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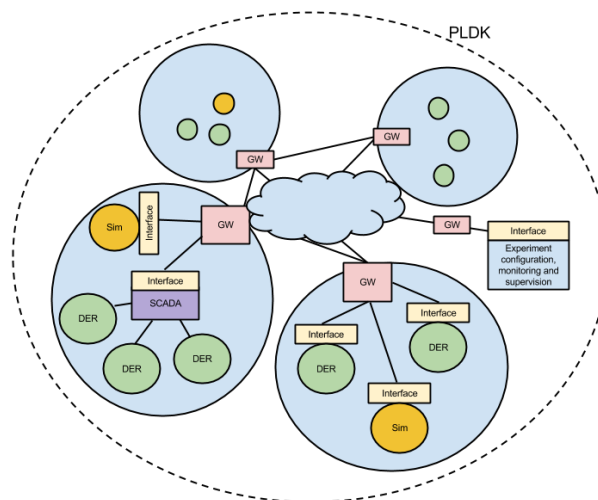
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State of the Art Smart Grid Laboratories - A Survey about Software Use

RTLabOS D1.2



Kai Heussen and Oliver Gehrke

November 2014

DTU Electrical Engineering

State of the Art Smart Grid Laboratories - A Survey about Software Use

Report RTLabOS Phase I: D1.2
2014

By
Kai Heussen and Oliver Gehrke

Based on questionnaire developed in collaboration with Evgenia Dmitrova

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Preface

In the course of over a year, we have researched, structured and formulated the software needs of smart grid laboratories. With the aim to identify central common needs and requirements to support a “next generation” of Smart Grid laboratories, we held international workshops, carried out exploratory feasibility studies, structured our ideas into formal use cases and carried out surveys.

Intended as a State of the Art assessment, this report is among the first conceived in the project. The survey questionnaire was motivated by questions raised in the first RTLabOS workshop and our first structuring of the domain in the report “D1.1 Domain Study”. It quickly came clear that establishing a “state of the art” in a field that is so broad and under such rapid development was a fool’s errand; instead, this report offers a qualitative study of actual developments and focus areas in Smart Grid laboratories. The study can be viewed as a snapshot of the different characteristics exhibited by a selected range of smart grid laboratories with a focus on ‘system testing’. With the small number of participants, the diversity of focus areas and resources, and the rapid development of the labs investigated, we focused on summarizing information combining “statistical” evidence from the survey with qualitative insight gained from interviews.

In hindsight, most valuable, we find anecdotal evidence of the different scientific and commercial value propositions and development paths and that come with interpretations of the term “smart grid laboratory”.

Last, not least, I should mention all those who have made this survey possible by filling out the extensive questionnaire and responding to my questions:

- Filip Andrén, Roland Bründlinger and Thomas Strasser, SmartEST Lab, AIT
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- Lars Nordström, PSMIX, KTH
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- Sami Repo, Smart Grid Lab, TU Tampere
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I would like to thank all for their patient collaboration and insightful comments-

Copenhagen, November 2014

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1. Overview and Characterization of Participating Smart Grid Laboratories

The labs participating in this survey cover a wide area of applications and funding scales. All labs can be said to support “system testing” in the sense of the RTLabOS project, but only a subset also supports component tests.

The labs selected who have participated in the survey are:

- AIT, SmartEST Lab (Research Institute, certified test laboratory, Austria)
- KTH (University, Sweden):
 - SmartSLab (Department of Electric Power Systems)
 - PSMIX Power System Management with Related Information eXchange (Department of Industrial Information & Control Systems)
- NREL, Energy Systems Integration Facility (Research Institute, Colorado, US)
- TUT, Smart Grid Lab (University, Finland)
- CSU & Spirae, InteGrid Lab (co-owned by university and company - Colorado, US)
- DTU, PowerLabDK (University, Denmark)
 - SYSLAB
 - Intelligent Control Lab & Electric Lab

To indicate the ambition scale of each laboratory, we provided categories for the (logarithmic) scale of initial and cumulative investments into the lab:

<i>Category</i>	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>	<i>V</i>
<i>Investment € / US\$</i>	<i>10.000</i>	<i>100.000</i>	<i>1.000.000</i>	<i>10.000.000</i>	<i>100.000.000</i>

All participating labs were of at least category II, of which several have cumulated to cat. III. While several labs have been funded in a range of 10 Million €, NREL’s ESIF stands out with around 100 Million € invested.

A number of factors characterizing the participating labs are summarized in Table 1. From these overview criteria we can draw some preliminary insights:

- Larger labs and labs that support commercial use employ more technical staff:
 - In research labs only 5-20% of staff are technical/administrative
 - In commercial labs the 20-40% of staff are technical/administrative
- Funding models vary greatly among labs;
 - project-based funding is most common
 - concentration on either fixed base funding or returns from commercial use are specific for smaller and focused labs with either teaching or commercial focus
- Combining research and commercial lab use is a common model; on the contrary, combination of teaching with commercial use is hardly seen
- Power system real-time simulators (PS-RTS) are the most common asset;
 - commercial use is only common if combined with power hardware in the loop (PHIL) equipment – expensive labs;
 - commercial automation testing is also feasible without PS-RTS (InteGrid)

Table 1 Overview of participating Laboratories

Lab	AIT SmartEST Lab	KTH SmartSLab	KTH PSMIX	NREL ESIF	TUT Smart Grid Lab	CSU & Spirae InteGrid	PLDK SYSLAB	PLDK EL + ICL (+HV)
Investment Scale	IV	II-III	II-III	V	II	II-III	II-IV	IV
Commercial?	X			X		X	X	X
Research?	X	X	X	X	X		X	X
Teaching?			X		X		X	X
Prior-lab redesign	X			X				X
Incre. development		X	X		X	X	X	
Lab-opening	4/2013	3/2011	Ca.2011	2013	Ca.2002	2006	2006	2011
Staffing								
Research (incl. visit)	8	Ca. 12	Ca. 10	Ca.300	6	5 sen. +x	Ca. 11	Ca. 40
Technical+ Adm.	3	1	0.6	60	0	3	Ca. 1,5	Ca. 1,5
Usage focus								
Electric components	24%	16%	0%	4%	11%	7%	2%	13%
Energy Conversion and Flexibility	24%	11%	8%	23%	24%	39%	43%	26%
Systems Integration, Automation&Control	36%	35%	68%	50%	36%	23%	34%	28%
Systems-Modelling and Analysis	16%	38%	24%	23%	29%	31%	21%	33%
Lab equipment features								
(1): CHP units, heating spaces, multiple-energy conversion								
(2): large screen visualization in separate room								
Actual grid	LV+adj.imp.			LV+MV		LV	LV	LV (+HV)
Power System RTS	OpalRT + TyphoonHIL	OpalRT	OpalRT	OpalRT RTDS	RTDS			RTDS
C-HIL (Autom.Equ.)	X	X (PMU)	X	(x)	X	X		X
P-HIL (grid-simul.)	800kVA			1MW	10kW			150kVA
DC Source/PVsimul.	x			X		X	X	X
HP/HDR-DAQ	X			X		X		
Adjust. Load & Gen.	RLC-Load			X		X	X	X
Environm. chamber	X			X				
“cross-energy” ⁽¹⁾	X			X			X	X
“control room” ⁽²⁾				2				1
High-perf.-comp.				X				(x)
Operation Funding basis *								
Fixed base			70 %	50%	40%	N/A		17%
Long-term partnership						N/A	33%	8%
Project -based	25%	100%	30%	35%	50%	N/A	66%	70%
Commercial use	75%			15%	10%	N/A		5%

From these initial values most significant and apparent differentiation is the hardware lab (HW-lab) vs. the simulation lab (Sim-lab):

- **HW-lab:** work on actual electric components and grids; simulation is secondary
 - Opt. 1: “emulation” of infeed and load via controllable sinks & sources
 - InteGrid, SYSLAB
 - Opt. 2: “closed loop PHIL” use of PS-RTS with ‘grid simulator’ (inverter)
 - SmartEST, ESIF, TUT, PLDK-ICL+EL
 - Sophisticated DAQ equipment is available in all commercial labs
 - SmartEST, ESIF, InteGrid
- **Sim-lab:** replaces electric current with a real-time simulator; hardware is at most control hardware (C-HIL).
 - PSMIX, SmarTSLab, TUT, PLDK-ICL
- Due to its scale, ESIF combines both types of labs and adds high-performance computing (HPC);
 - PLDK ICL+EL has a scale to combine the two as well; lacking sophisticated DAQ infrastructure and HPC.

The distinctions identified here find deeper elaboration in the reflections of Chapter 3 “Focus and Activity Areas”.

Finally, it should be remarked that this survey aims to characterize the activities in a smart grid lab (SG) in relation to lab features, software use and staff competences. In this sense, we aim to characterize the labs as ecosystems including

- Physical installations of a lab (as reported above)
- Software for managing, operating and interfacing with the lab
- Software and control systems tested by means of lab experiments
- Software used by researchers in context of preparing
- Staff associated with a lab
(primarily technical and research staff directly in contact with the physical lab)
- Activities (research, testing, etc.) in context of the lab, both directly associated with experiments and for preparation and processing of results

With responses from about eight labs, and considering the large number of factors taken into account, we should view the following results as anecdotal evidence and can only expect to draw conclusions in a qualitative sense.

2. Individual Laboratory Profiles

The laboratories participating in this survey are characterized in the following by providing a short context as well as key focus areas, design philosophy and key features as stated in the survey response.

2.1 AIT SmartEST Lab

AIT's SmartEST Lab was conceived as a re-design of an earlier inverter testing facility at a 30kW scale which operated as test and research lab for distributed generators for about 10 years; the over 30x increase in inverter scale was enabled by a significant investment and meets current industry demands for testing and validation.

As key focus areas, SmartEST Lab works on

1. Research/development/testing of network devices and components of distributed generation
2. DER components system integration & system control/automation
3. P-HIL-based DER inverter system integration research.

The design philosophy is formulated as:

Freely configurable AC LV grid for component and integration tests with flexible and configurable components (i.e., laboratory grids (test grids), adjustable loads, grid and PV simulator)

The key features of the SmartEST Lab are:

1. Advanced testing infrastructure for Distributed Energy Resources up to about 1 MVA power rating
2. Full power LV grid and PV array simulation
3. Hardware-in-the-loop testing possibilities (incl. power-hardware-in-the-loop)

2.2 KTH – SmartSLab and PSMIX

At KTH we talked to two different labs which were established between 2010 and 2011 and with an initial internal funding in range of 11 and have been build up in context of a local research group. Yet, despite technical similarities their focus, approach and funding model are very different. While the driver for both labs has been a specific identified research gap, their fields are quite different and are thus treated separately in the following.

2.2.1 Department of Electric Power Systems - SmartSLab

Located in the Power Systems department, the SmartSLab is designed for tackling genuine power system stability issues. It was built from scratch as test-bench for interfacing power system real-time simulations with monitoring, control and protection equipment as well as the necessary ICT systems. The controlled lab environment provides a platform for closed loop testing of system integration of PMUs and PMU-based technologies.

