Test Case 4

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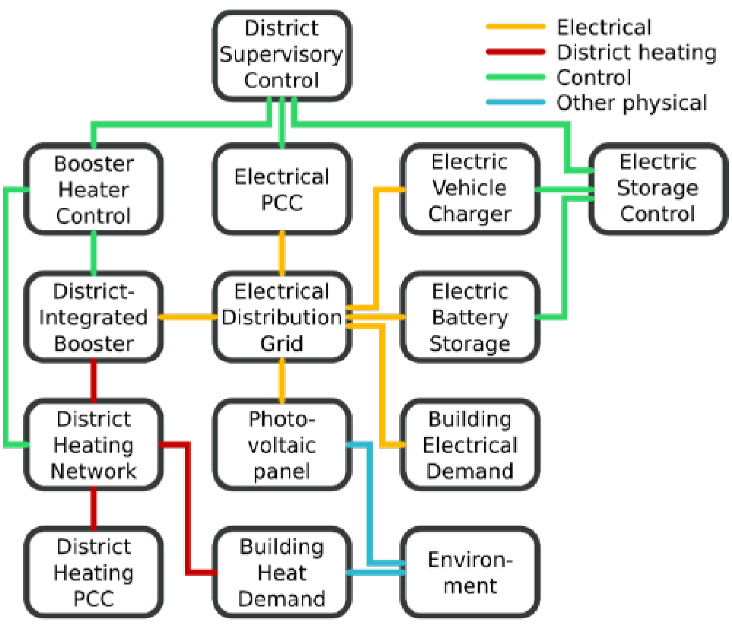
Name of the Test Case	Multi-Energy District Flexibility
Narrative	This test aims to investigate the power-to-heat service provision in a local multi-energy district and its impact on the electric and thermal networks. The flexibility requested by the DSO can be provided by a combination of electric and thermal storage systems as well as flexible controllable loads, such as Heat Pumps, Thermal Loads, Electric Boilers, etc.
Function(s) under Investigation (*FuI*) "the referenced specification of a function realized (operationalized) by the object under investigation"	The heating system provides services to the electrical system (a) congestion management - electrical import and export limitation; and (b) regulating power provision.
Object under Investigation (*OuI*) "the component(s) (1..n) that are to be qualified by the test"	The characterization concerns the Centralized Supervisory Controller (CSC) of a local multi-energy system.
Domain under Investigation (*DuI*): "the relevant domains or sub-domains of test parameters and connectivity."	• Electrical domain • Thermal domain • Control and ICT systems
Purpose of Investigation *(PoI)* The test purpose in terms of Characterization, Verification, or Validation	Verification of the impact of local flexibility on available regulating power from a local district.
System under Test (*SuT*): Systems, subsystems, components included in the test case or test setup.	 "PCC" denotes the point of common coupling for the district to the external networks. All units connected downstream of the

