

RECENT RESEARCH TRENDS IN ENGINEERING AND VALIDATING CYBER-PHYSICAL ENERGY SYSTEMS

Presenter: Dr. Thomas I. Strasser – AIT Austrian Institute of Technology & TU Wien, Austria Dr. Filip Pröstl Andrén – AIT Austrian Institute of Technology, Austria

Webinar by IEEE Industrial Electronics Society – June 29, 2021





OUTLINE

- Higher complexity in cyber-physical energy systems
- Engineering problems and needs
- Status quo in research and development
- Validating controllers for cyber-physical energy systems
- Example Demo
- Conclusions and outlook
- References



HIGHER COMPLEXITY IN CYBER-PHYSICAL ENERGY SYSTEMS

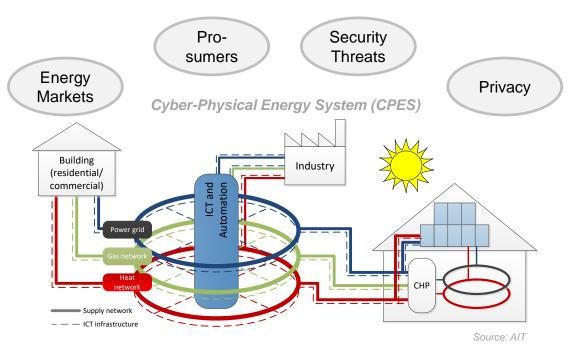
Webinar "Recent Research Trends in Engineering and Validating Cyber-Physical Energy Systems"





HIGHER COMPLEXITY IN CYBER-PHYSICAL ENERGY SYSTEMS

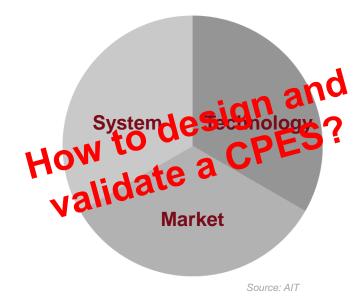
- Planning and operation of the energy infrastructure becomes more complex
 - Large-scale integration of renewable sources (PV, wind, etc.)
 - Controllable loads (batteries, electric vehicles, heat pumps, etc.)
- Trends and future directions
 - Digitalisation of power grids
 - Deeper involvement of consumers and market interaction
 - Linking electricity, gas, and heat grids for higher flexibility and resilience





HIGHER COMPLEXITY IN CYBER-PHYSICAL ENERGY SYSTEMS

- Key elements of future integrated smart grids for mastering the increasing requirements and system complexity are
 - Power electronics
 - Advanced communication, automation, and control systems
 - Smart algorithms
 - Monitoring and data analytics
- Engineering and validation of power and energy systems characterized by
 - Lots of manual engineering steps
 - Partly missing integrated view on sub-domain's (power, ICT, etc.)
 - Usage of less formalized approaches and tools (compared to other areas)





ENGINEERING PROBLEMS AND NEEDS

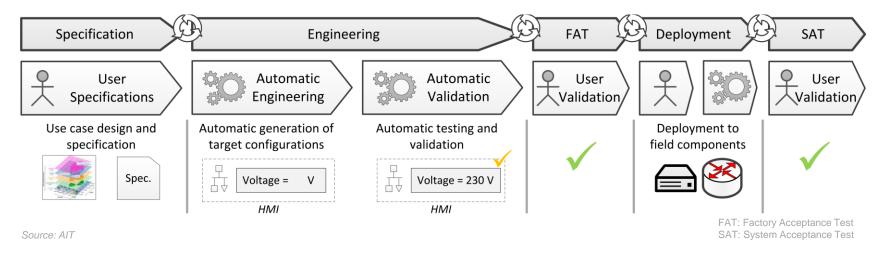
Webinar "Recent Research Trends in Engineering and Validating Cyber-Physical Energy Systems"





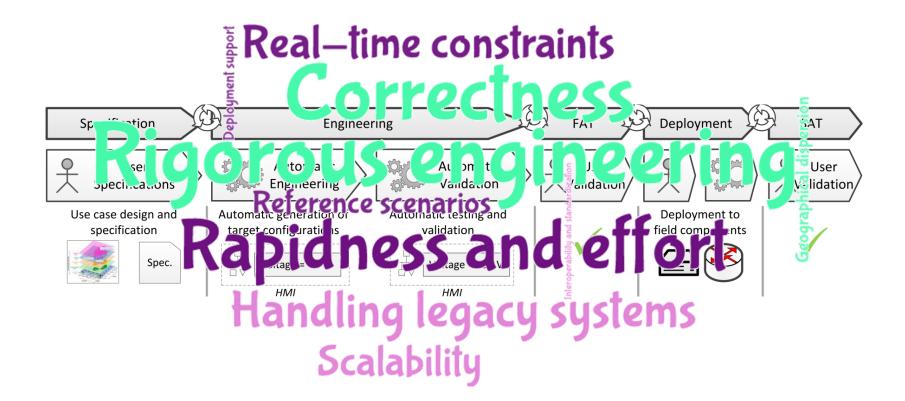
ENGINEERING PROBLEMS AND NEEDS

- Background and motivation
 - Reduction of manual steps necessary to handle complex CPES configs
 - Reduction of potential error sources due to manual steps and improvement of application/software quality required
 - Faster application development needed due to market behaviour and trends
- Providing support from design to implementation and installation