As *key focus areas*, SmarTSLab aims for

1. real-time system health monitoring
2. control techniques for system health and performance optimization
3. Wide area protection

The *key features* of the SmarTSLab are:

1. RTS-HIL for PMU applications
2. IEC61850 compliance for protection
3. custom software libraries for PMU integration

In summary, SmarTSLab provides a versatile platform to develop and test the full infrastructure of advanced PMU-based power system stability, protection and decision support systems. Correspondingly, SmarTSLab has collaborations with several utilities, vendors and universities.

2.2.2 Dept. of Industrial Information & Control Systems - PSMIX - Power System Management with Related Information eXchange

Located in the Department of Industrial Information & Control Systems, the PSMIX lab focusses on software and interoperability. The laboratory platform has been optimized to allow distribution of controllers and at the same time mimicking as much as possible industrial architectures for control systems; i.e. including real hardware devices for measurement, protection and control to which prototype distributed controllers can interface.

Aiming to support activities related to System Integration of industrial equipment, SCADA software and architectures, the *key focus areas* are:

1. Distributed control schemes
2. Cyber physical systems, interdependence of Power and ICT
3. Control system architectures

As a redesign, PSMIX is based on two earlier teaching facilities: one distributed control platform for Railway train operation built and one basic SCADA system laboratory for simple power system remote control applications, both developed for teaching. The main learning carried forward from these systems were the teaching module that could to some extent be reused. From a technology perspective some limited parts of instrumentation and communication devices could be used in the new platform.

The *key features* of the PSMIX are:

1. Hardware in the loop for automation equipment
2. Real-time integration of power and ICT system
3. Ease of configuration

It should be noted, that this is the only lab in the survey which was designed to also support teaching in the field. This aspect is related also in the funding, which has a significant fixed operational funding contribution from the university.

As of now, PSMIX does not collaborate with utilities, but with several vendors and scientific partners.

2.3 CSU & Spirae - InteGrid Test and Development Laboratory (InteGrid Lab)

The InteGrid lab is located inside a larger lab of Colorado State University (CSU) and is co-owned and operated by CSU and Spirae.

Intended as a scaled-down test bed for testing control in the context of a Danish distribution grid, the InteGrid lab was designed with the flexibility to grow to include additional asset types and control scenarios.

Even though it is a small lab, it started with a high ambition level with respect to the effective support of the control systems development and deployment process: from green field to demonstration of control concepts with natural gas reciprocating engines and Danish style wind turbines in 7.5 months with a budget of \$500k.

Instead of real-time simulators and P-HIL setups with, the lab works with real electric machines.

Design *focus areas* have been:

1. Development and testing of coordinated microgrid controls
2. Development and testing of asset level controllers. (“Asset” includes such items as generators, load banks, etc.)
3. Commercial and publically funded demonstrations.

While in design, testing and validation, time series acquisition, and demonstration have been in focus, in actual use its capability to support controller development and deployment has proven more important than time series acquisition in general.

The *key features* of the InteGrid lab are:

1. Wind turbine and solar simulators to mimic real-world wind and solar transients
2. Bumpless islanding/resynchronization of microgrid with 1 s load profiles
3. Interconnect license that allows power export of up to 2 MW

Collaborations include several utilities, vendors, universities, and public sector entities.

2.4 Technical University of Tampere – Smart Grid Lab

The Smart Grid Lab at TU Tampere (TUT SGL) has grown incrementally with a central piece being the RTDS power system real-time simulator. While the strong power system analysis focus by means of real-time simulation is comparable to KTH SmarTSlab, it is distinct with capabilities of Power-HIL simulation and that research activities are rather focused on distribution systems.

In the lab design the guiding ideas have been: Interoperability at function level ; focus on controls; study interactions of controls & markets.

The *focus areas* of the lab activities are:

1. Congestion management in Distribution grids
2. Automation development

3. Home automation & grid interaction

The most distinguished capabilities of the lab:

1. RTDS with PHIL
2. Advanced distribution automation & Real-time communication
3. Home automation

For the operation of the TUT SGL, it has shown that while demonstration has been prioritized along with testing and validation over controller development and deployment, this last activity has proven the most important in practice. Collaborations include utilities, vendors, and scientific entities. In particular, a TUT internal cross-department collaboration with an industrial automation department helps providing software for system integration at a service level. The TUT is currently undergoing an investment program, where the lab will have stronger hardware based focus. Components are PV emulator, EV, stationary batteries. Also more commercial IEDs and communication equipment will be purchased.

2.5 NREL – Energy Systems Integration Facility (ESIF)

The ESIF facility has a lone leading position as the only 'Category V' lab. With its mere scale it covers the activities of other labs, but it also includes many researchers and activities outside the power system scope, who utilize the multi-energy systems capacities and the supercomputing centre for e.g. climate research. Funded and owned by DOE, it is operated by NREL – Alliance for Sustainable Energy (MRI & Batelle). More information on the facilities is found in [1].

A prior lab at NREL that provided some experience for the design of ESIF was the DER-test facility (DERTF), which enabled electrical testing of distributed energy resources and grid interactions to some extent. Compared to DERTF, ESIF represents a shift in focus from component (DERs) to energy system testing, along with a roughly 100-fold increase in investment scale (driven by: a scale-up of the inverter (grid interface); addition of thermal and fuel-based energy forms, as well a world-scale high-performance computing facility).

The top three focus areas of the lab may be summarized as:

1. Energy systems integration and interoperability across energy forms and data
2. Facilitating industrial development of cross-energy solutions
3. High-performance computing, data analysis and visualization

Top three most distinguished capabilities of the lab:

1. MW-scale system testing with 1MW grid-simulator
2. Interconnectability of labs across energy (electricity, thermal, fuels & data)
3. HPC facility

Collaborations include several utilities, vendors, universities, and public sector entities.

NREL also includes other associated labs, the DERTF mentioned above, a thermal test facility (TTF), a vehicle testing and integration facility (VTIF) and a renewed MW-scale wind turbine test facility (NWTC), which has been considered for comparison; however, while a very advanced

facility with 5MW P-HIL 'controllable grid interface', the focus of the NWTF is component-oriented and thus not suited for the scope of this work.

Cross-site integration of lab & simulation facilities, e.g. between the NWTC and ESIF is considered for future activities.

2.6 DTU – PowerLabDK

At DTU Center for Electric Power and Energy, the [PowerLabDK](#) facilities encompass several originally independent laboratories: the Bornholm Island Power system, Electric Lab, High Power Lab, High Voltage Lab, Intelligent Control Lab, Nordic Electric Vehicle Interoperability Center (NEVIC), PowerFlexHouse, Power Student Lab, and SYSLAB.

Of these labs, three have been identified as relevant for system testing in the sense of this research:

- SYSLAB (located on Risø campus);
- Intelligent Control Lab (ICL; Lyngby campus), and
- Electric Lab (EL; Lyngby campus)

ICL and EL are integrated via a professional ABB SCADA system, which also supervises the local High-voltage Lab (HV) and integrates data from the Bornholm island power system. Electric lab and HV lab are electrically interconnected (configurable), furthermore the ICL and EL can be integrated via a P-HIL setup. The PowerFlexHouse, HV-lab and the Bornholm power system are potentially relevant for system testing, but have been excluded from the further analysis here, as the core activities at present go beyond the scope of this report.

While the potential and vision for PowerLabDK (PLDK) clearly offer perspectives of further integration of the laboratories, at the time of analysis, the coupling across facilities was less significant in the ongoing activities, such that we could use the opportunity to gain insight into characteristic features by looking at the three labs separately where it was helpful, and otherwise at combining them where it was meaningful.

2.6.1 SYSLAB

Building upon an earlier test facility for Wind/Diesel isolated power systems, SYSLAB has been conceived as a laboratory for testing new control concepts in power systems, with a special focus on distributed and decentralized control. A significant part of the development work has been invested in a software platform which allows independent as well as interconnected operation of all power system components without enforcing a particular control topology. The electrical backbone of SYSLAB is a 400V distribution grid which, after multiple extensions, currently counts 16 busbars and covers an area of almost 1km². The topology of the grid can be chosen with exceptional flexibility, allowing feeder lengths up to several kilometers. A wide range of different DER - conventional and renewable generation, storage and various types of load - are connected in different parts of the distribution grid. Each DER is equipped with a dedicated computing node on which the SYSLAB software platform executes and on which custom controllers can be deployed.

In the design, key focus areas have been

1. (Supervisory) control concepts for power grid applications
2. Integration of renewables (Wind, PV)
3. DER components with "smart grid features"

In recent years, SYSLAB has grown to integrate a test center for electrical vehicles and charging infrastructure as well as three smart buildings (a small office building and two residential buildings) which, in addition to their role as components in SYSLAB, can be used as standalone facilities for research in building automation and flexible demand.

The top three *most distinguished capabilities* of SYSLAB are:

1. Distributed control platform (one instance per DER)
2. Complex distribution network with variable topology
3. A wide spectrum of DER technologies including smart buildings

Due to its deep integration with the DER, the SYSLAB ICT platform is used both for lab-supervision and monitoring (as Lab SCADA or “LabOS”; cf. RTLabOS Use Case reports [2]) as well as a platform for control software deployment.

SYSLAB has ongoing collaborations with several utilities, vendors, and scientific partners.

2.6.2 Intelligent Control Lab and Electric Lab (ICL+EL)

The PLDK Intelligent Control Lab and Electric Lab on DTU Lyngby campus offer unique capabilities, combining significant power system real-time simulation resources, and a professional SCADA system, in the ICL with a configurable lab grid, which allows, e.g. to connect the 150kVA 4-quadrant power amplifier with one or several of the 22 lab cells.

The labs were designed and build in a first development step which was partly inspired by local experience with an earlier lab, but to a large extend also on a study of existing power system labs, an analysis of technical needs and market development.

The labs are currently undergoing a second development step in which is beyond the scope of this report.

The key focus areas of the combined EL + ICL labs have been identified as:

1. Power system stability and operation
2. Active Distribution Networks operation & management
3. Flexible generation & demand components adaptation to smart grid

From experience in lab operation, at least for the electric lab, it proved that experimentation and the acquisition of time series for further analysis has been of primary importance as opposed to demonstration & system integration, as considered in the design phase. Testing & validation is a key activity for both labs, in practice as considered during design.

The combined top three most distinguished capabilities of PLDK ICL+EL are:

1. RTDS real-time simulators with 10 racks (for simulating up to 480 nodes)
2. A 150kVA 4 quadrant power amplifier in a flexible lab grid (400V) with 22 Lab cells
3. A full scale control room with ABB Network Manager SCADA, and IBM Blade Center

3. Focus and Activity Areas

The most characteristic driver for laboratory design should be the activities performed in its daily operation. Naturally, there can be a shift between the activities anticipated and prioritized in the lab design phase and those which dominate during lab operation. We considered two main approaches to characterizing this activity: 1. Activity types and 2. Research Focus areas.

