Test Case 3

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Name of the Test Case	Accelerated Time-to-Experiment for remote RI testing
Narrative	Distribution networks are becoming increasingly “smarter”, as well as more complex, with the addition of power electronic devices, ICT, smart meters, and more. As a result, advanced control strategies to manage such networks are becoming necessary. Testing these systems in their entirety is becoming a challenge which is progressively accomplished by distributing parts of the system between multiple Research Infrastructures (RI) in order to cope with the increasing number of involved components and stakeholders such as grid operators, device manufactures, market participants as well as regulators. However, distributed experiments represent a challenge in itself as the coordination of interactions between these participants is an additional burden added to the already complex system under test. This test case aims to demonstrate tools to accelerate the setup and the coordination of such distributed experiments. As use case, an optimal Coordinated Voltage Control (CVC) operating as a distribution management system is chosen. The algorithm manages all the devices of the network that are capable of regulating the voltage either directly (OLTC), or through the injection of active/reactive power, such as Battery Energy Storage Systems (BESS) and Photovoltaic (PV) inverters. Management is based on the solution of an optimization problem, which minimizes a predefined objective function, subject to linear and non-linear constraints. Previous work has implemented this CVC algorithm in central controller installed at substation level. However, this has several drawbacks for the scope of this test case: • A centralized controller is not well suited to demonstrate the benefits of the tested tools for accelerating the setup of highly distributed experiments as the controller only consists of a single instance. • A centralized controller represents a Single Point of Failure (SPoF) in the distribution grid. An outage of the controller would result in a non-optimal configuration of the system leading to increased losses and costs. At the same time, maintenance of such control systems becomes more difficult if it needs to be conducted on a live system. Hence, for this test a distributed version of a Coordinated Voltage Controller is used to provide redundancy and demonstrate the capabilities of a highly distributed experimental setup. The CVC controller is initialized with all the necessary static data of the network: network topology, admittance of

	lines and transformer, nominal power of DERs units and storage systems, operating limits, tap change operations of the OLTC, etc. While it operates, it requests and receives real-time power measurements from the smart meters of loads and DERs units, as well as the State of Charge (SoC) of the storage systems and the current tap position of the OLTC. Using this dynamic data, it formulates the optimal power flow problem, whose objective function involves the minimization of voltage deviation of critical nodes from the nominal value, power losses of the lines and transformer, and tap change operations of the OLTC.
Function(s) under Investigation (*FuI*) “the referenced specification of a function realized (operationalized) by the object under investigation”	• Data-exchange for RI coupling • Deployment and configuration of SW controllers • Network Emulation for inter-controller communication • Time-synchronization • Coordinated Voltage Controller
Object under Investigation (*OuI*) "the component(s) (1..n) that are to be qualified by the test”	• Multi IO Box (MIOB) • RIasC cluster
Domain under Investigation (*DuI*): “the relevant domains or sub-domains of test parameters and connectivity.”	Electrical Domain & ICT Domain
Purpose of Investigation *(PoI)* The test purpose in terms of Characterization, Verification, or Validation	The purpose of this test is the characterization of an extended research infrastructure which utilizes new tools to accelerate the setup for complex system level tests.
System under Test (*SuT*): Systems, subsystems, components included in the test case or test setup.	PV inverter, OLTC, transformer, distribution lines, upstream network impedance, Low Voltage (LV) monitoring, DRTS
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.	• Data-exchange between controllers • Data-exchange for Quasi-Static Power Hardware-in-the-Loop (QS-PHIL) interfaces • Network-emulation between controllers
Test criteria: Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.	Evaluation of accuracy of the setups realized through the incorporation of the time-delay compensation methods
target metrics Measures required to quantify each identified test criteria	The measure required: • Initial setup time in person-hours • Repeated setup time in person-hours • Manual configuration effort in person-hours • Re-configuration time for SW controllers (parameter change) in seconds

		• Required personal resources for experiment setup (IT, Administrative, Technical, Supervisory) in number of persons.
	variability attributes controllable or uncontrollable factors and the required variability; ref. to PoI.	Variability factors include: • Controllable: – Number of involved RIs – Degree of CHIL, PHIL provided by each RI vs. simulation • Uncontrollable: – Communication Network conditions: * Quality of Service * Existing Firewall and Network security Policies
	quality attributes threshold levels for test result quality as well as pass/fail criteria.	• Number of required manual configuration changes / adjustments is lower than X • Initial setup time lower than X hours • Repeated setup time lower than X minutes

Qualification Strategy

i.e. how are the PoI to be met by the different tests and how will the test results be combined to yield the desired PoI outcomes (see guideline)

