Test Case 5

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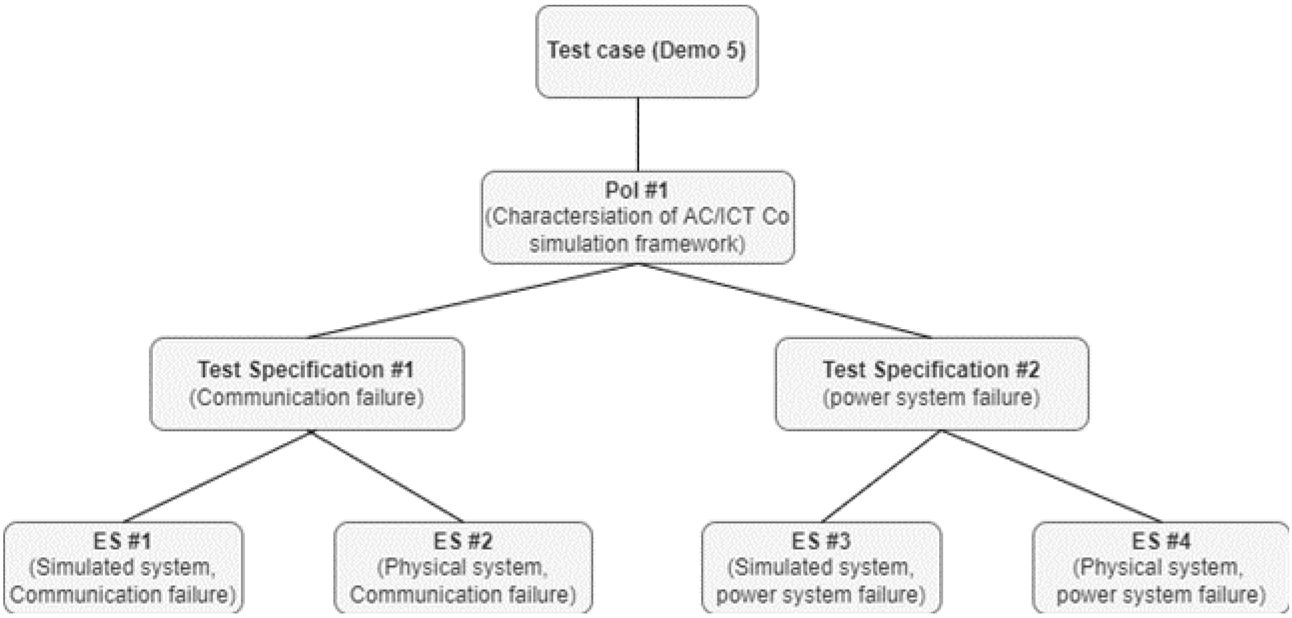
Name of the Test Case	Demo 5
Narrative	Smart grids have become complex system of systems characterized by mutual interactions and interdependence between the power system and the ICT systems. To evaluate the system level integration and validation of such a system, proper attention should be focused on the design of the simulation tool, that can simulate the two systems holistically. So far, there is no established cyber-physical approach/ software tools for designing, analyzing, and validating smart grid systems sufficiently in such manner. The lack of such system validation for smart grids is addressed by the European ERIGrid 2.0 project where a co-simulation based approach is developed. The software co-simulation in ERIGrid is realized by employing the Mosaik framework as a co-simulation master and interfacing all simulators (AC, ICT and controller) via the Functional Mock-up Interface (FMI) standard. The aim of this test case is to characterize the achievable accuracy of this simulation approach. To achieve this, simulation results will be compared to hardware based laboratory tests. The case assumes a section of an electrical distribution grid, multiple (>=2) aggregators that operate independently of each other. Each of the aggregators maintains a portfolio of flexible DERs units that can provide on-demand delivery of a grid service (e.g. load reduction/production increase). The primary customer for the grid service is assumed to be the local DSO where a dispatch unit is tasked with continuously matching the service demand indicated by the DSO, and to submit service activation requests to the appropriate aggregators. During the simulation, a communication fault (either temporary or permanent) disrupts communication between the dispatch unit and one of the aggregators. To ensure that the service demand is met, the dispatch unit must arrange to meet the service demand with the remaining aggregator(s). It is assumed that an aggregator affected by a communication fault will continue to deliver the service agreed upon. However, due to the lack of updates from the dispatch unit, these services will eventually diverge from the evolving needs of the grid. The purpose of the test is to characterize the performance of the simulator coupling in a co-simulation setup, rather than the performance of the individual domain simulators. Therefore, two points must be observed: • The simulated system must exhibit a strong enough (and ideally closed-loop) coupling between the individual domains • While applying variations to input parameters during the characterization test, known corner cases for the individual

