ERIGrid Holistic validation procedure and test specification

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Workshop "Designing and Validating the Future Intelligent, Electric Power Systems"

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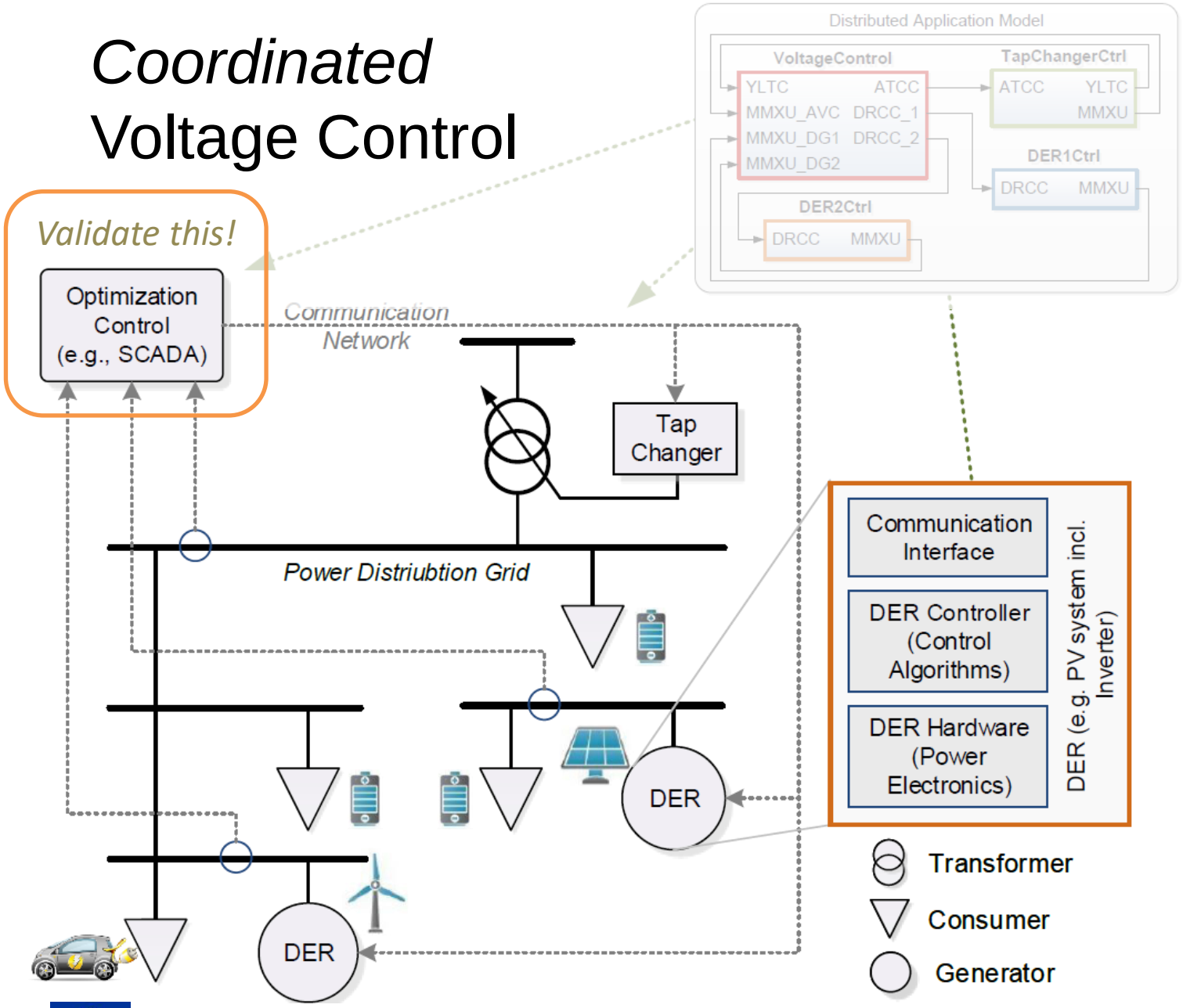
EU H2020 Programme GA No. 654113

Coordinated Voltage Control



The Vision

HOLISTIC SYSTEM VALIDATION

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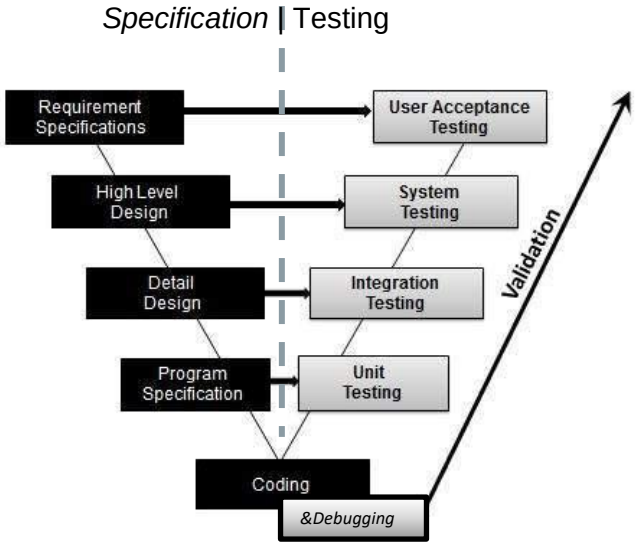
“Holistic” System Validation

I. **System validation**:
alignment of Specifications & Testing

II. **Integrated hardware & software testing**
Validate “systems” not components.

III. **T**ests that **combine multiple domains**
e.g. Power, Comm. and Automation

IV. **Systematically design tests & integrate results** from various experiments for a holistic assessment
i.e. combine simulation, co-simulation, HiL, PHiL, CHIL, different Labs, ...



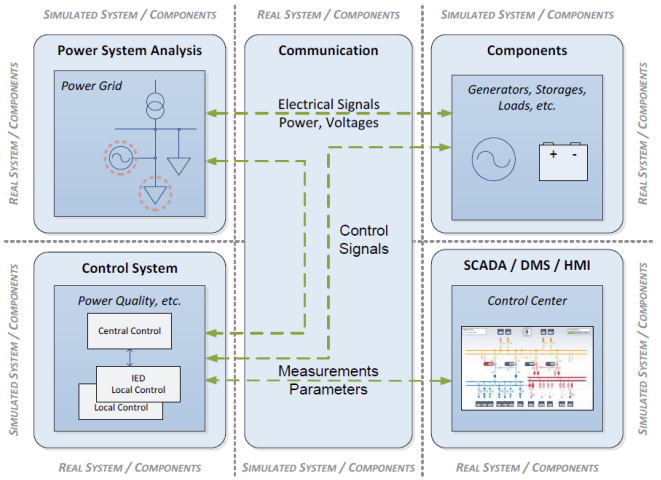


Figure 1.3: Improved methods and tools for Smart Grid validation and testing – possibility to combine virtual (simulated) and real components