3.1 Prioritized activity types during design and lab use

The first characterization is based on activity types as identified in RTLabOS report D1.1 [3], identifying ten types of activities. We asked the participants to reflect upon and identify the *top three* the priorities during design phase as well as the top usage activities in the past 3 years. Table 2 summarizes and highlights the results.

Table 2 Summary of prioritized activity focus during design and actual lab use

<u>Activity Classification</u>	<i>Focus during design</i>	<i>In Focus during actual use</i>	<i>Sum</i>	<i>Change, incl. rank change</i>
Demonstration	4	6	10	4
Experimentation	4	3	7	-2
Testing and validation	8	7	15	0
Models development	1	2	3	1
Decision support and tool development	1	1	2	0
Maintenance and monitoring of equipment	0	0	0	0
Controller development and deployment	3	4	7	1
System Integration	4	2	6	-2
Time series acquisition	1	2	3	1
Teaching	1	0	1	-1

We interpret the sum of the occurrences as “intensity” or overall importance. If there has been a difference in priority between intention and actual use, this is indicated by the “Change” value. The top two activities are clearly “Demonstration” and “Testing and validation”. Next in importance are “Experimentation”, “Controller development and deployment” and “System integration”. We observe that “Controller development and deployment” as well as “Demonstration” proved to be more important than expected during the design stage. “Experimentation”, in general, and “System Integration” are common, but not as much shared; comparing across labs these two activities are mostly mutually exclusive, and in sum also significantly less relevant than expected. An explanation may be that both “System Integration” and “Experimentation” as activity focus both require a longer experience with the lab system infrastructure.

Further, “Models development” and “Time series acquisition” have been activities of higher relevance than expected whereas “Teaching” and “Maintenance and monitoring of equipment” have not been in focus of actual lab activities.

3.2 Research Focus Areas

Secondly, we asked the participants to indicate the activity level in the lab within specific technical areas, in Q15 (of Part I of questionnaire, cf. Appendix A). The following table shows the aggregated results for the four categories.

	SmartEST	SmarTSLab	PSMIX	TUT	InteGrid	ESIF	PLDK SYSLAB	PLDK ICL	PLDK EL
Electric components	24%	16%	0%	4%	11%	7%	2%	7%	20%
Energy Conversion and Flexibility	24%	11%	8%	23%	24%	39%	43%	21%	32%
Systems Integration,	36%	35%	68%	50%	36%	23%	34%	26%	30%
Systems-Modeling and Analysis	16%	38%	24%	23%	29%	31%	21%	47%	19%

Based on clustering of labs by assets into “Hardware” (HW) and “Simulation” (SIM) labs, we get the following impression of the research topics addressed in the labs (by category):

1. *Electric Components* related challenges are primarily
 - a. In HW-labs: power electronics (SmartEST; ESIF), electric machines (InteGrid)
 - b. In ‘simulation labs’: electric transients & HVDC (SmarTSLab)
2. *Energy conversion and flexibility*
 - a. *Wind power*: Mostly via simulation; exceptions: SYSLAB (kW-scale wind turbines); InteGrid (emulated HW via controlled Diesel gen)
 - b. *PV technology*: focus on HW: inverter testing and incl. panel emulation via DC
 - c. *EVs and Energy Storage*: Mostly in HW with actual components
 - d. *Buildings, thermal loads & cross-energy management* is currently mostly addressed by HW-labs
3. *Systems integration, Automation & Control*
 - a. *Protection systems*: clearly preference for SIM-labs (classic C-HIL case)
 - b. *Interoperability*: Is relevant for all labs; yet, only a work focus for PSMIX & ESIF
 - c. *Distributed automation & Controls design*
This subject is a key area for all participating labs without exception
4. *Systems Modeling & Analysis*
Is ‘key business’ in relation to system experiments; there is little variation across most labs; what can be observed:
 - a. SmartEST lab has less focus here; SmarTSLab marks the other end.
 - b. “DER-grid interactions”, “Isolated power systems” and “stochastic behavior” are more of interest to HW labs.
 - c. *Diagnostic methods and monitoring* are not a focus activity area, except for the SmarTSLab; yet all labs consider its relevance at least sporadically.

Among the HW labs, we observe a differentiation between ‘classical’ electric labs in that the focus shifts from electrical testing to energy-flexibility and cross-energy system integration (e.g. thermal and battery energy storage). Labs with a strong focus on energy flexibility this is trade this off for reduced activity in electric component testing.

Simulation labs primarily focus on systems modelling and analysis, as well as systems integration and control. Also here, a focus on either one of those two focus areas is observed between System Integration (PSMIX & TUT) and Modelling & Analysis (SmarTSLab and PLDK ICL).

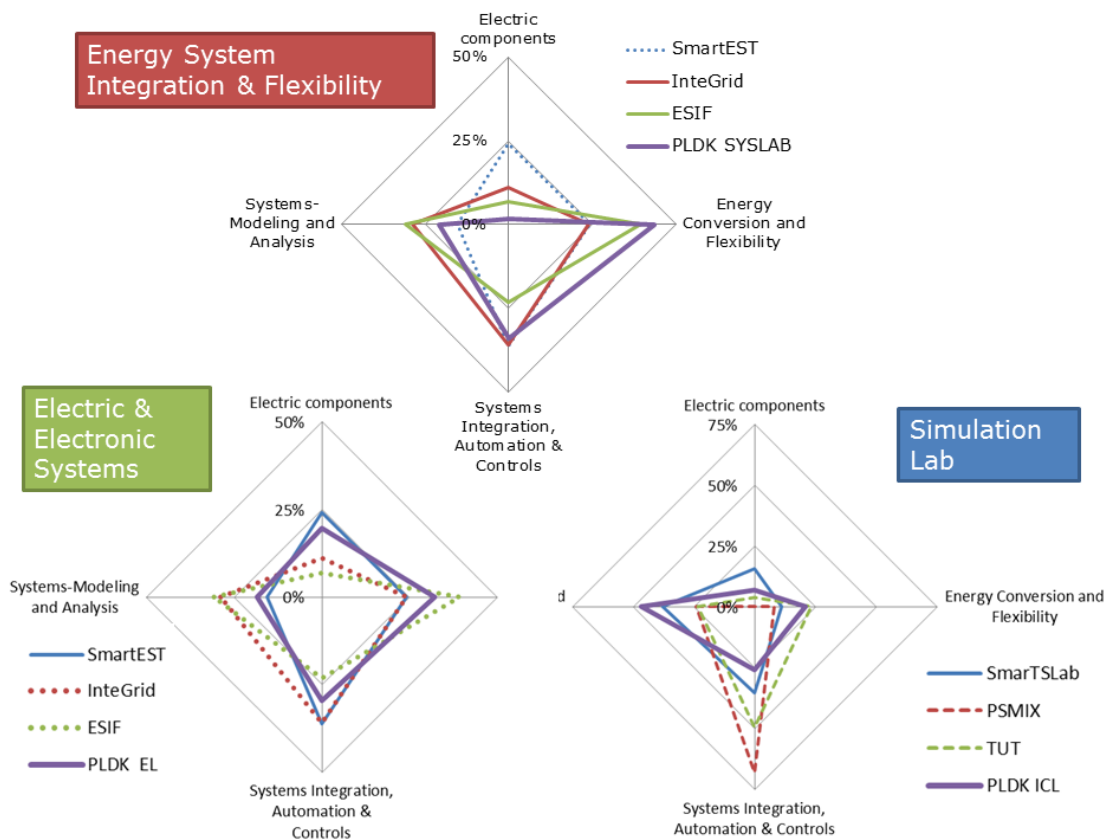


Figure 1 Clustering of activity focus areas.

These observations are strongly guided by intuition on the research subject areas and understanding of the lab activities. Figure 1 illustrates the evidence clusters the labs into these three “strategic” profiles:

1. Energy System Integration & Flexibility Lab (InteGrid, ESIF, PLDK SYSLAB)
2. Electric & Electronic Systems Lab (SmartEST, PLDK EL)
3. Simulation Lab (SmarTSLab, PSMIX, TUT, PLDK ICL)

One factor driving the research focus is naturally the scale of a lab: to contribute to research in several academic disciplines requires active research in each discipline, which can only be achieved by a larger scale. The alternative, achieving interdisciplinary results relevant for a given application requires a special, application-driven culture.

Whether these profiles will prevail as natural focus areas, or if a strategic convergence across profiles is possible is unclear from the limited available data.

4. Software Competences and Tools

In this chapter direct software aspects, including software competences, simulation tools and programming languages.

4.1 Strategic Software competences

The level of software competence is decisive for the flexibility with regard to handling less mature (research-level) software and to adapt or advance it to new research purposes. Mature software supports a user in carrying out a focus activity; it requires a relatively stable methodological or application focus for the software not to require further development. We asked for the level of competences with regard to different types of tools and offered a range of answers covering different levels of usage competences (1-3; yellow marker) and development competences (4-5; green marker); the questions were asked with respect to the current level (Table 3), as well as future competence development.

Table 3 Strategic Software Competences

<i>strategic software competences</i>	SmartEST Lab	SmarTS Lab	PSMIX	TUT	InteGrid	ESIF	PLDK SYSLAB	PLDK EL+ICL	
Simulation tools	4	5	3	3	3	5	4	3	18
Data Analysis & Modeling tools	4	5	4	5	4	5	3	3	27
Control Software	5	4	4	5	5	4	5	4	32
Interfacing & Protocols	3	4	5	4	4	4	4	3	25
Visualization & HMI	3	4	2	2	4	5	4	4	17
SCADA software	3	4	4	3	3	3	5	3	13

Range: 1 Rare use; 2 Occasional Use; 3 Frequent Use; 4 Part-time Development; 5 Development focus

Control software is a common development focus among the participating labs. Next are data analysis and interfacing software competences. Four labs each have development competences on Simulation tools and Visualization & HMI, and three labs actively develop SCADA software (refer to Section 5.1 for a discussion on the meaning of “SCADA” for labs). With regard to future competence development, this picture is reinforced with a slight increase of focus on interfacing and control software.

The practical focus of a lab’s activities is characterized a mix of types of software competences, the available equipment and the research focus areas. Combining these different sources with background on software development activities, we interpret characteristic coverage areas of the labs. Figure 2 presents these coverage areas of labs with respect to types of development activities, maturity of the software subject, and in relation to execution platforms.

The *vertical axis* corresponds to different levels of realism of the “execution platforms” such as various simulation environments and a physical lab, with field testing being the next level beyond this scale (see also RTLabOS D2.1 [2]). The *horizontal axis* indicates the maturity of these platforms as testing environments: *right*: early-stage prototype/conceptual; *left*: stable and mature.

Research and development activities in SG labs can be focussed either on refining such platforms and tools horizontally (*yellow arrows*), or on developing, maturing and testing smart grid solutions (*green arrows*). Whereas, conceptually, platform and solution development are

completely separate activities, in practice they cannot be fundamentally separated: smart grid research labs evolve both the smart grid solutions and the labs' testing capabilities.