	domain simulators should be avoided, to prevent in-domain inaccuracies to shadow for intra-domain inaccuracies.
Function(s) under Investigation (*FuI*) “the referenced specification of a function realized (operationalized) by the object under investigation”	Multi-domain simulation of coupled AC+ICT systems, consisting of • Electrical network simulation • Communication network simulation • Simulator coupling/integration
Object under Investigation (*OuI*) "the component(s) (1..n) that are to be qualified by the test”	AC/ICT cosimulation setup, consisting of a power system simulator, a communication network simulator, a simulator coupling framework and a cosimulation master algorithm. The investigation is specifically focusing on the performance of the cosimulation setup, not on that of the simulated system.
Domain under Investigation (*DuI*): “the relevant domains or sub-domains of test parameters and connectivity.”	• Electrical domain • ICT
Purpose of Investigation *(PoI)* The test purpose in terms of Characterization, Verification, or Validation	Characterization of the properties of the cosimulation framework by comparing the dynamics of the simulated system to the dynamics of a comparable physical (laboratory) setup. This is the first step towards a validation test, by exploring the range of achievable performance. The data collected would allow a reference scale (pass/fail) to be developed at a later time.
System under Test (*SuT*): Systems, subsystems, components included in the test case or test setup.	The SuT consists of the OuI (AC/ICT cosimulation) plus the simulated multi-domain system. The latter consists of an electrical grid section, energy resources, aggregators, a dispatch unit, a service requester (DSO) and an ICT command and control infrastructure. The electrical grid section is a part of a LV and/or Medium Voltage (MV) distribution grid (e.g. 0.4kV and 10kV) with a number of flexible DERs units distributed across one or multiple feeders. The ICT infrastructure includes three separate control entities (dispatch unit, aggregator and DERs controller) as well as a wide area communication network between these entities.
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.	The FuT consists of the FuI (Multi-domain simulation of coupled AC+ICT systems) as well as the following functions of the simulated system: • Communication fault detection and impact mitigation • Coordinated congestion management, consisting of an algorithm for congestion management as well as the communication between units needed to implement the algorithm (i.e. between unit controllers and aggregators and between aggregators and dispatch unit) • Aggregator internal dispatch mechanism, consisting of portfolio management and unit dispatch • Unit controller functionality, consisting of local flexibility calculation and management

	• A dispatch mechanism for aggregators, executing on the dispatch unit. • A congestion detection method, emulating the determination of service requirements by a DSO.
Test criteria: Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.	The expected accuracy of the simulation is currently unknown in relation to a laboratory setup. Therefore, the test focuses on a quantification of the accuracy, and to identify factors influencing the achievable accuracy. A challenge in determining overall accuracy are the strongly different time scales of the two domains. The test criteria are therefore designed to compare overall system performance rather than the performance of subsystems or individual domains. • TCR1: Deviation of service delivered from service requested (long-term performance) • TCR2: Time to restore steady-state operation after a failure event in the communication domain (nonresponsive aggregator) • TCR3: Time to restore steady-state operation after a failure event in the electrical domain (failure of controllable resource)
target metrics Measures required to quantify each identified test criteria	TCR1: • Overall integral error [kWh] • Maximum overall service deviation [kW] • Mean overall service deviation [kW] • Maximum individual integral error [kWh] • Maximum individual service deviation [kW] TCR2: • Time from occurrence to detection of communication failure [ms] • Time from detection of communication failure to end of distribution of new setpoints to unit controllers [ms] • Time from reception of new setpoints at unit controllers to (physical) service restoration [ms] TCR3: • Time from occurrence to detection of electrical equipment failure [ms] • Time from detection of electrical equipment failure to end of distribution of new setpoints to unit controllers [ms] • Time from reception of new setpoints at unit controllers to (physical) service restoration [ms]
variability attributes controllable or uncontrollable factors and the required variability; ref. to PoI.	Controllable factors: • Duration of communication failure [100 ms to permanent] • Variability of baseload profile [0 to 100% of mean baseload] • Round-trip communication latency in the wide-area sections of the network [10...200 ms]
quality attributes threshold levels for test result quality	Confidence in the accuracy and synchronicity of time measurements (accuracy better than 1 ms, clock synchronicity bet-