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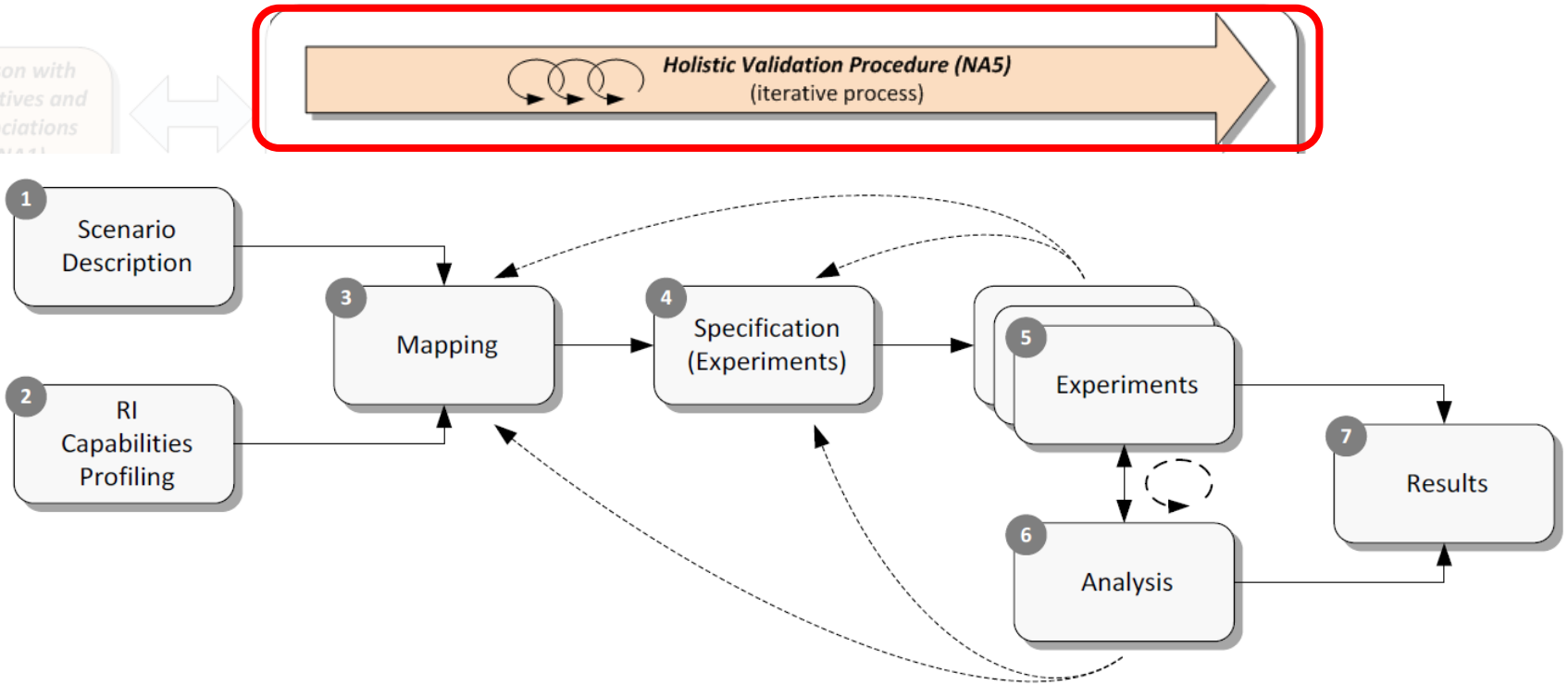
System validation - a holistic procedure



"**Holistic testing** *is the process and methodology for the evaluation of a concrete function, system or component (object under investigation) within its relevant operational context (system under test), corresponding to the purpose of investigation"*

A generic experiment / validation

- Defines components of a system
- Includes: Object of investigation

System Configuration

- Defines functions of a system
- Requirements define Test Criteria

Use Case

SGAM? CIM? IEC62559

Test Case

Purpose of Investigation

- Experimental design
- Test procedure

Configuration

Input
controllable & uncontrollable
input parameters

Test/ Experiment

Target
Test Criteria
Performance indicators/ Test metrics

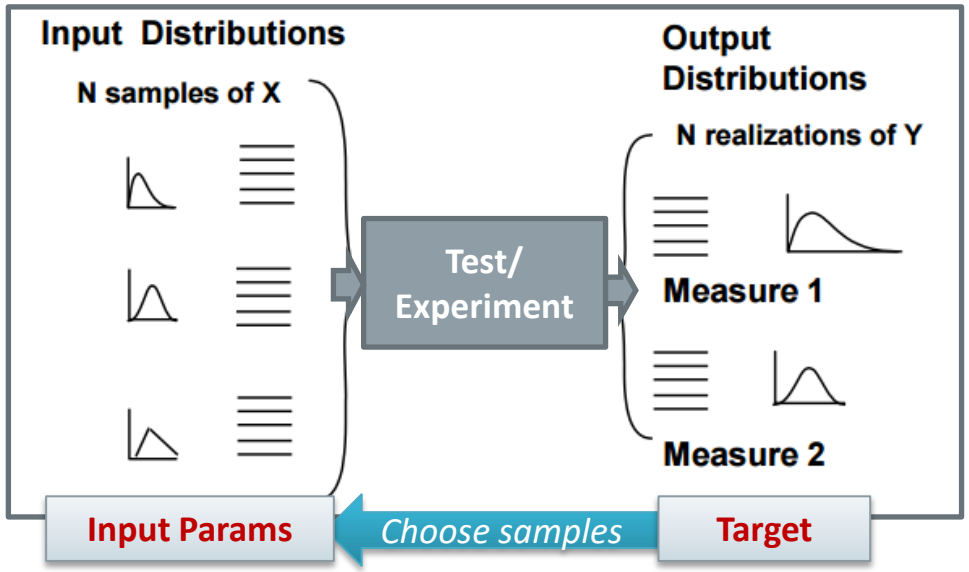
Object of investigation
Experimental setup
Boundaries of experiment
Testing Tools
Data Exchange

experiment **assessment**:

Quality of experiment: error type; **uncertainty**; **quantification of error**

‘Design of Experiments’

- efficient test design due to sampling-oriented approach



- Target measures / metrics
  e.g. “average control error”
- design sampling space on a ‘need-to-know’ basis
  e.g. 3 levels of package loss rate, 20 levels of disturbance, …

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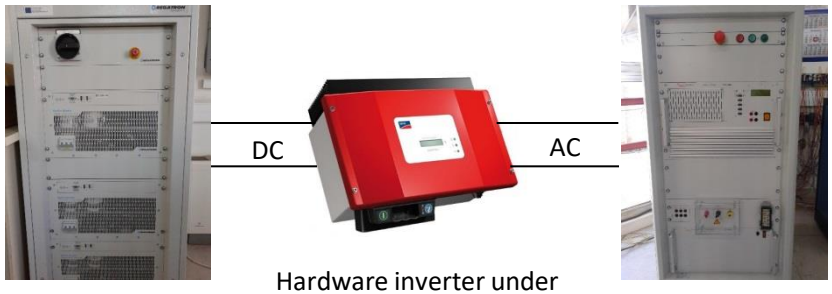
Holistic Test vs. Component Test

Component Test

- e.g. Inverter MPPT test, anti-islanding
- No interactions with the system
- Usually open loop test (predefined voltage, frequency etc setpoints are applied to the DuT)