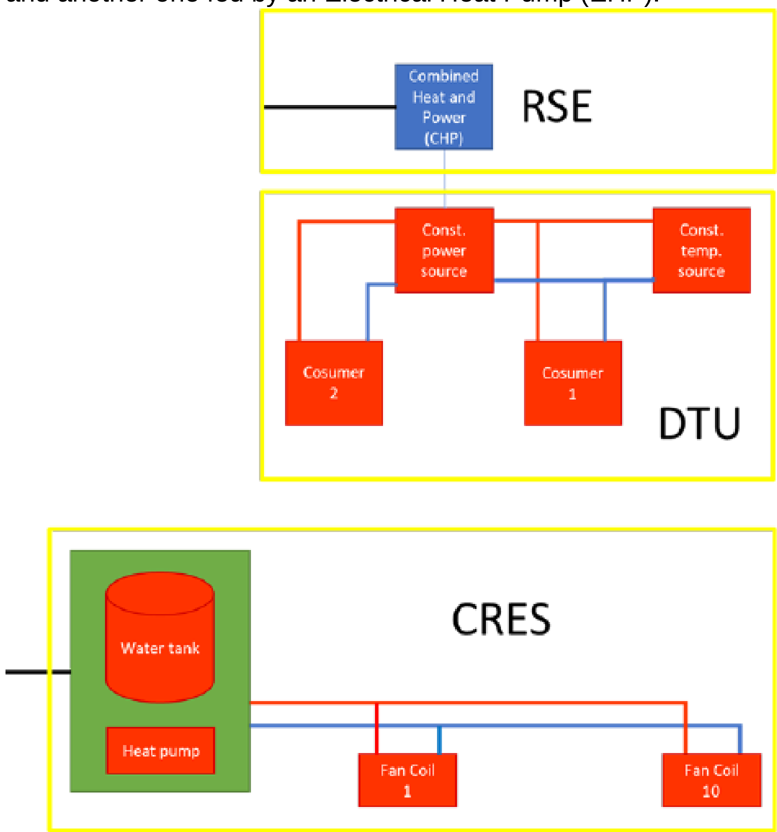
	respective PCCs must be considered.
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.	• P-f and Q-v control of single devices. • Local district CSC • Services provision by the CSC
<u>Test criteria</u>: Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.	The TCR (test criteria) aims to verify the ability of the local district to provide services to the electric network: • Congestion management • Active power control at the electric network PCC • Regulating power provision
target metrics Measures required to quantify each identified test criteria	The measure required: • **electrical energy bound violation [MWh]**: given a limit P_k^{max} of a system component $k \in K$ (e.g. power line, power transformers, electric bus, etc.) at $t \in T' \subseteq T$, measure the energy violation as: $$E_k^{bound} = \sum_{t \in T'} (P_{k,t} - P_k^{max})^+$$ • **electrical energy balance deviation [MWh]:** given a set point P_{PCC}^{set} at the electric network PCC at $t \in T' \subseteq T$, measure the energy violation as: $$E_{set} = \sum_{t \in T'} \lvert P_{PCC,t} - P_{PCC,t}^{Set} \rvert$$
variability attributes controllable or uncontrollable factors and the required variability; ref. to PoI.	Controllable factors: • heat pumps set-point • electrical and thermal storage system set-point Uncontrollable factors: • demand (electrical and thermal) • PV generation
quality attributes threshold levels for test result quality as well as pass/fail criteria.	n/a

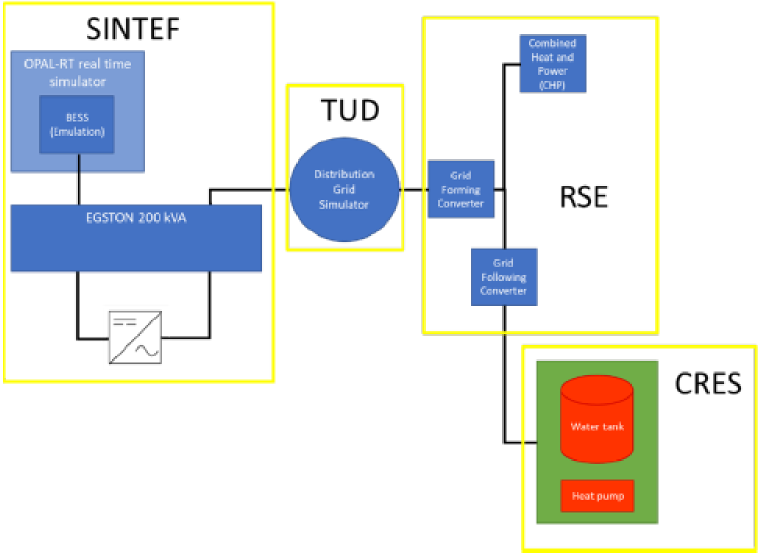
Qualification Strategy

The PoI is addressed through the implementation of a single Test Specification (TS1), which includes multiple RIs. A first phase (ES1) will verify the ERIGrid 2.0 extended research infrastructure capability and set-up the main experiments:
• ES2: Congestion management
• ES3: Active power control at the electric network PCC
• ES4: Regulating power provision