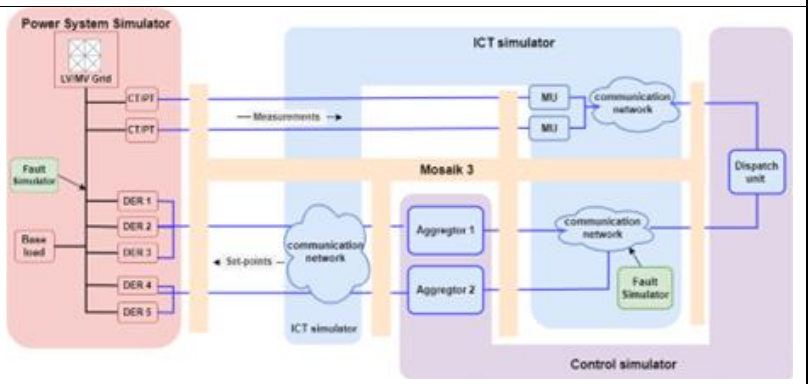
	as well as pass/fail criteria.	ter than 100 µs)

Qualification Strategy



• The simulated system can be excited in two ways, by events (e.g. equipment failure or limit violations) on the communication side or by events on the electrical network side. It is assumed that both types of events need to be tested against since they will result in different dynamics due to the unequal strength of the domain coupling between the two simulated domains. The differences in the setup for the triggering event require two different test specifications.
• Each test will require two experiments – one with a simulated system, and the other one with a physical lab setup. This results in a total of four experiment specifications.

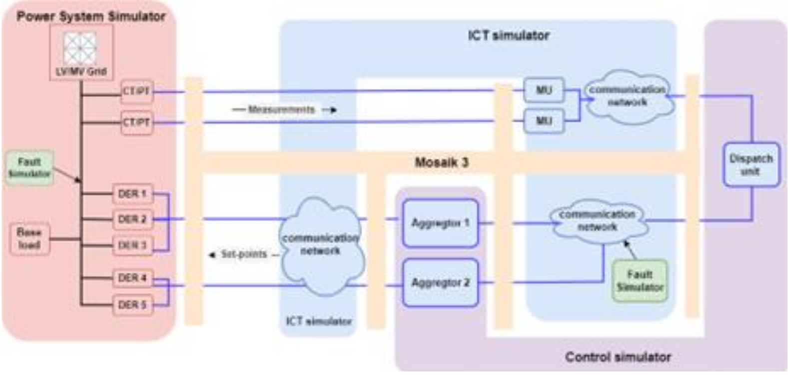
Test Specification D5.1

Reference to Test Case	*TC-17*
Title of Test	***Communication failure***
Test Rationale	*The test will establish the performance of the multi-aggregator system simulated by the co-simulation setup in comparison to the physical system test of a similar setup, when a communication failure is introduced. The communication failure will disrupt the flow of information between one of the aggregators and the dispatch unit.*
Specific Test System (graphical)	