PV simulator

Hardware inverter under test

AC gid simulator

Holistic/System Test

- Combining several tests (testing process)
- Using simulations

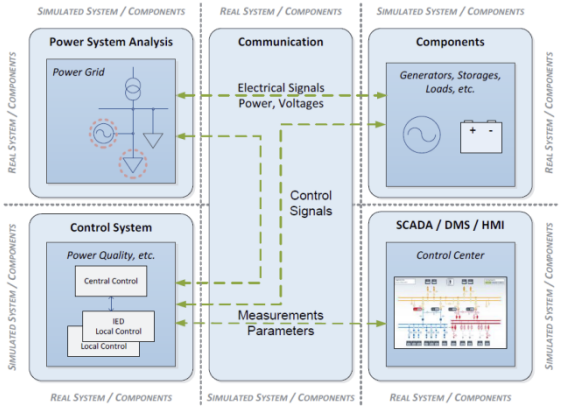
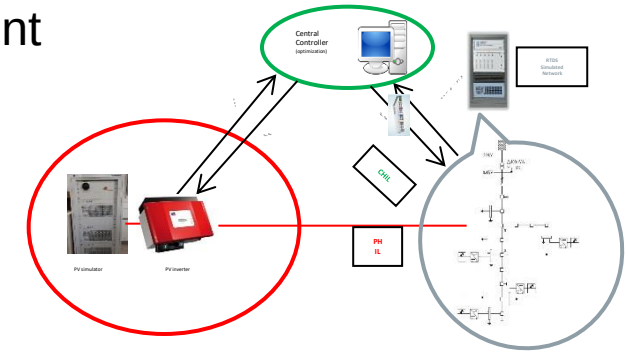


Figure 1.3: Improved methods and tools for Smart Grid validation and testing – possibility to combine virtual (simulated) and real components

- Testing a system rather than just component



Images: Panos Kotsampopoulos (NTUA); DoA

The basics

HOLISTIC TEST DESCRIPTION

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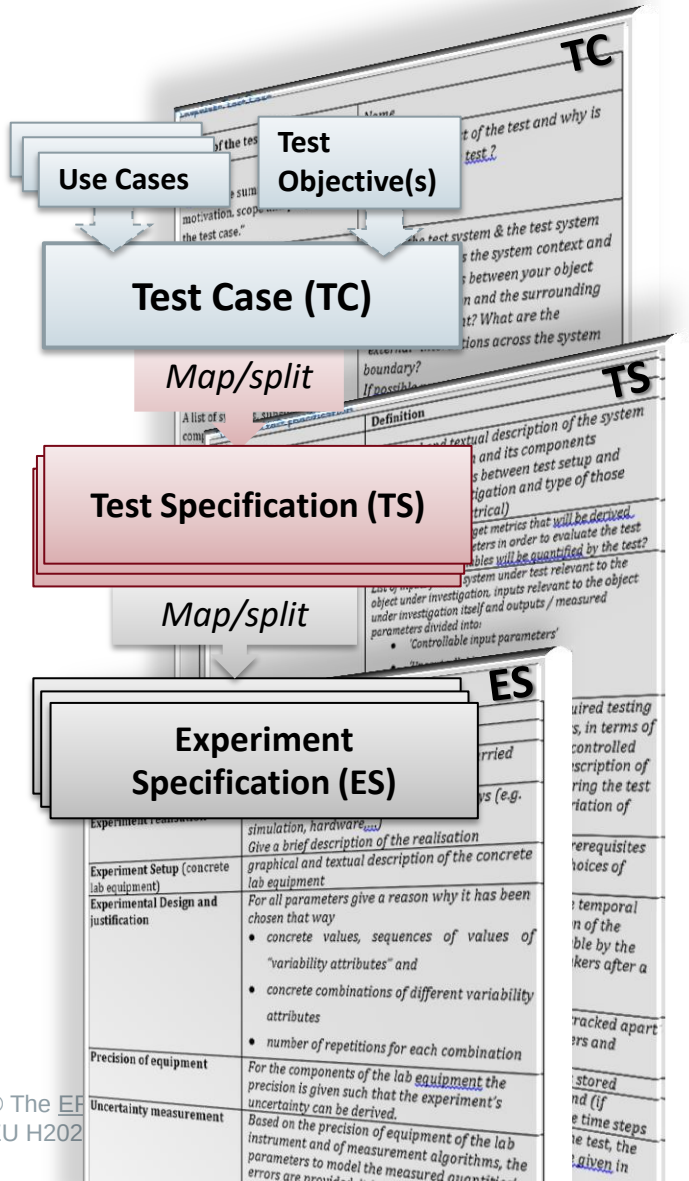
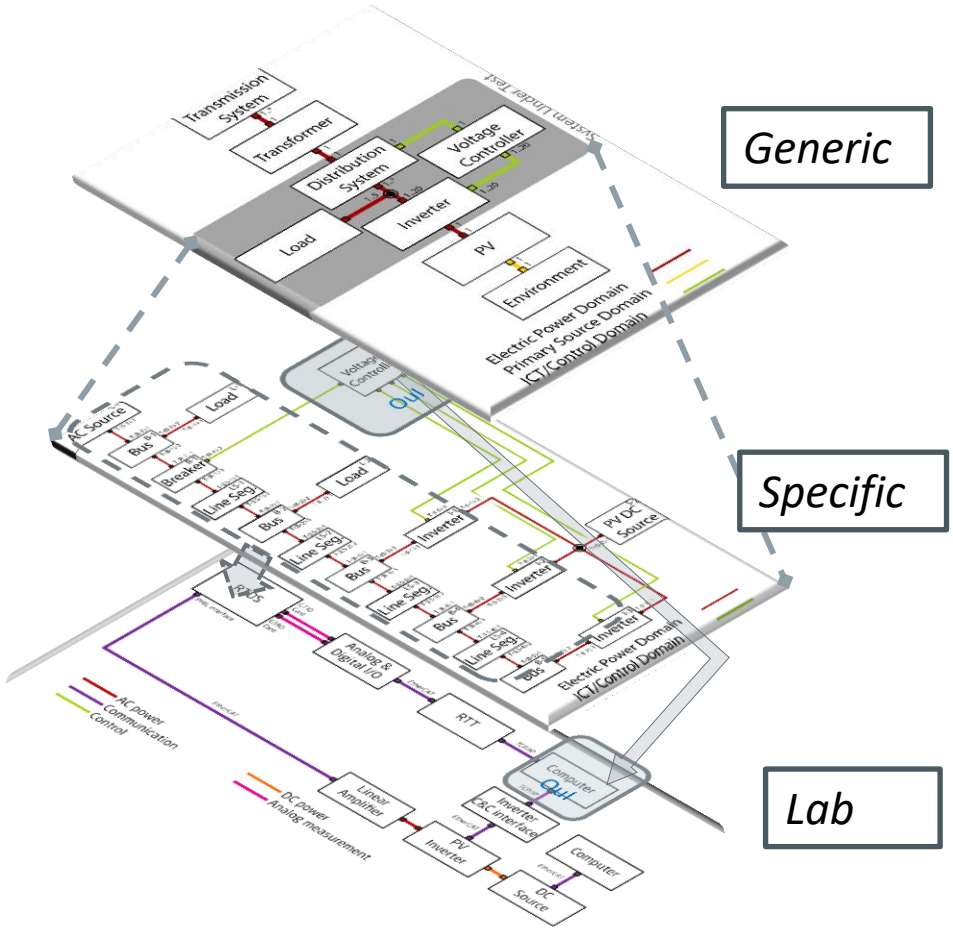
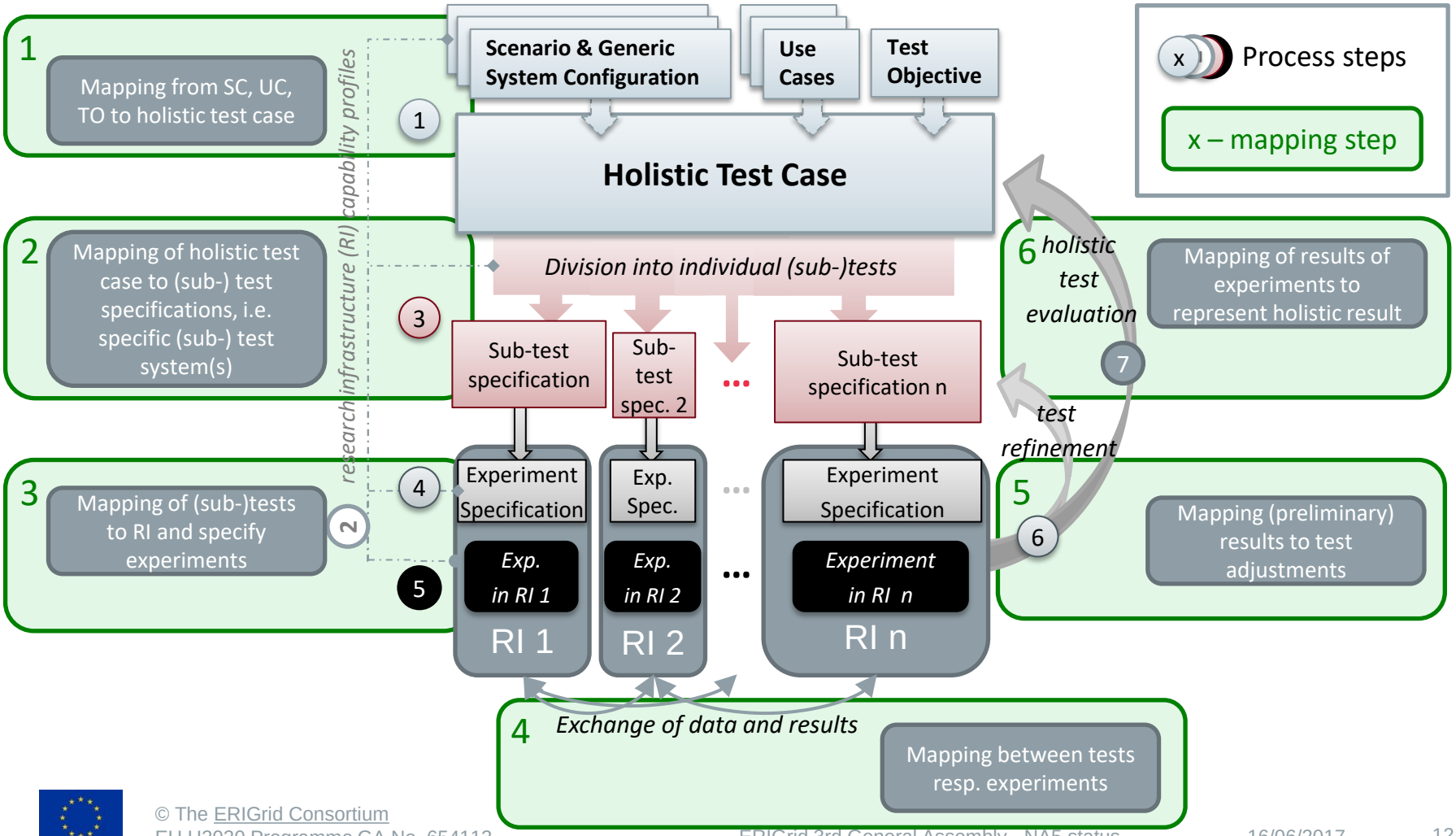
Holistic test *description*