Test Specification D4.1

Reference to Test Case	*TC D4*

Title of Test	***CSC service provision verification.***
Test Rationale	*This test verifies the local district operation seeking to demonstrate that the CSC respond to a service request:* • *Congestion management* • *Active power control at the electric network PCC* • *Regulating power provision*
Specific Test System (graphical)	The system under test includes an electrical system, a district heating system and a control system. Each is sketched below. **Thermal system** The thermal system is composed by two subsystems, one connected to a District Heating Network (DHN) and interfaced to the electrical system through a Combine Heat and Power (CHP) and another one fed by an Electrical Heat Pump (EHP).  **Electrical system** The electrical system is composed by three main physical feeders and a simulated grid portion. The physical feeders connect a simulated BESS, a CHP and an EHP.

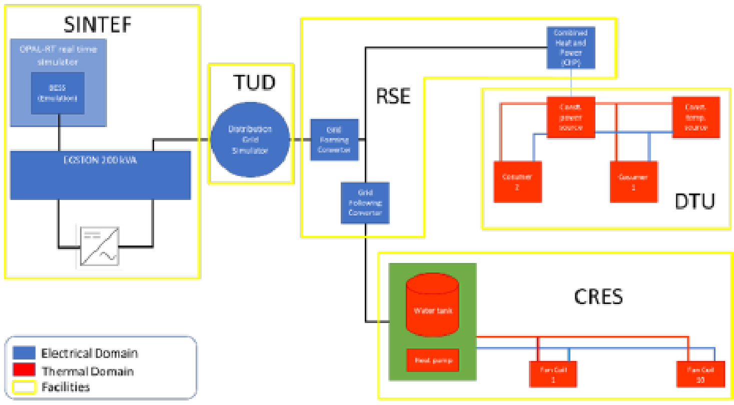
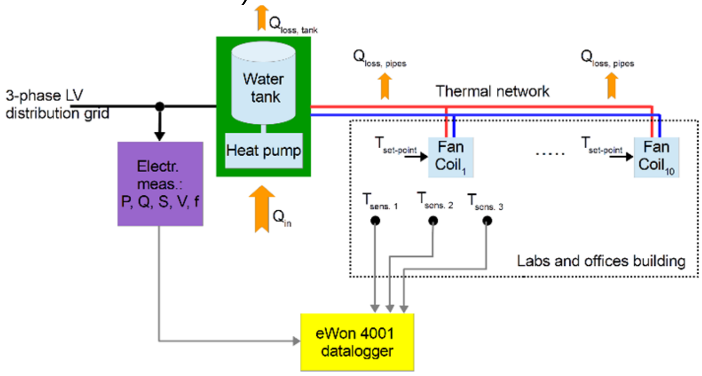
	 **Control domain coupling** Control system which determines the set-points for the controllable resources in order to provide the requested services.
Target measures	*See Test Case Template.*
Input and output parameters	*Input:* • *Electrical PCC voltage and frequency.* • *Set-point of the requested services.* • *Non programmable generation and demand profiles.* *Output:* • *Energy fluxes in the electrical and thermal networks [kW]* • *State of the electrical and thermal networks (in terms of voltage, current, in-jected active and reactive power, temperature, pressure, etc.)*
Test Design	*The test comprises three experiments, 2 hours of district operation each.* *During these 2 hours, in each experiment the CSC keeps the tem-perature* *at each load in a range from 70°C to 90°C, while one of these services to the electrical net-work is provided:* • *Congestion management* • *Active power control at the electric network PCC* *– for 09:30 to 10:00, keep district electrical consumption below Plimit, import [kW].* *– for 10:00 to 10:30, keep district electrical consumption above Plimit, export [kW].* *– for 10:30 to 11:00, keep district electrical consumption below Plimit, import [kW].* • *Regulating power provision* *– for 17:00 to 18:00, keep district electrical consumption equal to Ps,et [kW].*
Initial system state	• *each component is initialized to the state given in the associated dataset.* • *the battery and thermal storage state of charge is set to 50% of their nominal energy.* • *The thermal set-point of the CHP is such that its delivery tem-perature is Tset, CHP[°C].*
Evolution of system state and test signals	*The thermal system serves real-world load, that will be considered as exogenous disturbances. The thermal PCC temperature and pressure are considered as exogenous variables as well. The electrical loads, except the EHP, and the electrical generation, except the CHP, are simulated based on predetermined profiles.*