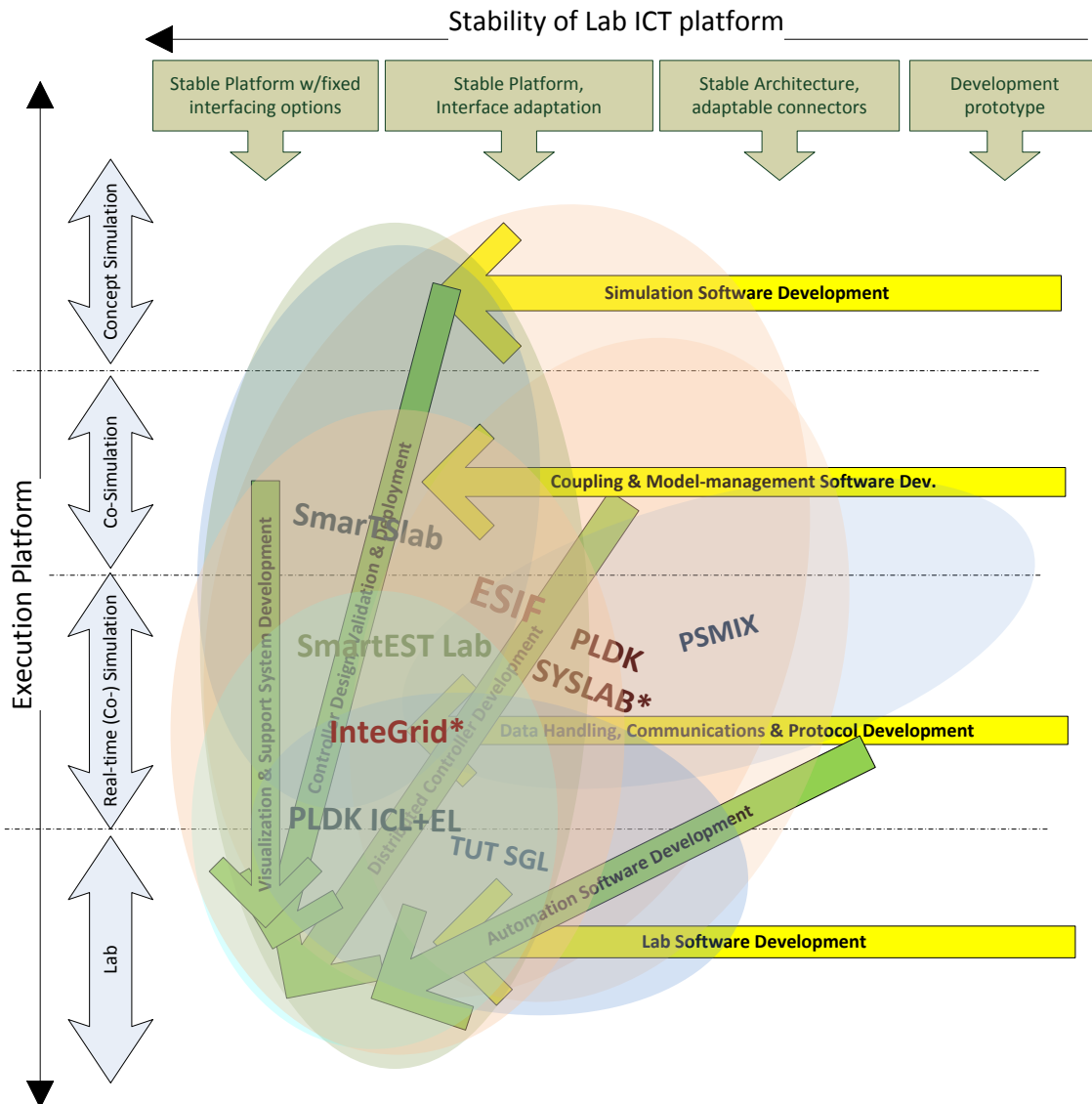


Figure 2 Association of software competences with application-oriented (green) and software domain-oriented (yellow) development streams. (*) indicates that InteGrid Lab and SYSLAB do not include real-time simulation facilities.

Yellow arrows represent platform development and green arrows represent application-oriented development (from left to right: *Visualization & Support System Development*, *Controller Design, Validation & Deployment*, *Distributed Controller Development*, and *Automation Software Development*). The increasing angle relates to increasing software-orientation of the related work. Each ellipse represents one lab, where the color coding is based on the three lab stereotypes illustrated in Figure 1 (red, green and blue). Here PLDK ICL+EL are clustered together as blue/green. The location, extent and size of the bubbles reflect focus area, relation to development streams, and overall competence level, respectively. Note that this illustration is naturally oversimplified, and the ellipse is not be the appropriate geometry in all cases. For *simulation labs* (blue), the focus & competence areas fan out strongly with horizontal and

vertical activities; *electric labs* (green) are associated primarily with vertical development and *energy system flexibility labs* (red) tend to more diagonal.

4.2 Simulation tools and Programming

Next to the lab, the main working tool for researchers is either a simulation tool, to analyse data or prepare & design solutions that are later tested in the lab, or a programming language and platform.

4.2.1 Simulation and Models

A short list of the most common simulation tools in use by the labs is provided in Table 1. The most common simulation tools are Matlab, R, PowerFactory and LabView.

Table 4 Simulation tools by lab.

Simulation Tool	SmartEST	SmartSLab	PSMIX	TUT	InteGrid	ESIF	PLDK SYSLAB	PLDK ICL+EL	SUM
Power Factory	x	x			x		x	x	5
RSCAD				x				x	2
PSS/E		x		x				x	3
PSCAD		x		x				x	3
GridLab-D	x								1
OpenDSS				x					1
PowerWorld				x					1
Eurostag		x							1
Matlab	x	x	x		x		x	x	6
MatPower/PSAT/SimPowerSystems	x	x	x				x		4
Simulink/eMegasim		x	x						2
other Matlab LF				x					1
GAMS			x						1
LabView	x	x			x	x*		x	5
DSPACE				x				x	2
R (statistics)	x		x		x		x		4
Other	1	3	1	0	0	0	2	1	8
<i>sum/lab</i>	7	11	6	7	4	1	6	8	

*) ESIF could not reply with reference to too large a staff base. LabView, however is in use in the lab.

Matlab and R are general purpose tools which offer a scripting environment, so they can be used for controller prototyping. Most other common tools are power system simulation tools. The more platform development-focussed labs, such as SYSLAB, InteGrid, and PSMIX tend to use the smaller number of domain-specific (Power System) simulation tools. An explanation could be that, by limiting the number of tools, interfacing requirements are also limited.

LabView and DSPACE are not primarily simulation tools, but offer direct interfacing between desktop simulation and lab environments. In particular labs with a focus on systems integration and automation software development use such tools less (SYSLAB, PSMIX); also InteGrid uses LabView primarily for controlling the 'simulation' and 'monitoring' aspects of their experiments, not as software / controller deployment platform.

4.2.2 Programming Languages and Platforms

Programming languages are fundamental to development, and shared languages are one key enabler of information sharing in the lab (as with simulation tools). Table 5 summarizes the programming languages reported in the survey.

Surprisingly, the two labs with the most 'system development' focus in their competences also are those with the smallest number of programming languages reported (SYSLAB & PSMIX).

On the other hand, commercial development at Spirae (in context of InteGrid) reports the largest number of programming languages in use, followed by SmarTSLab.

The number of different programming languages seems to be higher the more 'engineering'-practical and applied the focus is; in contrast, consensus on programming languages is useful for developing larger systems.

The most common languages are Java, LabView and C(++), followed by Python and Matlab. IEC-based and PLC programming languages only occur in commercial labs (SmartEST and InteGrid).

Table 5 Programming Languages by Lab

	SmartEST	SmarTSLab	PSMIX	InteGrid	PLDK SYSLAB	PLDK ICL+EL	SUM
Java	x		x		x	x	4
C#		x		x		x	3
Matlab		x			x	x	3
R				x	x		2
PowerFactory DSL/DPL				x		x	2
LabView	x	x		x		x	4
Python		x		x	x		3
C(++)	x	x		x		x	4
Perl		x		x			2
SQL		x				x	2
IEC61499 or 61131	x			x			2
other	2	2		2		1	6
Sum:	6	9	1	10	4	8	

Table 6 Development tools








Development Environment?			
	Visual Studio & .Net		4
	Eclipse		5
	other:		5
Code management?			
	dropbox		1
	SVN		2
	GIT		2
	Mercurial		1

Table 6 presents results from six labs (excl. ESIF and TUT). There is almost consensus on usage of Eclipse (except Spirae / InteGrid), generally a strong variability and no dominant result.

For code management, only one sharing tool is typically chosen, but no consensus on across labs is observed.

5. Lab Operation and Software Support

This chapter is dedicated to the many ways in which software influences the operations in a laboratory.

Two main aspects with respect to software are

- the domain in which the software applies.
- the competences of the person working with the software (user or developer)

For orientation, we can generally distinguish software used in a horizontal fashion- between humans (H2H) and between machines (M2M), and, especially in a lab, in a vertical fashion: between human and machines (H2M). These different types of relations can also be associated with different types of software tasks.

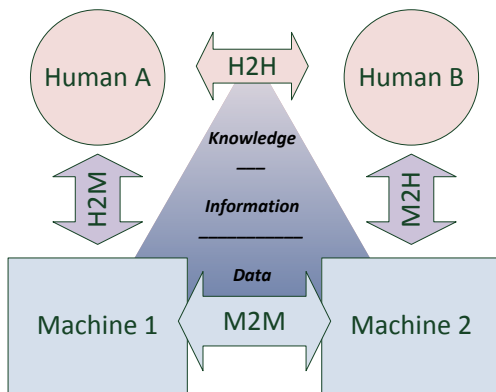


Figure 3 The three relations discussed in this chapter: M2M, H2H, H2M.

Another principle seems to govern the diversity or alignment with respect to software tools: With respect to alignment of tools and sharing of information:

- top-down decision and obligation, versus
- bottom-up appearance of coordinated behaviour.

In Sections 5.1 to 5.4, we focus on software in support of lab operations and development, whereas Sections 5.5 is focussed on human coordination and knowledge sharing.

5.1 Data acquisition and lab monitoring

Four questions in the questionnaire are related to data acquisition and monitoring functionality, i.e. the kind of functionality commonly summarized as SCADA (Supervisory control and data acquisition):

- Is there a dedicated SCADA system for the lab? What features does it have?
- GUIs for monitoring and lab management
- Please describe the features of your data acquisition infrastructure
- How is historical data stored in your lab?

The replies are collected in the following table. From the answers given by the participating laboratories it became evident that the terminology in these questions is not precise; some of the terms are used in different ways depending on context.