THREE levels of specification





Holistic testing procedure – different mapping steps



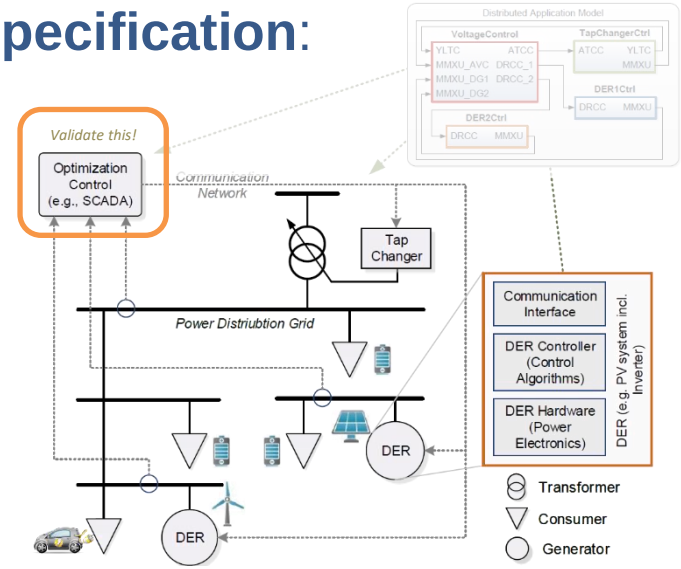
Key Questions to be answered for **test specification**:

WHY TO TEST?

WHAT TO TEST?

WHAT TO TEST *FOR*?

HOW TO TEST?



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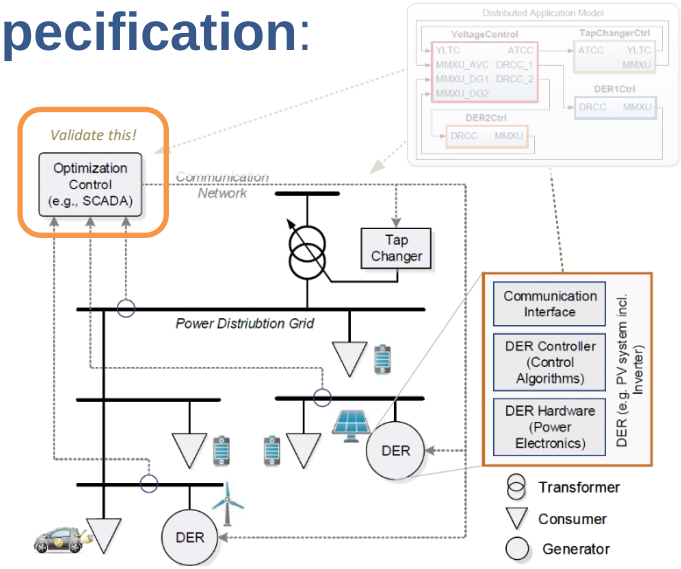