ENGINEERING PROBLEMS AND NEEDS





Webinar "Recent Research Trends in Engineering and Validating Cyber-Physical Energy Systems"





Specification

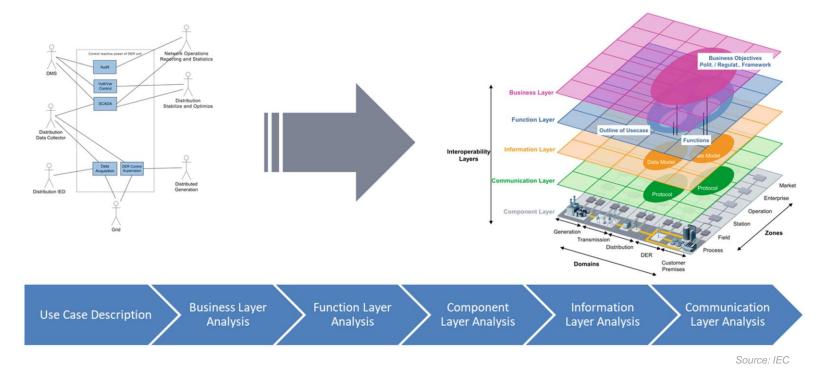
- IntelliGrid (IEC 62559) use case engineering approach
 - Structured process for specifying smart grid related applications
 - Identification of requirements and needs
 - Provision of use case templates

2	Actors Grouping Group Description				
oduce Use Case Spec	Group Description				
Jse Case Template	Actor Name archemics	Actor Type www.harcor	Actor Description	Partner information specific to this Use Case	
- case remplate	Device Management Server	Application	This application detects newly connected devices, a use saves their capabilities, configures the devices, and sets there into an operational mode. Example: FOIServer.	IEC 62769-3 (FDI), IEC 62541 (OPC UA), IEC 62453 (FDT)	
<u> </u>	Intelligent Field Device	Device	A field device can be an actuator or sensor. It is equipped with standardized communication capabilities and a self-description.	IBC 62541 (OPC UA), eCI (bia, NAMURINE 131	
<u>≜ _ ⊼</u>	Controller	Device	A controller can execute control algorithms based on sensor inputs and passes actions to a classions. If is equipped with standardized communication cas phillies, and a set-description.	TEC 62541 (OPC UA)	
	Network Configuration Service	Service	cap adulties, and a set-description. The network configuration service provides IP addresses, network, masks, gateway information and naming services for thickents.	PIPC 21 31 (DHCP), IEC 625 41-12 (OPC UA Discovery)	
	Validation Authority	Service	Verifies the validity of a digital certificate.	X.5.09, RPC 528.0 (Public Key Infrastructure)	
e e	Authentication Service	Service	A central distabase that can verify user tokens provided by clenits. It may also tell servers what access rights the user has. The authentication service depends on the user (dentity token; It could be a certificate subhority, a Karbers toket granting service, a WS-Tout Server or a proprietary dabase of zone eact.	TBC 62841-4 (OPC UA)	
2	Process Engin sering To ol	Application	The application provides configuration data for a plant, which may include specific configuration parameters for field devices.	IEC 62424 (Automation ML), NAMURI NE 150, Whitepaper "Automation ML and sCI (Bus. Integration", VDMA-Elinbeitsblatt 654 15	
	Process Control System 1-0/1	System.	Handware Software system that visualizes operator screens to supervise an industrial process.		
	Commissioning Engineer	Huttan	Persponsible for the installation and constitutioning of an automation system.		
	Plant Operator	Human	Supervises the operation of an industrial plant vis the Process Control System HML		



Specification

- Smart Grid Architecture Model (SGAM)
 - Supports the specification of smart grid applications
 - Provides a structured process linking use cases into system architectures





Engineering

- Power System Automation Language (PSAL) model-based engineering for smart grids
 - Model-Driven Engineering (MDE) of smart grid applications will reduce the amount of manual work needed to describe information in multiple models
 - Integrated MDE approach covering the whole engineering process to handle the multi-domain aspect of smart grids



Holistic approach

An approach that combines design, implementation, validation, and deployment is missing



Model-based

Model-based engineering concepts for smart grids are missing or only partly available



Multidisciplinarity

The multi-domain character of smart grids is not covered by existing approaches

→ Domain-specific approach Power System Automation Language (PSAL)

