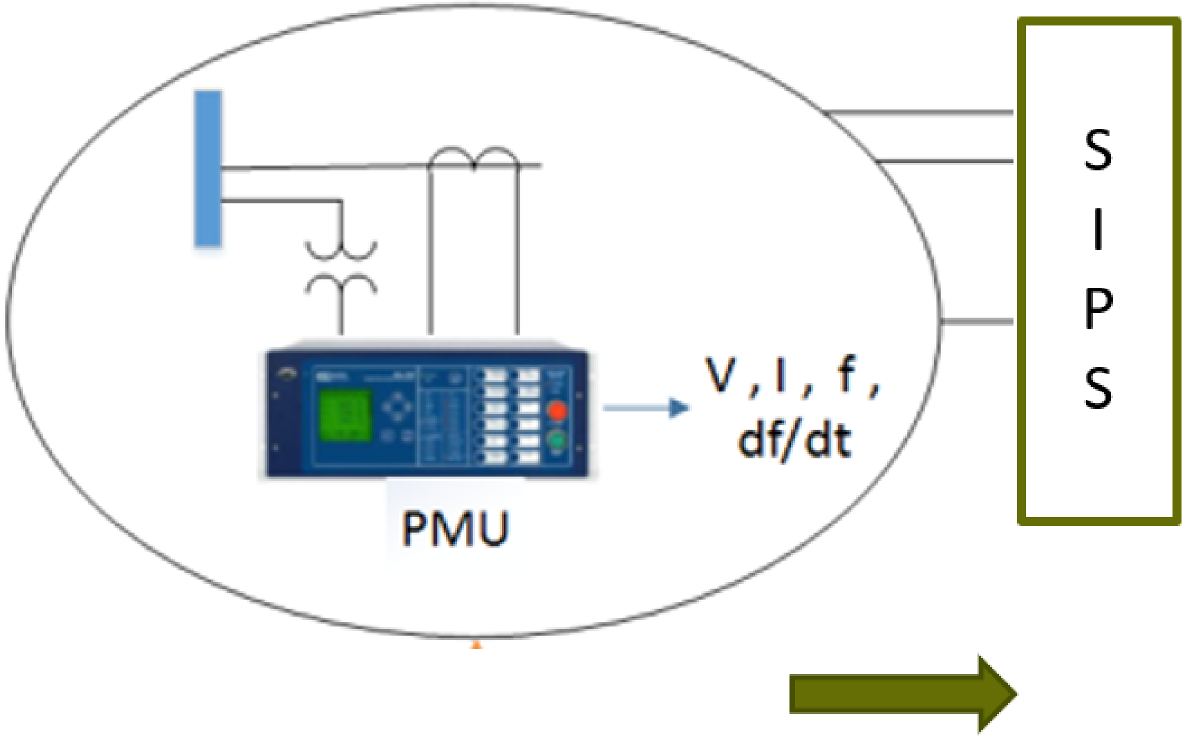
# Time-Synch Data for SIPS



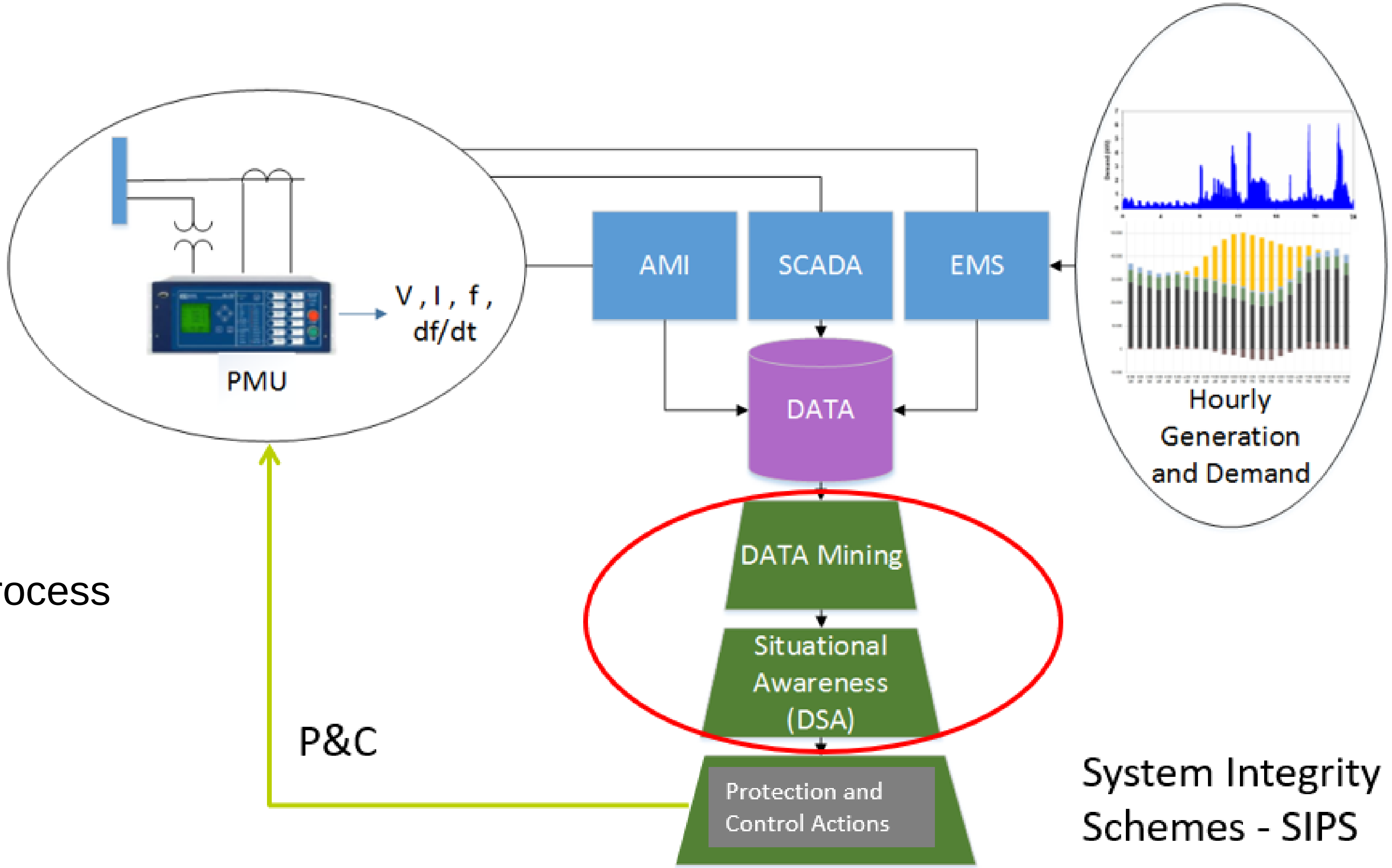

WAMPAC

# Time-Synch Data for SIPS




1) Underfrequency Load Shedding
2) Undervoltage Load Shedding
3) Power Swing Blocking
4) Intentional System Islanding
5) Other…

# PMU and ICT Supported SIPS




System Integrity Protection Schemes - SIPS

Massive data-integration
Usage of historical data
Complex decision-making process

Integrated monitoring, P&C

Reliable ICT-infrastructure

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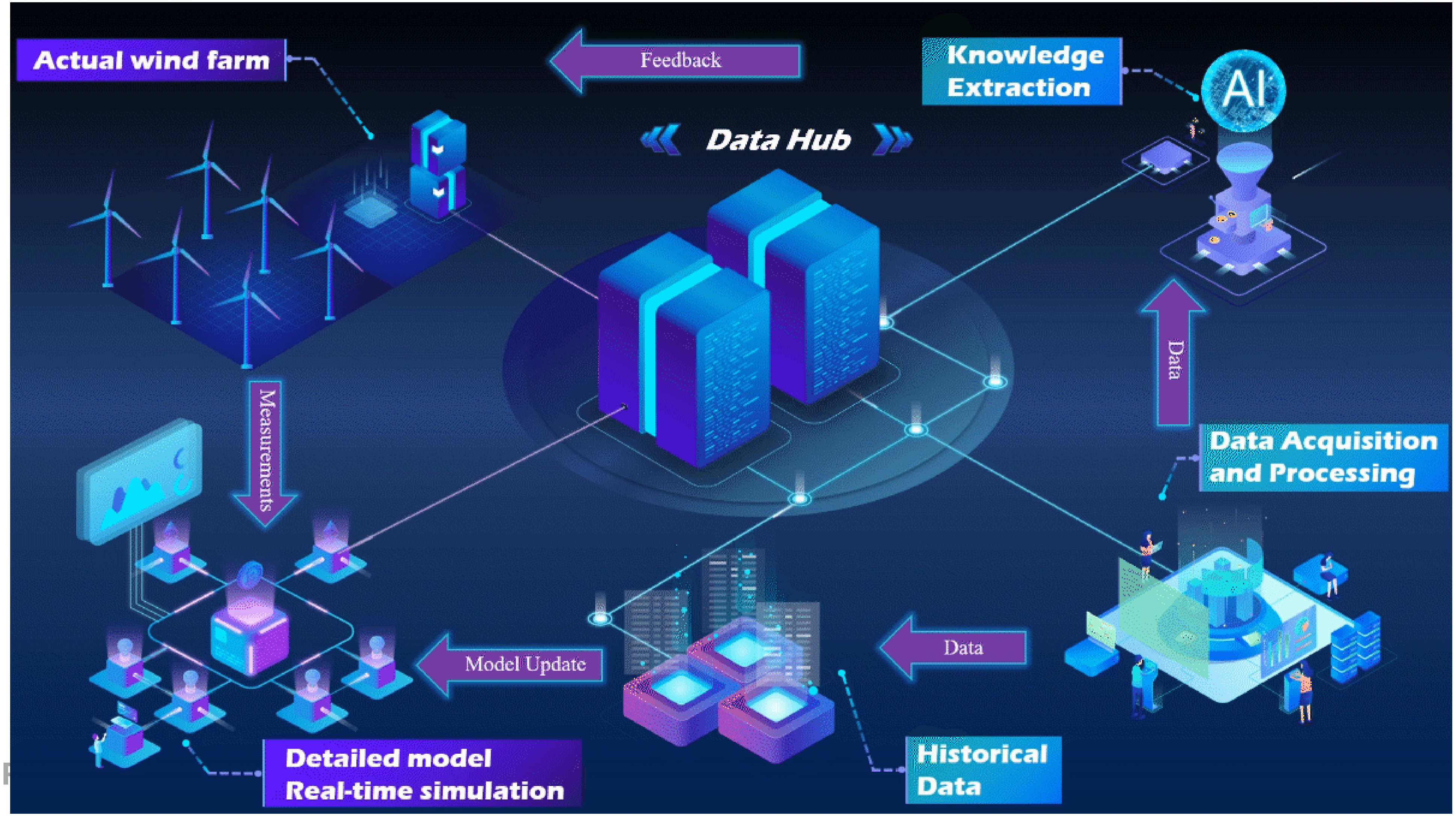
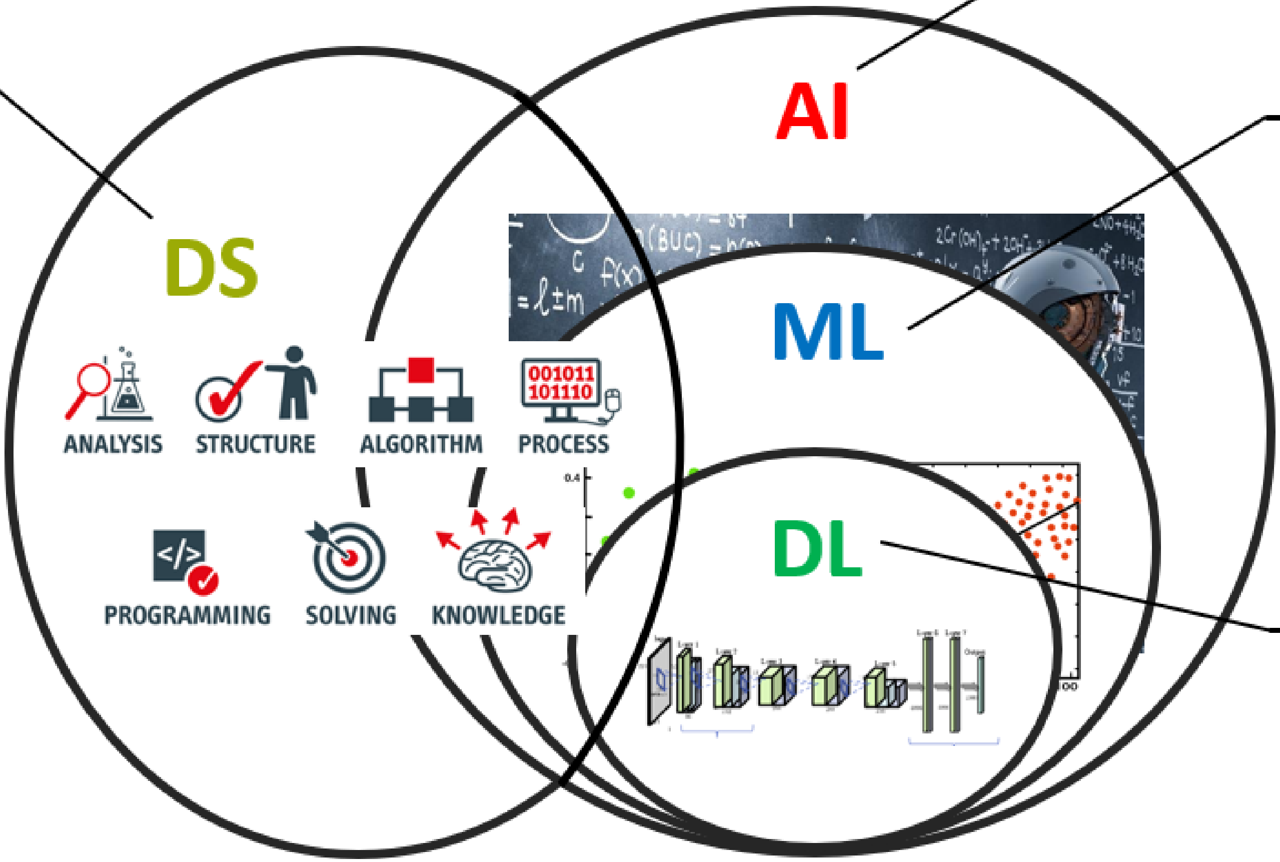
# Digital Twin Based Concepts