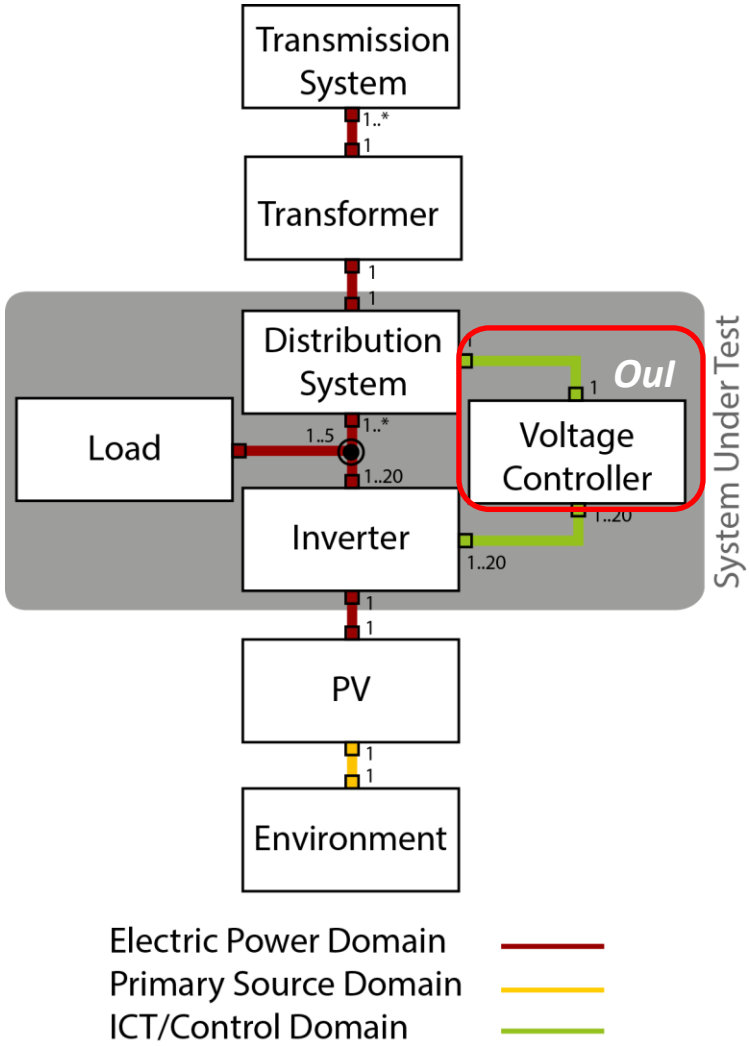
Test **System & Domain**

System under Test (SuT):
is a system configuration that includes all relevant properties, interactions and behaviors (closed loop I/O and electrical coupling), that are required for evaluating an OuI as specified by the test criteria.

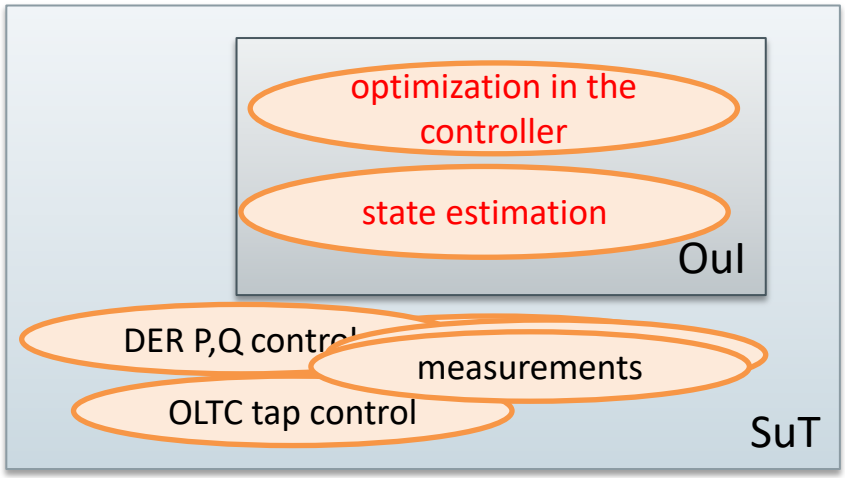
Object under Investigation (OuI): the component(s) (1..n) that are subject to the test objective(s).

Remark: OuI is a subset of the SuT.

Domain under Investigation (DuI)*:*
Identifies the domains of test parameters and connectivity relevant to the test objectives.



Test System **Functions**



Use Cases define Functions
Of **Systems** *(IEC 62559 approach)*

Functions under Test (FuT): the functions relevant to the operation of the system under test, as referenced by use cases.

Function(s) under Investigation (FuI): the referenced specification of a function realized (operation-alized) by the object under investigation.

Remark: the FuI are a subset of the FuT.

Key Questions to be answered for **test specification**:

WHY TO TEST?

WHAT TO TEST?

WHAT TO TEST *FOR*?

HOW TO TEST?

Purpose of Investigation (PoI)

- **Verification**
- **Validation**

- **Characterization**

Modeling / Understanding

Scoring / Performance

Test objectives/PoI: *Characterization and validation* of the DMS controller

1. Convergence of the optimization (*validation*)
2. Performance of the optimization under realistic conditions (*characterization*)
3. Accuracy of the state estimation (*characterization*)

Designing Test Criteria
Detailing Sequence

- **Test objective → PoI → Test Crit.**
- **Test criteria:** How to break down the PoIs?
  - *Target metrics* (criteria): list of metrics to quantify each PoI
  - *Variability attributes:* controllable or uncontrollable parameters to "disturb" SuT
  - *Quality attributes* (thresholds): test result level or quality of the TM required to pass or conclude the testing.

Target metrics:

1. 1.1 convergence (when/how often?), 1.2. How fast?, 1.3. solution quality
2. 2.1 Voltage deviation
   2.2 number of tap changes,
   2.3 network losses
3. Voltage, P, Q estimation errors

Variability attributes: Load patterns (realistic, annual variation; applies to criteria 1-3);
Communication attributes (packet loss, delays)

Quality attributes (thresholds):

"1.2: convergence within 2 sec" (*validation*)
"3.* estimation quality characterized with confidence 95%" …

Key Questions to be answered for **test specification**:

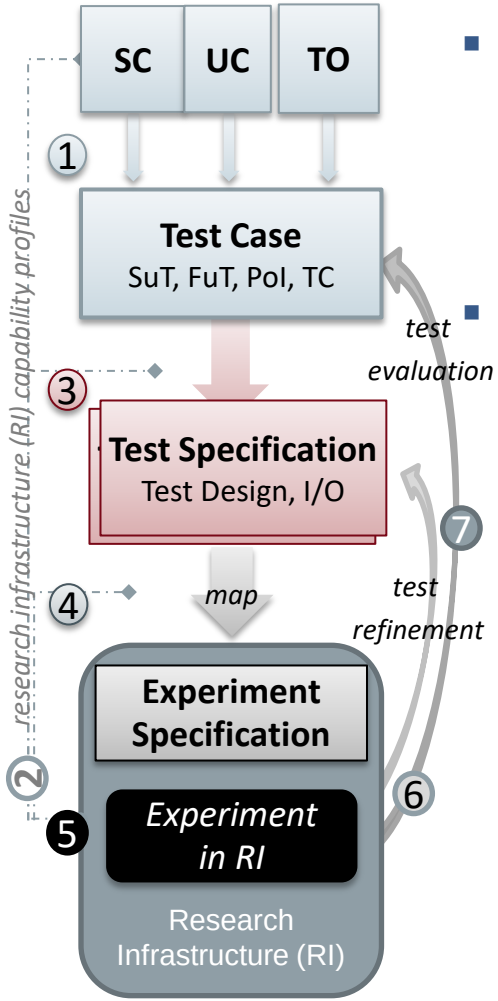
WHY TO TEST?