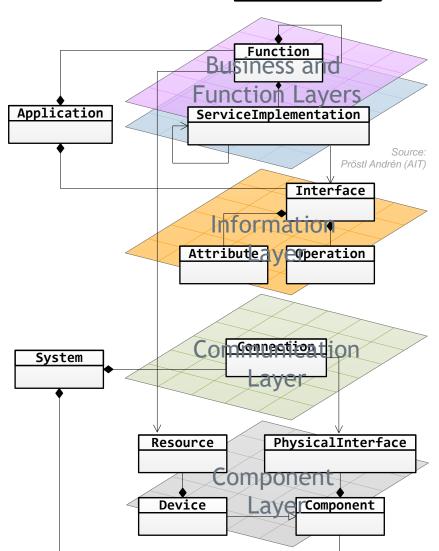


Engineering

- PSAL model-based engineering for smart grids
 - Based on SGAM

```
application VoltageControl {
  function VoltVArCtrl at DSOComputer.VoltVAr {
    requests Field.Controls fieldControls
  }
  module Field {
    interface Controls {
      attribute float32 activePowerSetpoint
  }}}
```

```
system DistributionSystem {
   device DSOComputer {
     ethernet eth0 {ip = "10.0.0.1"}
     resource VoltVAr
   }
   router StationRouter
   generator DER
   connect DSOComputer.eth0 with StationRouter
}
```

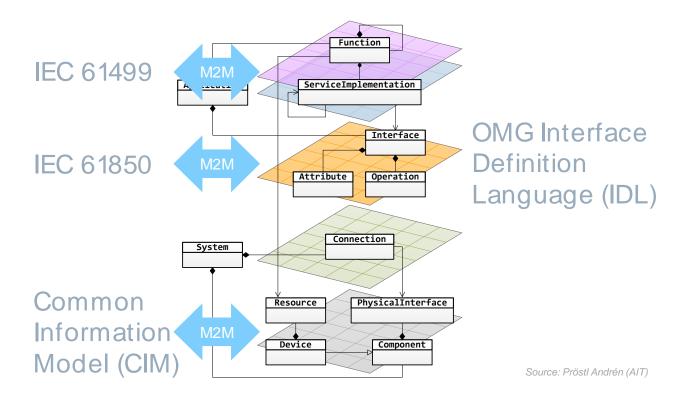




Engineering

- PSAL model-based engineering for smart grids
 - Basis for PSAL

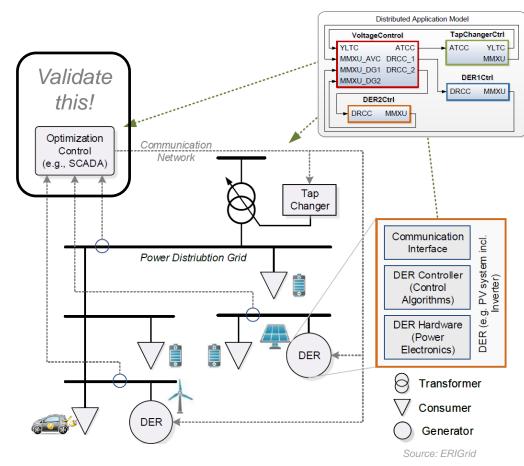
SGAM for the approach





Validation & Testing

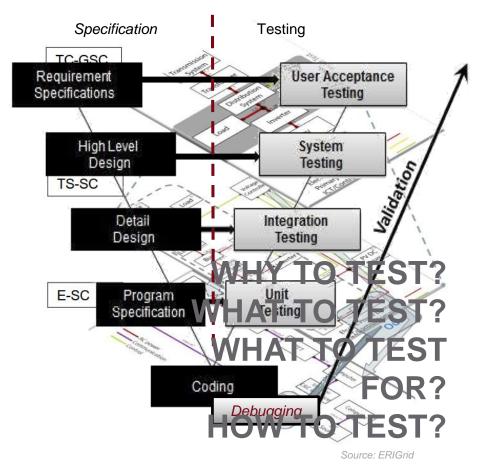
- ERIGrid holistic testing approach for smart grid systems
 - Testing of CPES components and concepts
 - Many domain involved (holism)
 - Setups and workflows differ across Research Infrastructures (RI)
 - Experiments are often hardly reproducible
 - Often limited by RI capabilities





Validation & Testing

- ERIGrid holistic testing approach for smart grid systems
 - Formalize testing process
 - Testing → documented and reproducible
 - Basis for knowledge exchange
 - Formal process covering all stages of test planning
 - Overview of resources
 - Consider state-of-the-art
 - Operationalize, refine



