Development and Testing of Resilience Grid Automation using RT simulations

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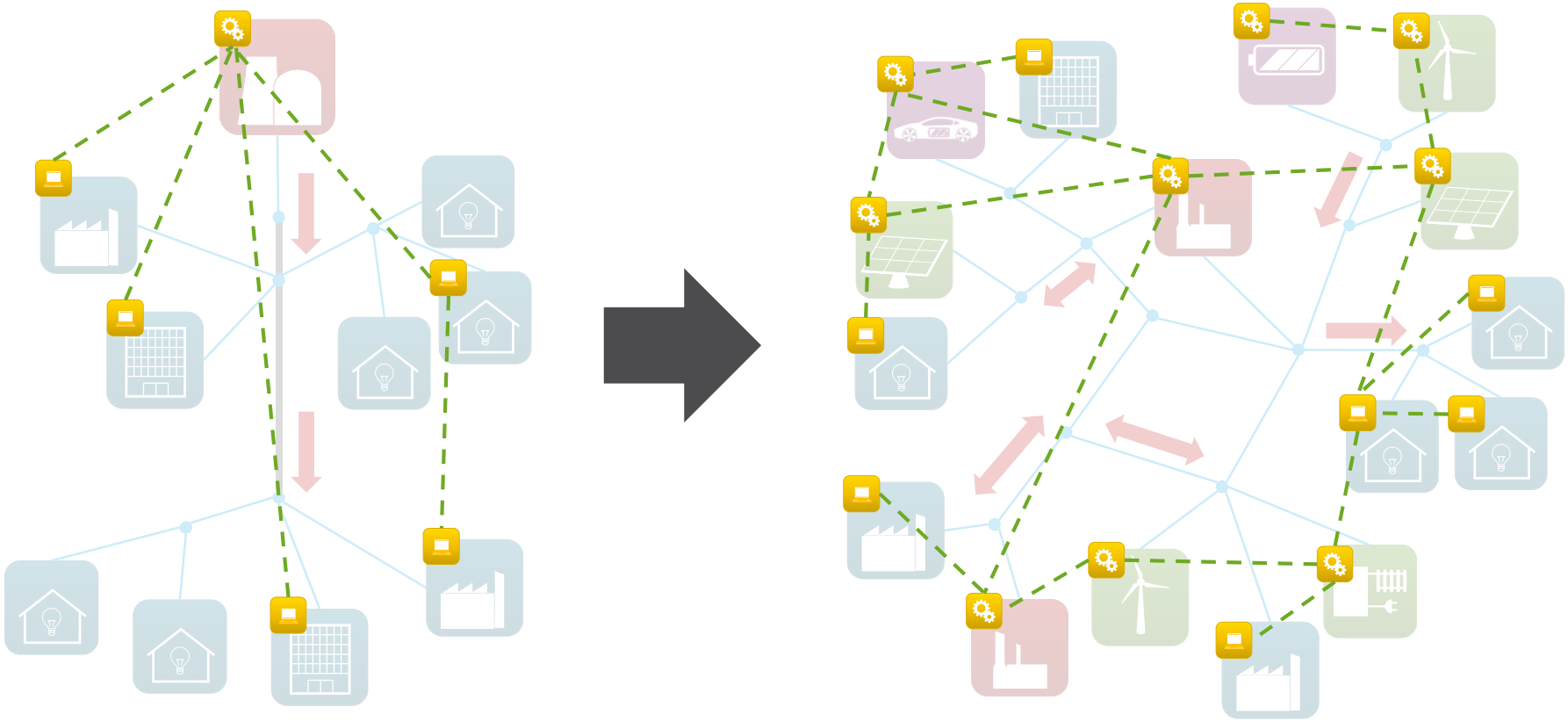
Motivation

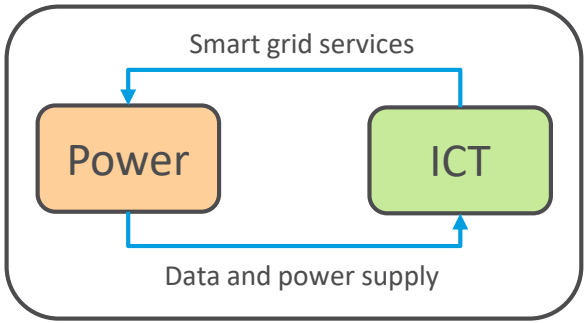
Paradigm Shift to Distributed Smart Grids