Other parameters	*n/a*
Temporal resolution	*The test is run at a fixed time step of 15 min.*
Source of uncertainty	*Since the exact electrical demand signal consists of a deterministic trend and a randomized factor, each "run" above should be repeated 10 times, with the mean and standard deviation of each target metric recorded.*
Suspension criteria / Stopping criteria	*n/a*

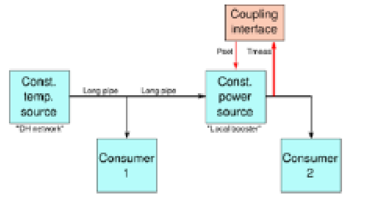
Mapping to Research Infrastructure

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

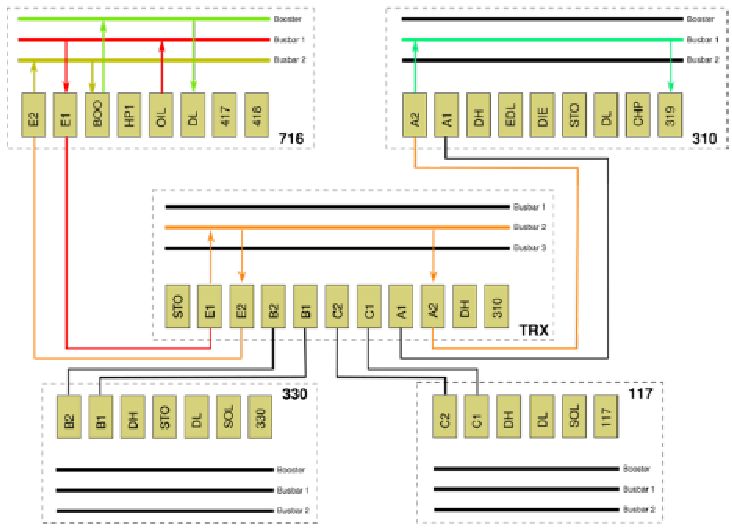
Experiment Specification ES.D4.1

Reference to Test Specification	*TS D4.1*
Title of Experiment	*Experimental Test Case and extended research infrastructure validation*
Research Infrastructure	RSE, CRES, DTU, TUD, SINTEF
Experiment Realisation	• Hardware interfaces • ICT interfaces design and implementation • Overall system functions validation
Experiment Setup (concrete lab equipment)	 **Heat Pump (CRES):** • Nominal capacity (electrical): S=18 kVA, P=16kW • Controllable variables: Operating state (on-off) • Measurement points: Active (kW)/Reactive (kVAr)/Apparent power (kVA), Active (kWh)/Reactive (kVArh) energy, Voltage (Line-to-line and Line-to-neutral) (V), Frequency (Hz), Indoor Temperature at 3 different points (oC) • Normal operating conditions: Indoor temperature 18 _ 22° • Maximum operating limits: Indoor temperature 15 _ 25° • Interfacing with other RIs: Currently, all measurements are collected and published on the Internet via an eWon 4001 datalogger, which is accessible in the following IP address: 195.251.43.80 (username and password are required). The current data resolution setting is 5min (averaging values) but higher sampling resolution is possible (eWon provides instantaneous values as well).  **Heat network (DTU):** • Coupling device is a stack of 9 electrical flow heaters of 2.5kW each (22.5kW total) which can be individually controlled through semiconductor relays. The heaters feed into a 200 l accumulator tank. The device can operate as a constant-power source by controlling the discharge of the tank via a remote-controllable feed pump. • Each of the lines E1, E2 has a length of about 400m (=1600m

	total for two lines w/ forward and return circuit each) • The load in the middle of the line is the controllable heating system (water-to-air heat exchangers) of a laboratory hall. • The load at the end of the line is a controllable heat dumpload. • Measurements at each bay: Tforward, Treturn flow, differential pressure • Distributed temperature measurements (forward+return) along each line, every 100 m.