# Artificial Intelligence and Machine Learning based Solutions




Enable machine to think

All about data

1. Statistics
2. Probability
3. Linear Algebra

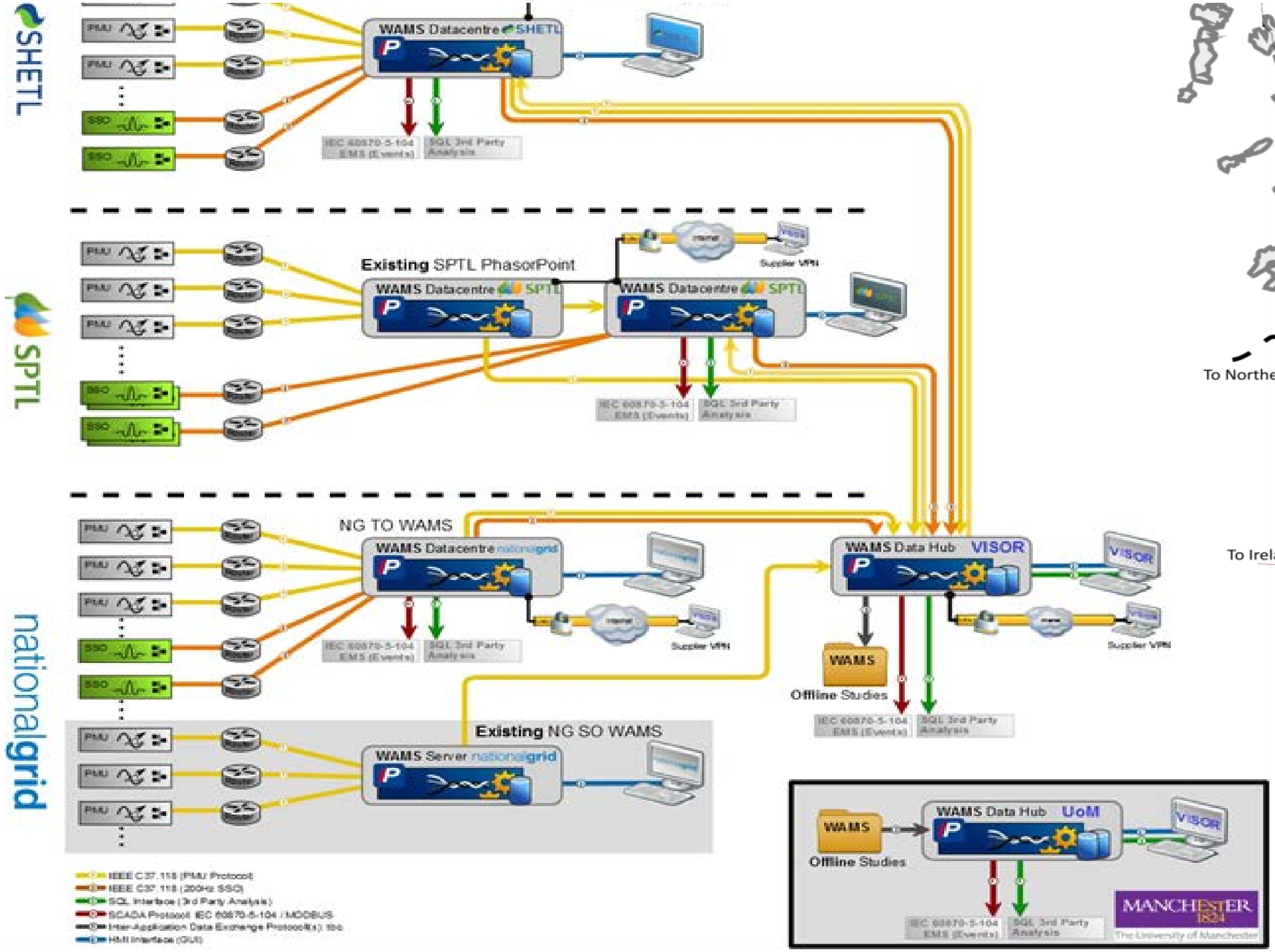
Statistical tools to explore and analyze the data

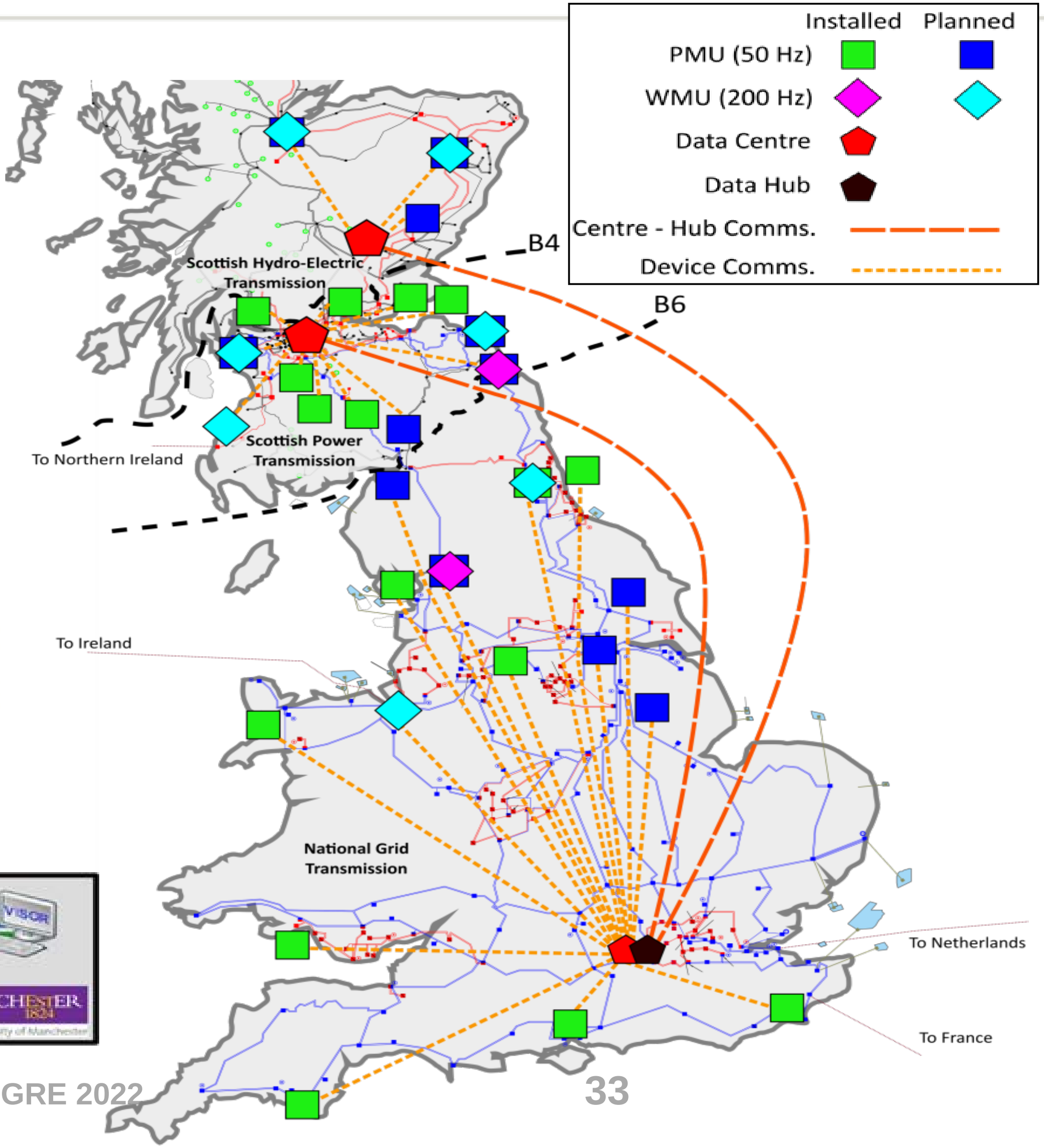
1. Supervised
2. Unsupervised
3. Semi-supervised
4. Reinforcement

Multi Neural Network architectures

1. Fully Convolutional NN
2. Convolutional NN
3. Recurrent NN/GRU/LSTM

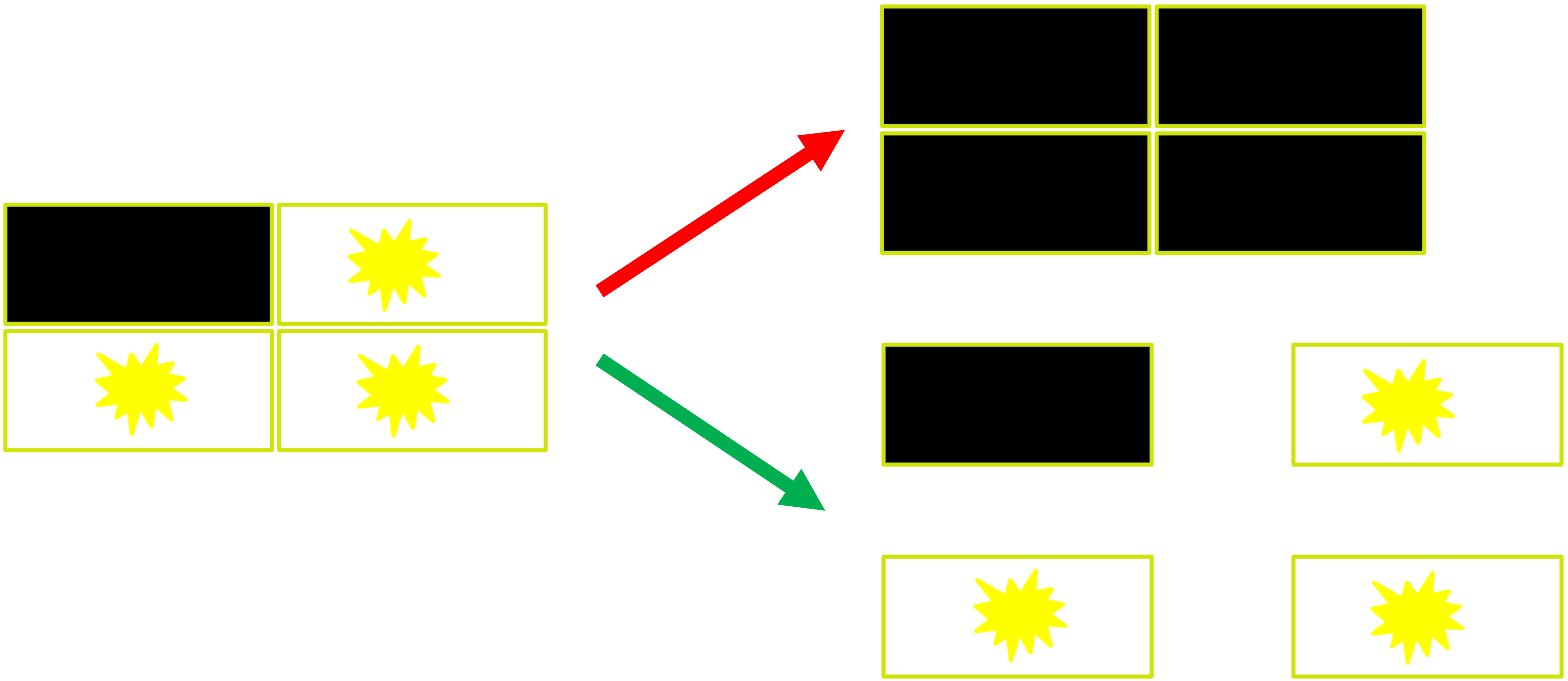
# VISOR Project, £7m, Ofgem, UK (2013-2017)



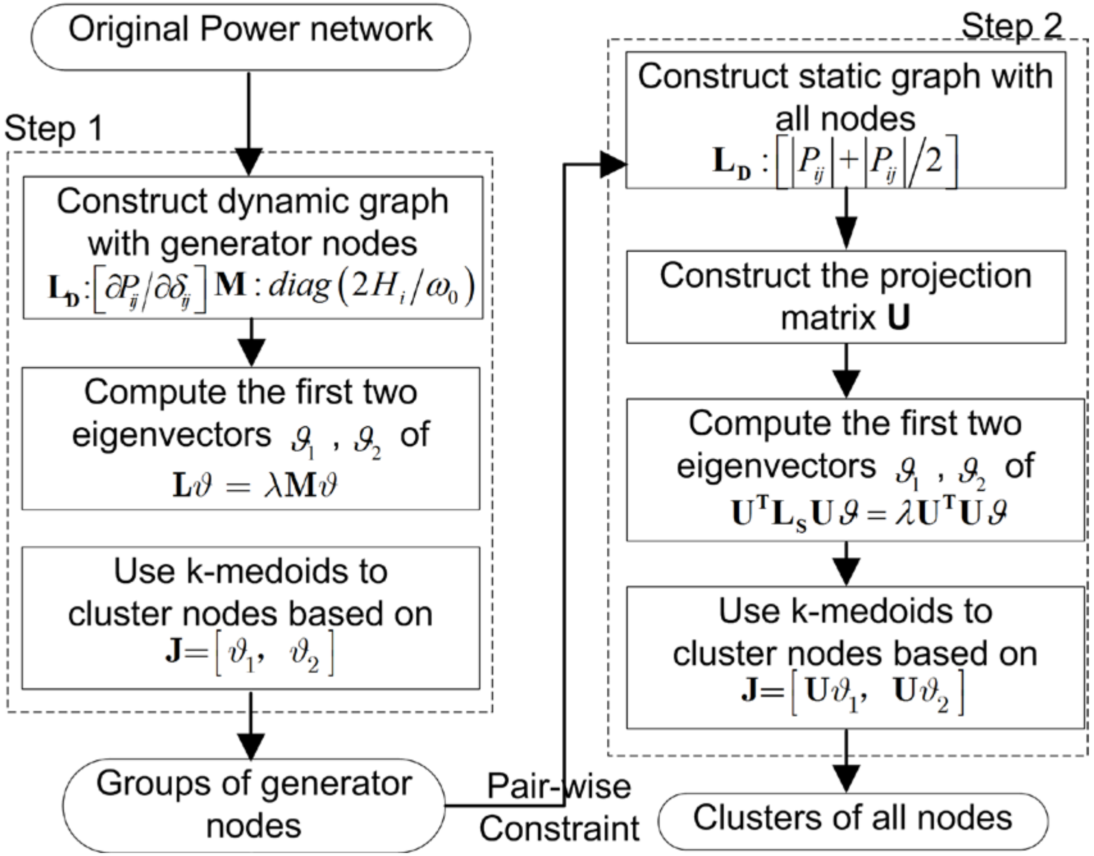



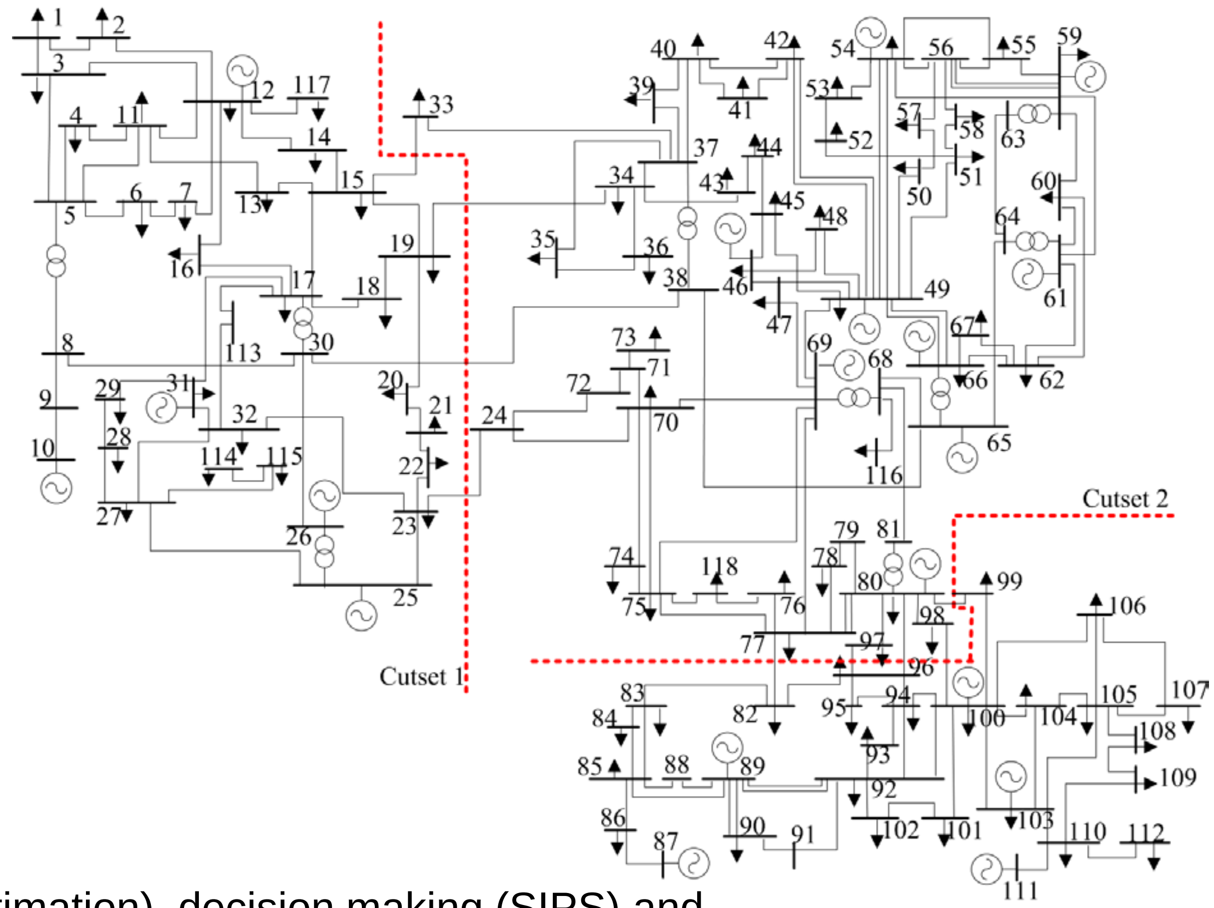

Advanced monitoring, enabling efficient SIPSs

# Intentional Controlled Islanding of the System



# Intentional Controlled Islanding of the System




Complex schemes requiring reliable monitoring (real-time state estimation), decision making (SIPS) and Control of newly created islands. Technology used must be secure and reliable.