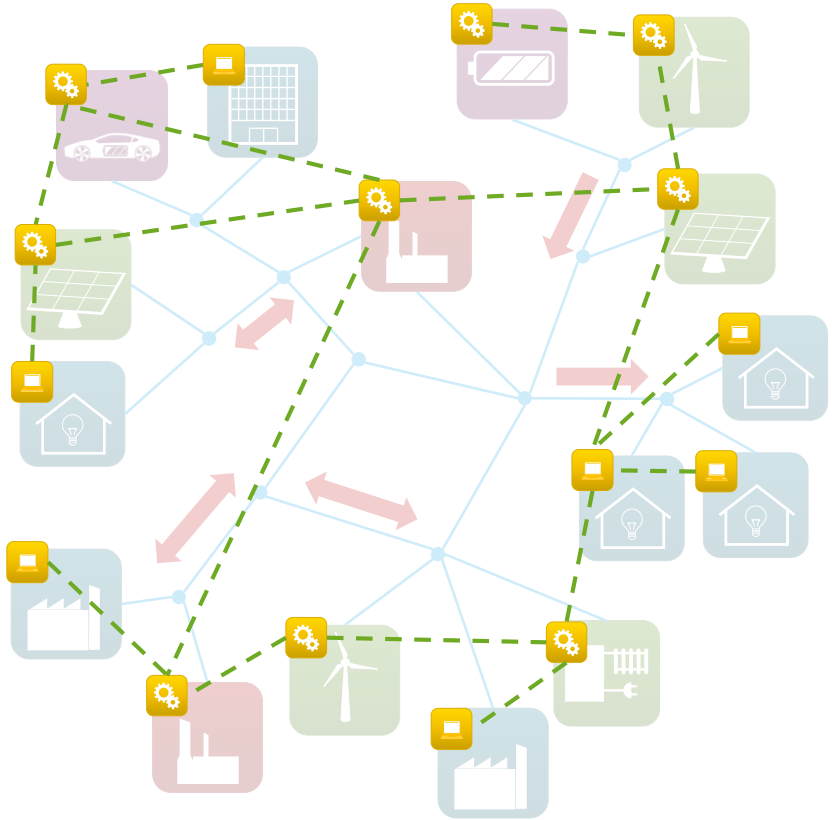


Motivation

Paradigm shift to Complex Smart Grids

- **DER** – Clean resource and too some extend flexible, but more uncertainties.
- **ICT (i.e. automation sys.)** enables better monitoring, operation, decision making and control
  - Smart grid services – State estimation, voltage control, unit commitment, etc.
  - Strong coupling between the systems

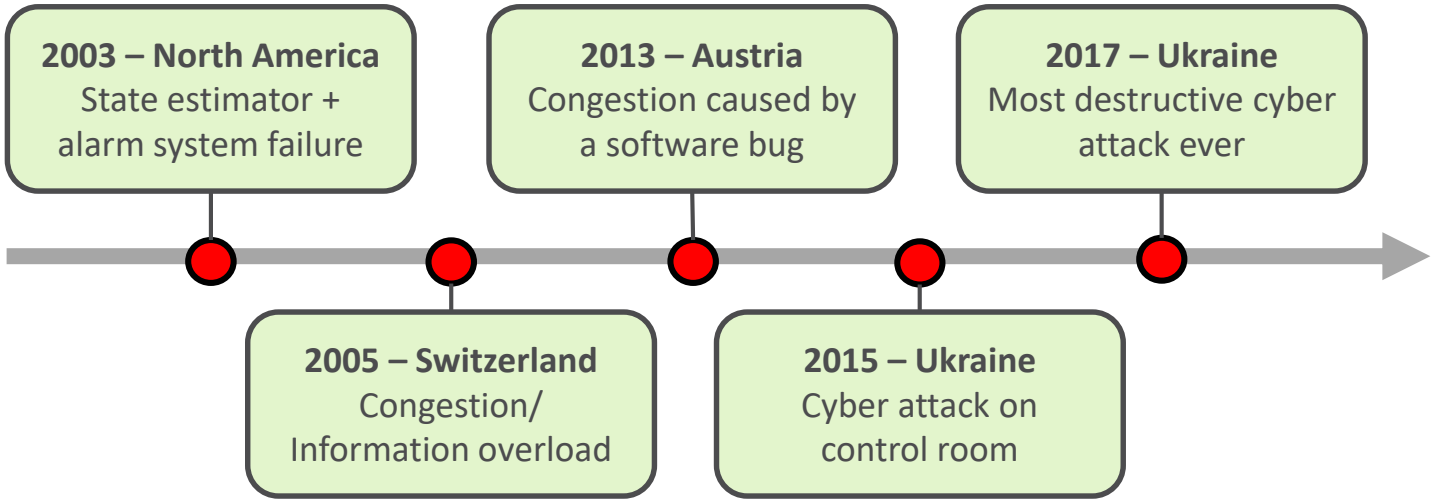




Motivation

Analysis of past events

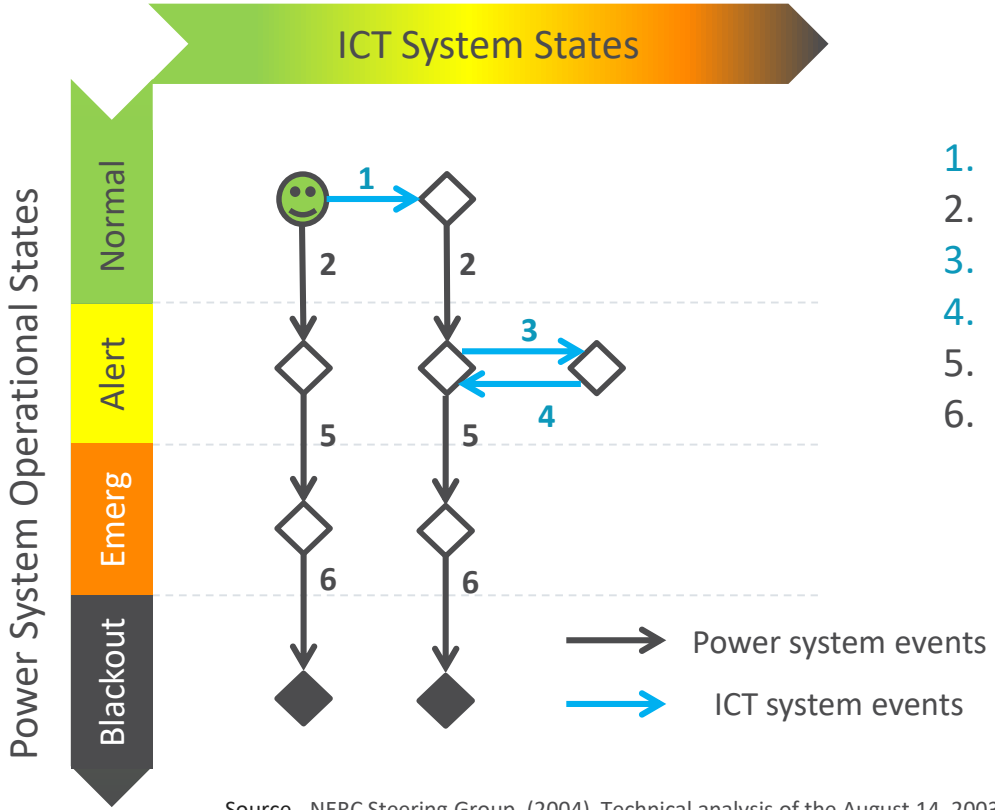
Strong interdependency brings-in new threats and vulnerabilities



Events are caused or aggravated by ICT events ➔ Need to consider ICT in power system planning and operation

Motivation

Mapping of 2003 North American blackout



2003 North American blackout Events

1. State Estimator failure
2. Tripping of lines (DP&L)
3. Alarm system failure
4. State Estimator fixed with incorrect data
5. Tripping of lines (Chamberlin)
6. Voltage collapse

ICT status is missing!