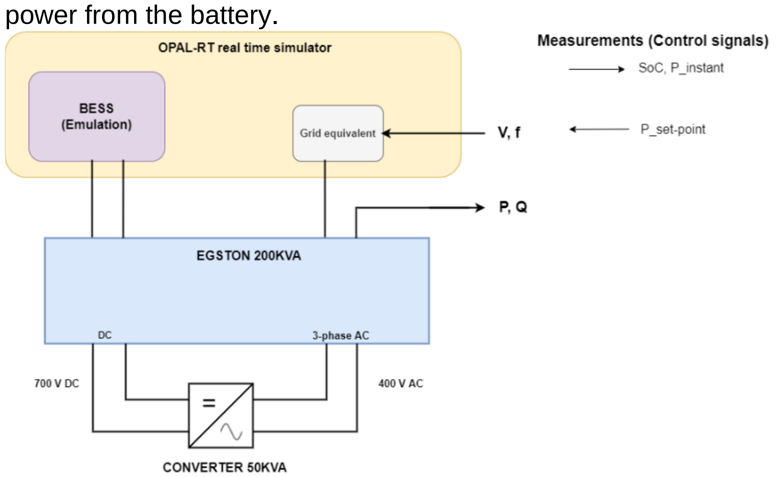


Scenario option 1: Temperature booster in the heat distribution network (enabling lower network feed-in temperatures while ensuring quality of supply at the most remote consumers / at the extremes of the network)



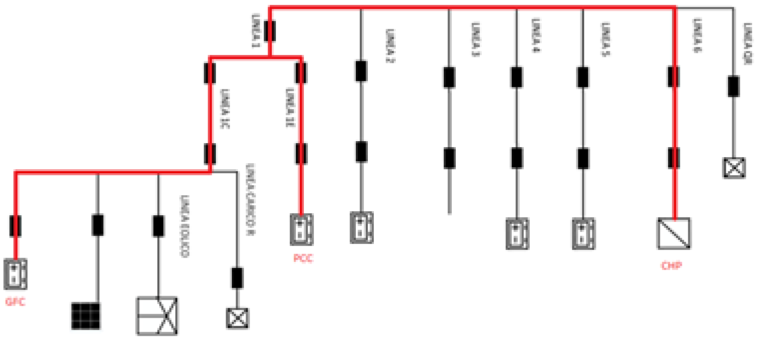
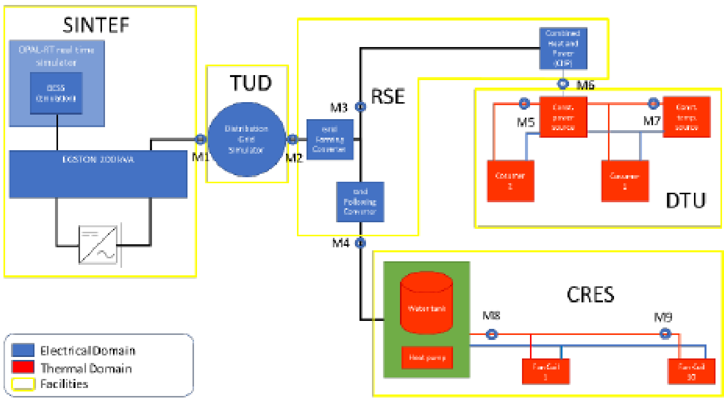
Energy Storage Systems (ESS) (SINTEF)

• Converter with a nominal capacity of 50KVA
• Power amplifier (200 KVA) with 700 V DC and 400 V AC ports
• BESS emulator
• Measurement points: the state of charge (SoC), instantaneous power from the battery.