Raw answers

Lab	SCADA system	GUI	Data acquisition	Historical data
SmartEST (AIT)	ScadaBR for configuring the laboratory, Siemens Desigo for ventilation, cooling and air conditioning; both have usual SCADA functions	GUIs are used to control and monitor the lab	PC-based high precision measurement system is used which has oscilloscope functions (e.g. waveform representation, phasor representation)	Data storage for experiments uses a file server and the laboratory SCADA database
PSMIX (KTH)	ABB network manager with RTUs, operator training simulator, state estimation and OPF	None specific beyond the GUIs of the individual tools	IEDs with sample value capacity including GPS time, openPMU, RTUs for lower resolution, PS700 controllers with RT kernel 4kHz sampling rate on I/Os	Several systems
SmartTSLab (KTH)	Yes (SCADA BR), Open source	Buit-in SCADA Master GUI, Pachube Data Dashboard Application as SCADA client on smart phones and tablets	using multiple SCADA protocols (Modbus (ASCII, RTU, TCP and UDP), DNP3), and C37.118 (PMU).	For SCADA data-points logging, the server is configured with MySQL 5.5 data base
InteGrid (CSU/Spirae)	Yes. Schneider Electric ClearSCADA, customized and adapted for the lab. New devices can be integrated easily. Historical DB can be archived at will. The SCADA system is not the primary configuration tool as configuration is rarely on the basis of creating a suitable lab grid topology	Small screens in asset panels exist for assets. General screens for overall lab monitoring exist. General screens for operating the simulators (load, wind, solar) exist. Additional screens can be created in ClearSCADA.	ClearSCADA use for historical data, but no long term (life) historian. Time resolution in the ms range. Meters typically push on deadband violation, as fast as 2-5Hz. Disturbance recordings at 60Hz with ms timestamping based on GPS synced time signal. Waveform recordings <=7500 Hz, μ s time stamping. Access to data for SCADA is managed by Windows domain. Access to disturbance and waveform recordings (and meter event logs) is limited by lab network access	SCADA DB for historical meter data, breaker data and some control points. However, disturbance recordings, waveform recordings etc. not tied to this. No mechanism for central tagging of these resources. However, SCADA DB may be exported (and thus moved to restricted access) and working DB reset. Exported DBs can be reloaded for post processing and analysis
Smart Grid Lab (TUT)	n/a	n/a	n/a	n/a
ESIF (NREL)	WonderWare (commercial SCADA, specially adapted). All of the above functionality	As part of WonderWare SCADA	Up to 55kHz sampling	SCADA, historical (mostly experiment specific)
SYSLAB (DTU)	SCADA functionality covered by SYSLAB platform (in house), access control specified by resource/user/time interval. Access control currently implemented for circuit breaker permissions. SYSLAB platform is modular - new device integration is simple unless new hardware drivers have to be written. Data access secured by Unix host access.	Individual DER "control panel" GUIs are standalone applications (e.g. VRB battery GUI). Software framework for distributed visualisation ("monitorwall", several display machines controllable from a single UI). Monitorwall applets ("displets") can run standalone as well (e.g. switchboard breaker control). Everything is modular and decentralized; new GUIs can be started on any host.	Data generally acquired (and available through SCADA) as fast as the update rate of the DER allows (0.2-100Hz). Logging of all data once per second. All nodes NTP-synchronized to GPS clock for time-stamping. IEC61850-style flags (quality, validity, source) logged together with data and timestamp	Data is stored on DER nodes and is automatically moved to central "database" (i.e. NAS with flat file storage) once a day.
ICL+EL (DTU)	ABB Network Manager	Part of ABB NM	RTUs connected to ABB NM; ELSPEC DAQ for power quality assessment	Central ABB NM data warehouse (SQL), every 10s for most data.

In particular, one term interpreted differently is SCADA, which may refer to

- A. *(In a general context)*: an abstract infrastructure for collecting data from a physical system (possibly a remote and/or distributed system) and distributing control signals back to said physical system. The SCADA concept in general does not prescribe or exclude a particular system architecture (centralized vs. hierarchical vs. peer-to-peer), a particular distribution of master, slave, client or server roles, or a particular type of automated control or human intervention.
- B. *(In a power systems context)*: An integrated software and hardware solution which includes remote (slave) units, a central (master) processor, a human-machine interface (HMI) and databases for storing live and historical data. This definition is narrower than the previous one and implicitly linked to the architecture and functionality of commercially available SCADA systems as they are found e.g. in utility control centers.
- C. *(In a facility management context)*: Synonymous with a building automation system, often focused on HVAC aspects of building management.

In context of the smart grid labs, there are two main uses of the word SCADA: one refers to a system for monitoring and management of the lab as a whole (A.), or specific software for subsystems (C.). SG labs also contribute to development of utility level power system SCADA software (in sense of B.); therefore the reported installations are meant to either i) operate the lab, or ii) present a test-beds for SCADA solutions development (such operator support systems or PMU data infrastructure); or iii) mimic actual utility installations as a whole. In many cases several apply.

To avoid this ambivalent terminology, in the following we refer to LabSCADA or “LabOS” if the object in focus is a system with scope toward the lab (i.e. A.i and A.ii). This notion is further developed in RTLabOS D2.1 [2].

It is noted that two SCADA systems are mentioned twice:

- The commercial ABB Network Manager (PSMIX and PLDK ICL+EL)
- The open source SCADA BR (SmartEST and SmartSLab)

A further (statistical) evaluation beyond the compilation of the raw answers does not seem meaningful.

5.2 Custom control in the lab

Five questions in the questionnaire are related to the use of a laboratory for testing controllers and control algorithms:

1. Is remote control possible? How?
2. Is there an API for remote closed-loop control?
3. What infrastructure do you have to deploy controllers onto your lab equipment?
4. Does your lab offer standardized functionality to deploy controllers onto devices?
5. Is this (deployment) mechanism based on a particular standard?

Whether at the component or the system level, smart grid research aims at developing improved ways of controlling the power system or its parts. For this reason, the ability to test new control algorithms, systems and architectures is a design motivation in all smart grid laboratories, although the scope and extent to which this capability is required varies.

Three general scenarios can be distinguished:

- a. Installation of third-party equipment with an embedded controller (e.g. as device under test)
- b. Remote control of lab equipment via an API.
- c. Deployment of custom controllers on existing hardware equipment in the lab

Scenario a. does not necessarily require integration with laboratory software; therefore Scenarios b. and c. are the most relevant in the lab software context.

Raw answers

Lab	Remote control	Remote API	Controller deployment	Standardized controller deployment
SmartEST (AIT)	Depends on the test case; SmartEST is used for component and system tests mostly from partners and customers	Depends on the test case; SmartEST is used for component and system tests mostly from partners and customers	n/a	Depends on the test case; For some experiments IEC 61850 and IEC 61499 are used
PSMIX (KTH)	For parts yes (COPA-DATA XENON is used for remote access and visualisation)	OPC-UA interface to remote sites for ARISTO power system simulator is in test stage	Virtual machines as backup, remote logins to access systems	None
SmartTSLab (KTH)	Via remote desktop (dangerous when we have amplifiers in the loop)	No, but we do it from Opal's RT-Lab, however, if there is a failure in the device, the simulation can't be repeated until someone fixes/resets the device	National Instruments CRIO platforms. New ABB UNITROL (excitation and PSS) but we have just started with it	No, only NI CRIO platform
InteGrid (CSU/Spirae)	Yes, via lab SCADA and Spirae BlueFin	It's on the BlueFin roadmap. Right now it's not public	Yes, via Spirae BlueFin. At the lowest levels, PLCs can theoretically be reprogrammed using IsaGraf from a networked machine	Yes (usage) at both the device and the coordinating levels. No (particular standard) but we hope to make the APIs for area controls public
Smart Grid Lab (TUT)	n/a	n/a	n/a	n/a
ESIF (NREL)	n/a	n/a	none specific	n/a
SYSLAB (DTU)	Remote access via network bridging, data push server, blackboard server or tunneling	Proprietary API as part of the SYSLAB platform, various options	Manual deployment on each node (usually by checking out source code from version control). Limited scripting support for semiautomatic deployment	No
ICL+EL (DTU)	Yes, but only from within lab IP network.	None specific; some via RESTful services; data reading from ABB NM via OPC-DA	n/a	n/a

5.3 Advanced lab management tools

Four questions in the questionnaire are related to automating the management of experiment configurations, permissions and experiment data:

- Are dedicated services available in your lab that simplify merging of data from different sources?
- What tools are available and actually used in your lab to reserve experiment space and equipment, lock access to breakers?
- Is it possible to unify these permissions under a single experiment access 'tag'?
- Consider advanced configuration management as outlined in the 'domain study' report. Which features does your lab support already?

The questionnaire allowed for free text answers which are compiled in the following table.

Raw answers

Lab	Data merging	Experiment booking	Tagging	Configuration management
SmartEST (AIT)	Not at the moment	Shared calendar; only authorized persons are able to operate the lab	Depends on the kind of experiment/test	Currently the configuration is done manually but there are some plans to have a higher automation degree (but not yet implemented)
PSMIX (KTH)	Previous use of XML Spy tools for model merging, currently Enterprise Architect for meta-model mapping	None	?	None
SmartTSLab (KTH)	None so far	We use a booking "board" using Trello	No	None in reality - we are quite primitive and don't have any resources to get organized. It's more of a "survival mode".
InteGrid (CSU/Spirae)	No. It's build-your-own	Calendar managed by lab supervisor	No such system exists.	Under Bluefin platform, asset and system control parameters can be stored in a single file.
Smart Grid Lab (TUT)	n/a	n/a	n/a	n/a
ESIF (NREL)	n/a	n/a	Yes - in Wonderware.	n/a
SYSLAB (DTU)	Basic helper scripts for access/query of the history database / NAS storage	Access control system (web interface) for breaker reservations. Currently mainly used to keep SYSLAB and the NEVIC center from stepping on each other's feet.	no	Recording of breaker configuration, storage together with timeseries data.
ICL+EL (DTU)	n/a	n/a	n/a	n/a

Due of the broad range of laboratory types involved in the survey, due to differences in interpreting the survey questions, and because the sample size for each type is small, a direct statistical evaluation of the answers has not been considered meaningful. Instead, it was chosen to develop a *six-step scale for each question* in order to be able to categorize the

answers according to their level of automation. This process inevitably adds some subjectivity, and not all survey answers can be matched to the scale categories without information losses.

Data merging

Smart grid laboratories are complex environments which usually integrate equipment from a variety of manufacturers. Data collected from these different sources during an experiment is heterogenous with respect to time resolution, precision, quality and other factors. Some data sources may generate nonperiodic events, others will produce time series data. Some data may be collected in short, high-resolution bursts (e.g. event recorders), other data will have lower resolution but cover the experiment period continuously.

After an experiment, there is often a requirement to consolidate this heterogenous collection of data by merging: The timing of time series and events may need to be synchronized, or low-quality data may be replaced by high-quality data from a different source. If an aspect of the system can be observed through more than one data source, it may be possible to validate the data through redundancy.

If this process is not automated, it can be very tedious, and the quality and/or consistency of the outcome may depend on who performs it.

We have defined the following six levels of *data merging automation*:

1. No automation
2. Documented manual procedures to achieve consistent quality
3. Standalone software ("scripts") to help with certain aspects of data merging such as format conversion or timestamp-based merging
4. Automatic acquisition of data into a single, unified database, with a global data model and consistent time stamping
5. Like 4), but with support for manually triggered fusion of e.g. high-quality and low-quality sources
6. Like 4), but with fully automated fusion of separate data sources

The distribution of answers from the questionnaire is as follows:

Level	1	2	3	4	5	6
Count	3	1	1	0	0	0

Experiment booking

In most cases, smart grid laboratories are multi-user environments. Usually it is desirable to be able to run more than one experiment at a time, for example if long-term testing of a power component uses a small number of assets but does not require the rest of the lab.