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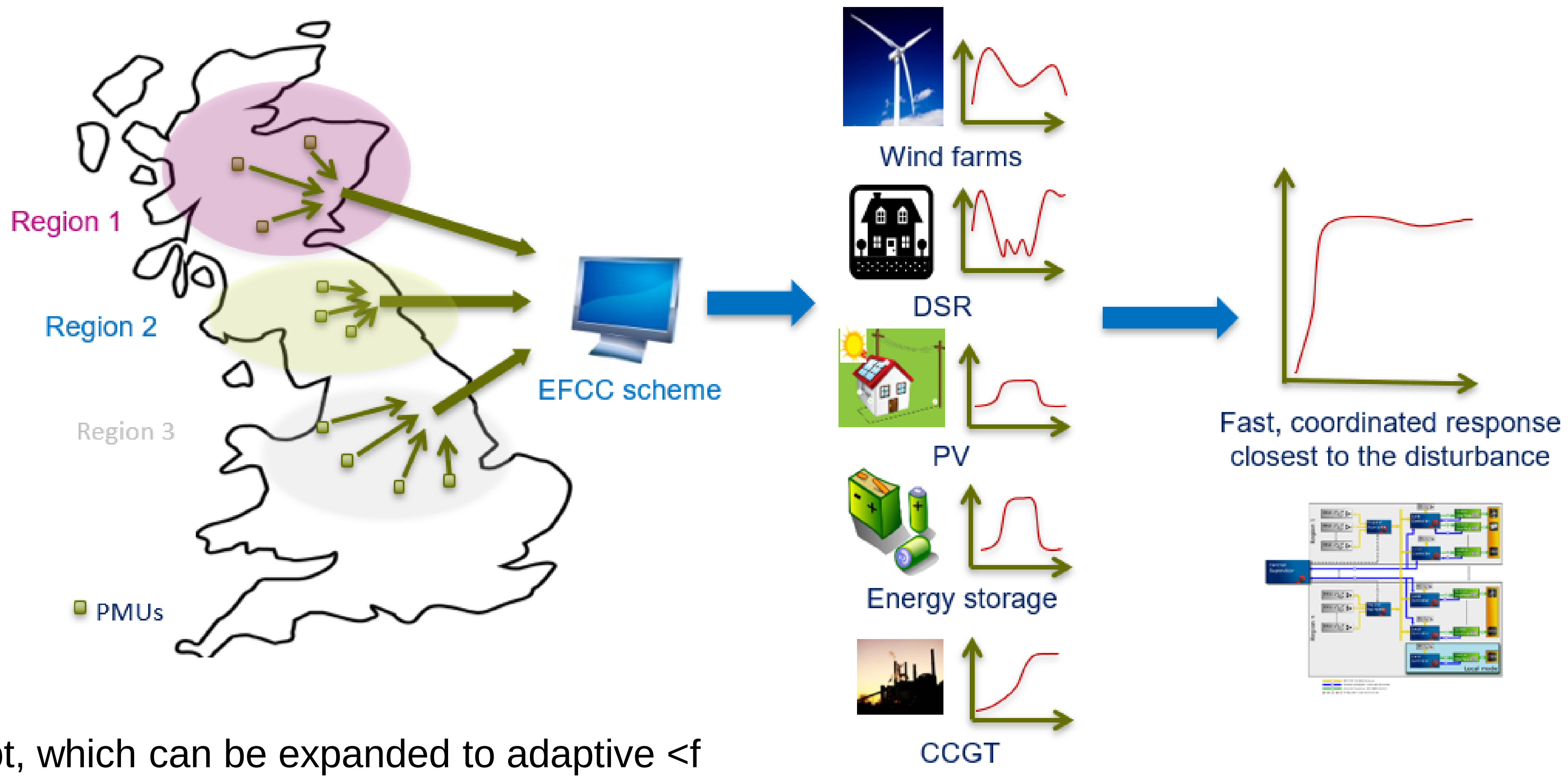
# EFCC Project (2016-2020), Ofgem, UK, £9.2m




Smart f-control concept, which can be expanded to adaptive <f

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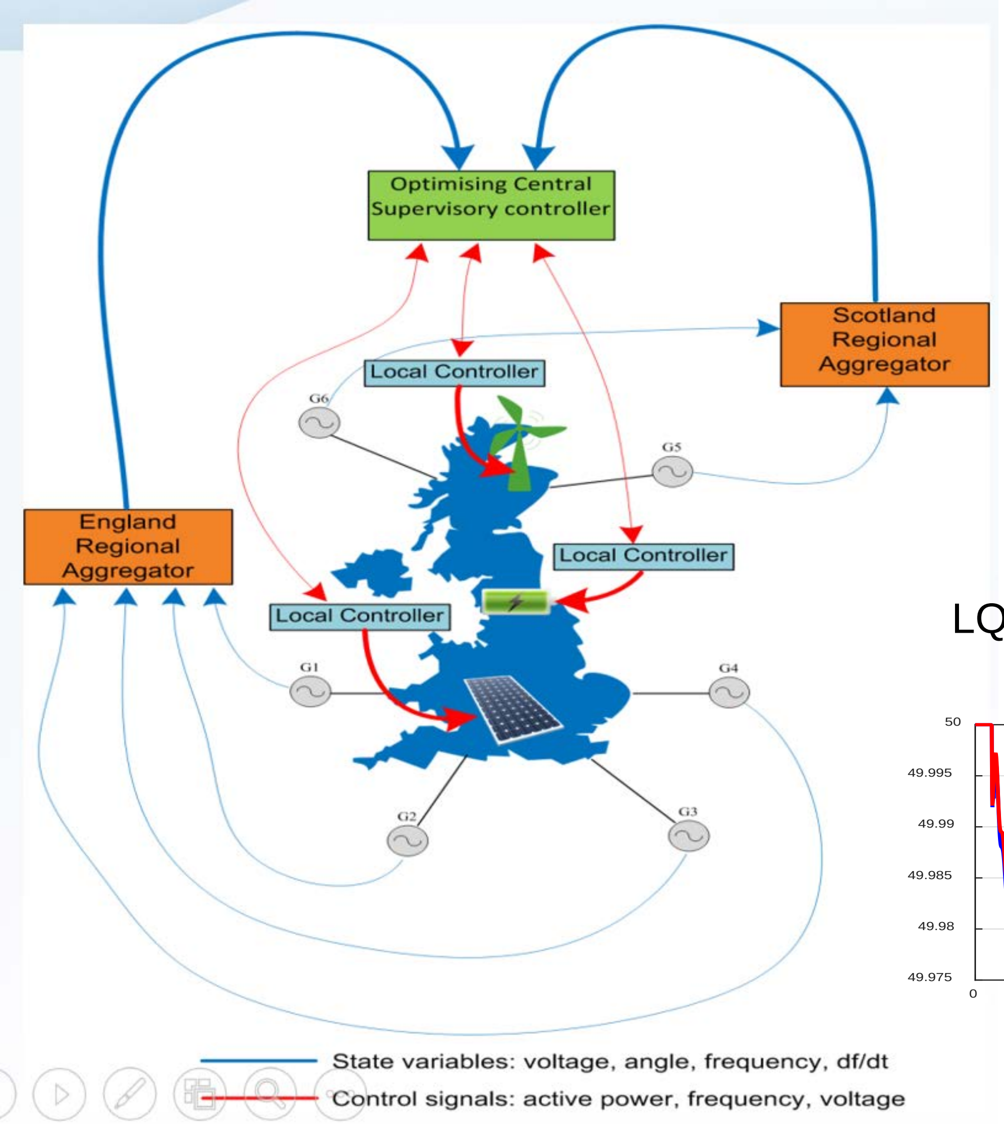
# Centralized Schemes Requiring Reliable ICT

Wide area data acquisition
Synchronized data acquisition

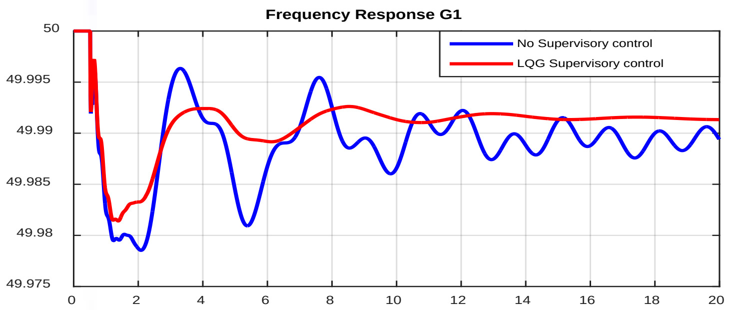
Centralized data processing and decision making

ICT transfer commands back to the system

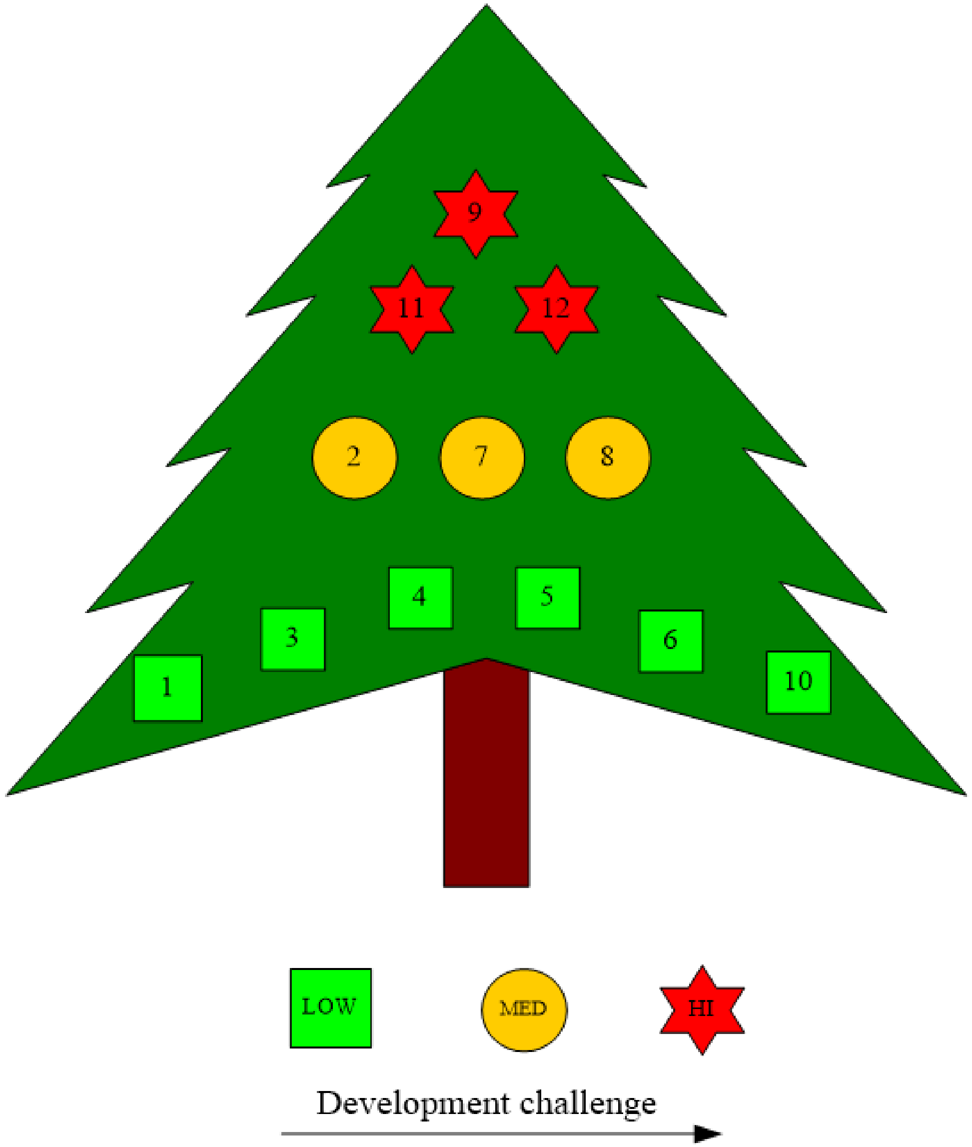
Concerns about ICT and backup local-control based actions




LQGC-based oscillations control:



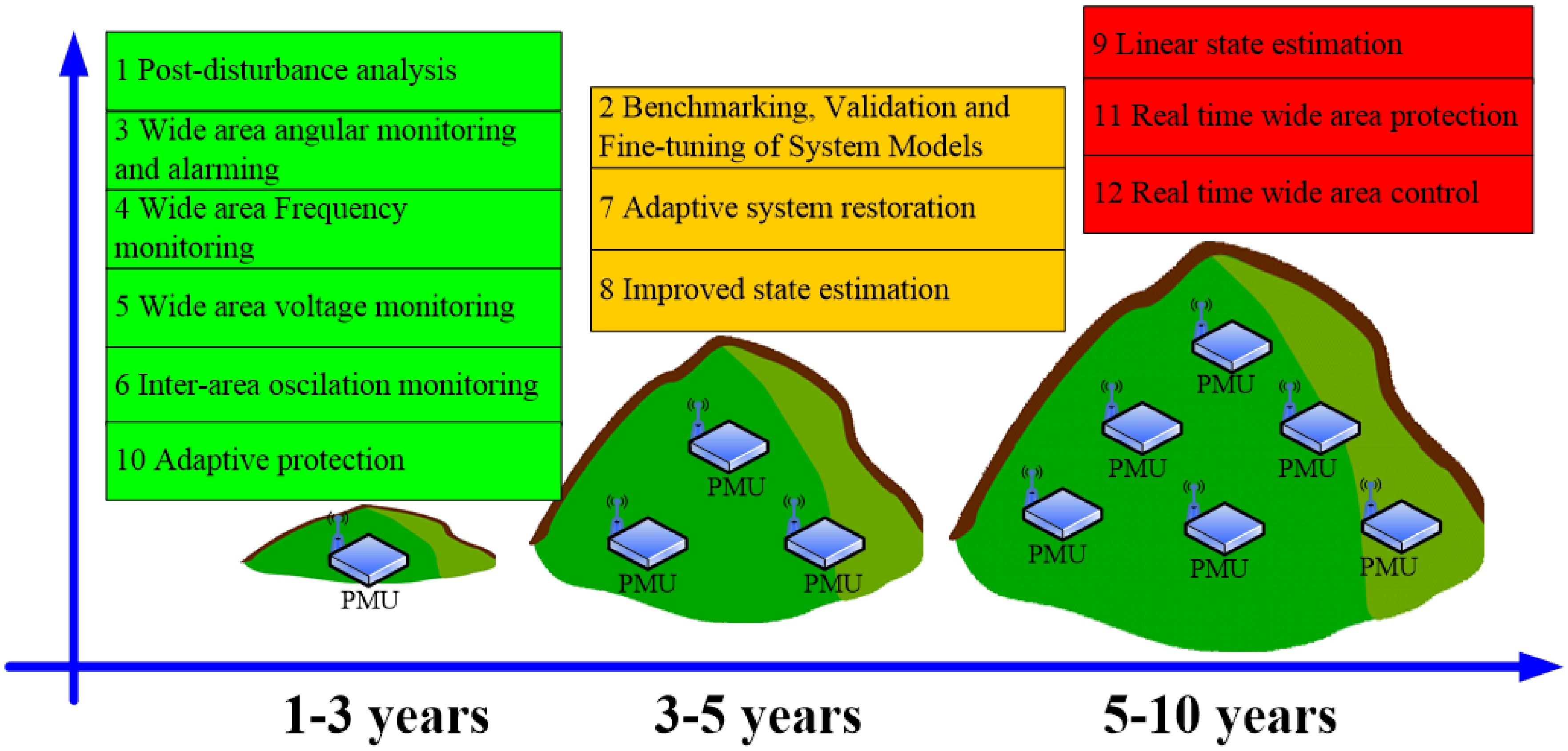
# WAMPAC Roadmap - Methodology




| |
|---|
| 1 Post-disturbance analysis |
| 2 Benchmarking, Validation and Fine-tuning of System Models |
| 3 Wide area angular monitoring and alarming |
| 4 Wide area Frequency monitoring |
| 5 Wide area voltage monitoring |
| 6 Inter-area oscilation monitoring |
| 7 Adaptive system restoration |
| 8 Improved state estimation |
| 9 Linear state estimation |
| 10 Adaptive protection |
| 11 Real time wide area protection |
| 12 Real time wide area control |