Source - NERC Steering Group. (2004). Technical analysis of the August 14, 2003, blackout: What happened, why, and what did we learn. *Report to the NERC Board of Trustees*, *13*.

How to start with ICT testing?

Appropriate information, communication and automation systems are known from other domains

- But: long-term use in safety critical energy systems mostly untested
- Highly fraught with risk to stakeholders in the energy domain

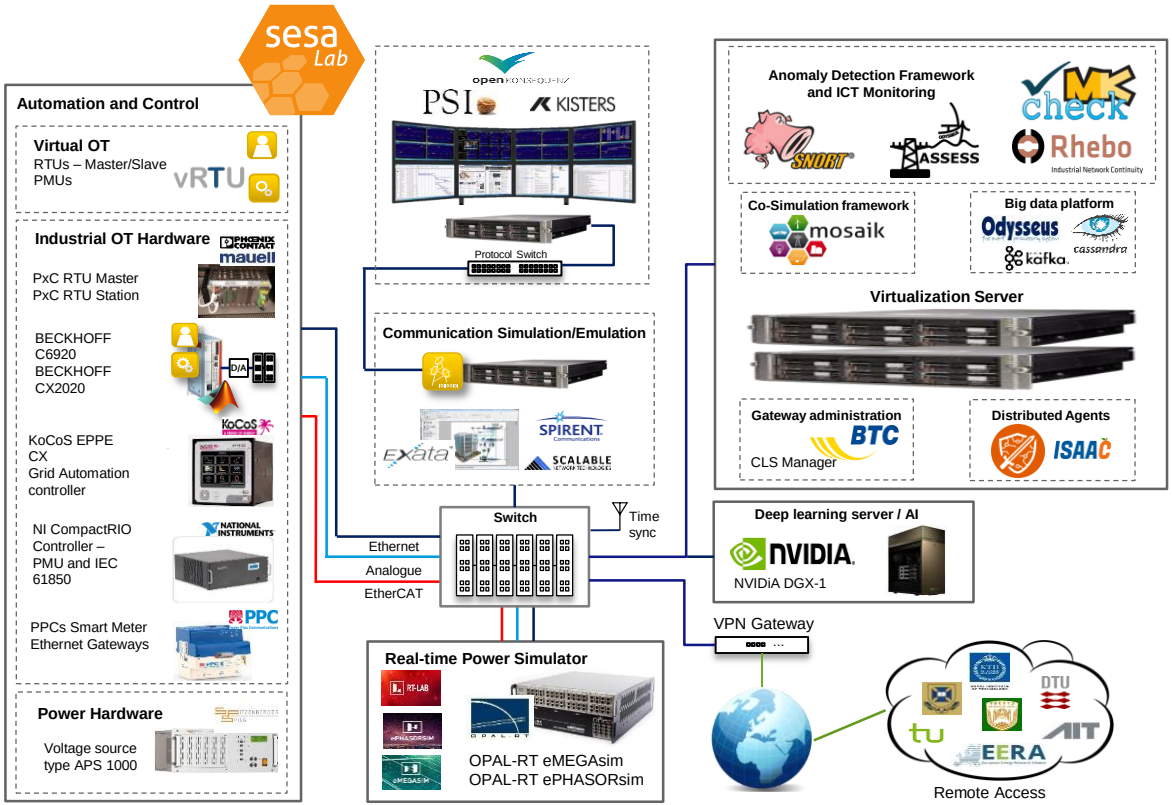
Rigorous testing necessary!

- Learning from other industrial domains...
- **„Hardware in the Loop“**
- Operation of a real el. controller hardware or a mechatronic component in a simulation of the real environment

- *But: what belongs into this simulated environment?*
  - How and on what parts of the system?
- Remember: *…**holistic!***