As in any shared resource environment, access and use of lab components have to be coordinated in order to prevent disruption of experiments by e.g. sending conflicting control signals to an energy resource, or by de-energizing parts of the power system that are in use by an experiment. This coordination can be done manually, usually through an established

procedure, or by different levels of automation which may prevent human error, particularly in systems with many assets.

We have defined the following six levels of *experiment booking automation*:

1. No procedure or system in place
2. Manual procedures, e.g. involving a shared calendar
3. Dedicated booking system which allows some level of granularity in selecting which parts/resources in the lab are being reserved
4. Like 3), but integrated with a lab-level access control system, for example keycard access to doors or login to control computers
5. Like 3), but integrated with the a system controlling access at the circuit-breaker level, i.e. which parts of the lab can be (de-)energized or coupled together
6. Like 3), but full integration with the LabOS system [2] in order to directly manage access to all controllable lab assets.

The distribution of answers from the questionnaire is as follows:

Level	1	2	3	4	5	6
Count	1	3	0	1	0	0

Configuration management

While the survey shows that smart grid laboratories may follow very different concepts and cover different domains of smart grid technology, they are frequently characterized by integrating devices of different type and from different manufacturers. Many of these devices are configurable and have a large configuration space; examples include DER such as diesel generator sets or wind turbines whose controllers each may have hundreds of configuration parameters. Other examples may be advanced networking equipment or software in embedded systems.

In addition to these software configured devices, labs often allow for manual changes to their physical configuration as part of an experiment. Common cases are the installation of a device under test, or the connection of a mobile apparatus, for example a load bank or an electric vehicle which can be grid-connected in more than one location of a power grid.

When treating the lab as an integrated system, the lab configuration space is the sum of all device configuration spaces and manual configuration changes. Not all elements in the configuration space have an impact on the outcome of an experiment; *configuration management* is the tracking, recording and manipulation of those elements which do have an impact. In order to understand the conditions under which an experiment was performed, and in order to make experiments repeatable, the lab configuration which was active during the experiment must be known. For large laboratories, this configuration can easily contain thousands of parameters; it is therefore desirable to have an automated system to help with recording and/or deployment of a particular configuration.

We have defined the following six levels of *configuration management automation*:

1. No capability/no procedure
2. Manual procedure exists

3. Machine-aided (i.e. not fully automated) recording of configurations possible
4. Automated recording of configurations possible
5. Partly automated recording, deployment and restoration of configurations possible
6. Fully automated recording, deployment and restoration of configurations possible

The distribution of answers from the questionnaire is as follows:

Level	1	2	3	4	5	6
Count	4	1	0	0	0	0

5.4 Simulation, Co-Simulation, HIL

Three questions in the questionnaire are related to different aspects of simulation capabilities in connection with the laboratories:

- How would you qualify the relationship between controllers used in simulation and those deployed on equipment?
- Does your lab provide Hardware-in-the-loop facilities? Of which type?
- What types of co-simulation can be performed in your lab?

The questionnaire allowed for free text answers which are compiled in the following table. As in the previous section, it was chosen to develop a six-step scale for each question in order to be able to categorize the answers according to their level of automation.

Raw answers

Lab	Controller exchange	HIL	Co-simulation
SmartEST (AIT)	Both concepts are applied "needs adaptation & redesign" or "same code"	Yes, power-hardware-in-the-loop and controller-hardware-in-the-loop	Co-simulation of power systems, automation approaches and communication networks/protocols
PSMIX (KTH)	needs adaptation	Yes, direct connection at physical interface, emulated communication network. Analog I/O connection to power system alternately using 61850-90-2 SV streams or GOOSE messages	Power-ICT
SmartTSLab (KTH)	Simulated controllers would need some adaptation depending on model	Yes, PMUs, relays, amplifiers and NI CRIO controllers	Opal-RT has a system called Orchestral. For offline we use the FMI standard under Modelica tools and under Matlab using FMI toolbox.
InteGrid (CSU/Spirae)	Same code	Yes, co-simulation	BlueFin controls can be deployed against PowerFactory simulations.
Smart Grid Lab (TUT)	n/a	PHIL (1-3MW ?)	n/a
ESIF (NREL)	n/a	PHIL (1MW?)	n/a
SYSLAB (DTU)	Needs adaptation and redesign	Remote control of components can be individually integrated into other software using the SYSLAB component API	Currently only supported as hacks
ICL+EL (DTU)	n/a	n/a	n/a

Exchange of controllers between simulated and physical components

A common challenge when trying to replicate a laboratory environment in simulation or vice versa (for example to validate a simulation with a lab experiment, or to use simulation for replicating a lab experiment at a larger scale) is due to different runtime environments for controllers. Because controllers and control algorithms are a central research focus in the field of smart grids, the testing of new controllers is a common task in smart grid laboratories. Unlike e.g. physical models of DER components which can be validated once between simulation and lab and do not commonly change, ensuring identical behaviour between simulated and lab-deployed controllers is more difficult.

The fewer steps are necessary to share controller code between simulation and lab implementation, and the higher the portion of the source code that can be shared, the fewer resources need to be spent on time-consuming validation of identical controller behaviour and the fewer errors can be made in the porting/exchanging process.

We have defined the following six levels of *controller exchange capability*:

1. No capability
2. Manual process
3. Controller container (no recompilation)
4. Automated deployment
5. Cross-deployment of purpose-built controllers
6. Cross-deployment of generic controllers

The distribution of answers from the questionnaire is as follows:

Level	1	2	3	4	5	6
Count	1	3	1	0	0	0

HIL capabilities

Hardware-in-the-loop (HIL) capability is very relevant for smart grid laboratories in a number of scenarios: Testing of components, testing of controllers and the upscaling of experiments beyond the complexity of the laboratory hardware by simulating parts of the grid are all common uses of HIL.

Two general HIL types are commonly distinguished in this context: Power-hardware-in-the-loop (PHIL) inserts a device under test into a simulated environment (e.g. represented by a line voltage and frequency) while controller-hardware-in-the-loop (CHIL) simulates a system of controllable devices represented by sensor readings and actuator outputs to a physical controller.

We have defined the following six levels of *hardware-in-the-loop capability*:

1. No capability
2. Generally possible, but all integration has to be done manually on a case-by-case basis
3. Standalone software ("scripts") to set up PHIL and/or CHIL
4. GUI for manual setup of PHIL and/or CHIL

5. GUI for initiating automatic setup of PHIL and/or CHIL
6. Seamless integration of laboratory and simulator

The distribution of answers from the questionnaire is as follows:

Level	1	2	3	4	5	6
Count	0	0	3	1	0	0

Co-simulation capabilities

While co-simulation tools and technology are typically separated from a physical laboratory, many of the technological issues are very similar to those encountered in hardware-in-the-loop (HIL) setups: Co-simulation can be seen as simulator-in-the-loop between different simulation tools. Issues of time synchronization and/or artificial time, the exchange or sharing of controllers between simulation tools and communication between simulators are related to their counterparts in HIL.

We have defined the following six levels of *co-simulation capability*:

1. No capability
2. Generally possible, but all integration has to be done manually on a case-by-case basis
3. Some integration between isolated simulators
4. Cosimulation of power and control
5. Cosimulation of power, control and communication
6. Cosimulation of power, control and communication with complete lab models

The distribution of answers from the questionnaire is as follows:

Level	1	2	3	4	5	6
Count	0	1	1	1	2	0

5.5 Coordination, information sharing and formal barriers

A high share of informal cooperation is essential in labs. Yet, informal knowledge sharing and coordination is limited due to a number of factors:

- The larger a lab gets, the less likely relevant information will diffuse automatically,
- Lab safety standards require a degree of formality,
- Structured resource booking systems and approval processes in larger labs,
- Intellectual property concerns.

In this section we discuss the application of top-down principles such as rules or formal procedures in the lab context of

- Intellectual property handling,
- Lab safety and experiments execution,
- Lab booking for experiments, and
- Information sharing, e.g. for project management & tools.

Introducing formal procedures is tedious and creates some overhead that complicates lab operations. On the other hand, once there are strictly formal procedures and structured information these are more easily facilitated by software. There is a resulting trade-off between scalability and flexible and agile lab operations.

To shed light on this trade-off, Questions 20.1, 20.2 and 21 address formal procedures, intellectual property and information sharing. Finally, in Part II of the Questionnaire, we inquired about tools in use to software in use to support those activities in Q6.1-6.3.

5.5.1 Intellectual Property and Sharing

Intellectual property protection is a natural concern, for both research and commercial labs. We inquired the sharing policies with respect to data, models, and software.

Data

In the electric power systems domain, data is often concerned with privacy, so if data is acquired via non-disclosure agreements, this data is not easily shared.

In this study, the sharing approaches in two groups:

- a. as *commercial lab* (SmartEST, InteGrid) data is shared against fees.
- b. *research labs* (here: SmartS Lab, PSMIX, ESIF, SYSLAB) generally share data with collaborators; in some cases only under NDA, in other cases fully open.

Models

The distribution with respect to sharing of models is similar to that of data. We observe a slightly more restrictive use of models, where also some research labs tend to inquire fees (e.g. ESIF: more open about data, more likely to require fees for models), and some commercial labs do not share models externally at all. This may be because data is often more easily generated, whereas models result from a dedicated effort and can become a competitive element, both in research and commercial activities.

Software

Software development can be a core research activity as well as the commercial selling point. The split into *research & commercial labs* also applies to software. One should not, however, that ESIF is on average more restrictive about sharing software than about data.

5.5.2 Formal Procedures

The application of formal procedures for handling specific activities can apply to several activities in the lab. The formal approach is typically employed to satisfy some strict legal requirements and responsibilities, but they may also be considered a way of streamlining common activities and facilitating economic bookkeeping.

Addressing the topics,

- a. Safety in the lab,
- b. Booking of lab for experiments,
- c. Experiment execution,

we asked survey participants to consider the following levels of formality:

1. No Formal Procedure;
2. Informal knowledge with go-to persons

3. Dedicated staff roles
4. Forms facilitating a semi-formal process
5. Strictly formal procedure

For HW labs, electric *safety* is very important, and the most regulated activity (scoring 3 or 5, with average 4; with 5 for commercial labs). Naturally, in simulation labs safety is less of an issue and there is simply informal exchange.

Lab booking for experiments is either facilitated by a form (4) or, less formal, by a dedicated responsible (3). Only in one case strictly formal booking procedure is applied.

Experiment execution follows a strict procedure in InteGrid lab, whereas most labs have less structured approach with either dedicated staff roles (in most of the hardware labs), and informal go-to persons at the remaining four respondents.

5.5.3 Internal Information Sharing and Coordination

Information sharing is natural in direct personal collaboration, but when the lab complexity increases and more staff uses a lab, direct communication can become an overhead. On the other hand, writing a manual for every single step in the lab seems overkill – too much work. How do the participating labs balance these conflicting needs?