- Create a list of system needs
- Assess development challenges
- Rank the needs

# WAMPAC Roadmap (from 2010, UK)



# References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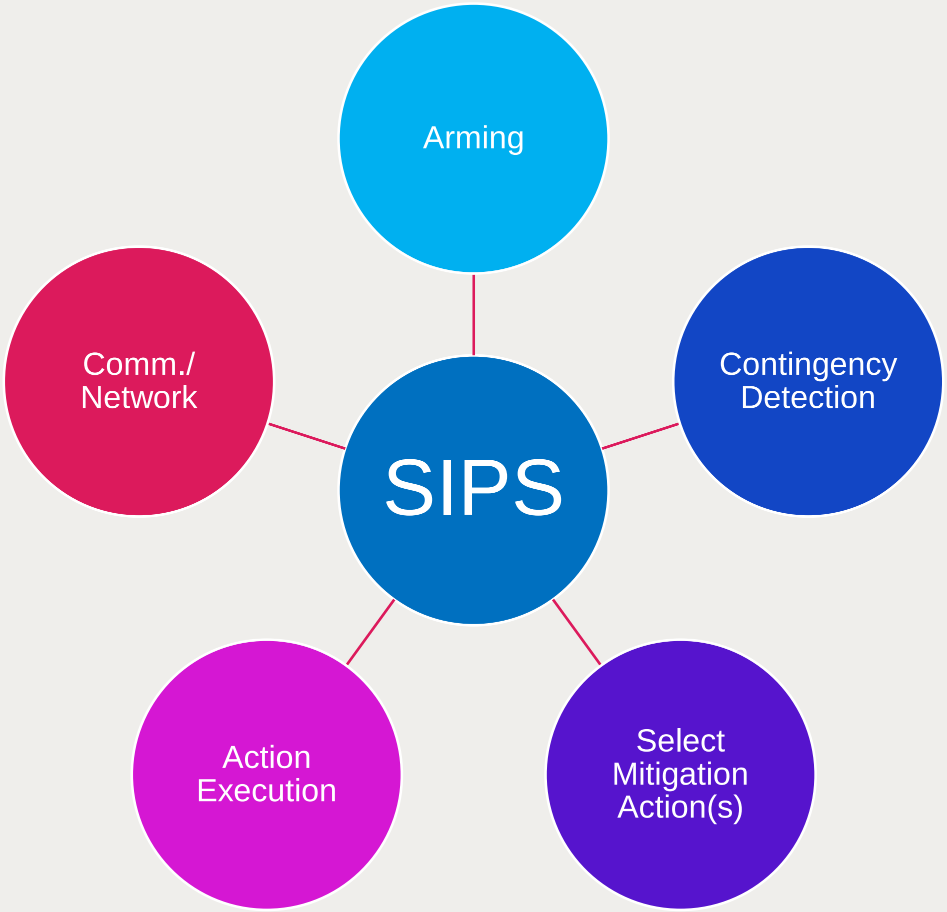
# Part 3 - Introduction to the typical architecture of System Integrity Protection Schemes

Alex Apostolov

# SIPS Functionality

- System Integrity Protection Schemes are distributed applications based on:
- Exchange of information and control signals between substation intelligent electronic devices located
- Exchange of information and control signals between substation and the different levels of the SIPS hierarchy.

# SIPS Basic Operational Elements




- Arming – Enable SIPS action when it may be needed
- Contingency Detection – Controller to determine if mitigation is needed
- Select Mitigation Actions – Select the right mitigation actions
- Action Execution – Take the selected actions
- Communication / Network – Connect all components together





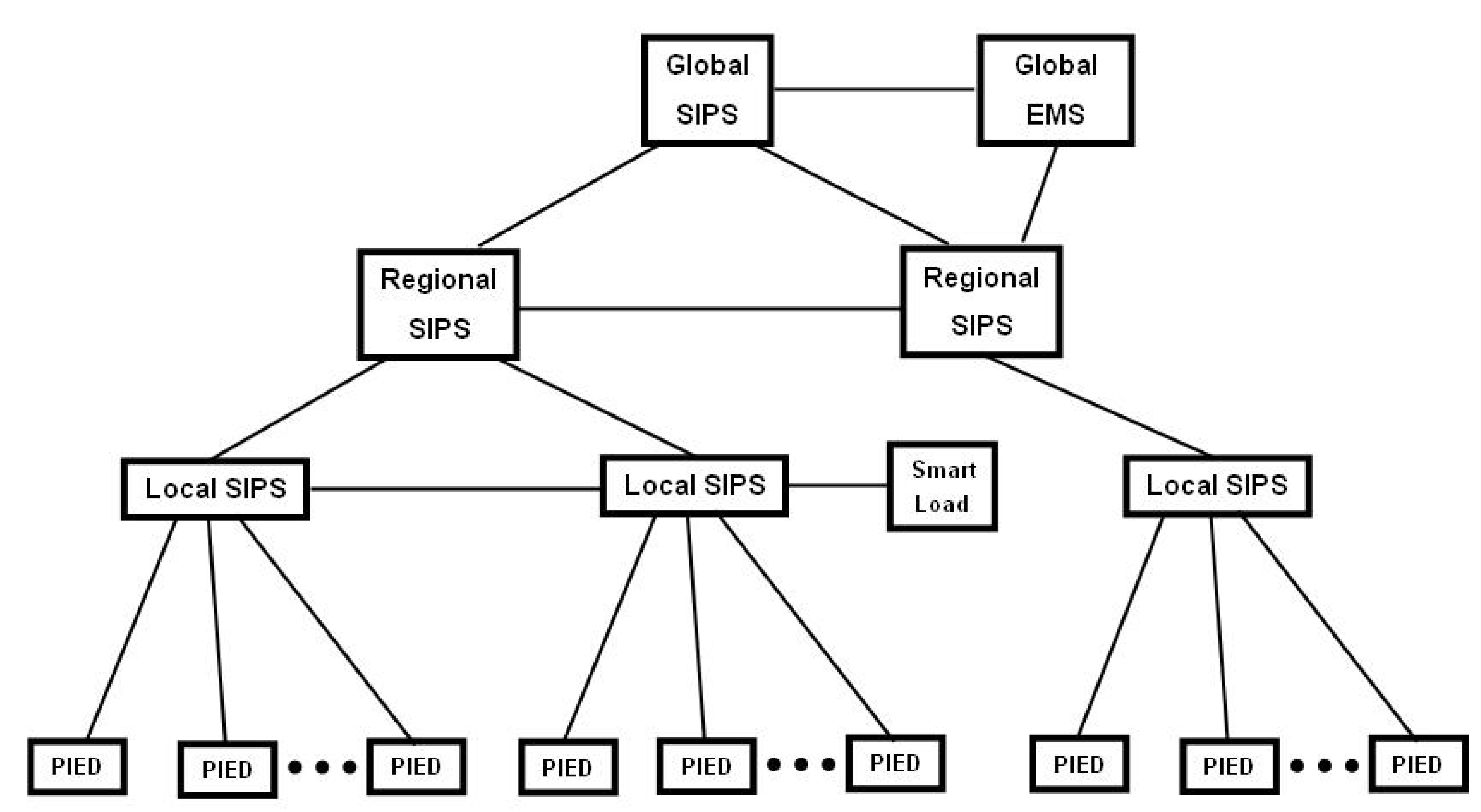


43

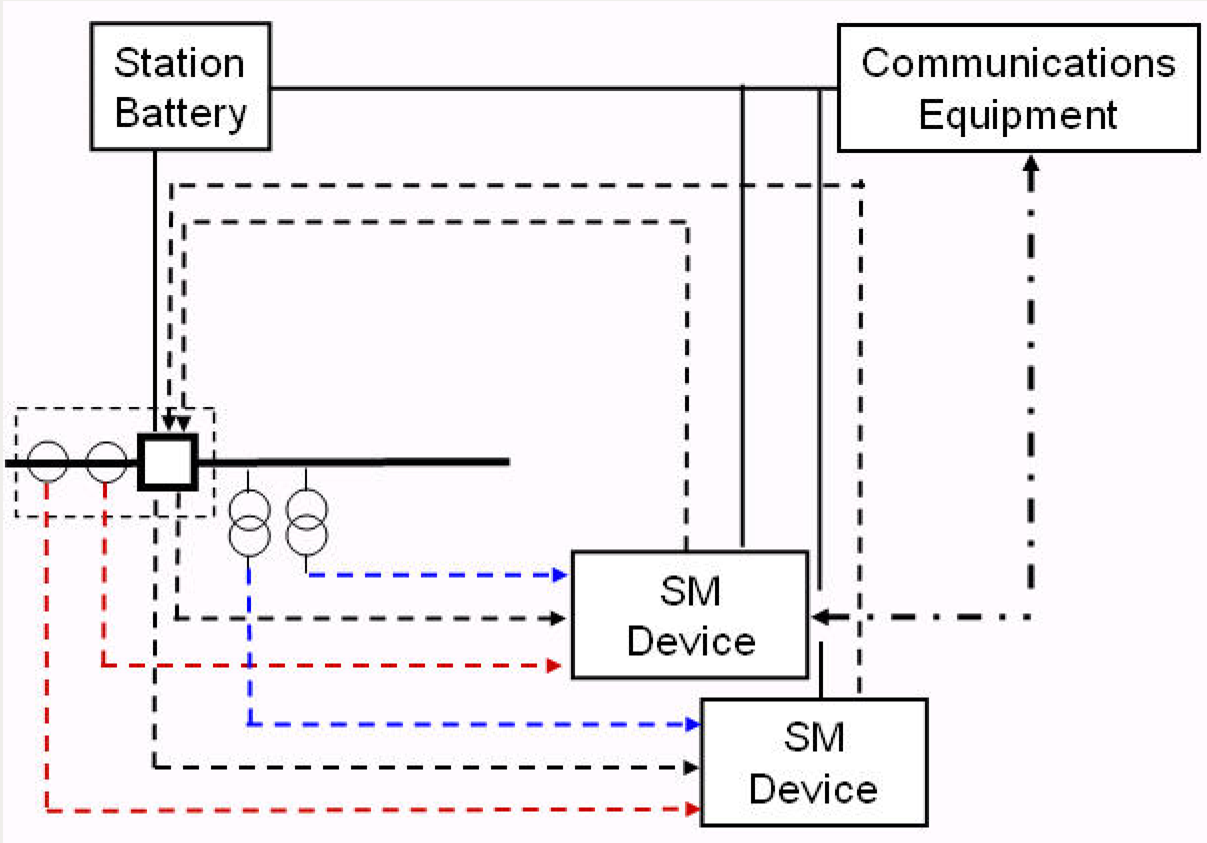
# SIPS Functionality

- SIPS can be considered as systems that have three main types of functional elements:
  - System monitoring elements
  - Protection elements
  - Execution elements
- The function of the system monitoring elements is to:
  - Detect a change in power system topology
  - Detect a change in system load
  - Detect a change in generation