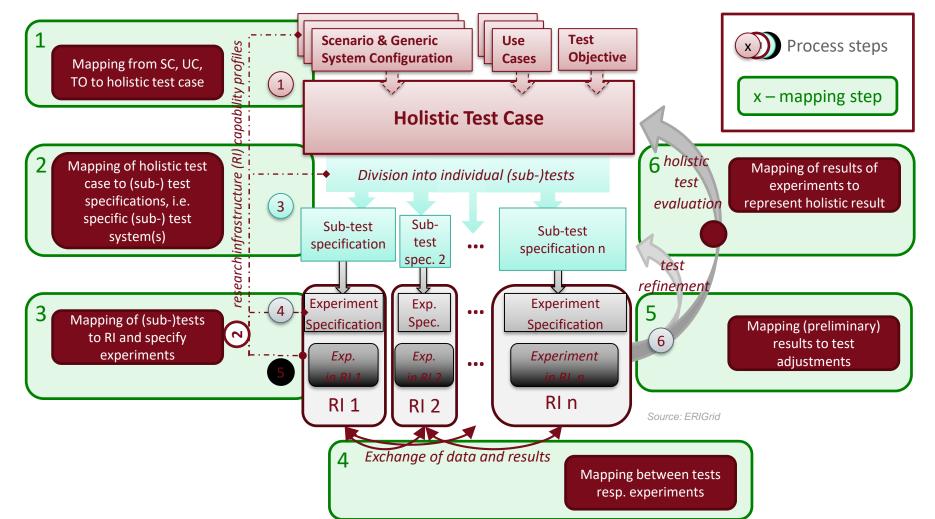


17

STATUS QUO IN RESEARCH AND DEVELOPMENT

Validation & Testing

• ERIGrid holistic testing approach for smart grid systems





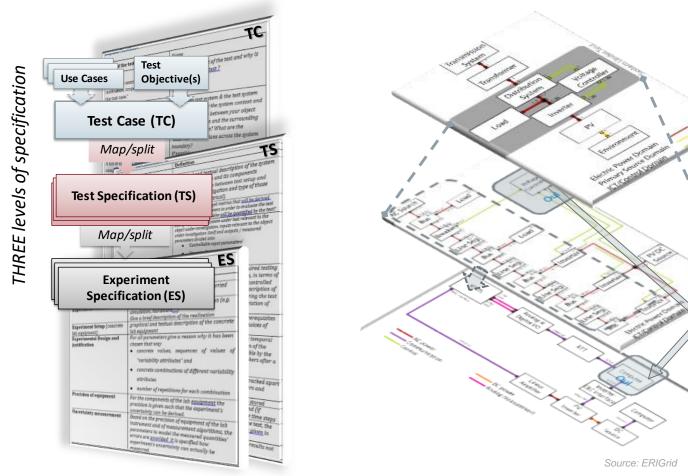
Validation & Testing

Generic

Specific

Lab

• ERIGrid holistic testing approach for smart grid systems





Webinar "Recent Research Trends in Engineering and Validating Cyber-Physical Energy Systems"





Increased complexity and dynamics in the electrical energy system

- Massive deployment of volatile Distributed Energy Resources
- Paradigm change in terms of planning and operation of the distribution system

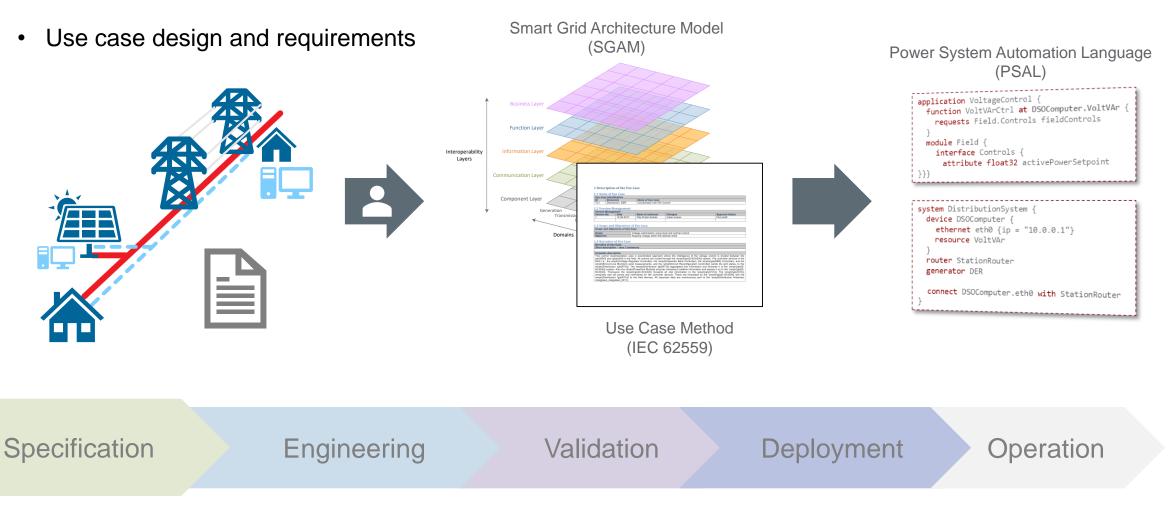
Increased engineering and validation costs

 Traditional engineering and validation methods were not intended to be used for applications of this scale and complexity