CHP (RSE):

• CHP plant with a NG Internal combustion engine (50kWe,

<table>
<tr><td></td><td>81 kWth);
• 1 Bidirectional DC/AC Front-end-converter (30 kVA)
• 1 Bidirectional B2B converter (30 kVA)
• Three-phase LV grid

</td></tr>
<tr><td>Experimental Design and Justification</td><td>This test case aims to validate the capability of the extended research infrastructure for real-world multi-energy system experiments. The use of the extended research infrastructure increases the reality of the experiment by including real components and real-world user behavior.</td></tr>
<tr><td>Precision of equipment and measurement uncertainty</td><td>

• M1: Active power and voltage magnitude at the SINTEF facility;
• M2: Active power and voltage magnitude at the RSE facility;
<table>
<tr><th>Quantity</th><th colspan="3">% Full Scale</th></tr>
<tr><th></th><th>0-5 %</th><th>5-20 %</th><th>20-100 %</th></tr>
<tr><td>Voltage</td><td colspan="3">0.20%</td></tr>
<tr><td>Current</td><td>3.03%</td><td>1.55 %</td><td>1.08 %</td></tr>
<tr><td>Active Power</td><td>3.06%</td><td>1.62 %</td><td>1.17 %</td></tr>
<tr><td>Reactive Power</td><td>3.19 %</td><td>1.86 %</td><td>1.48 %</td></tr>
<tr><td>Apparent Power</td><td>3.06%</td><td>1.62 %</td><td>1.17 %</td></tr>
<tr><td>Frequency</td><td colspan="3">± 0.10 mHz</td></tr>
</table></td></tr>
</table>

	• M3: CHP active power (RSE); Same (M2) • M4: EHP active power (CRES); – Precision=0.01kW • M5-M7: Temperature and mass flow (DTU); • M6: CHP Temperature and mass flow (RSE); – Mass flow Accuracy: _ 0.5 kg/s – Temperature Accuracy: _ 0.2 K • M8-M9: Temperature and mass flow (CRES); – Temperature precision = 0.1 °C
Storage of experiment data	*Data of each facility will be stored in a separate database at the experiment temporal resolution with a common temporal reference.*

Experiment Specification ES.D4.2

Reference to Test Specification	*TS D4.1*
Title of Experiment	*Congestion management*
Research Infrastructure	RSE, CRES, DTU, TUD, SINTEF
Experiment Realisation	• Initlal conditions definition • Control system implementation • Experiment execution
Experiment Setup (concrete lab equipment)	See ES D4.1
Experimental Design and Justification	*This test case aims to demonstrate the ability of a multi-energy district to solve or mitigate congestion on the electric power distribution network.*
Precision of equipment and measurement uncertainty	See ES D4.1
Storage of experiment data	*See ES D4.1*

Experiment Specification ES.D4.3

Reference to Test Specification	*TS D4.1*
Title of Experiment	*Active power control at the electric network PCC.*
Research Infrastructure	RSE, CRES, DTU, TUD, SINTEF
Experiment Realisation	• Initlal conditions definition • Control system implementation • Experiment execution
Experiment Setup (concrete lab equipment)	See ES D4.1
Experimental Design and Justification	*This test case aims to demonstrate the ability of a multi-energy district to limit power absorption at the electric network PCC.*
Precision of equipment and measurement uncertainty	See ES D4.1
Storage of experiment data	*See ES D4.1*

Experiment Specification ES.D4.4

Reference to Test Specification	*TS D4.1*
Title of Experiment	*Balancing power provision.*
Research Infrastructure	RSE, CRES, DTU, TUD, SINTEF
Experiment Realisation	• Initlal conditions definition • Control system implementation • Experiment execution
Experiment Setup (concrete lab equipment)	See ES D4.1
Experimental Design and Justification	*This test case aims to demonstrate the ability of a multi-energy district to limit power absorption at the electric network PCC.*
Precision of equipment and measurement uncertainty	See ES D4.1
Storage of experiment data	*See ES D4.1*