Quelle: Daimler „Driving Simulator in Sindelfingen“, 2014

Smart Energy Simulation and Automation Lab



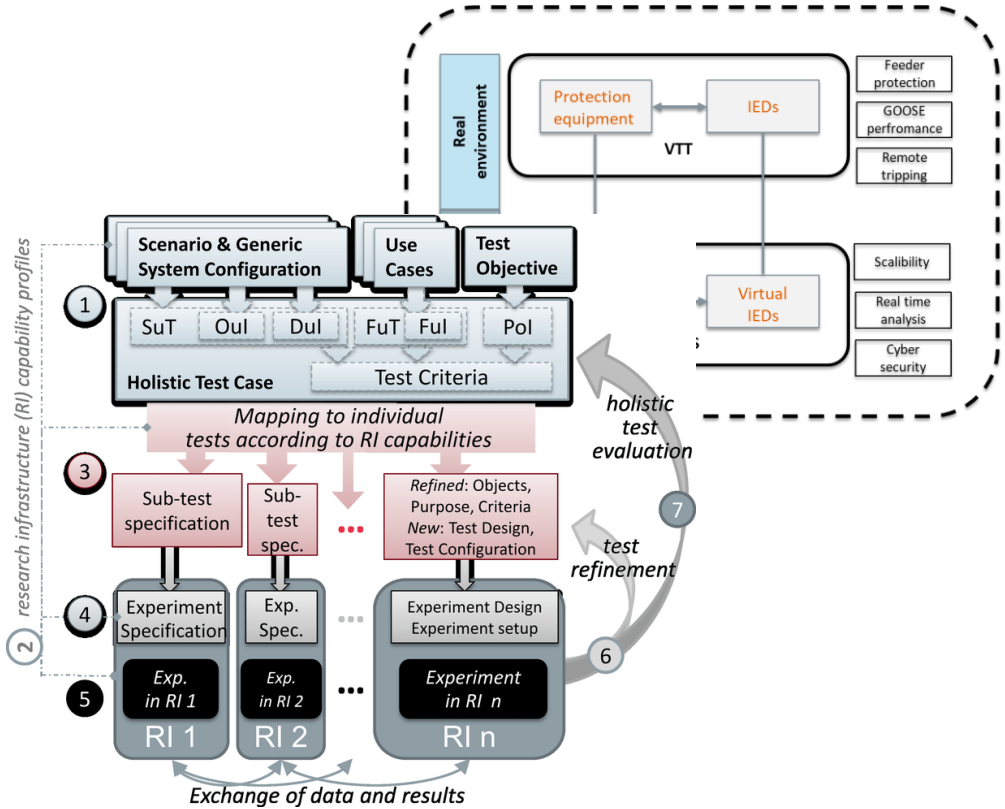
Examples of Testing Projects

ERIGrid vIED	Cross validation of virtual vs physical IEDs Use-case: GOOSE messages quality test
Enera	Testing performance of distributed controllers **Use-case:** communication round trip testing
CybResLab	How to increase resilience of Smart Grid Services Use-case: improved state estimation

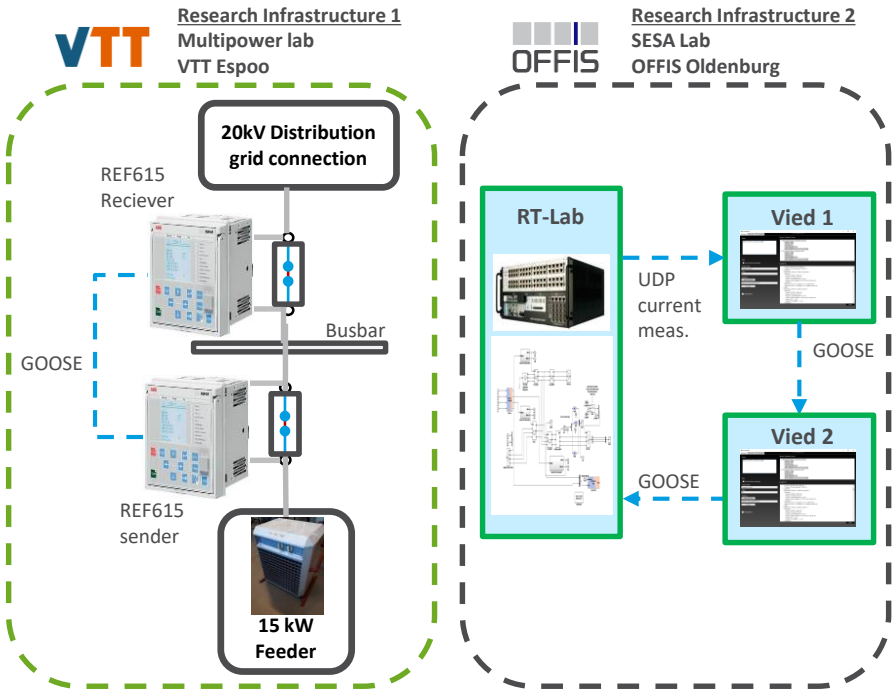
ERIGrid vIED

Testing Performance of Virtual IED

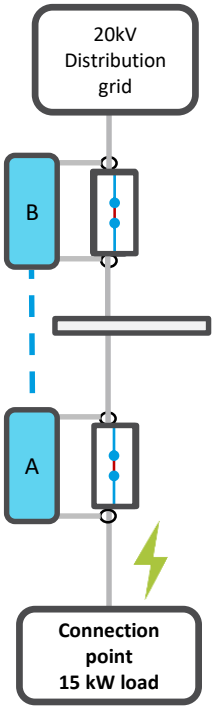
- Develop a virtual IEC61850 compliant virtual environment for large-scale simulation / virtualization studies
- Validate the performance of virtual IED in a real-time set-up with the results from a physical set-up
  - Test the performance of GOOSE and IEDs for reverse blocking scheme and validate it with physical set-up
  - Define KPIs (GOOSE Transmission time, circuit breaker tripping time)
- Use a **Holistic Testing Procedure** developed at ERIGrid for multi-domain multi-laboratory validation



ERIGrid vIED
Test Platform



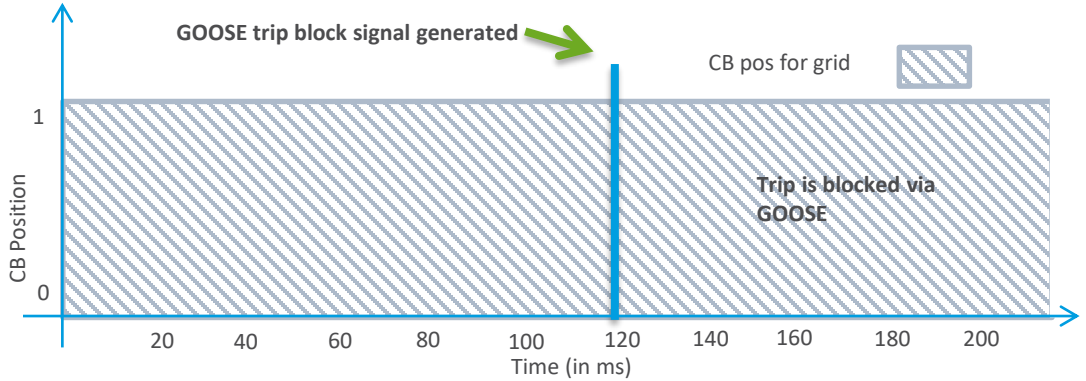
- **Test case 1:** Overcurrent at feeder load
- Relay A would trip and send blocking signals and circuit breaker status information to B
- Message: Shirt circuit fault - do not trip IED B
  - PTOC start
  - XCBR status value
  - 4ms average time
- The messages are sent via GOOSE communication - Loss of mains protection
- Fault is cleared and breaker is reclosed
- **Test case 2:** GOOSE communication failure
  - Blocking signal not sent