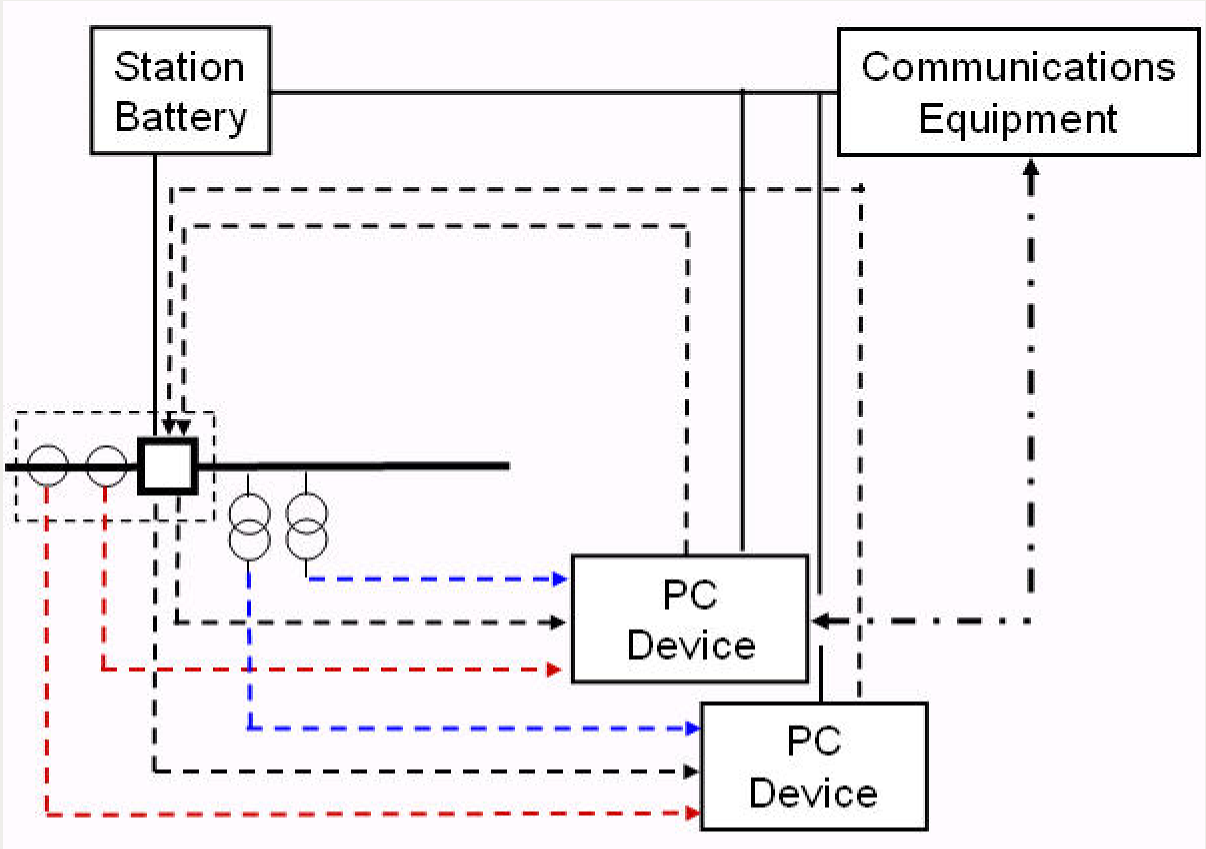
# SIPS Hierarchy



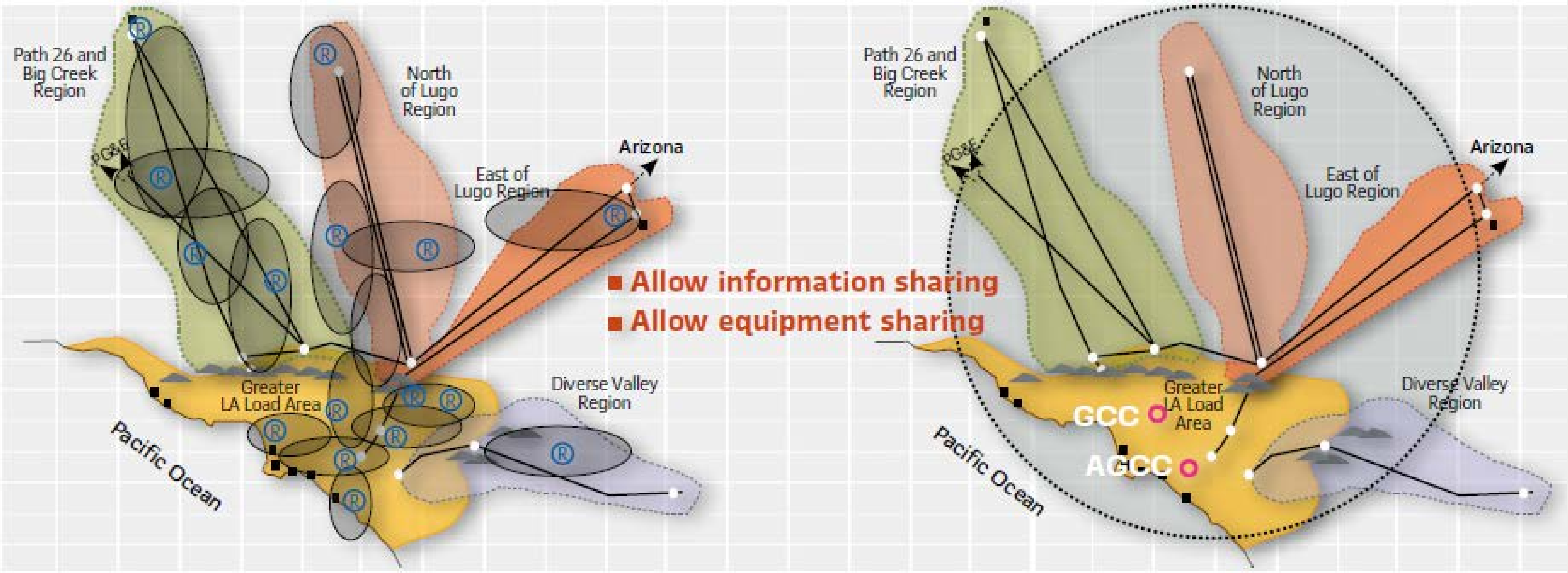
# SIPS Components: System Monitoring



# SIPS Components: Process Control

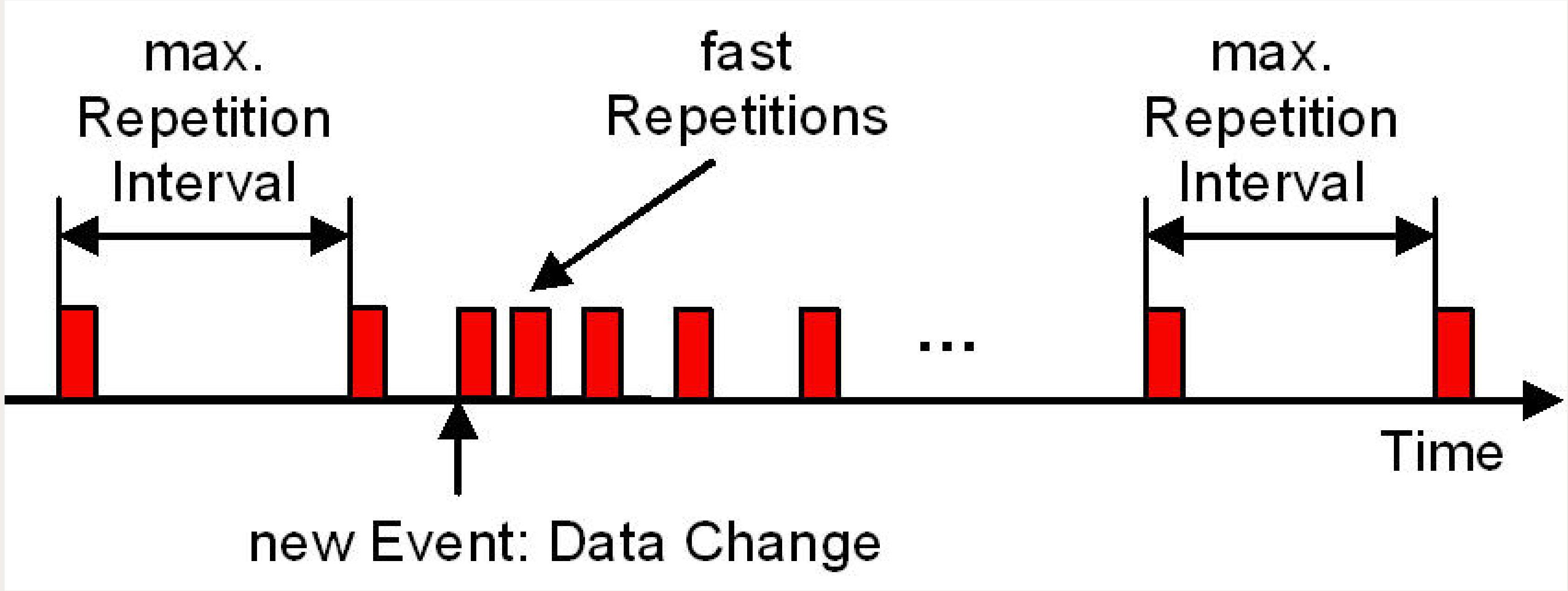


# SCE C-RAS

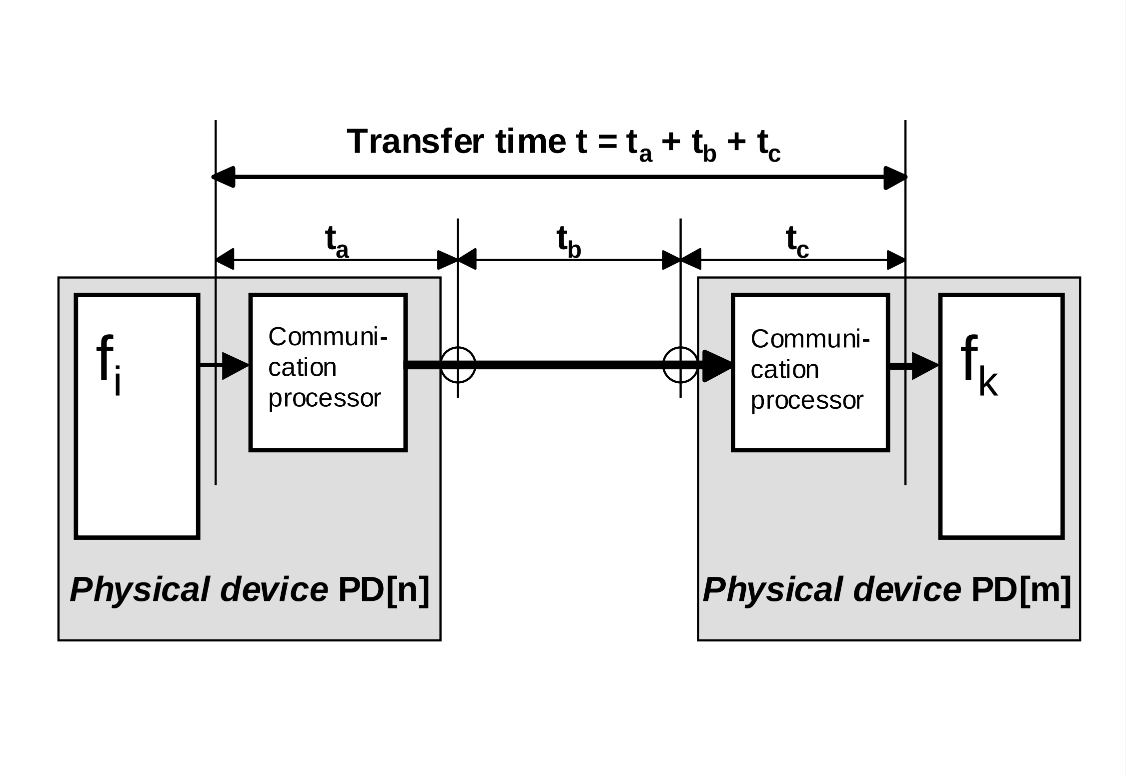


Path 26 and Big Creek Region
North of Lugo Region
Arizona
East of Lugo Region
■ Allow information sharing
■ Allow equipment sharing
Greater LA Load Area
Diverse Valley Region
Pacific Ocean
GCC
AGCC

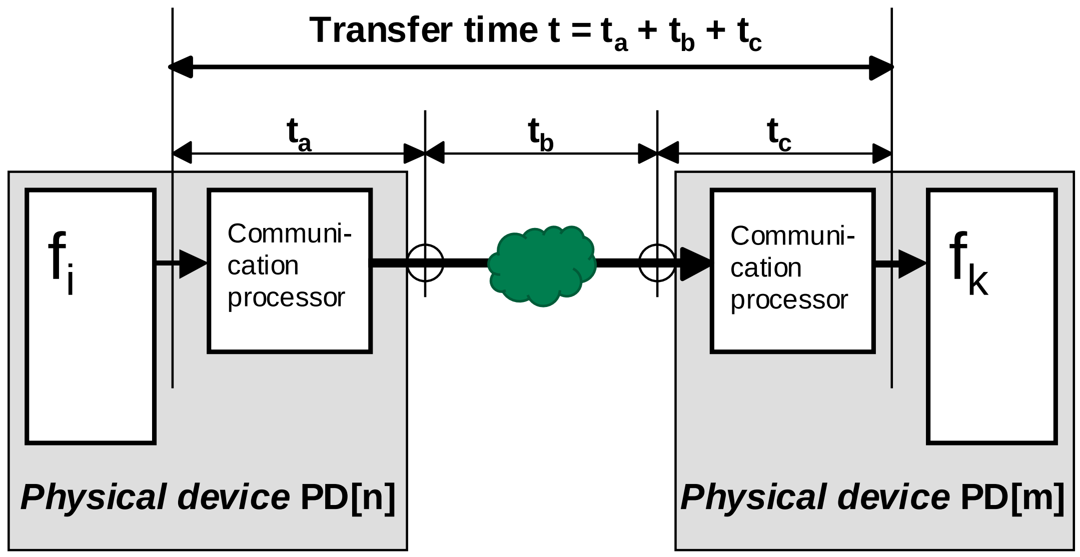
# GSE Messages:



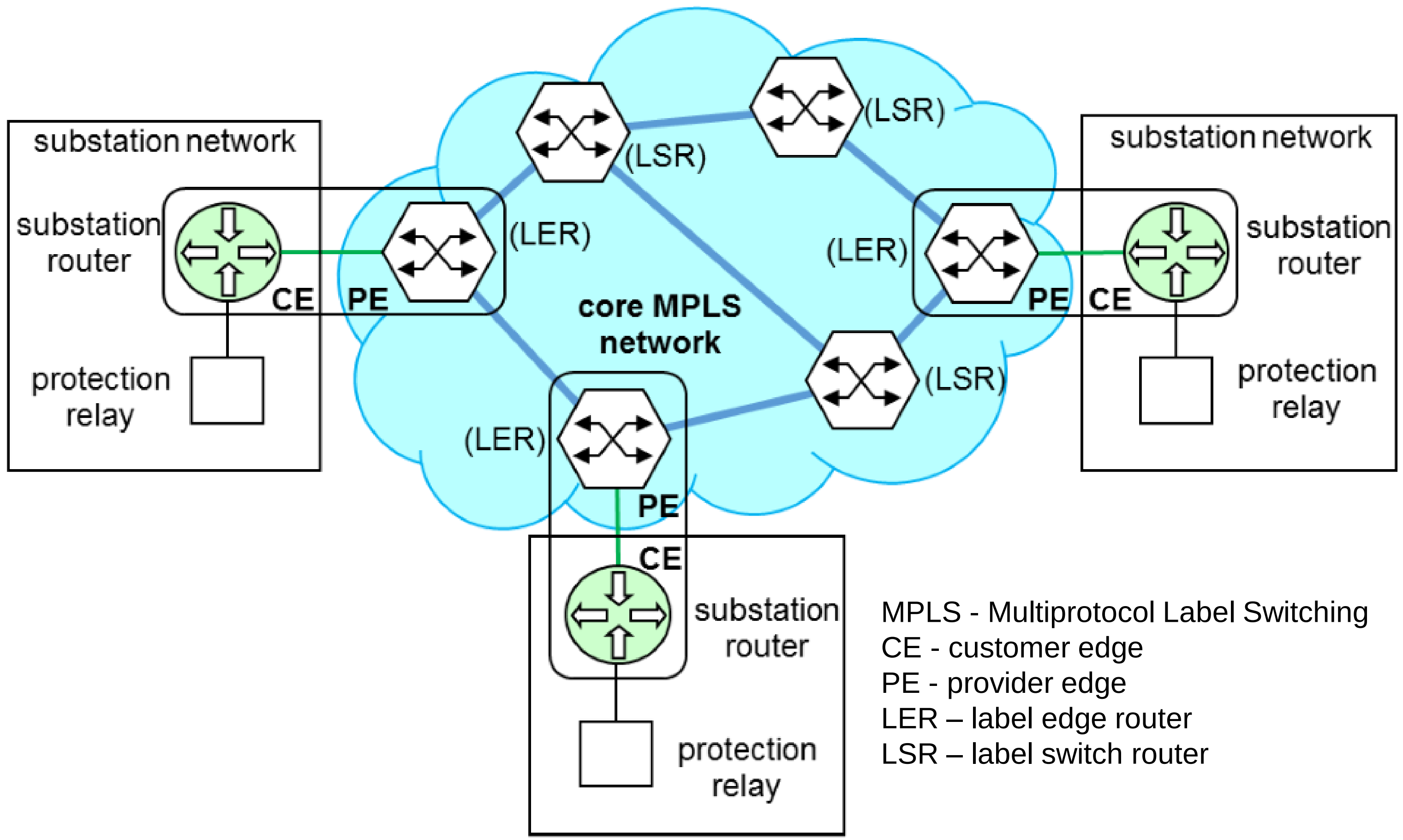
# GOOSE Performance



# GOOSE WAN Performance

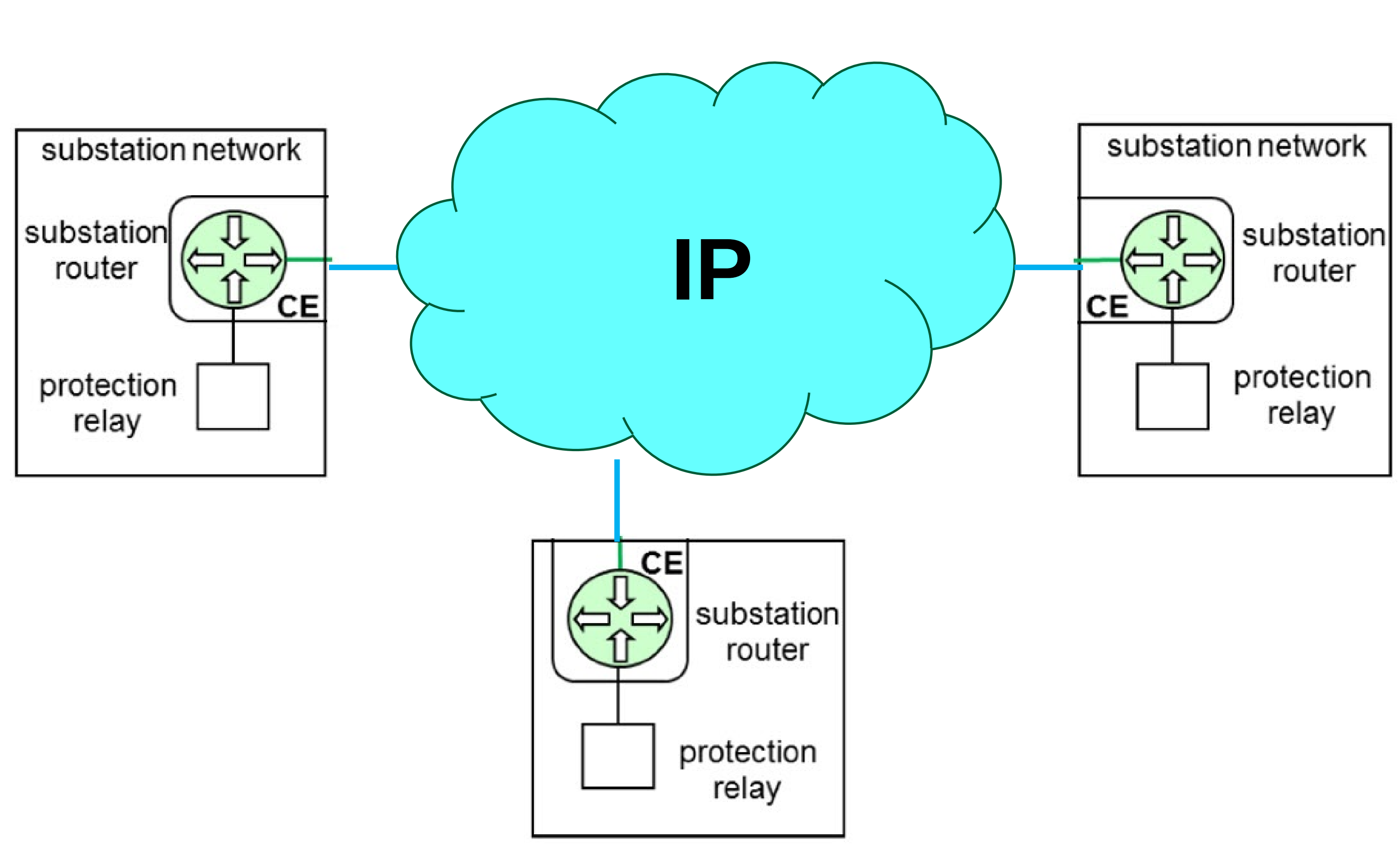


# MPLS for Wide Area GOOSE

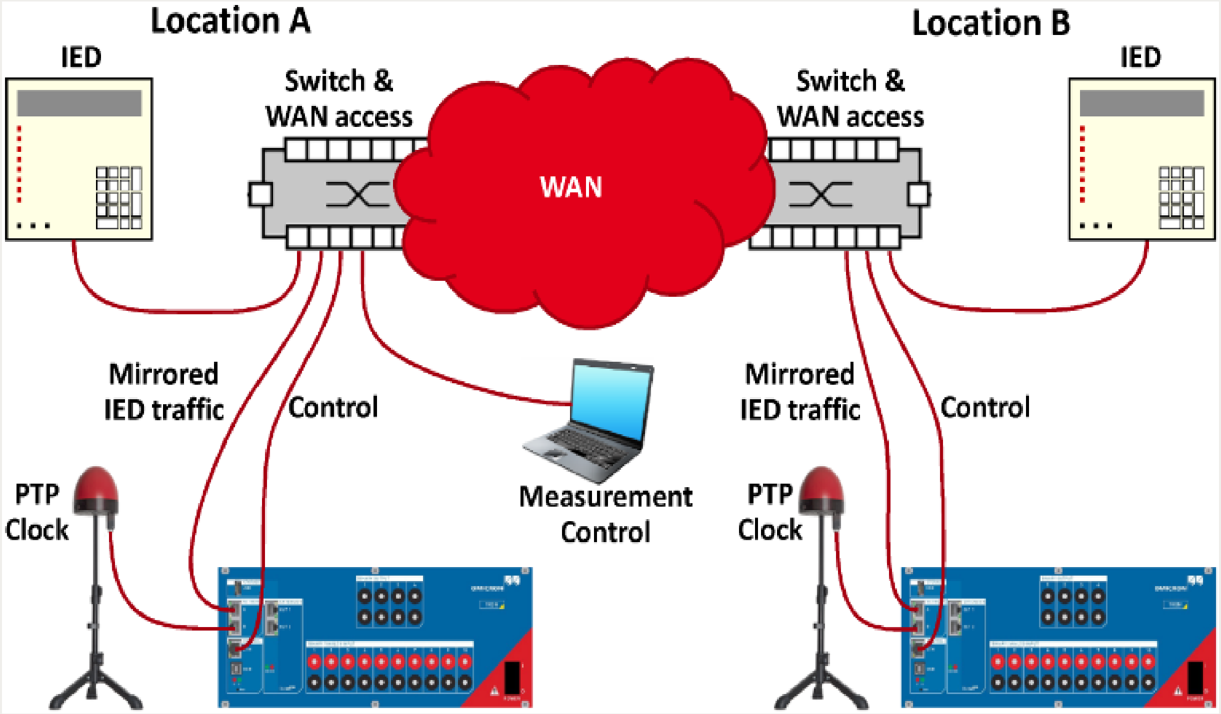



MPLS - Multiprotocol Label Switching
CE - customer edge
PE - provider edge
LER – label edge router
LSR – label switch router