Test Specification D3.1

Reference to Test Case	*TC D3*
Title of Test	***Validation of Model, HIL Interfaces and CVC Controller***
Test Rationale	*This test validates the function of the CVC algorithm and the LV model and PHIL setup in three experiments. First the test setup is validated in a single RI using a single CVC instance. Afterwards the second experiment will extend the setup to multiple RIs running multiple instances of the CVC controller. This requires a data-exchange between RIs for the controller communication. Lastly, the HIL setup shall be extended to incorporate also electrical interface signals by labs contributing simulated Distributed Generation (DG) units. The integration of PHIL setups is spread across multiple RIs. Previously simulated DG units will be subsequently replaced by real lab setups involving physical PHIL setups. This test case lays the ground work to demonstrate the capabilities of the tools for providing an extended Research Infrastructure.*
Specific Test System (graphical)	• 1 RTDS digital real-time simulator • 1 PB5 / Novacor Rack • 1 GTNET card with SKT protocol • N Raspberry Pi single-board computers • M simulated DG units in remote RIs or PHIL setups
Target measures	
Input and output parameters	*Inputs:* *• Number of CVC controller instances (N)* *• Number of coupled DG units (M)*
Test Design	*This initial test can be conducted fully within a single RI. A single DRTS and one or more controller instance are required and coupled via existing communication protocols like Internet Protocol (IP) or User Datagram Protocol (UDP). The CVC controllers shall be deployed via software containers on an embedded controller*

	running Linux. The simulation of the distribution grid will be carried out on a RTDS digital real-time simulator.
Initial system state	*LV-grid in steady-state, HIL interfaces deactivated, CVC controllers inactive*
Evolution of system state and test signals	*1. Validation of measurement signal received by CVC controllers* *2. Validation of successful leader election in case of a distributed setup of CVC controllers.* *3. Activation of CVC controllers*
Other parameters	*OLTC activated/deactivated*
Temporal resolution	*• DRTS simulation time-step: 50 µs* *• CVC cycle time: 10 s* *• Data-exchange rate for remote PHIL coupling: 1-10 Hz*
Source of uncertainty	*• Communication network characteristics:* *– Latency, Packet-loss, Jitter* *• PHIL setups:* *– Environmental factors: solar irradiation, wind speeds*
Suspension criteria / Stopping criteria	*• Suspension:* *– Missing or incorrect measurements received by controller* *– Failed leader election of controller* *– Instabilities in LV-grid during coupling procedures of PHIL setups.* *• Stop:* *– CVC successfully optimized system state after activation*

Test Specification D3.2

Reference to Test Case	*TC D3*
Title of Test	***RI Substitution***
Test Rationale	*This test validates the ability of the extended Research Infrastructure to quickly substitute and swap RIs in case some parts of the overall test case are unavailable due to human or physical scheduling constraints. A first experiment tests how fast and to which degree the function of one RI can be substituted by another. A second experiment tests the flexibility of the extended RI by changing the PCC at which an RI is interfaced to the larger test setup.*
Specific Test System (graphical)	Same as in D3.T1
Target measures	*The number of required changes made to the LV system model an the data exchange configuration.*
Input and output parameters	*Same as in D3.T1*
Test Design	*This test repeats test D3.T1 by replacing one HIL interface with another RI.*
Initial system state	*LV-grid in steady-state, PHIL setups coupled, CVC controllers active*
Evolution of system state and test signals	*Same as in D3.T1*
Other parameters	*Same as in D3.T1*
Temporal resolution	*Same as in D3.T1*
Source of uncertainty	*Same as in D3.T1*
Suspension criteria / Stopping criteria	*Same as in D3.T1*

Test Specification D3.3

Reference to Test Case	*TC D3*

Title of Test	***Network Emulation***
Test Rationale	*The extended RI provides features such as network emulation which can be used to simulate real communication network behaviour. This test uses the network emulation functionality to reproduce contingencies in the communication network used by the OLTC and CVC controllers.*
Specific Test System (graphical)	Same as in D3.T1 plus: • Software network-emulation for communication between CVC controller instances • Various different profiles for network emulation modelled to represent common communication networks (DSL, 4G, 5G, Fiber-Backhaul)
Target measures	*Same as in D3.T1*
Input and output parameters	*Same as in D3.T1*
Test Design	*In this test network emulation will be applied to the communication interfaces of the SW controller components such as the CVC, OLTC and LV monitoring components.*
Initial system state	*Same as in D3.T1*
Evolution of system state and test signals	*Same as in D3.T1*
Other parameters	*Same as in D3.T1*
Temporal resolution	*Same as in D3.T1*
Source of uncertainty	*Same as in D3.T1*
Suspension criteria / Stopping criteria	*Same as in D3.T1*

Test Specification D3.4

Reference to Test Case	*TC D3*
Title of Test	***Repeatability and Time-to-first-Simulation***
Test Rationale	*A major objective of the extended RI is the acceleration of complex system level tests. This test evaluates the degree of automation which the tooling of the extended RI provides.*
Specific Test System (graphical)	Same as in D3.T1
Target measures	*• Time-to-first-simulation: How long does it take to setup the experiment from scratch based on an existing experiment configuration* *• Number of manual configuration actions: How many steps are required to performed manually as there exists no automation tooling for them?*
Input and output parameters	*Same as in D3.T1*
Test Design	*In this test network emulation will be applied to the communication interfaces of the SW controller components such as the CVC, OLTC and LV monitoring components.*
Initial system state	*Same as in D3.T1*
Evolution of system state and test signals	*Same as in D3.T1*
Other parameters	*Same as in D3.T1*
Temporal resolution	*Same as in D3.T1*
Source of uncertainty	*Degree of automation*
Suspension criteria / Stopping criteria	*Same as in D3.T1*