Possible countermeasures

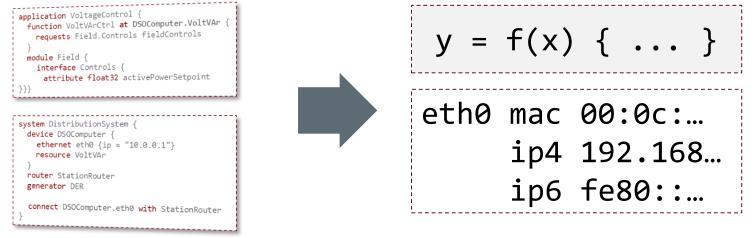
- Automation and control systems
- Automated engineering and validation
 - Exhaustive testing is manually time consuming and error prone
 - Formalized use case and requirements engineering
 - Automated setup of cyber-physical test-beds
 - Speed up iterations between testing and development







• Implementation according to design

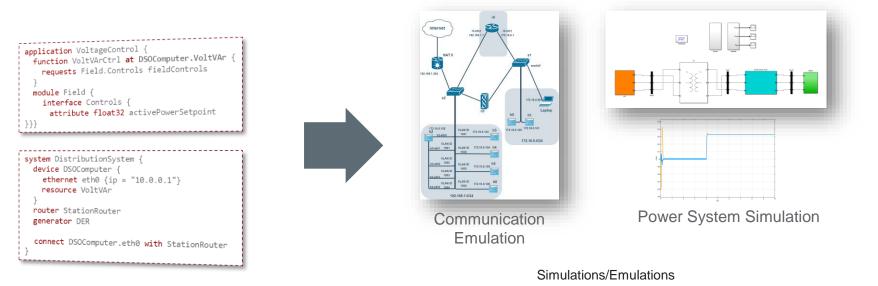


Code and configurations





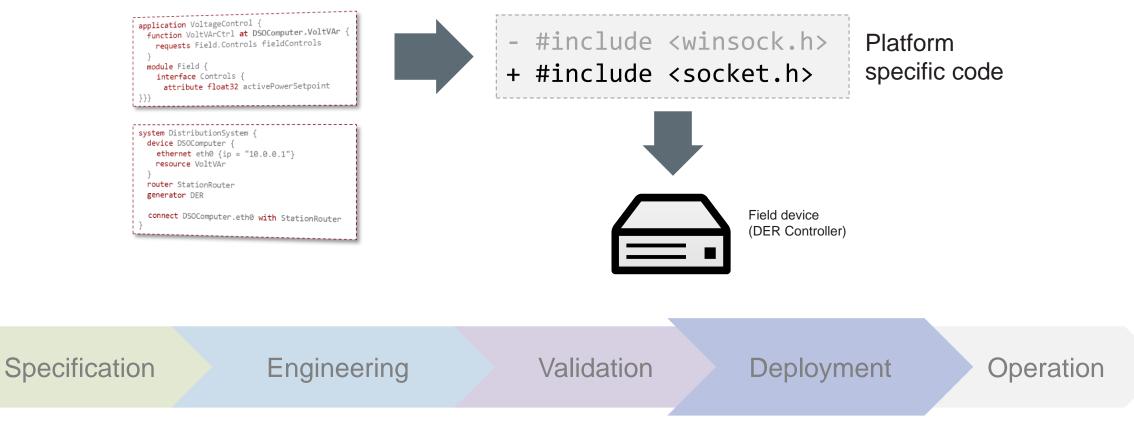
• Testing and validation of requirements