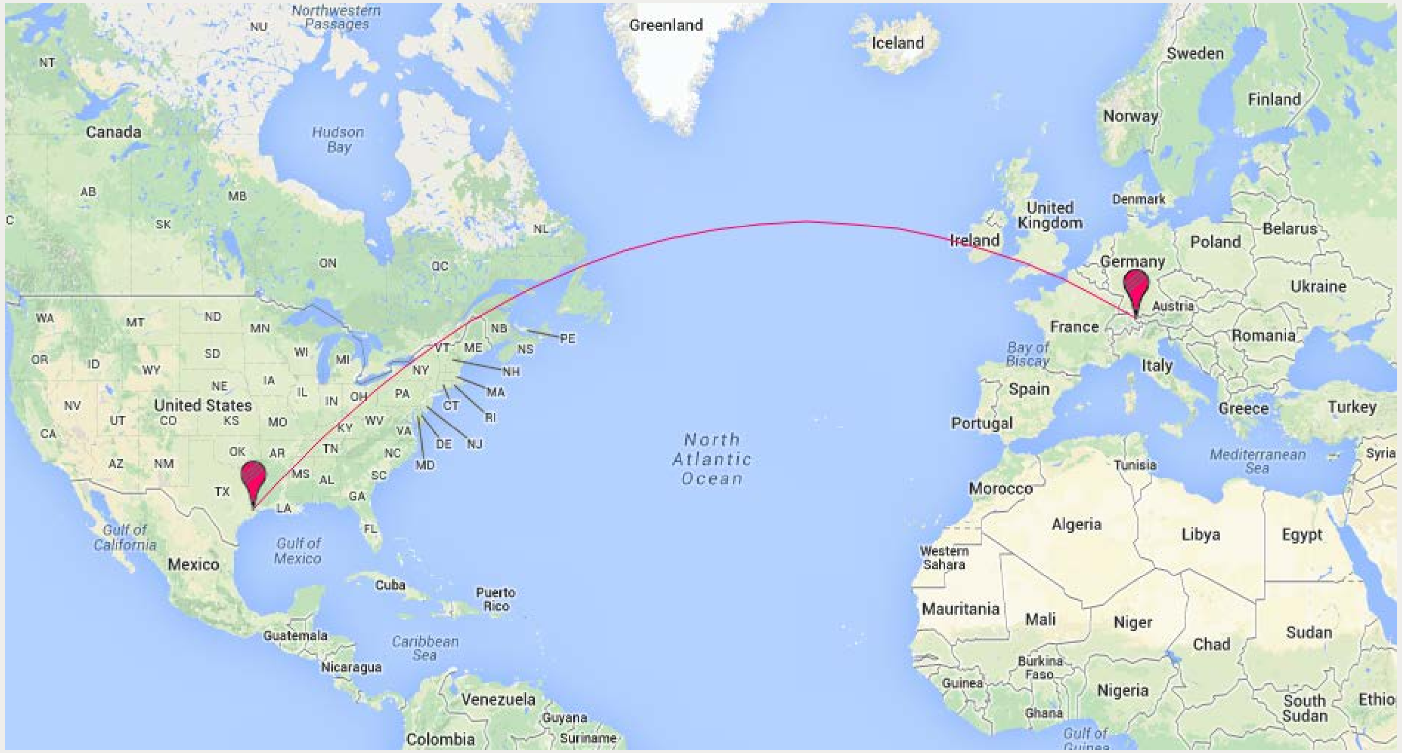
# Wide Area R-GOOSE



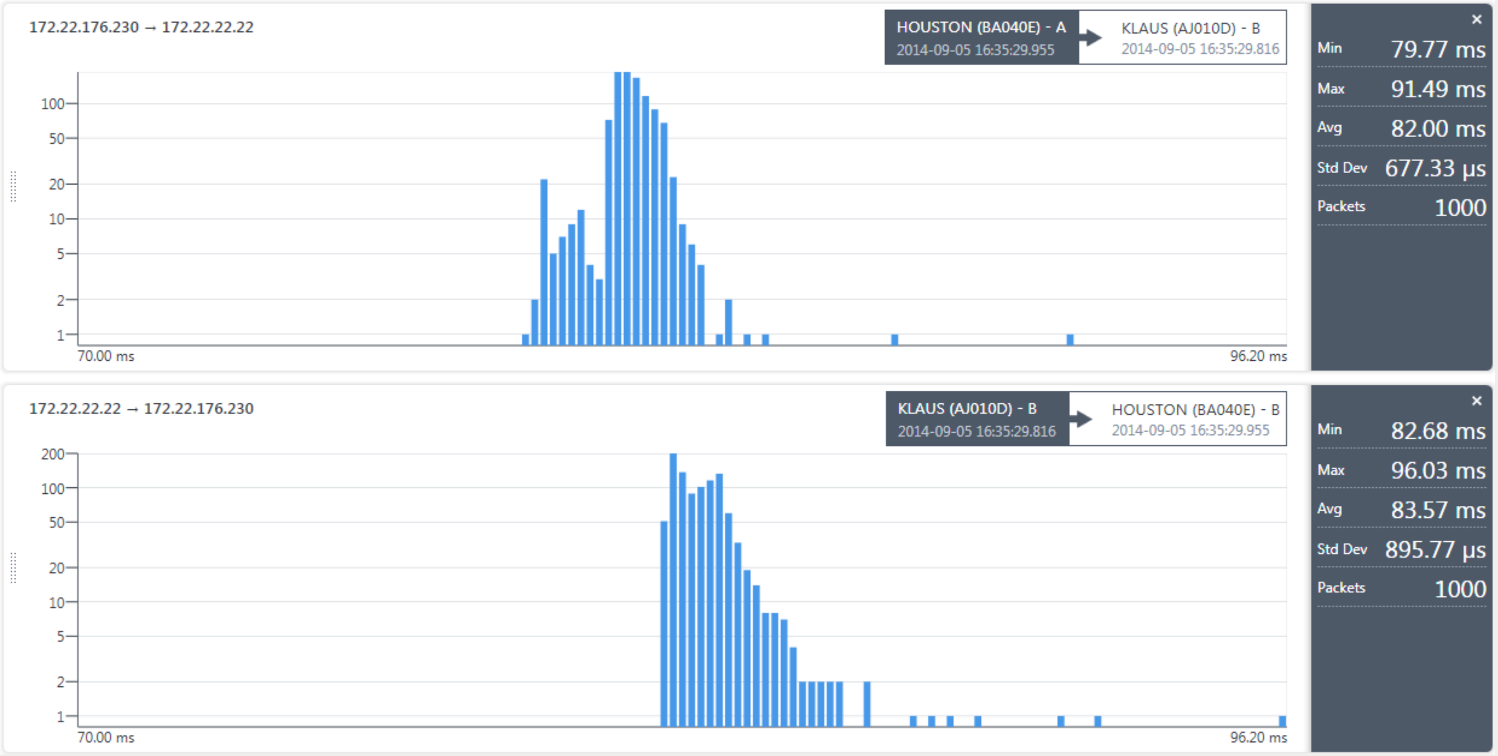
# Propagation time measurement



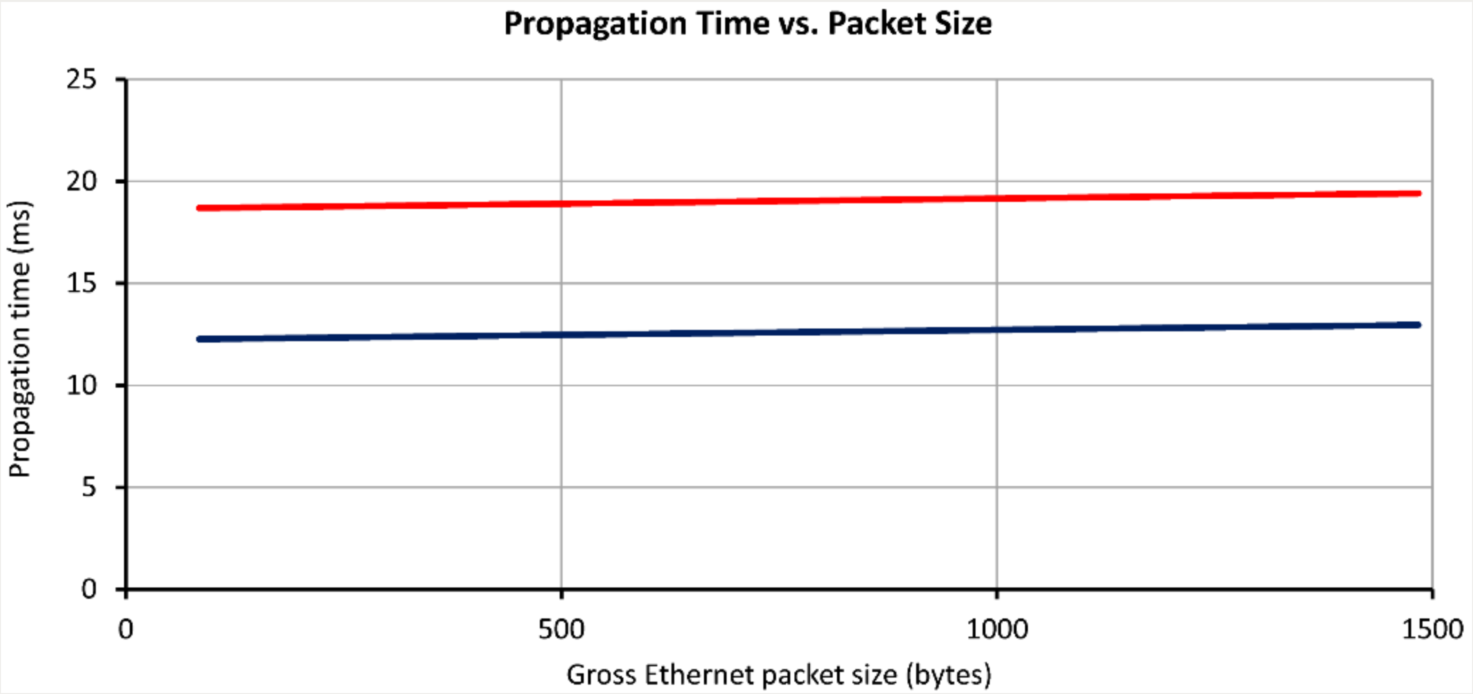
# Transatlantic latency



# Propagation delay Texas - Austria



# Two way propagation delay Germany - Austria

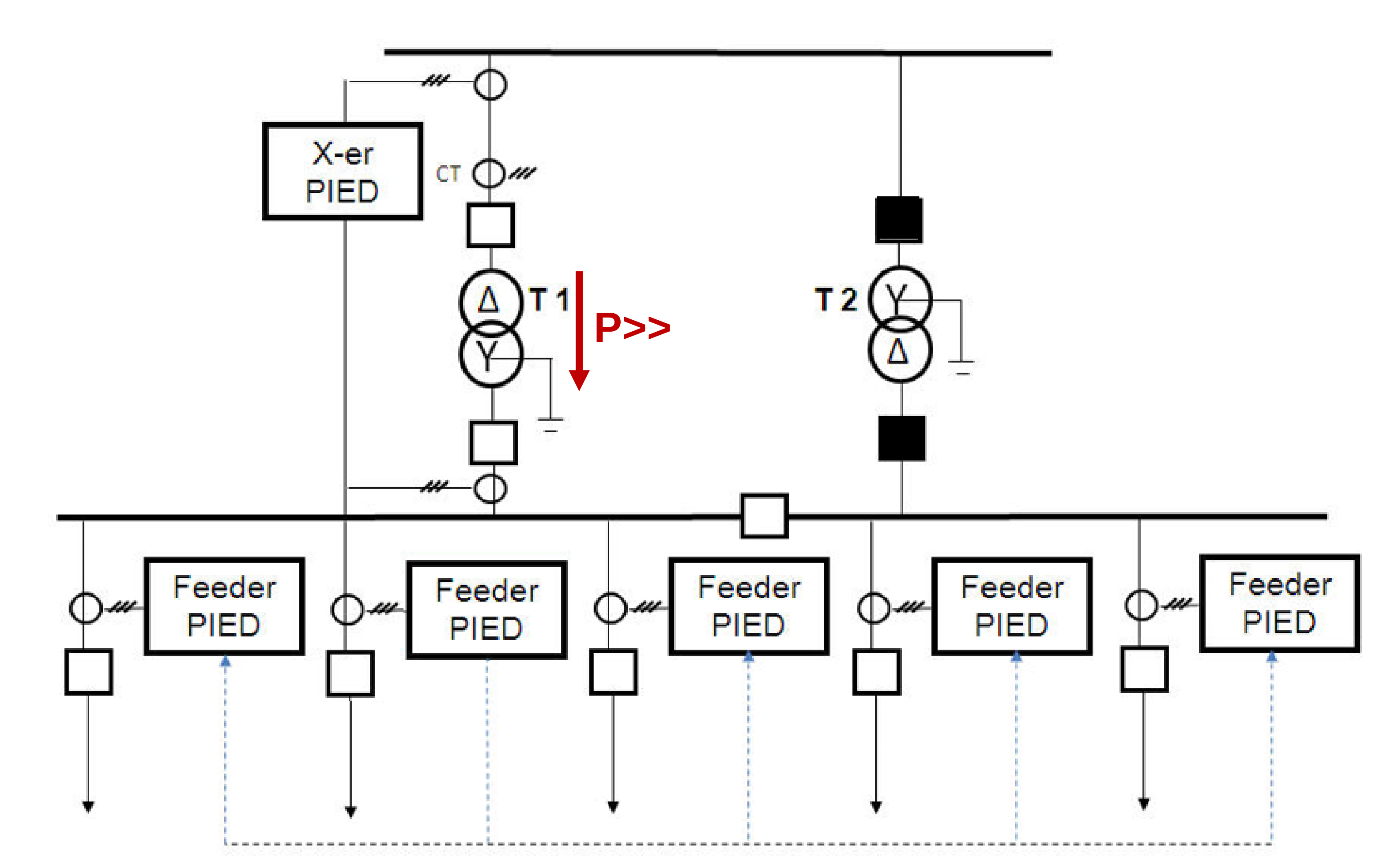



CIGRE Session 2022

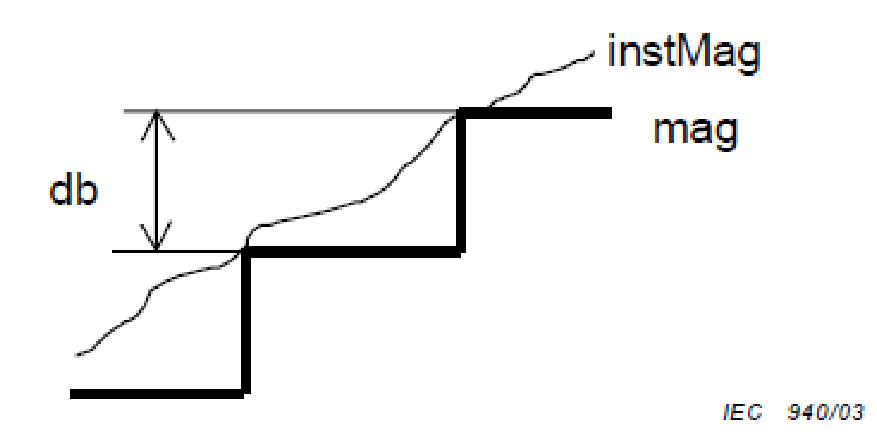
# GOOSE Control Block

| Attribute name | Attribute type | r/w | m | Value/value range/explanation |
|---|---|---|---|---|
| GoEna | Boolean | rw | m | |
| GoID | Visible-string | r | m | |
| DatSet | Visible-string | r | m | |
| ConfRev | Unsigned | r | m | |
| NdsCom | Boolean | r | m | |
| DstAddress | PHYCOMADDR* | r | m | |
| MinTime | Unsigned | r | o | |
| MaxTime | Unsigned | r | o | |
| FixedOffs | Boolean | r | o | |
| SecurityEnable** | ENUMERATED | r | o | None, DigitalSignature, DigitalSignatureandEdgeAuthentication |
| *Revisions to PHYCOMADDR can be found in clause 8.1.1.3.2<br>**Additional attribute to be added to the control block. | | | | |

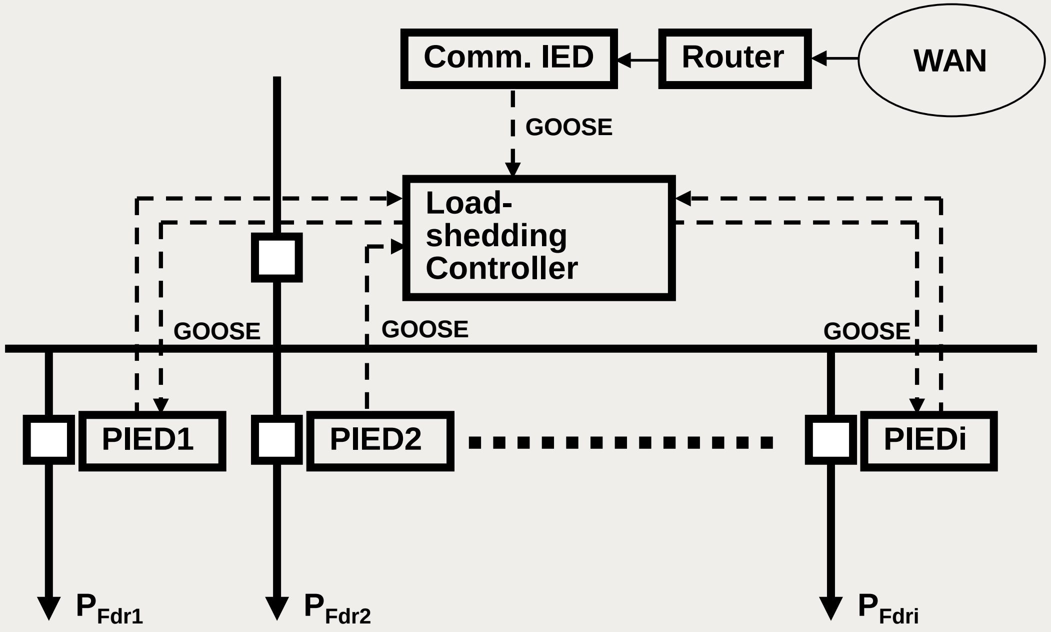
# Local SIPS


X-er
PIED
CT
T 1
P>>
T 2
Feeder
PIED
Feeder
PIED
Feeder
PIED
Feeder
PIED
Feeder
PIED