Results

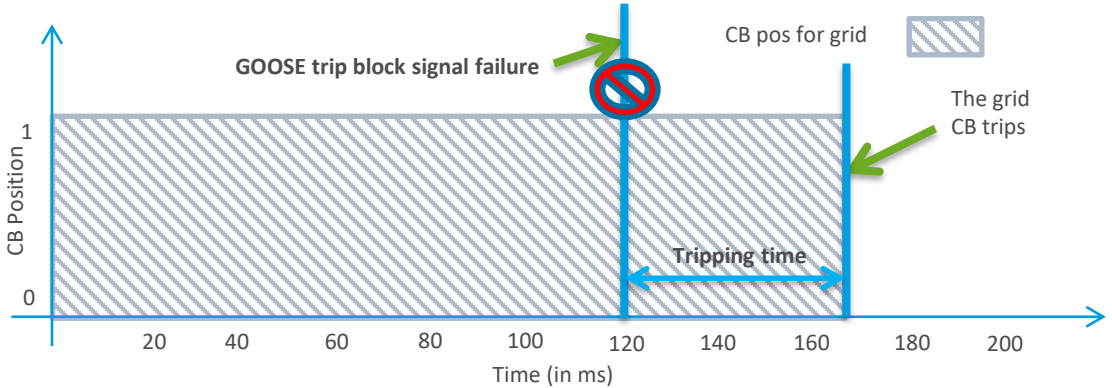
Test case 1

- GOOSE message trip time
  - RI 1 = 1.71ms
  - RI 2 = still working on it



Test case 2

- GOOSE communication is impaired
  - Grid CB trips and grid connection point is lost



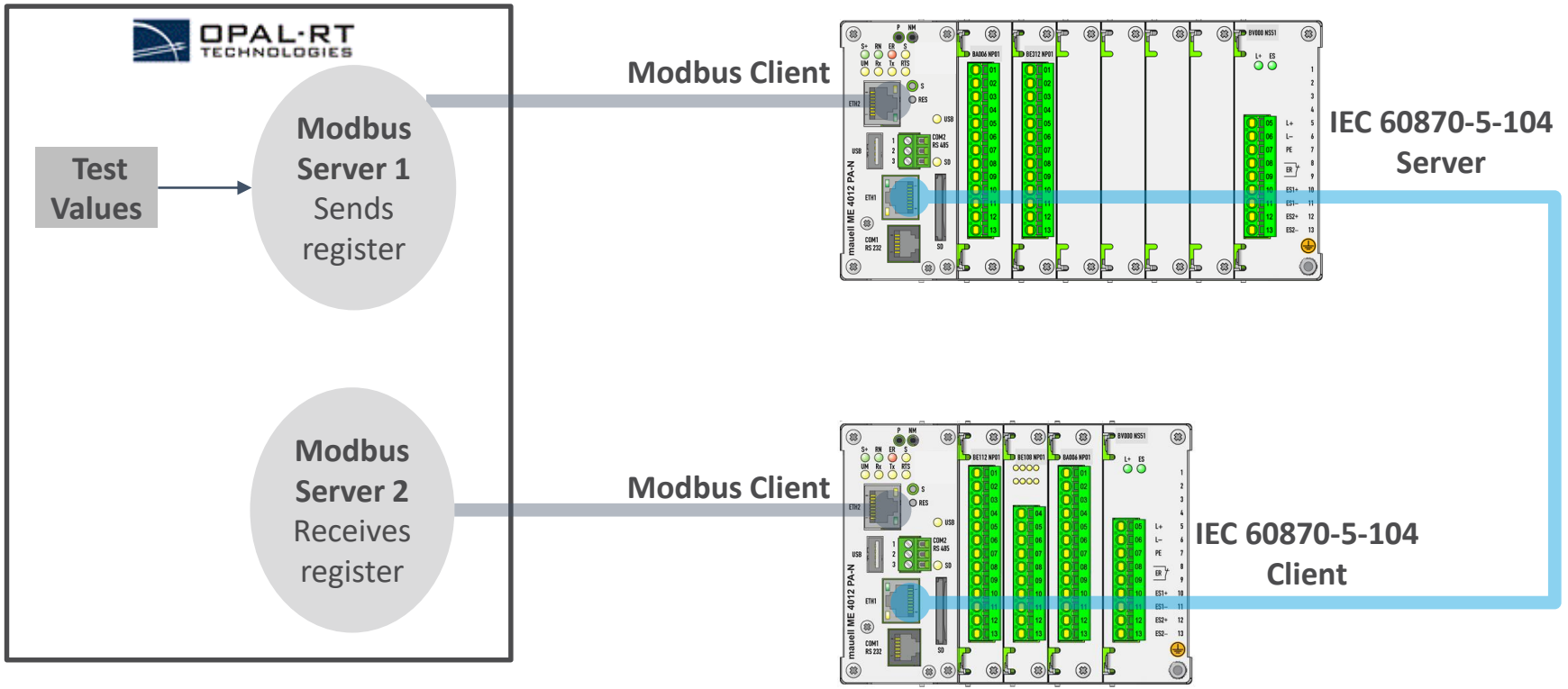
Distributed Controllers Testing

Hardware-in-loop Test

Determine capabilities and characteristics of Physical RTUs via HIL test.