We asked for knowledge sharing with respect to *software* and *hardware* referring to

- a. Operation manuals and functional description, i.e. the ‘original’ documentation,
- b. “How-to know-how” – for tacit knowledge e.g. for operating a lab-specific setup.

For **a.** the range of choices was: (1) It’s hard, it could be anywhere; (2) just ask the right person; (3) “Once you get a feel for it, there is a kind of system”; (4) Strictly organized, structured folders; (5) Search engine enabled.

Here, the diversity of practices is significant. All answers from (1) to (4) appear, with (2) being most common. Comparing the replies for software vs. hardware, the answers are mostly the same.

For **b.** the formality of enforcing information sharing is when code comments and documentation writing are part of common practice (here: 3 and higher). For software only one lab claims a common practice here, whereas for hardware it is common practice for three labs. For software, installation routines and wizards often simplify the need for know-how exchange (four labs). Almost all labs at some point had manuals written, but view those as outdated.

Internal information sharing with respect to models, data and code is, again, handled quite differently. The range (1) some people use external file sharing tools (e.g. dropbox); (2) a central drive network exists; (3) shared folders are strictly organized and typed; (4) common file types are in use and deviations are documented; (5) standard information models are employed / usually a conversion tool is provided for application formats

Code is here most likely to be shared systematically (>3). *Models* are only shared systematically (3) in one case. *Data* is shared systematically in a central location in two cases.

In question we inquired about software coordination tools, e.g. for project management and development tasks. One lab uses “Trello” as an online tool for lab coordination, other two other labs refer to Outlook & One Note.

6. Conclusion

Summarizing the survey outcomes, we will first look at the main results, then discuss some specific insights, and finally look toward possible continuation on the basis of these results.

6.1 Main results

This survey investigated nine smart grid laboratories, six of which outside DTU and three labs under the umbrella of PowerLabDK. This, statistically, small number of labs, allowed to study and characterize each in more depth. The labs represented a wide spectrum of labs, including recently established, some grown over several years, different scales of investment (from ca. 10.000€ to 100 Million€), and including both labs with primarily commercial and a primarily research focus. For each lab a case story was developed, including design objective, resources, staff, research focus & software aspect. All-in-all, this characterization went the typical focus on technical resources. As a result, we gained an understanding of 'What is a smart grid lab?' As there clearly is not a single definition doing justice to all the labs, we invite the reader to browse through Chapters 1 and 2.

In Chapters 3 and 4, we further identified stereotypical lab profiles studying the relations between infrastructure, focus area, and software competence. The results are illustrated in Figure 1, p. 18 and Figure 2, p. 20. For software competence, it shows that for most participating labs, the level of software competence was generally very high: five of eight labs perform active software development in at least four of six categories; all in at least two categories. Development, however, can have with very different outcome foci (e.g. application-oriented or platform oriented). Some common tools and an indicative connection between tools and focus areas have been observed; but the large variety of replies and the small data basis do not allow for strong conclusions here.

Some part of the survey could be based on self-ranking based pre-established ranking indicators; other parts were necessarily more open and free-text. As analysis result, in Chapter 5, new ranking criteria have been established and applied to the available data. These new indicators together with the ones provided in the survey may serve as foundation for further studies.

6.2 Specific insights

At the outset of this survey, it was anticipated that some harmonization could be visible and established across labs with respect to:

- programming languages,
- information sharing,
- modeling & simulation tools, and
- control interfaces.

However, apart from some expected or obvious overlaps in simulation tools, programming languages, or standards re-surfacing in different contexts, (e.g. IEC 61850, OPC-DA, OPC-UA, Modbus, CIM), not a single one of these can be said to be commonly adopted.

Further, 'adoption' for standards is often only partial (e.g. only the information model or only the communication protocol) and adoption does not appear to be systematically organized.

According to some comments, more organized forms are

- a) very project dependent, and

- b) driven by engineering focus and applications needs - which differ greatly among labs.

This is surprising on the first glance, as, for example, many would have suspected a wide-spread adoption of IEC61850. While this is generally the case for the European labs, the adoption is often only partial.

One explanation may be that full adoption of standards requires significant development efforts (also as part of an open source initiative), or integration of commercial protocol stacks. With the diverse needs and focus areas of the labs investigated, such adoption may only occur if either a) commercial testing requirements are driving the development, or b) coordinated user groups form across labs (or industry). Diversity of programming languages (Java vs. C++/C# silos) and tools may also be a barrier for such a community to emerge.

Some further observations:

- It is common practice to ‘wrap’ low-level process control (e.g. device-level) into a locally preferred protocol
- Visualization and operator support (e.g. experiments with actual operators), though supported by many, seems a complex use cases and is hardly practiced by SG labs
- Clearly, several types of ‘system testing’ are practiced, in particular “hardware based” and “simulation based” testing are both common.

For example, InteGrid Lab performs integration tests on hardware that could in part also be performed on real-time simulators. On the other hand, co-simulation has been surprisingly common practice across labs, and seems to be on the rise as the most important trend in ‘lab software’. A common focus is development and testing of control systems, which are an important driver for testing due to need for closed-loop dynamics.

Finally, some common “pains” across labs are:

- a) Information sharing internally difficult to organize, often due to quick growth
- b) Establishing norms internally vs. growth and flexibility
- c) Reproducibility of tests is difficult as configurations are complex
- d) Common data formats are desirable for model exchange

These pains can be viewed as potential drivers for future initiatives on lab software.

6.3 Possible future work

With focus on lab support software, this survey has been a new initiative in the context of smart grid labs. Several follow-up options could be thought of, including

- a larger, statistical, survey based on the developed capability classifications for (e.g. via DERlab or ISGAN networks), where further characterization should be more specific w.r.t. use case requirements (e.g. development, validation & demonstration)
 - use cases to map capabilities to testing needs;
 - to use the data as foundation for a SG lab capability model & map
- Initiate collaboration to facilitate (co-)simulation-based development across labs
 - Extent to definitions and requirements for simulation-based testing
- Extended initiatives on exchanging experiences and developing strategic roadmaps for convergence of tools or co-development open source tools can be applied.
- Identify potential strategic convergence of current lab stereotypes, e.g. via use cases that require the combined features of electric, simulation, and energy flexibility labs.

Such convergence may only be achieved in a larger lab where several of the focus areas are strongly represented¹, along with multi-disciplinary competences and cross-disciplinary projects.

Finally, it can be noted that the three labs studied within PowerLabDK PLDK cover all of the three profiles. Here it will be interesting to observe how the balance between application focus (ICL+EL) vs. platform development focus (SYSLAB) will evolve, and whether the future combined use cases requiring the combination of labs will evolve out of current structures.

¹ Apart from NREL's ESIF, which combines such capabilities in a national lab, a university laboratory not present in this study (E.ON Energy Research Center at RWTH Aachen University) presents a case where [infrastructure](#) and [independent research disciplines](#) have been assembled in the same context.

References

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Appendix A Survey Questionnaire

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SURVEY QUESTIONNAIRE

This questionnaire aims to collect background and technical information about participating laboratories. The structure and background concepts of this survey have been outlined in the accompanying document “Domain Study” (RTLabOS Deliverable 1.1).

A summary evaluation of this survey’s results will lead to a publically available report; a revision opportunity will be given to the survey participants before publication. If agreed, the full survey contents will be shared among participating laboratories.

Contact information

Organization & Laboratory (in the following ‘the Lab’):

Contacts (persons filling out questionnaire and authorization responsible):

[] I agree to share the information provided in the following with other participating laboratories.

_____ (authorization responsible)

PART I: Users and the Laboratory Environment

A) Lab Stakeholders & Ownership

Q1. Who is funding / owning / operating the Lab?

Funding:

Owning:

Operating:

Q2. Which stakeholders participate in Steering Committee / Advisory Board?

If possible group stakeholders into (Utility/ Governmental / Commercial / Academic)

Steering Committee:

Board of advisors:

B) Lab-Establishment

Q3. When was the lab established?

Funding Agreement:

Opening:

Q4. Classify the establishment process:

- incremental extension of an existing lab
- new facility based on new design
- re-design of a prior facility
- other: _____

Q5. Indicate the scale of the laboratory of investment costs

Here the question is about scales rather than absolute numbers. Encircle the range.

Initial investment (Eur / US \$): 10.000 100.000 1.000.000 10.000.000 100.000.000

Total (cumulative investment): 10.000 100.000 1.000.000 10.000.000 100.000.000

Q6. Qualify the essential drivers for the lab establishment:

- <___> Identified gap in research field
- <___> Identified gap in commercial testing needs
- <___> Lighthouse project as national priority area (attracting international attention)
- <___> General Government Policy
- <___> Commercial Interests

Q7. Please describe the key design objectives of the laboratory

Q7.1. Key applications/activities to be supported by lab

(e.g. Commercial testing & certification, research in systems / control, etc.; these activity categories are further defined in Section 2.2 of the “Domain Study”):

Please prioritize the first 3 activities in terms of their relevance in consideration during the design.

- <___> Demonstration
- <___> Experimentation
- <___> Testing and validation
- <___> Models development
- <___> Decision support and tool development
- <___> Maintenance and monitoring of equipment
- <___> Controller development and deployment
- <___> System Integration
- <___> Time series acquisition

Q7.2. List the top three specific key focus areas of the lab:

- 1.
- 2.
- 3.

Q8. Could you describe the design philosophy in a few words?**Q9. Please qualify the ambition level (e.g. scope of competitiveness) during the design:****Q10. Has there been a precursor to this Lab, i.e. is it a design evolution of a prior lab?**

__yes __no

Q10.1. If yes, please explain the evolution in terms of equipment and functionality:**C) Actual Lab Use****Q11. Users & Staffing:**

Please quantify the number of staff (on average):

- *PhD Students:*
- *PostDocs:*
- *Senior Scientific staff:*
- *Visiting Researchers:*
- *Technical Staff (incl. operation & maintenance):*
- *Administrative Staff:*

Q12. Please quantify the operation cost (excluding staff) of the laboratory:

Maintenance:

Other Operation costs:

Q13. Funding Sources of Staff and Operating costs

Please associate an approximate percentage value with each category:

- < ___ > Fixed base funding
- < ___ > Long-term partnership based funding
- < ___ > Project -based funding (public)
- < ___ > Return from commercial use of lab
- < ___ > Other funding source: _____.

Q14. Activities & Types of Experiments

Please prioritize the top 3 activities in terms of their relevance in actual lab use. (Scope: last 3 years)

- < ___ > Demonstration
- < ___ > Experimentation
- < ___ > Testing and validation
- < ___ > Models development
- < ___ > Decision support and tool development
- < ___ > Maintenance and monitoring of equipment
- < ___ > Controller development and deployment
- < ___ > System Integration
- < ___ > Time series acquisition

Q15. Topical diversity of Projects

For the following topical areas indicate the current level of project activity associated with the lab.