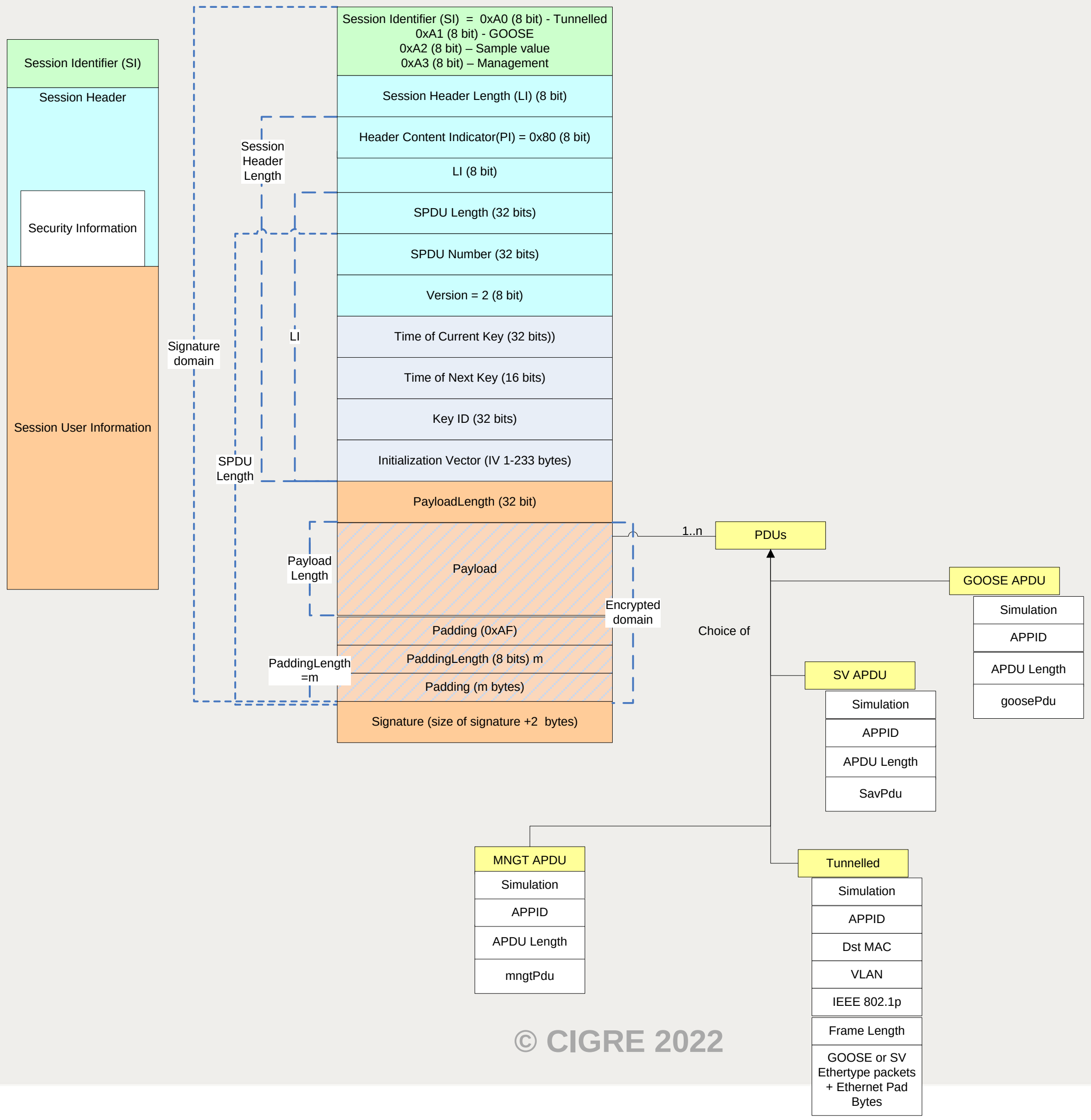
# Analog GOOSE Applications



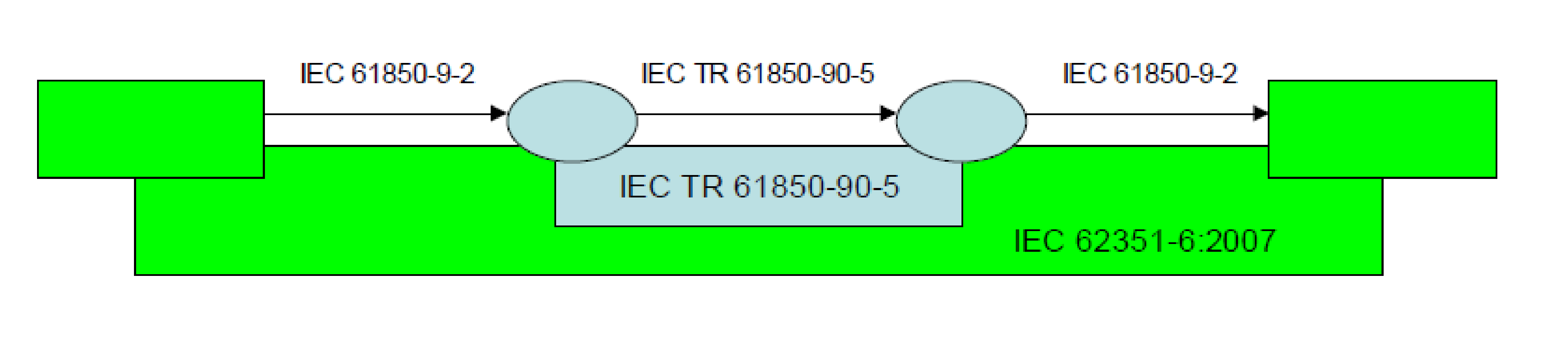
# Adaptive Load-shedding



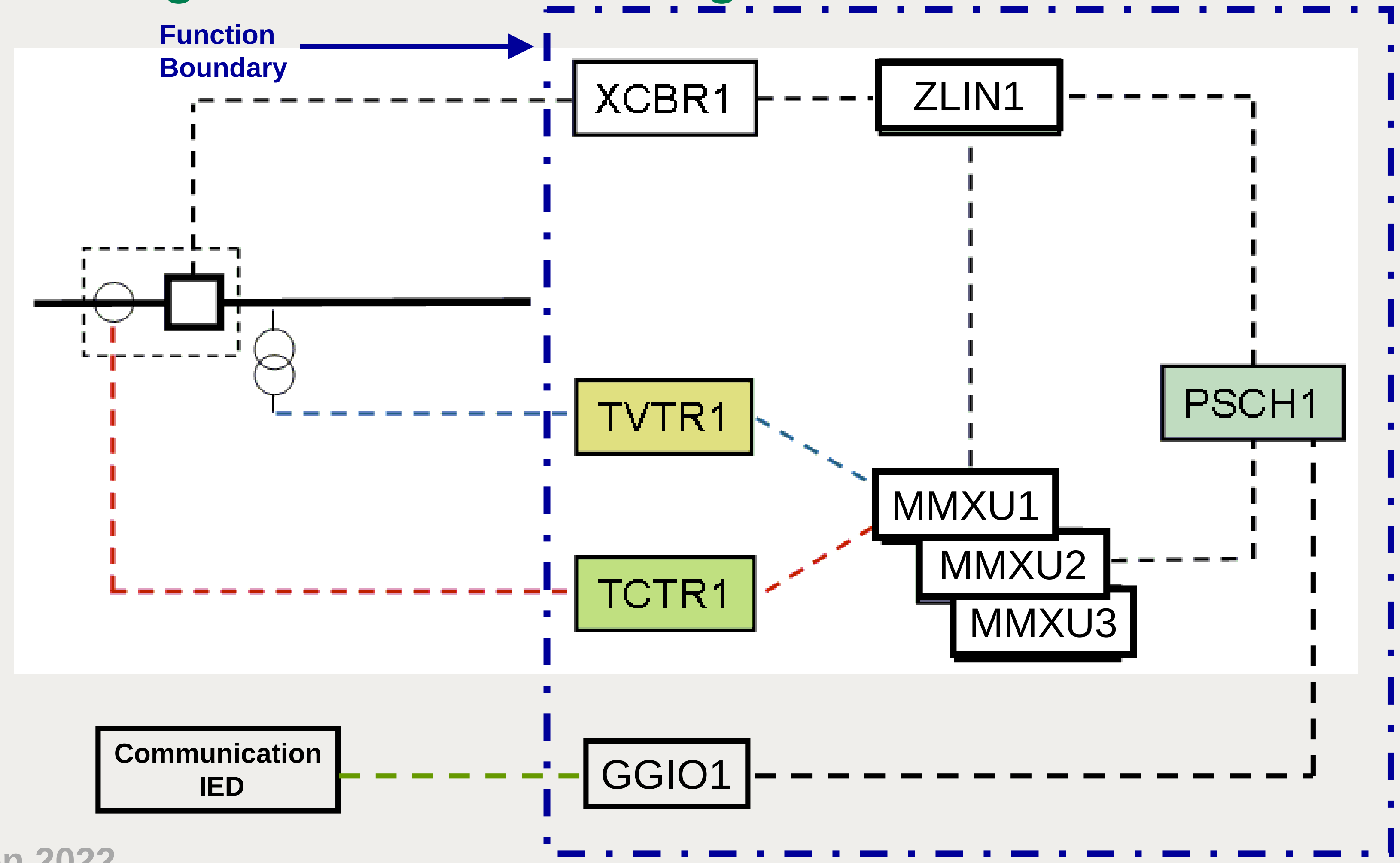
# IEC 61850 90-5 Session Protocol



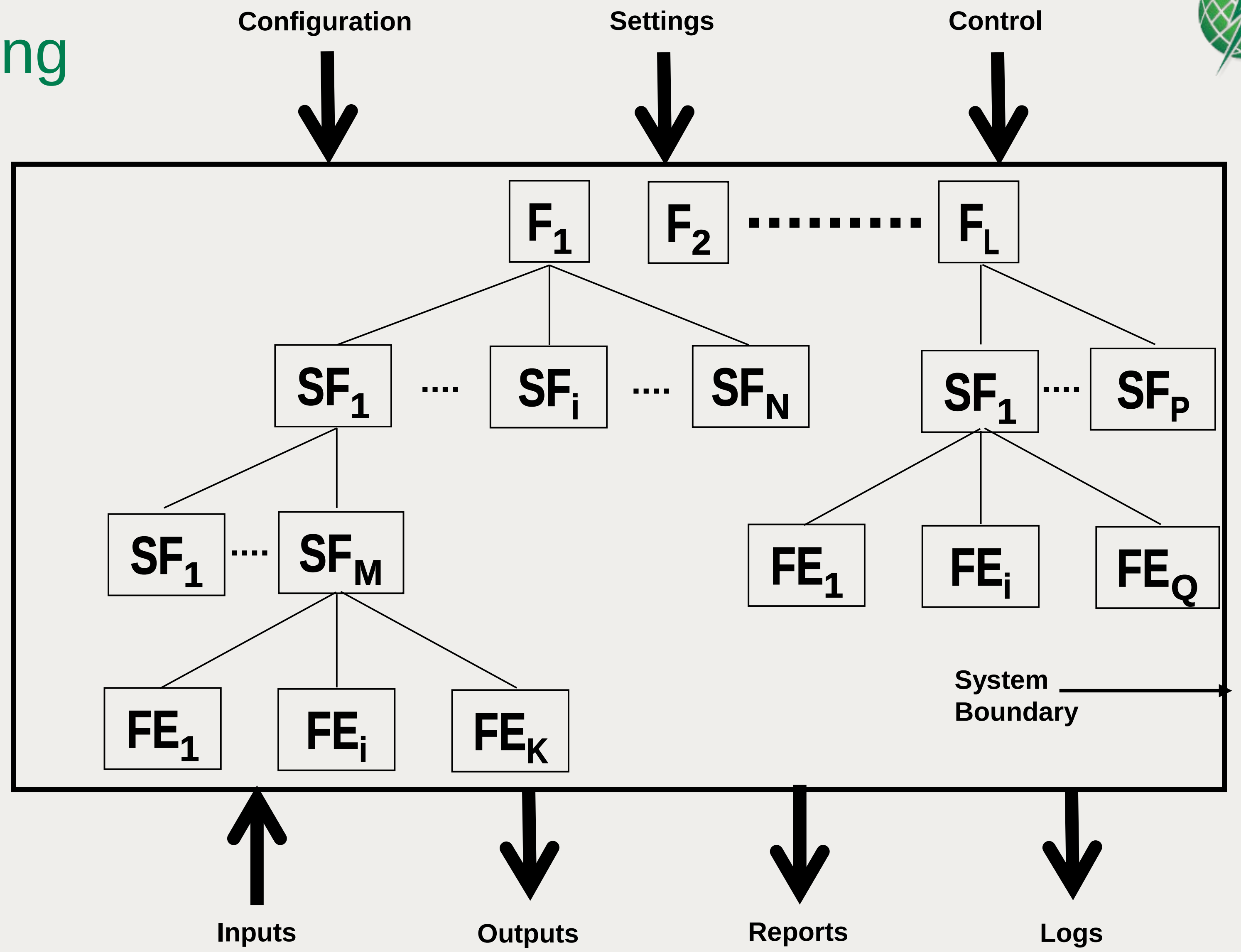
# E2E Cryptographic Integrity



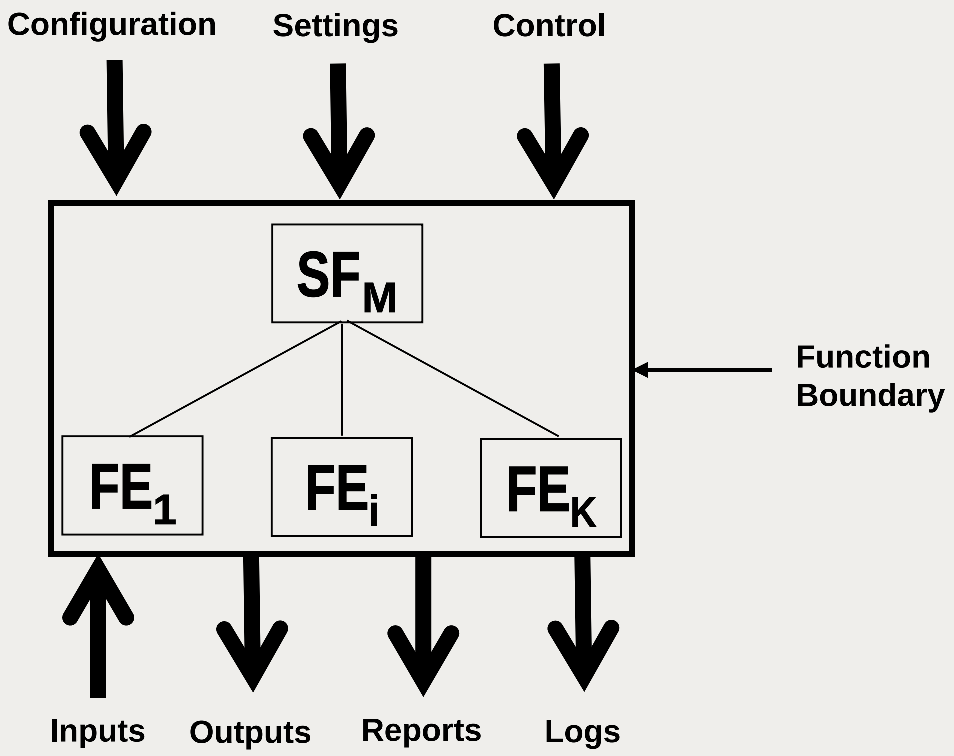
# Line Monitoring Function Modeling



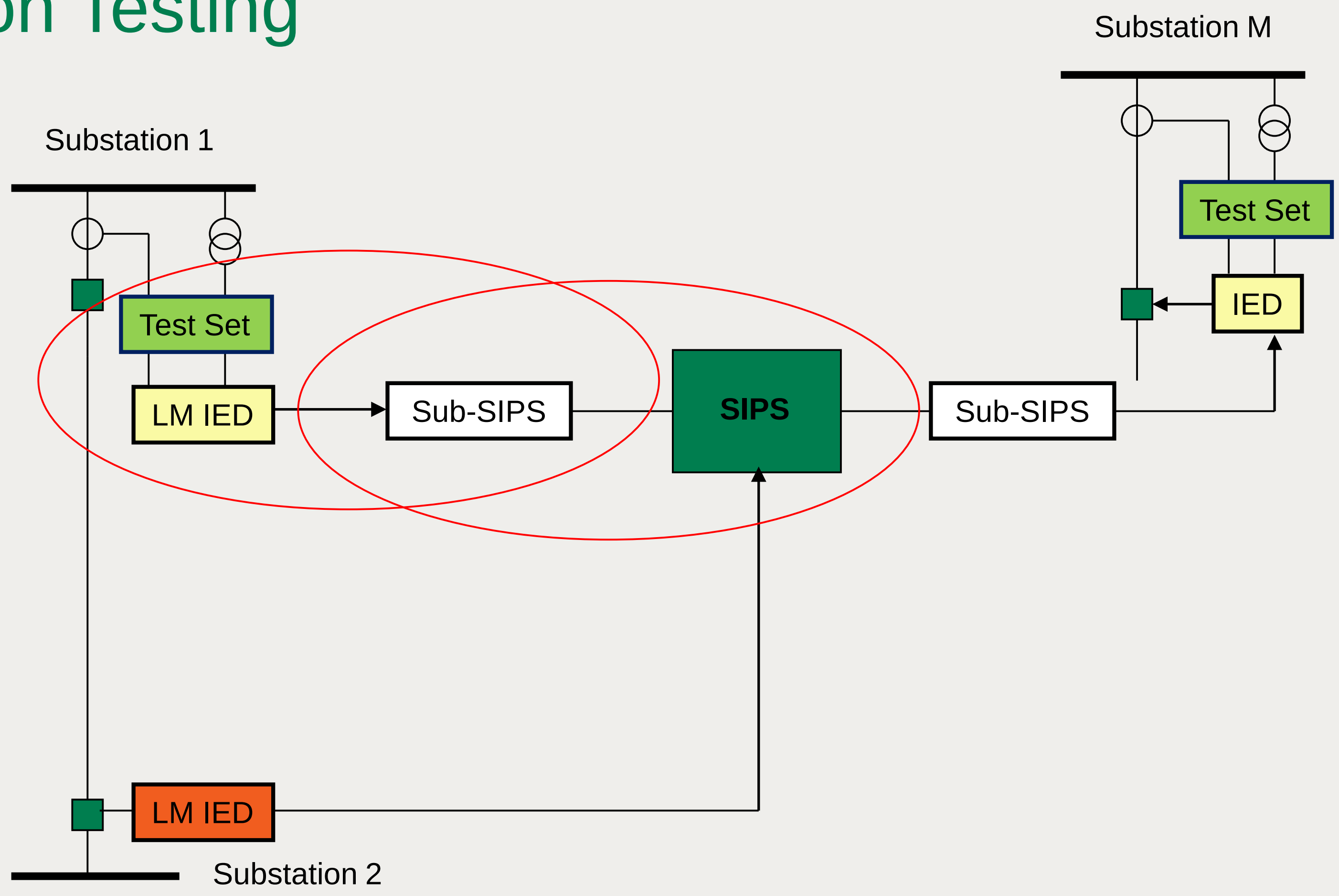
# Top-down Testing



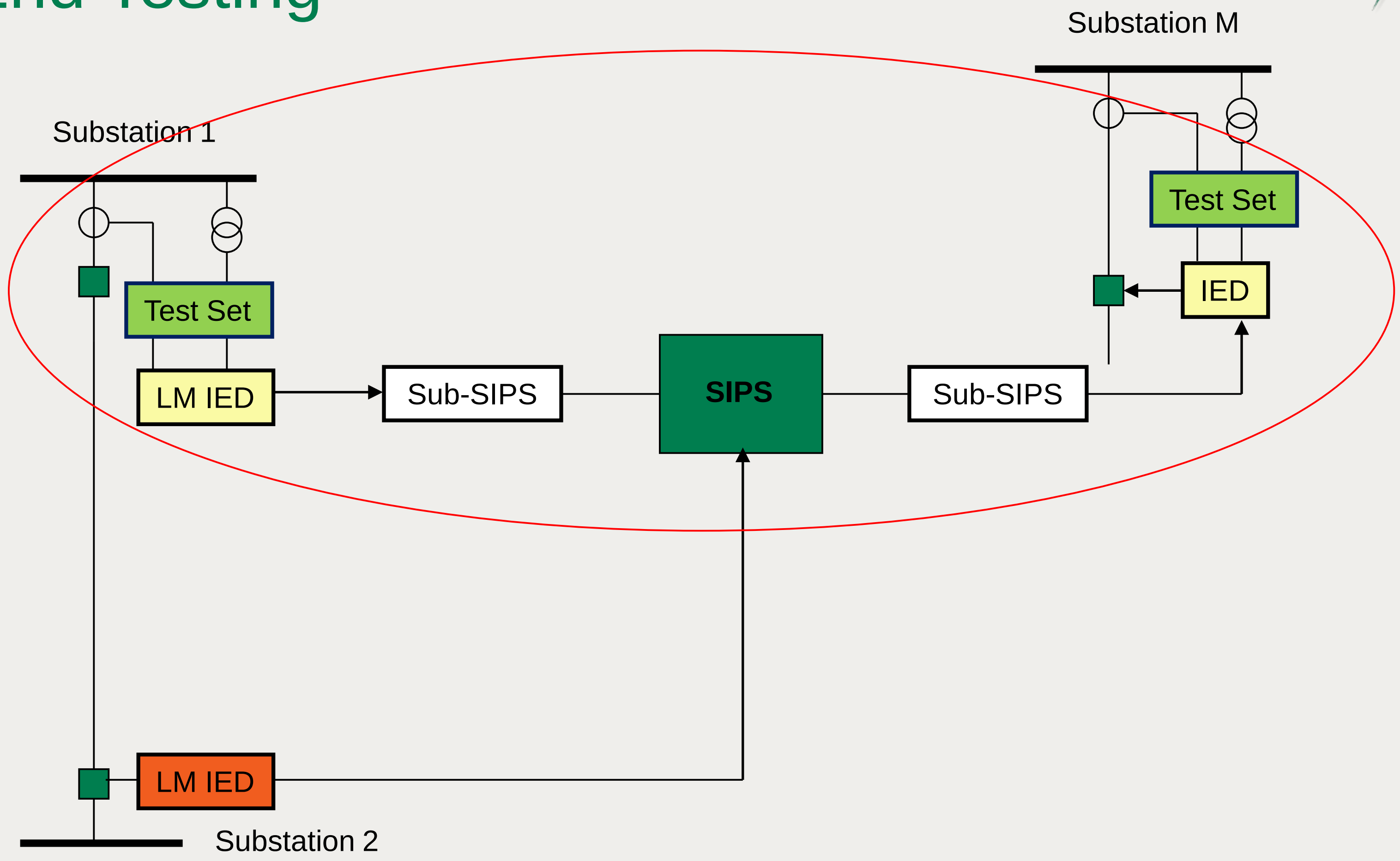
# Bottom-up Testing



# SIPS Integration Testing



# SIPS End-to-End Testing



Questions?