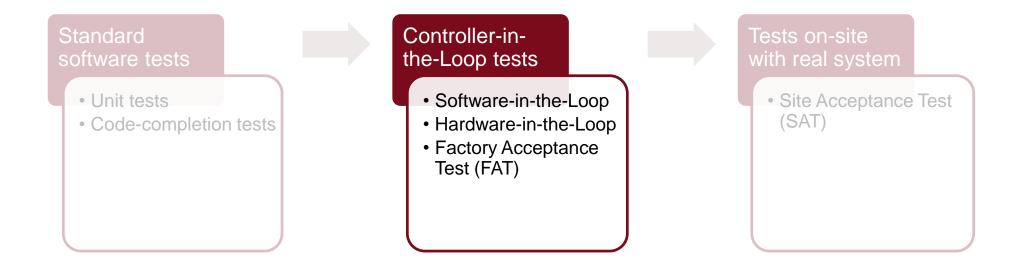


• Deployment to specific platforms



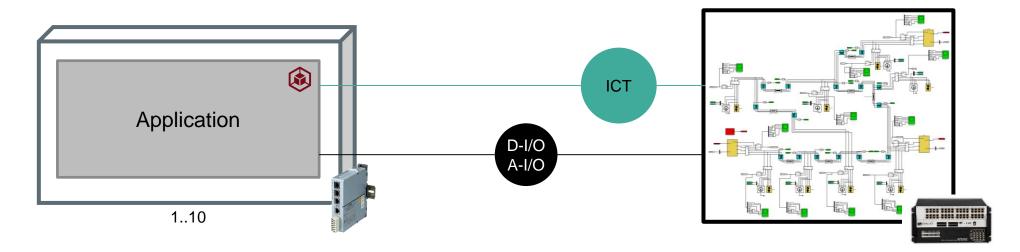


• Common approach to validation of CPES controllers



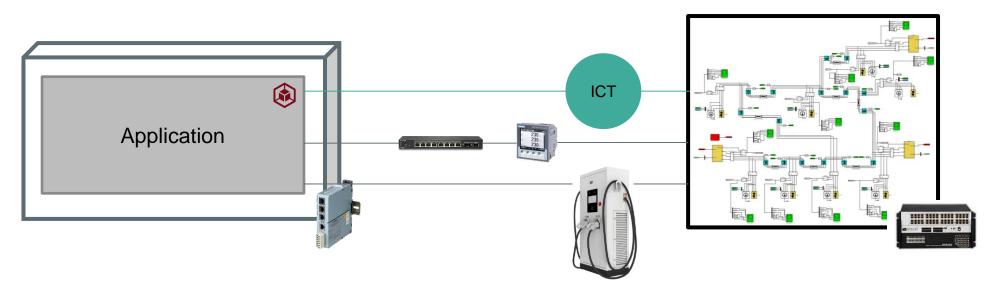


- Controller Hardware-In-the-Loop (C-HIL)
 - C-HIL tests with dedicated controller hardware
 - Deploy software on dedicated industrial hardware
 - Purpose
 - Validation on selected electrical networks



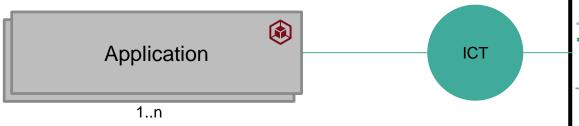


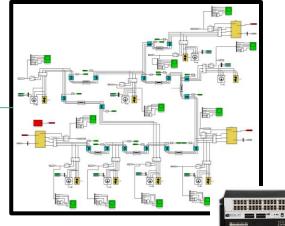
- Controller and Power Hardware-in-the-Loop (PHIL)
 - C-HIL and P-HIL interaction tests
 - Deploy software on industrial hardware
 - Purpose
 - Validation + interaction between controller and key components (charging stations, metering, etc.)





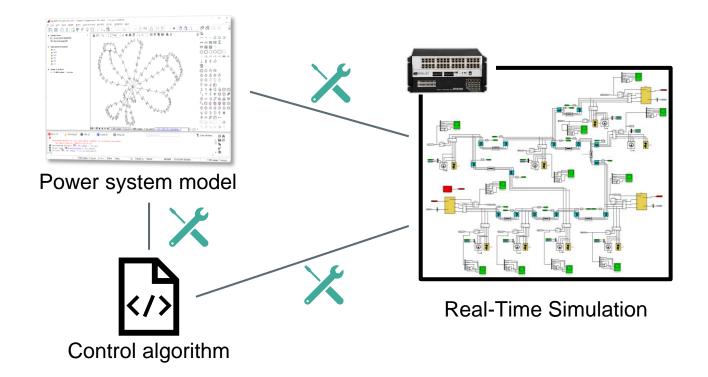
- Software-in-the-Loop (SIL)
 - Software tests without dedicated hardware
 - Software is connected to the real-time simulation using a communication protocol
 - Purpose
 - Development and optimization of control applications
 - Automated validation using multiple grids from grid operators
 - Stability investigations (e.g., impact of large number of controllers in the grid)