(Scope: last 3 years)

Activity Range: **0** none; **1** sporadic; **2** occasional; **3** regular; **4** frequent; **5** continuously

Electric components

- < ___ > Electric materials and aging
- < ___ > High voltage engineering, electric transients, lightning protection
- < ___ > Power electronics and drives

<___> Electric machines

<___> EMC

<___> HVDC

Energy Conversion and Flexibility

<___> Energy storage

<___> PV technology

<___> Wind power technology

<___> EV technology

<___> Intelligent buildings and building automation

<___> Thermodynamics and thermal energy systems

Systems Integration, Automation & Controls

<___> Protection & Protection systems

<___> Interoperability

<___> (Distributed) Automation

<___> Controls Design

Systems-Modeling and Analysis

<___> Power System Stability

<___> Isolated Power Systems

<___> Stochastic behavior and methods for power systems

<___> Diagnostic methods and monitoring

Q16. External Users & Collaboration

In which field do you have collaborations with respect to actual lab activity?

Please provide indicative numbers and names collaborators if possible.

<__> Utilities:

<__> Vendors:

<__> Scientific:

<__> Public Sector:

<__> Other: _____:

D) Hardware / Overall Lab setup

Q17. Hardware Data Sheet

Please supply a 'data sheet' of your lab, stating relevant facts about the technical equipment, including electrical infrastructure, energy conversion units, communication networks, data acquisition infrastructure and major computing hardware, including possible data concentrators.

(please attach a data sheet if available, and use space below for comments:)

Q18. List the top three most distinguished capabilities of the lab:

- 1.
- 2.
- 3.

E) Other Factors

Q19. Strategic Software Competence

Q19.1. How strong are your staff software competences today?

Range: **0** N/A; **1** Rare use; **2** Occasional Use; **3** Frequent Use; **4** Part-time Development; **5** Development focus

Please use the left column for this reply.

- <__|__> Simulation tools
 <__|__> SCADA software
 <__|__> Control Software
 <__|__> Visualization & HMI
 <__|__> Interfacing & Protocols
 <__|__> Data Analysis & Modeling tools
 <__|__> OTHER: _____.

Q19.2. Do you plan to recruit / develop further competences within the next 3 years?

Yes No (if yes, please use 2nd column in above list)

Q20. Procedures & Policies

Q20.1. With respect to lab use, to what extent do you have formal procedures to cover the following issues?

Range: **0** N/A; **1** No Formal Procedure; **2** Informal knowledge w/go-to persons; **3** Dedicated Staff Roles;
4 Forms with semi-formal process; **5** Strictly formalized procedure

- <__> Safety
 <__> Booking & Reservation
 <__> Experiment Setup & Conclusion

Q20.2. With respect to intellectual property of the lab (data, software and models), what is your general policy regulating exchange with external parties?

Range: **0** N/A; **1** Only internal use; **2** against fees; **3** under NDA; **4** Sharing with Collaborators (barter-basis);
5 Open to anyone (available online)

- <__> Data
 <__> Models

<__> Software

Q20.3. For the IP aspects marked between 1-3, please indicate if there are established/formal procedures to initiate the exchange.

Q21. Documentation

Q21.1. Functional Descriptions & Operation Manuals (official documentation):

Is it generally easy to find out what (Software/Hardware) is available in your lab the Specs? Is there some systematic organization of the information?

Range: 0 N/A (it's easy, there's only a few documents, everyone knows, all in one place);

1 It's hard, it could be anywhere; 2 just ask the right person; 3 "Once you get a feel for it, there is a kind of system"; 4 Strictly organized, Structured folders; 5 Search engine enabled

<__> for Software

<__> for Hardware

Q21.2. How-to-Know-How (internal knowledge-sharing about how to perform lab-activities):

For common lab tasks, do you have written checklists, how-to manuals or other kinds of instructions to guide new users: (I've read the manual, but still don't know what to do...)

Range: 0 N/A (Come on, you're an engineer!); 1 just ask the right person; 2 for some things someone once wrote a how-to manual (it's outdated); 3 It's common practice to contribute to written documentation (e.g. no code without comments); 5 'software wizards' / 'assistance robots'

<__> Software

<__> Hardware (Data sheet)

PART II: Core Software Functions

This part of the survey is aimed at understanding the existing lab software infrastructure. Lab software is not easily thought of as an infrastructure, but, possibly more appropriate, as a zoo – or a jungle. A taxonomy of lab software has been provided in the “Domain Study” (RTLlabOS Deliverable 1.1; Section 3: Software tools). The following questions aim to collect and index the most relevant software species and identify their contribution to the laboratory software ecosystem.

Questions include both multiple choice and open fields.

A) *Analysis and Development Tools*

Q1. Simulation Software

Q1.1. Which (modeling, simulation & calculation) software are used in your lab? (multiple ticks possible)

<input type="checkbox"/>	Power Factory	<input type="checkbox"/>	Eurostag	<input type="checkbox"/>	LabView
<input type="checkbox"/>	RSCAD	<input type="checkbox"/>	ETAP	<input type="checkbox"/>	Matlab
<input type="checkbox"/>	PSS/E	<input type="checkbox"/>	Mathematica	<input type="checkbox"/>	R (statistics)
<input type="checkbox"/>	PSpice	<input type="checkbox"/>	Maple	<input type="checkbox"/>	
<input type="checkbox"/>	PSCAD	<input type="checkbox"/>	SAS	<input type="checkbox"/>	Other tools, please list below.

Q1.2. Are licenses usually available to all employees? How are licenses managed? Is there a central license server for software licenses?

Q1.3. Open source software: Is there a local preference regarding open source tools? Does your lab contribute to OS developments? Please provide examples.

Q2. Model Types

Q2.1. What types of Models are in use in your lab?

(e.g. thermal models, power system models (transient, dynamic, power flow), forecast, ...)

Q2.2. Are there conventions on the model data types to be used? Which?

(i.e. CIM would be a common standard, but can hardly be used for all simulation programs)

Q2.3. Model Management: Is sharing of models across the lab common? How is it organized?
(i.e. is there central repository of folder structure, even a database? How are NDA aspects addressed?)

Q2.4. Model development: Are models developed systematically in the lab context? What type of models? Is model development driven by lab-related measurements?

Q2.5. Is there a policy or practice regarding sharing of models externally?

Q3. Data Storage, Extraction and Handling

Q3.1. Which are the common data types in use? Please list more specific types where possible

<__> time series from measurements:

<__> GIS data:

<__> market price data:

<__> forecast & meteorological data:

<__> other data:

Q3.2. Is there a central storage facility for time series data? What type?

Q3.3. What other types of data are common that have been missed here?

Q4. Objects of Development

Q4.1. What types of Controls and Algorithms are developed in you lab?
(consider control applications and layer)

Q4.2. Is simulation software developed in your lab? What kind?

Q4.3. Decision Support and Visualization: Is there dedicated research and development into decision support and visualization that integrates with the lab? Please indicate scope.

Q5. Development Environment

Q5.1. Programming Languages: Which languages are commonly used in your lab?

Q5.2. Development Environments: Which Development environments are most used?

(If there is a split, please estimate the proportions)

<__> Visual Studio & .Net

<__> Eclipse

<__> other:

Q5.3. Code Management: What forms of internal code sharing are common in your lab? Is there a general policy / preferred method?

e.g. from simple file based sharing (or Dropbox) to various forms of versioning systems (CVS / SVN / Mercurial / Git, etc.)

Q6. Knowledge Sharing

Q6.1. How is information access and sharing enabled in your lab?

Please qualify how information sharing is organized.

Range: **0** N/A; **1** some people use external file sharing tools (e.g. dropbox); **2** a central drive network exists; **3** shared folders are strictly organized and typed; **4** common file types are in use and deviations are documented; **5** standard information models are employed / usually a conversion tool is provided for application formats

<__> Models

<__> Other data

<__> Code / development files

<__> Experiment configuration data

Q6.2. Are tools in use for Document Management? For which documents are they used? How are NDA (non-disclosure agreement) aspects handled?

Q6.3. Which collaboration & coordination tools are in use?

(e.g. Outlook Exchange /shared calendar, Online project Management tools (Kanban, Podio, ..), Issue-tracking tools, ...)

B) Lab-Related Software

Q7. Is there a dedicated SCADA system for the Lab? What features does it have?

Please cover aspects such as: commercial (incl. brand) / open source; degree of tailoring & in-house development; granularity of user access; features for locking configurations for experiments; flexibility to integrate new devices; how is data access secured/structured

Q8. GUIs for monitoring and lab management

Please describe the types of GUIs that are in use for Lab management; are there dedicated GUIs for supervising experiments? How are new GUIs set up?

Q9. Data acquisition and storage infrastructure

Q9.1. Please describe the features of your Data Acquisition infrastructure.

Aspects: time resolutions; time stamping; types of measurements; live data vs. historians (e.g. in case of Power Quality recording); data access

Q9.2. Data Hosting & Storage: How is historical data stored in your lab?

Is there a central database for all data or are there several systems? Can data be 'tagged' for specific experiments? (e.g. as "restricted access")

Q10. Equipment and components control

What infrastructure do you have to deploy controllers onto your lab equipment?

C) Additional Tools and Advanced System Integration

The questions in this category are all open questions. If availability of related capabilities is available the respondent is requested to provide a free-text reply. Please refer to the “Domain Study” document for clarifications on the question topics.

Q11. Co-simulation and HIL coupling and interconnection

Q11.1. Does your Lab provide Hardware-in-the loop facilities? Of which type?

Q11.2. What types of co-simulation can be performed in you lab?

Q12. Remote access to equipment and simulation

Q12.1. Can data and time series of equipment in the lab be accessed remotely? Are visualizations supported? What platform is used for this purpose?

Q12.2. Is remote control possible? How?

Q12.3. Is there an API for remote closed-loop control? Based on what technology / standards?

Q13. Data merging tools

Q13.1. Are dedicated services available in your lab that simplify merging of data from different sources?

Q14. Experiment booking and permissions

Q14.1. What tools are available and actually used in your lab to reserve experiment space and equipment, lock access to breakers?

Q14.2. Is it possible to unify these permissions under a single experiment access 'tag'?

Q15. Platform for deploying and testing controls

Q15.1. Does your lab offer standardized functionality to deploy controllers onto devices?

Q15.2. Is this mechanism based on a particular standard?

Q15.3. Is the mechanism in use? What percentage of possible users actually employ the mechanism?

Q15.4. Is there an infrastructure that integrates development and testing of controls in simulations that can be (seamlessly) integrated with a deployment on laboratory equipment? How does it work? What are the elements of this toolchain?

Q16. Advanced configuration management

Configuration, Controls & Configuration Data Management

Q17. Software Interoperability and Interface Standards

Q17.1. Does your lab encourage use of standardized data exchange protocols?
Indicate for different layers.

Level 1: Process & Components

Level 2: (Distributed) Process Control

Level 3: SCADA (DA, Supervision and Visualization)

Level 4: Service Layer

(Level 5: System Engineering / Planning)

Q17.2. System Integration: With respect to integration of new software / components, do you have shared principles for alignment?

Range:

1 everything ad-hoc

3 shared principles & patterns

5 following strict architecture