WHAT TO TEST?

WHAT TO TEST *FOR*?

HOW TO TEST?

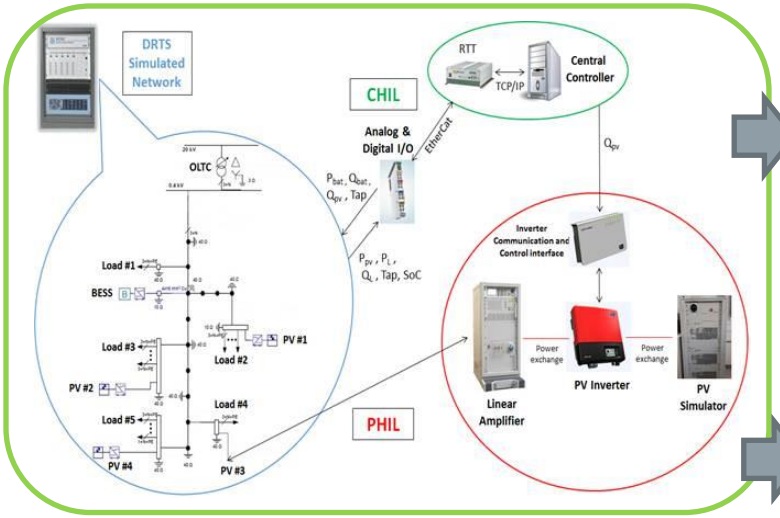
Test Specification & Design



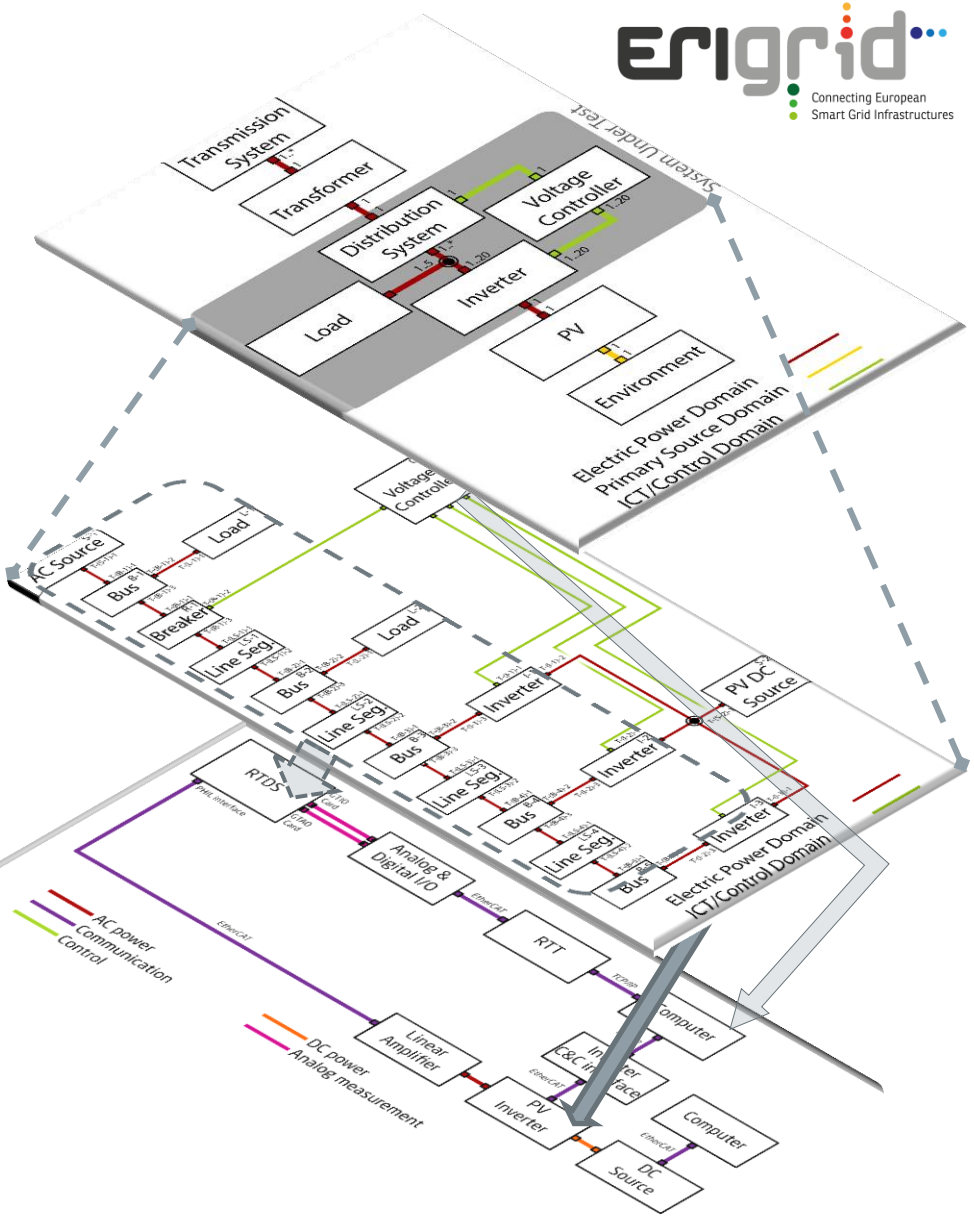
- **Given:**
  - ✓ Purpose of Investigation (PoI) & Test Criteria
  - ✓ System & Domain categories and relations
- **To Specify**:
  - ❑ Precise system (specific system configuration)
  - ❑ Which variables to manipulate & which to measure
  - ❑ How to quantify the test metrics (based on test data)
    - ❑ Sampling of the input spaces (design of experiments methodology)
    - ❑ Combination and interpretation of the outputs
  - ❑ The test design / procedure.
  - ❑ Mapping to actual lab setup (experiement setup)

Detailing test setup & Mapping to the Lab

Scoping & specification of test system.