Determine computational and communication delay

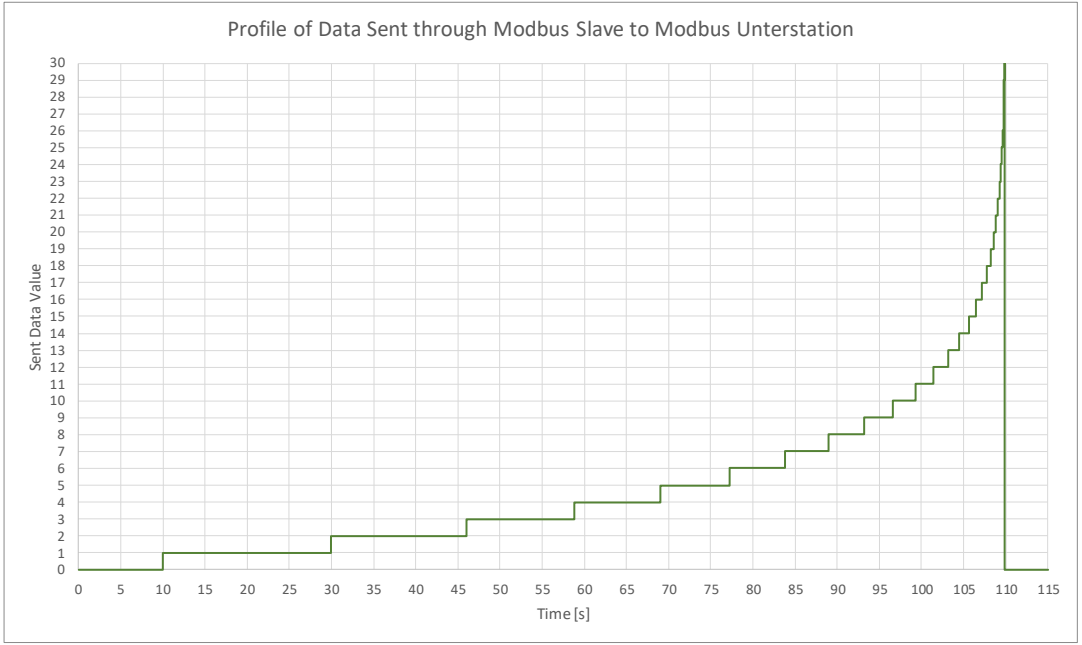
Test Set-up


OPAL-RT TECHNOLOGIES
Test Values
Modbus Server 1 Sends register
Modbus Server 2 Receives register
Modbus Client
Modbus Client
IEC 60870-5-104 Server
IEC 60870-5-104 Client

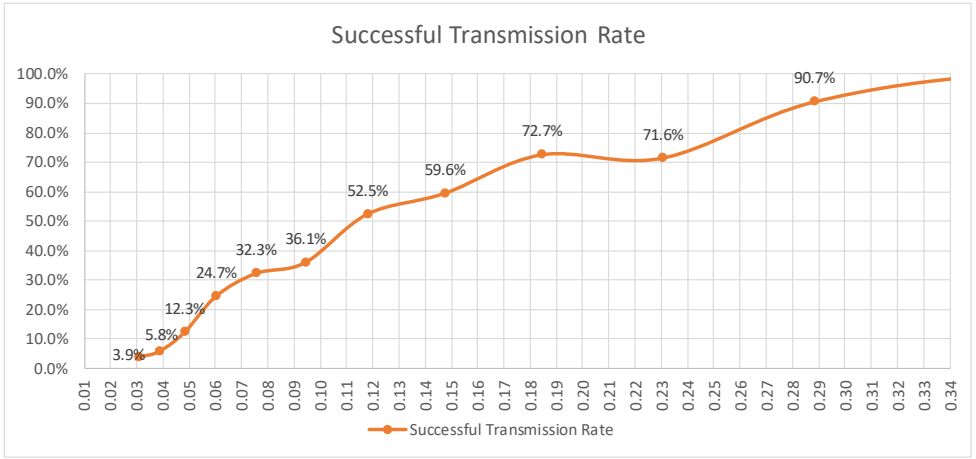
Statistical Approach

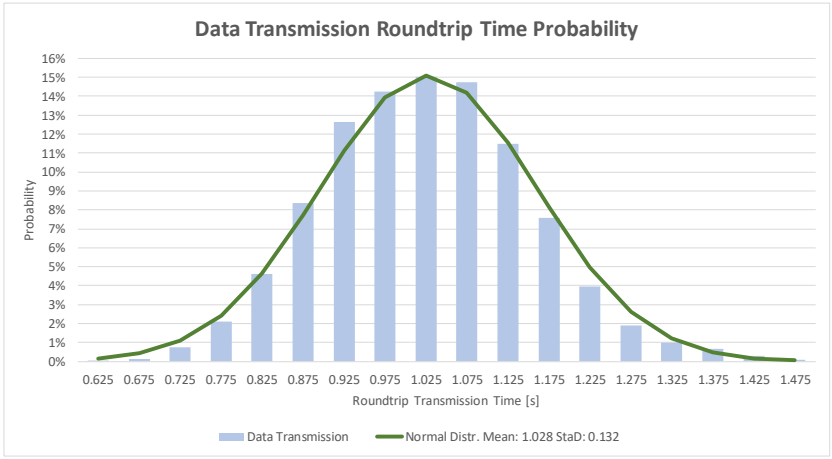
- Data is sent with progressing change frequency rate
- The successful data transmission is determined
- The cut-off change frequency rate is determined
- The experiment is performed ***500 times*** due to stochastic nature of communication.
- The statistical delay is determined