• Setup of a SIL experiment





Automated SIL setup using PSAL

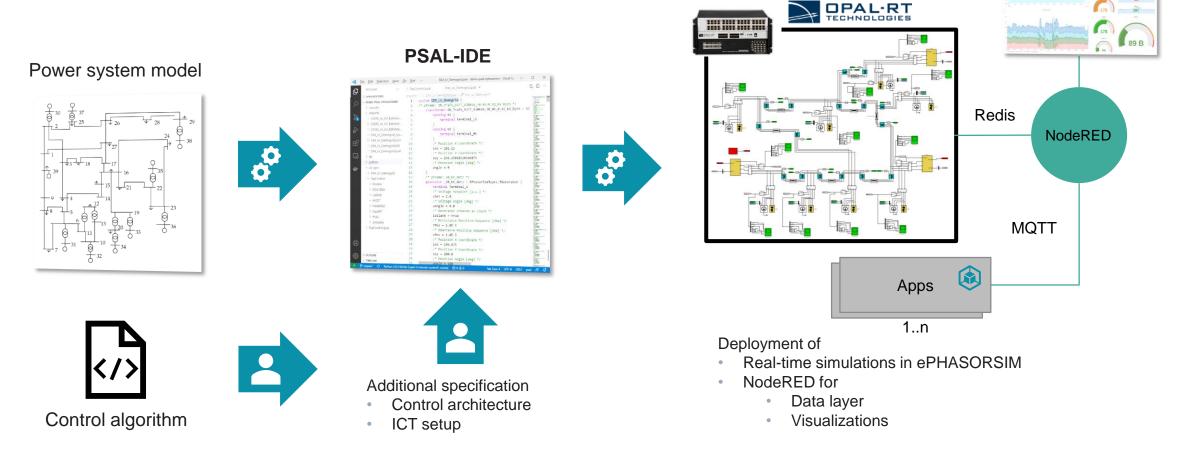
<u>File Edit Selection View</u>	ao <u>R</u> un	SIM_LV_Demogrid.psal - demo-psal-ephasorsim - Visual S —	th 🗆
	TapControl.ps	al SIM_LV_Demogrid.psal ×	GS LL
EXPLORER	- inperior of	M_LV_Demogrid.psal > D SIM_LV_Demogrid	IN COLUMN
> OPEN EDITORS			
✓ DEMO-PSAL-EPHASORSIM		CN THREE 0277 630KVA 30.05/0.42 KV DYILS /	-5.04
> .vscode	2 /* pf	name: ON_Trafo_9277_630kVA_30_05_0_42_kV_Dyn5 : ransformer ON_Trafo_9277_630kVA_30_05_0_42_kV_Dyn5 :	SI
✓ imports	3 t	winding W1 {	58
CIGRE_LV_EU_balance	5	terminal Terminal_LV	Sec.
() CIGRE_LV_EU_balance	6	}	No.
	7	winding W2 {	0.00
	8	terminal Terminal_HV	Signal.
SIM_LV_Demogrid_typ	9		1000
SIM_LV_Demogrid.json	10	/* Position X Coordinate */	The Nor
= Silvi_cv_beinographa	11	sxx = 201.25	Straig.
E SIM_LV_Demogrid.psal	12	/* Position Y Coordinate */	1000
> lib	13	sxy = 236.25018310546875	- Norman
> python	14	/* Position Angle [deg] */	10.00
✓ src-gen	15	angle = 0	A PROPERTY.
> SIM_LV_Demogrid	16 }		100
✓ TapControl	17 /	* pfname: 30_kV_Netz */	10.00
> Docker	18 g	enerator _30_kV_Netz : EPhasorSimTypes.TGenerator {	Distante.
> IEC61850	19	terminal Terminal_1	
> Lablink	20	/* Voltage Setpoint [p.u.] */	Contract of the local division of the local
	21	uSet = 1.0	0.00
✓ MQTT	22	/* Voltage Angle [deg] */	State.
> NodeRED	23	uAngle = 0.0	10 1 10 10 10 10 10 10 10 10 10 10 10 10
> OpalRT	24	/* Generator created as slack */	0.00
> PSAJ	25	isSlack = true	Exercite .
> Simulink	26	<pre>/* Resistance Positive Sequence [Ohm] */</pre>	19-ber
E TapControl.psal	27	rPos = 1.0E-5	C. del
	28	/* Reactance Positive Sequence [Ohm] */	Company.
	30	xPos = 1.0E-5	Signature.
	30	/* Position X Coordinate */	
	32	SXX = 196.875	100-2
> OUTUNE	33	/* Position Y Coordinate */	State.
> OUTLINE	34	sxy = 280.0	Ser.
> TIMELINE	35	/* Position Angle [deg] */	194
🖇 master* 🕂 Python 3.8.5 64-	bit ('opal-rt-remote	angle = 180 control: conda) $\otimes 0 \triangle 0$ Tab Size: 4 LITE 0 control	SHEEK.
		Condisis: condia) ⊗ 0 △ 0 Tab Size: 4 UTF-8 CRLF	psal 🔊

PSAL-IDE

- Formalized, domain-specific language
- SGAM compatible use case design
- Specifically targeted at rapid generation of code and configurations
 - Communication configurations
 - Simulation models
 - Deployment configurations



Automated SIL setup using PSAL





EXAMPLE DEMO

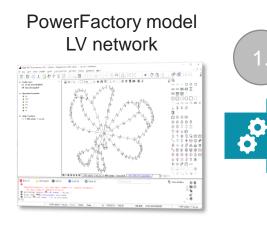
Webinar "Recent Research Trends in Engineering and Validating Cyber-Physical Energy Systems"



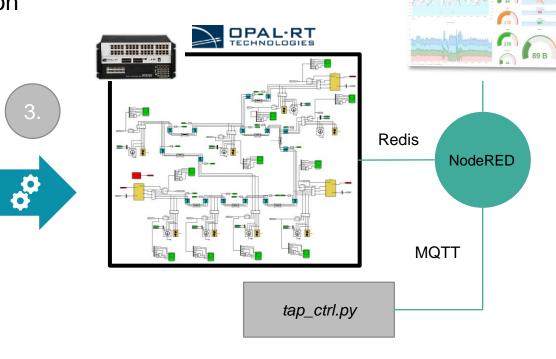


EXAMPLE DEMO

• Rapid validation of a tap controller developed in Python



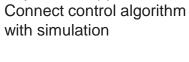




Deployment of

- Real-time simulations in ePHASORSIM
- NodeRED for
 - Data layer
 - Visualizations

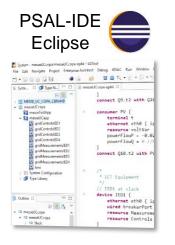
tap_ctrl.py Voltage control using tap changer