Separate specification of lab implementation

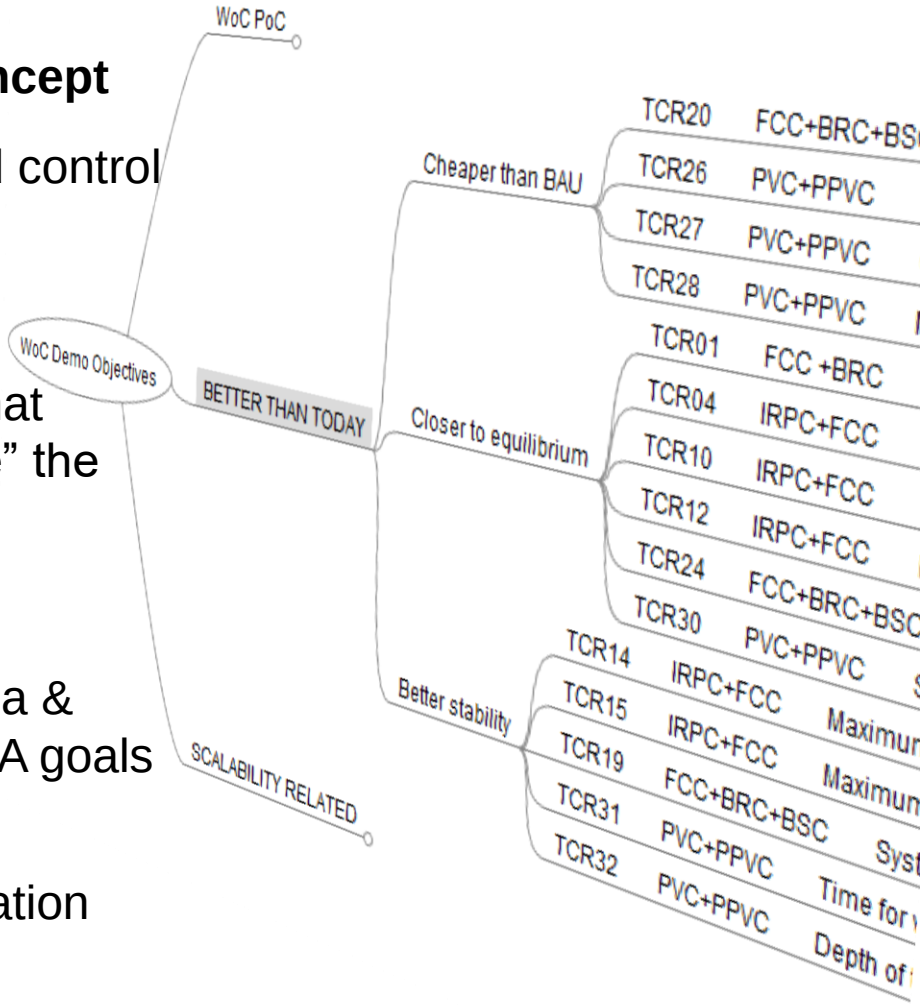


Can I just say, that it's very nice to get these questions sorted out now, rather than when you're sitting down and have to implement something.
You would then usually go "Oh shit, how does this work again?“ – ERIGrid participant

FIRST APPLICATION EXPERIENCE

Collaboration with ELECTRA

- **ELECTRA – Web-of-Cells (WoC) concept**
  - large set of Use Cases: distributed control
  - concurrent development & lab implementation
- **Challenge**: how to track & convince that ongoing experiments actually “validate” the ELECTRA WoC
- **Result** (intermediate):
  - Gap analysis based on Test Criteria & System configuration vs. ELECTRA goals
  - organization of test case clusters; collaborative design of test formulation



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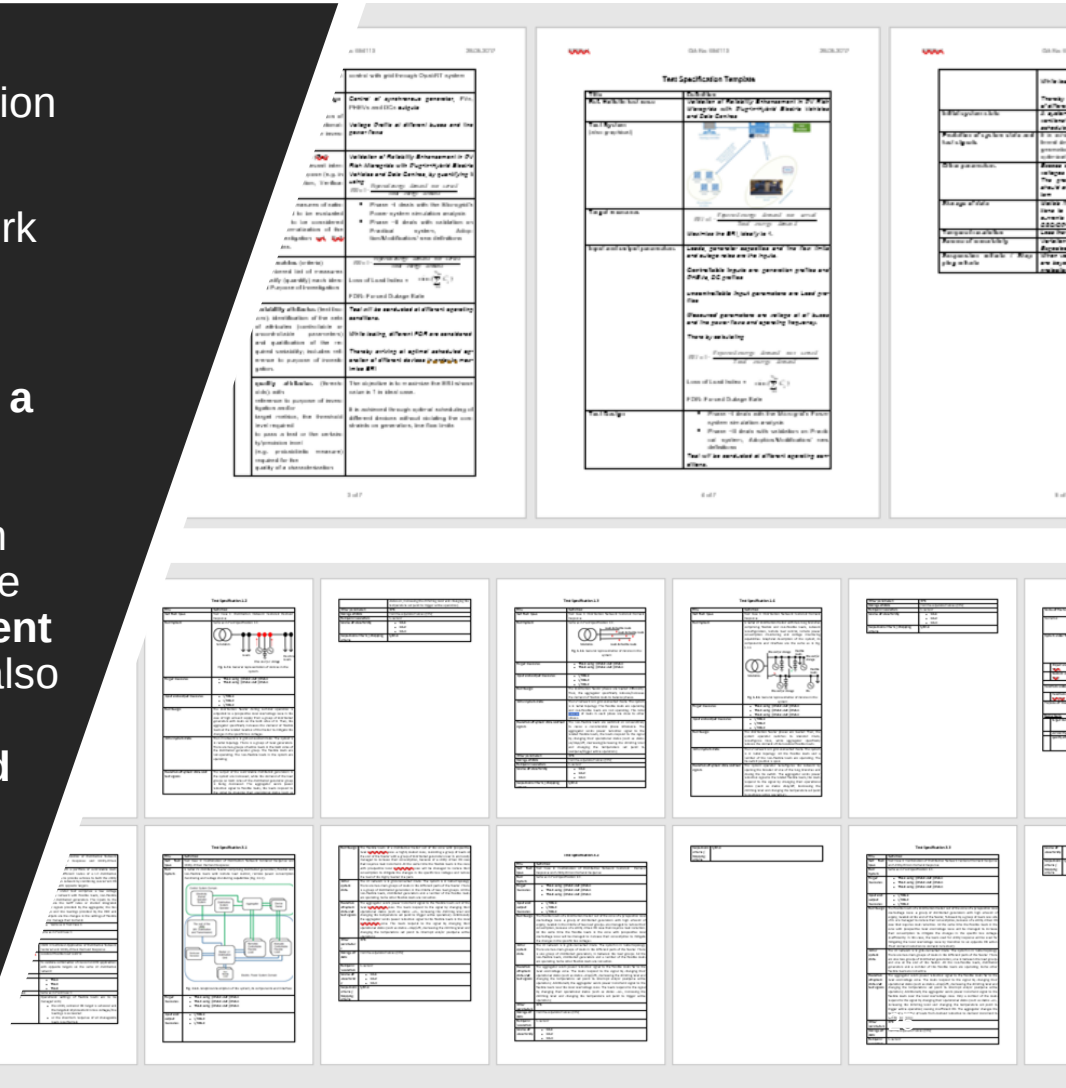
ERIGrid Transnational Access:
Preparation & Documentation

- External Lab users apply description procedure
- E.g. DiNODR – distribution network oriented application of demand response – *currently ongoing in SYSLAB*
- “The preparation work **helped us a lot**. Except minor changes in the plan and configurations due to a number of device, communication and control unavailabilities, we are **following our test and experiment specifications**. The template is also useful for our user team to **exchange ideas in an organized and effective** way. “
  - Alparslan Zehir (DiNODR)



Conclusions & Future work

- **A clear vision for “holistic validation”**

- **First results:**
  - *3-level* - Test Description template & guidelines
  - Multi-Domain System Configuration description (CIM compatible)
  - Several successful applications & encouraging feedback

- **Future work:**
  - Further exemplify, simplify & detail description method
  - Develop & apply full holistic validation procedure

Connecting European
Smart Grid Infrastructures

Thank you for your attention!