Value characteristic composed by integers



Highlights

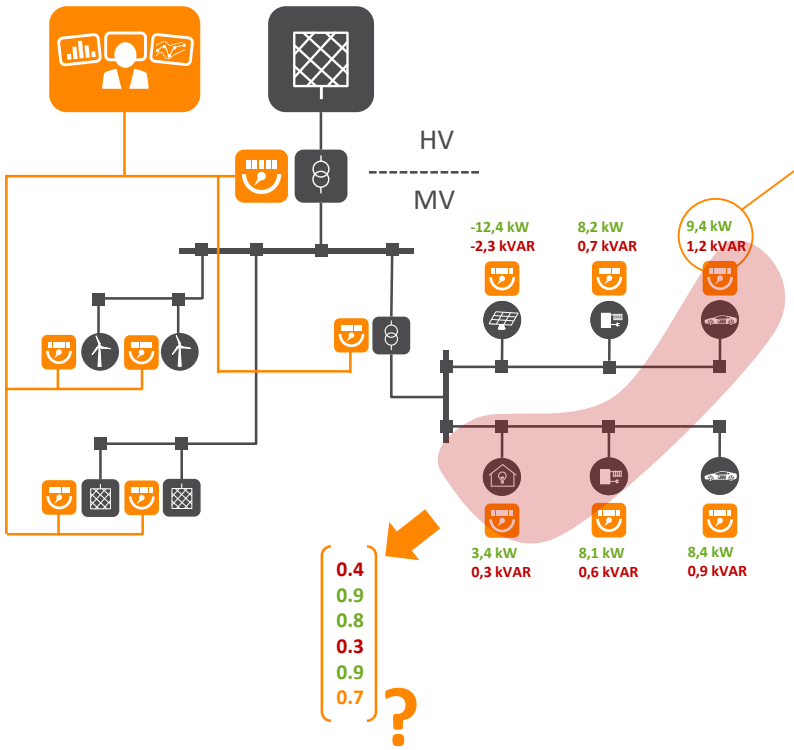


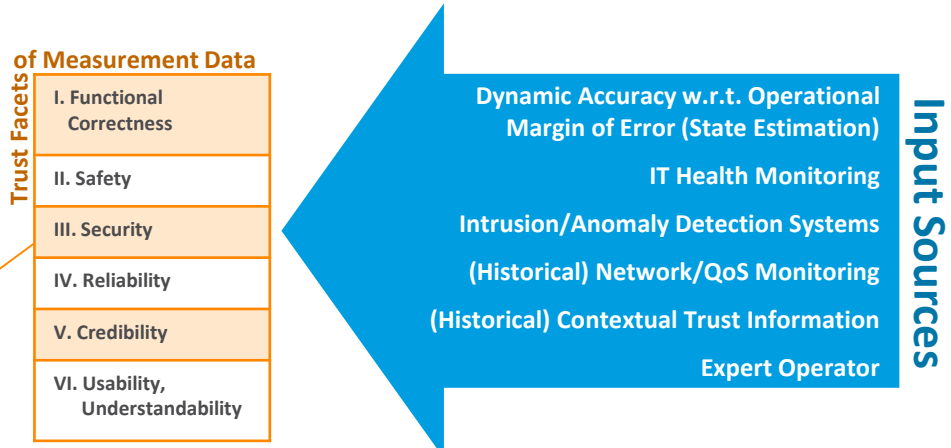


Average Real-Time Roundtrip: 1.028 s
Standard deviation: 0.132 s

Testing Grid Monitoring Applications

CybResLab





- **All conceivable attack vectors manifest themselves in a combination of (violated) trust facets**
- What to do with this multivariate assessment?
  - E.g. substitute measurements with historical/simulated values?
  - Do nothing?
- *What is the worst that could happen?*
- *What information could be used to improve/represent each Facet!*

Anomaly-Aware State Estimation

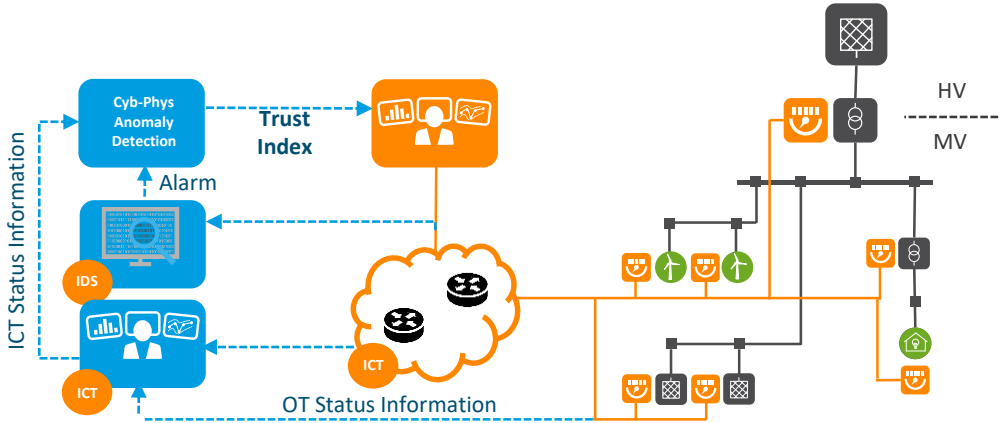
Federal Ministry for Economic Affairs and Energy

OFFIS

Integration of OT/IT health status

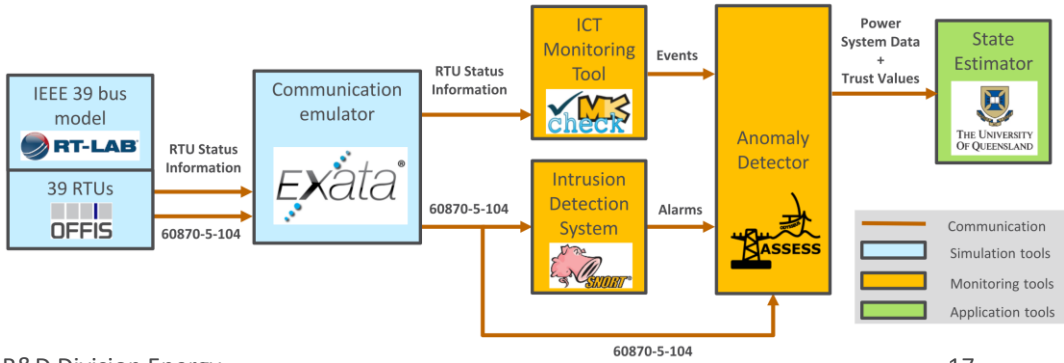
- ICT monitoring tools (e.g. interface and memory status,...)
- Intrusion Detection System (network malicious, ...)