Target measures	*Active power measurements:* *• Pr,i(t) as the requested service and* *• Pd,i(t) as the delivered service for each network segment I =1..n:* *Time measurements:* *• T0: the time of occurrence of a failure event* *• T1: Time at which new service requests are generated* *• T2: Time at which new setpoints are sent/received*
Input and output parameters	*Input:* *• Load profile (time series)* *• Communication delay and jitter* *Output:* *• Active power and time measurements*
Test Design	*The system starts with stable operation where the generation matches the consumptions.* *A small variation of the dynamic load is introduced that requires the dispatch and aggregators to respond by sending new service request/setpoints to the DERs controllers.* *A communication system failure is initiated, and the target measures will be recorded until a new equilibrium point is reached. This may be repeated for different type and location of faults.* *The above process/test will be conducted using both co-simulation and hardware-based experiments.*
Initial system state	*The system is initialised where the loads are kept constant, and no failure is introduced to the power or ICT system.*
Evolution of system state and test signals	*The system starts with its initial stage as presented above.* *At T1 and onwards, a small variation in the dynamic load is introduced that will continually initiate new service requests from the dispatch to the aggregators and new setpoints from aggregators to DERs controllers.* *At T2, to initiate more interaction between ICT and power system, a communication system tigering event/failure is introduced by removing one of the line of communication between the dispatch and aggregators.*
Other parameters	*Communication delay, time to resend service requests or frequency of heartbeat signals (between Dispatch - Aggregator - DERs controller)*
Temporal resolution	*0.1 ms for ICT and 1 s for Power system*
Source of uncertainty	*n/a*
Suspension criteria / Stopping criteria	*Stopping criteria: Elapsed time (fixed length experiment)*

Test Specification D5.2

Reference to Test Case	*TC-17*
Title of Test	***Grid event/power system failure***
Test Rationale	*The test will establish the performance of the multi-aggregator system simulated by the co-simulation setup in comparison to the physical system test of a similar setup, when a power system disturbance event/ failure is introduced. The grid disturbance event can be either a sudden increase in demand or a power system failure which will be large enough to require a rescheduling action by the dispatch/ aggregator system in order to ensure continued delivery of the service.*

Specific Test System (graphical)	
Target measures	*Active power measurements:* *• Pr,i(t) as the requested service and* *• Pd,i(t) as the delivered service for each network segment I =1..n:* *Time measurements:* *• T0: the time of occurrence of a failure event* *• T1: Time at which new service requests are generated* *• T2: Time at which new setpoints are sent/received*
Input and output parameters	*Input:* *• Load profile (time series)* *• Communication delay and jitter* *Output:* *• Active power and time measurements*
Test Design	*The system starts with stable operation where the generation matches the consumptions.* *A power system disturbance event / failure is initiated, and the target measures will be recorded until a new equilibrium point is reached.* *This may be repeated for different type and location of faults.* *The above process/test will be conducted using both co-simulation and hardware-based experiments.*
Initial system state	*The system is initialised where the loads are kept constant, and no failure is introduced to the power or ICT system.*
Evolution of system state and test signals	*The system starts with its initialized. At t1, to initiate more interaction between ICT and power system, a power system triggering event/failure is introduced by adding a load to emulate loss of supply/generation.*
Other parameters	*Communication delay, time to resend service requests or frequency of heartbeat signals (between Dispatch - Aggregator - DERs controller)*
Temporal resolution	*1 ms*
Source of uncertainty	*n/a*
Suspension criteria / Stopping criteria	*Stopping criteria: Elapsed time (fixed length experiment)*

Mapping to Research Infrastructure

The test specifications are implemented in several Quasi-Static PHIL (QS-PHIL) experiments in order to exploit them geographically separated over several research facilities.