Get your copy of the ERIGrid Test Description here.

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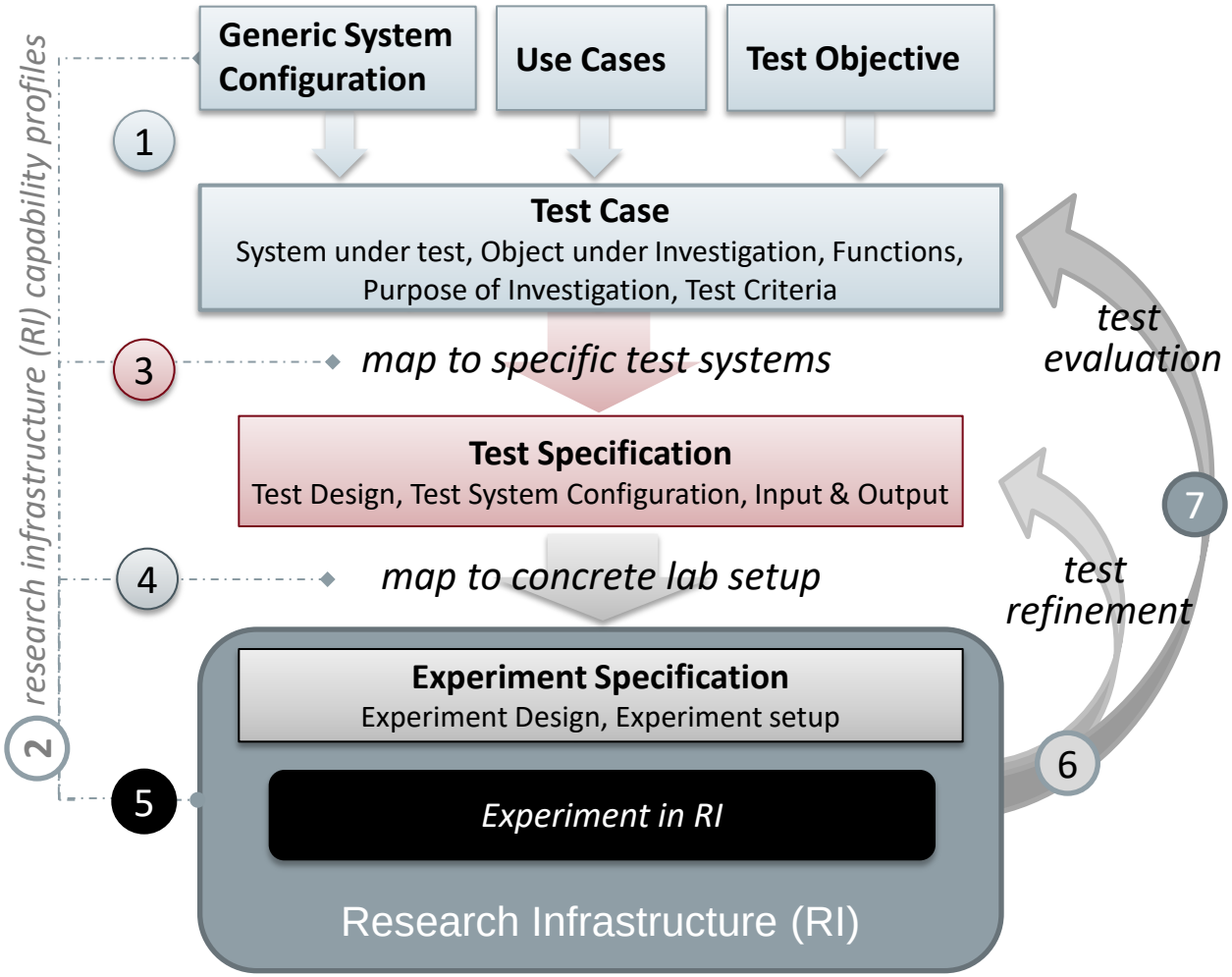
Overall Specification & mapping procedure



IEC TR 61850-7-6

Guideline for definition of Basic Application Profiles (BAPs) using IEC 61850

- **3.1 Compliance** → ***Validation***
  Accordance of the whole implementation with specified requirements or standards. However, some requirements in the specified standards may not be implemented. [SOURCE: CEN-CENELEC-ETSI SG-CG Report on Interoperability CEN_9762_CLC_9624 – clause 12.1 Terms and definitions]
- **3.2 Conformance**
  Accordance of the implementation of a product, process or service with all specified requirements or standards. Additional features to those in the requirements / standards may be included. [SOURCE: CEN-CENELEC-ETSI SG-CG Report on Interoperability CEN_9762_CLC_9624 – clause 12.1 Terms and definitions]
- **3.3 Conformance test** → ***Verification***
  check of data flow on communication channels in accordance with the standard conditions concerning access organization, formats and bit sequences, time synchronization, timing, signal form & level and reaction to errors. The conformance test can be carried out and certified to the standard or to specifically described parts of the standard. The conformance test should be carried out by an ISO 9001 certified organisation or system integrator. [SOURCE: IEC 61850-4]

Holistic Test Case Example

TEST CASE:

- **Narrative**: For a DMS controller in development stage (simple implementation) the performance of the DMS algorithm and controller should be evaluated under realistic conditions. This test, could be seen as the last step before installing the DMS in the field.
- **SuT**: DMS, DER, OLTC, transformer, distribution lines, telecom network
  - OuIs: DMS_controller
  - DuI: **Electric power** and **ICT**
- **FuT**: DER P,Q control, measurements, OLTC tap control, comm. via ICT
  - FuI: optimization in the controller, state estimation
- **Test objectives/PoI**: *Characterization and validation* of the DMS controller
  1. Convergence of the optimization (*validation*)
  2. Performance of the optimization under realistic conditions (*characterization*)
  3. Accuracy of the state estimation (*characterization*)
- **Test criteria** – *how to formulate these objectives?*

Target criteria - Variability attributes: - Quality attributes

Potential Test setups:

- Pure simulation (e.g. co-simulation)
- Combination of virtual & physical interfaces and simulated components. PHIL and CHIL
- Full hardware setup

Holistic Test Case Example

TEST CASE:

- **SuT**: … Ouls: DMS_controller; Dul: **Electric power** and **ICT**
- **FuT**: Ful: optimization in the controller, state estimation
- **Test objectives/PoI**: *Characterization and validation* of the DMS controller
  1. Convergence of the optimization (*validation*)
  2. Performance of the optimization under realistic conditions (*characterization*)
  3. Accuracy of the state estimation (*characterization*)

[ ] Test criteria –

Target criteria:

1. 1. convergence (when/how often?), 2. How fast?, 3. solutions quality (how suboptimal etc.?)
2. Voltage deviation of all the nodes from 1 pu, number of tap changes, network losses
3. Voltage, P, Q estimation errors

Variability attributes: Load patterns (realistic, annual variation; applies to criteria 1-3); Communication attributes (packet loss, delays)

Quality attributes (thresholds):

"1.2: convergence within 2 sec" (*validation*)

"3.* estimation quality characterized with confidence 95%" …