Creating data reliability index (trustworthiness)

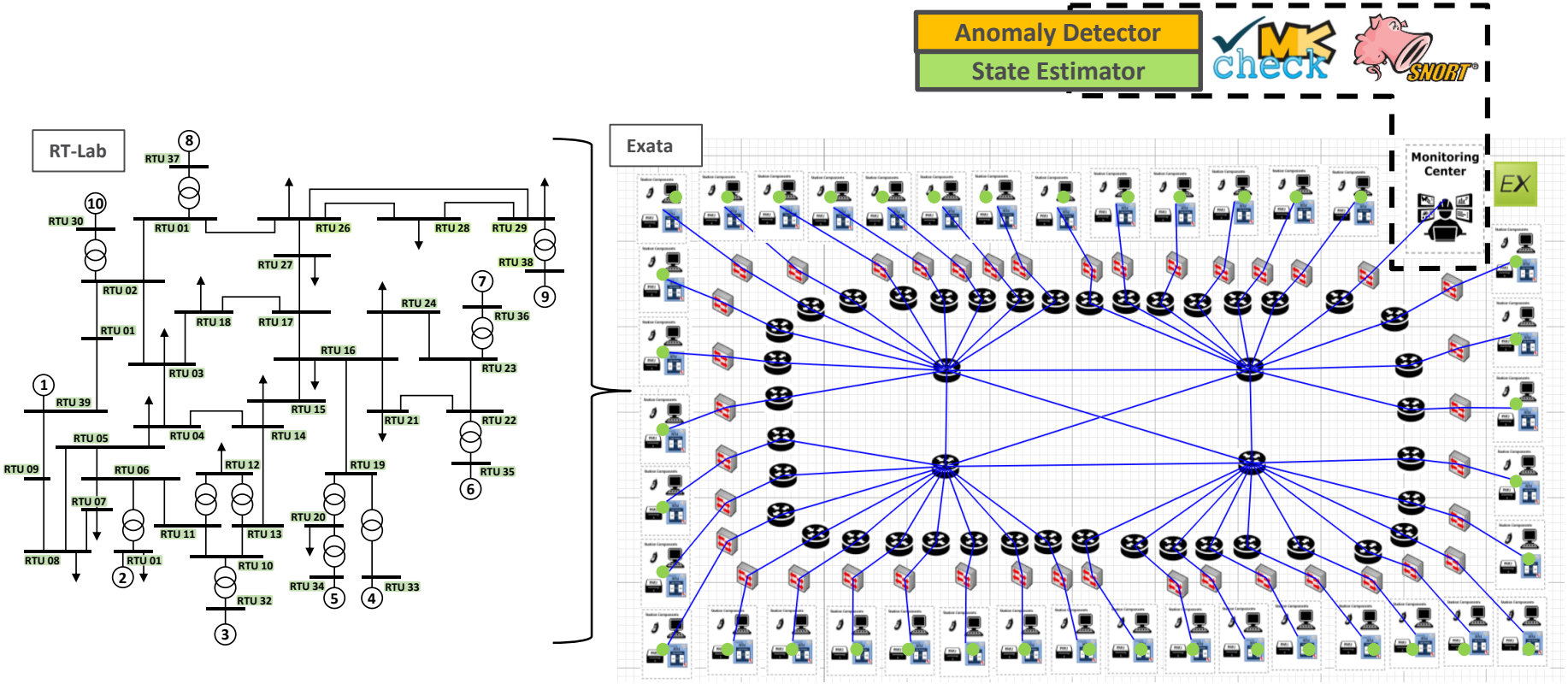


Application

- Improved (integrated) state estimation – identification and consideration of abnormal patterns
- ICT – Power systems state classification
- Selection of proper countermeasure
- Fault detection and management

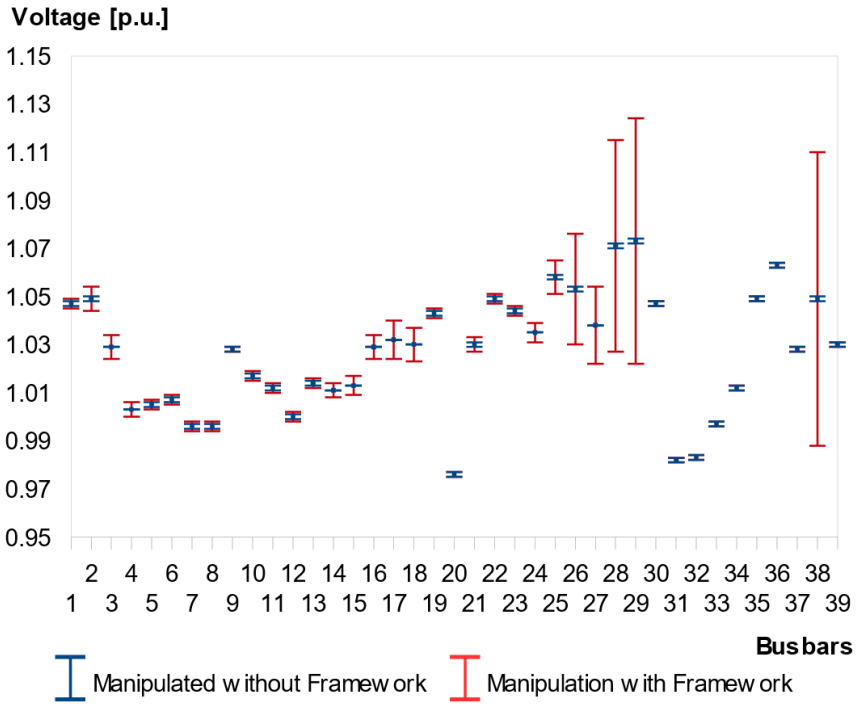


Set-up in detailed



Highlights

- **Estimated state variables:**
  - outside critical area: close to real values
  - inside ciritical area: different from real values
- **Uncertainties (as a measure of trust)**
  - without framework: almost zero everywhere
  - with framework: high inside critical area



Thank you!

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