Experiment Specification ES.D5.1

Reference to Test Specification	*TS #1 – D5.1*
Title of Experiment	*Simulated system, communication failure*
Research Infrastructure	NSGL (SINTEF) and Syslab (DTU)
Experiment Realisation	The simulation will be realized using the Mosaik 3 and FMI 3 based co-simulation framework developed in ERIGRId 2 - JRA 2. The test will be conducted on one machine (PC) where all the power and ICT simulators, control functions and the Mosaik framework runs.
Experiment Setup (concrete lab equipment)	The power system is simulated and the ICT will be simulated using NS3. FMI3 will be used for interfacing the power and ICT simulators and Mosaik for an orchestration. The control algorithms will be implemented in python within the Mosaik framework.
Experimental Design and Justification	*The test will establish the performance of the multi-aggregator system as simulated by the co-simulation setup, when a communication failure is introduced. The communication failure will disrupt the flow of information between one of the aggregators and the dispatch unit.*
Precision of equipment and measurement uncertainty	• Acquisition time and jitter of delay measurements
Storage of experiment data	*n/a*

Experiment Specification ES.D5.2

Reference to Test Specification	*TS #1 – D5.1*
Title of Experiment	*Physical system, communication failure*
Research Infrastructure	NSGL (SINTEF) and Syslab (DTU)
Experiment Realisation	It will be a single RI experiment where the whole system will be implemented in hardware and/ partly emulation in each laboratory.
Experiment Setup (concrete lab equipment)	• LV distribution grid in NSGL or Syslab • Measurement instruments - (CT/PT, MUs) • The dispatch and aggregator controllers will be implemented as Python algorithms running on a PC • IEC 61850 based communication for collecting measurements from the distribution grid • An emulation of the Wide Area Network (WAN) using mininet will be used for the communication between measurement units to DSO dispatch, DSO dispatch to aggregators and aggregators to DERs controllers.
Experimental Design and Justification	*The test will establish the performance of the multi-aggregator system as simulated by the co-simulation setup, when a communication failure is introduced. The communication failure will disrupt the flow of information between one of the aggregators and the dispatch unit.*
Precision of equipment and measurement uncertainty	• Acquisition time and jitter of delay measurements • Setpoint keeping precision of DERs components in the laboratory
Storage of experiment data	*n/a*

Experiment Specification ES.D5.3

Reference to Test Specification	*TS #1 – D5.2*
Title of Experiment	*Simulated system, grid event*
Research Infrastructure	NSGL (SINTEF) and Syslab (DTU)
Experiment Realisation	The simulation will be realized using the Mosaik 3 and FMI 3 based co-simulation framework developed in ERIGRId 2 - JRA 2. The test will be conducted on one machine (PC) where all the power and ICT simulators, control functions and the Mosaik framework runs.
Experiment Setup (concrete lab equipment)	The power system is simulated and the ICT will be simulated using NS3. FMI3 will be used for interfacing the power and ICT simulators and Mosaik for an orchestration. The control algorithms will be implemented in python within the Mosaik framework
Experimental Design and Justification	*The test will establish the performance of the multi-aggregator system as simulated by the co-simulation setup, when a power disturbance event is introduced. The power disturbance event will trigger a rescheduling action by the dispatch/aggregator system in order to ensure continued delivery of the service.*
Precision of equipment and measurement uncertainty	• Acquisition time and jitter of delay measurements
Storage of experiment data	*n/a*

Experiment Specification ES.D5.4

Reference to Test Specification	*TS #1 – D5.2*
Title of Experiment	*Physical system, grid event*
Research Infrastructure	NSGL (SINTEF) and Syslab (DTU)
Experiment Realisation	It will be a single RI experiment where the whole system will be implemented in hardware and/ partly emulation in each laboratory.
Experiment Setup (concrete lab equipment)	• LV distribution grid in NSGL or Syslab • Measurement instruments - (CT/PT, MUs) • The dispatch and aggregator controllers will be implemented as Python algorithms running on a PC • IEC 61850 based communication for collecting measurements from the distribution grid • An emulation of the WAN using mininet will be used for the communication between measurement units to DSO dispatch, DSO dispatch to aggregators and aggregators to DERs controllers.
Experimental Design and Justification	*The test will establish the performance of the multi-aggregator system as simulated by the co-simulation setup, when a power disturbance event is introduced. The power disturbance event will trigger a rescheduling action by the dispatch/aggregator system in order to ensure continued delivery of the service*
Precision of equipment and measurement uncertainty	• Acquisition time and jitter of delay measurements • Setpoint keeping precision of DERs components in the laboratory
Storage of experiment data	*n/a*