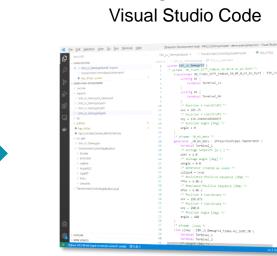


Specify control application



PSAL-IDE







· tap_chilps



PSAL-IDE

Available soon through ERIGrid 2.0 Virtual Access https://erigrid2.eu/lab-access/



CONCLUSIONS AND OUTLOOK

Webinar "Recent Research Trends in Engineering and Validating Cyber-Physical Energy Systems"





CONCLUSIONS AND OUTLOOK

- Formalized processes and approaches for CPES development necessary
- Integrated analysis of power and ICT needed
- Methods for system-level testing required
- Integrated analysis of power and ICT needed
- Several solutions available but several points still partly solved
 - Harmonization of existing approaches
 - Large-scale examples and scenarios
 - Integration with traditional engineering approaches
 - Introducing new abstractions and modelling options

phase	design					proof	impl.	rapid
approach	function	inform.	comm.	comp.	inconst.	function	function	prot.
UML	(×	×	×	×	×	Ş	×
SysML	(Ş	×	×	×	×	Ş	×
IntelliGrid	Ş	×	×	×	×	×	×	×
SGAM-TB	(×	Ş	Ş	×	×	Ş	Ş
PSAL	<u></u>	(\checkmark	\checkmark	×	\checkmark	\checkmark	\bigcirc
MATLAB	(Ş	×	Ş	×	\checkmark	\checkmark	\bigcirc
IEC 61499	(Ş	\checkmark	\checkmark	×	\checkmark	\checkmark	×
IEC 61131-3	(Ş	\checkmark	Ş	×	\checkmark	\checkmark	×
EMSOnto		\checkmark	×	×	\checkmark	\checkmark	✓	\checkmark

Source: AIT



CONCLUSIONS AND OUTLOOK



Webinar



REFERENCES

Webinar "Recent Research Trends in Engineering and Validating Cyber-Physical Energy Systems"





REFERENCES

- T. Strasser, E. de Jong, M. Sosnina (ed.): "European Guide to Power System Testing: The ERIGrid Holistic Approach for Evaluating Complex Smart Grid Configurations"; Springer Nature, Cham, Switzerland, 2020, ISBN: 978-3-030-42274-5; 141 pages.
- K. Heussen, C. Steinbrink, I. Abdulhadi, et al.: "ERIGrid Holistic Test Description for Validating Cyber-Physical Energy Systems"; Energies, 12 (2019), 14.
- T. Strasser, S. Rohjans, G. Burt (ed.): "Methods and Concepts for Designing and Validating Smart Grid Systems"; MDPI, Basel, Beijing, Wuhan Barcelona Belgrade, 2019, ISBN: 978-3-03921-649-9; 408 pages.
- F. Pröstl Andren, T. Strasser, W Kastner: "Engineering Smart Grids: Applying Model-Driven Development from Use Case Design to Deployment"; Energies, 10 (2017), 3.
- T. Strasser, F. Pröstl Andren, G. Lauss, et al.: "Towards holistic power distribution system validation and testing-an overview and discussion of different possibilities"; e & i Elektrotechnik und Informationstechnik, Vol. 134 (2017), Issue 1.
- A. Benigni, T. Strasser, G. De Carne, M. Liserre, M. Cupelli, A. Monti: "Real-Time Simulation-Based Testing of Modern Energy Systems: A Review and Discussion"; IEEE Industrial Electronics Magazine, 14 (2020), Vol. 2; 28 - 39.
- C. Zanabria, F. Pröstl Andren, J. Kathan, T. Strasser: "Rapid Prototyping of Multi-Functional Battery Energy Storage System Applications"; Applied Sciences, 8 (2018), 8; 1 34.
- C. Zanabria, F. Pröstl Andren, T. Strasser: "Comparing Specification and Design Approaches for Power Systems Applications"; 2018 IEEE PES Transmission & Distribution Conference and Exhibition - Latin America (T&D-LA), Lima, Peru; 2018.

Thomas I. Strasser Erik C. W. de Jong Maria Sosnina *Editors*

European Guide to Power System Testing

The ERIGrid Holistic Approach for Evaluating Complex Smart Grid Configurations

Erigrid"

DERlab

OPEN







Privatdoz. DI Dr. Thomas Strasser

Senior Scientist Center for Energy – Electric Energy Systems AIT Austrian Institute of Technology GmbH Giefinggasse 2 | 1210 Vienna | Austria T +43(0) 50550-6279 | F +43(0) 50550-6390

thomas.strasser@ait.ac.at | http://www.ait.ac.at

Dr. Filip Pröstl Andrén, MSc

Scientist Center for Energy – Electric Energy Systems AIT Austrian Institute of Technology GmbH Giefinggasse 2 | 1210 Vienna | Austria

T +43(0) 50550-6680 | F +43(0) 50550-6390 filip.proestl-andren@ait.ac.at | http://www.ait.ac.at

