Test Case 6
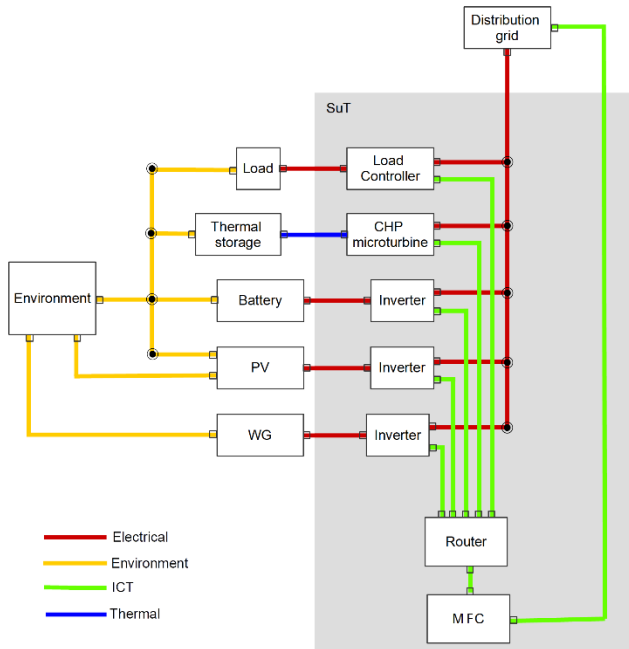
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Name of the Test Case	Evaluation of frequency restoration response in islanded power system
Narrative Incl. use case and test objectives.	One of the important functionalities of a microgrid is its ability to operate in islanded mode when the conditions of the system necessitate that. In such a mode the islanded microgrid should provide the functionalities to keep the frequency stable. With these functionalities the microgrid controllers (local and central) should contain frequency deviations and restore each deviation to zero from the nominal value. This test case examines the effectivity of the frequency restoration control of the microgrid under various operating conditions.
Function(s) under Investigation (*FuI*) "the referenced specification of a function realized (operationalized) by the object under investigation"	• Secondary/tertiary frequency control
Object under Investigation (*OuI*) "the component(s) (1..n) that are to be qualified by the test"	• Microgrid Frequency Controller (MFC)
Domain under Investigation (*DuI*) "the relevant domains or sub-domains of test parameters and connectivity."	• Electrical • ICT (time-delays) • Electrochemical • Thermal • Environmental
Purpose of Investigation *(PoI)* The test purpose in terms of Characterization, Verification, or Validation	• Validation of the controller/s for frequency stability and steady-state error elimination during restoration phase.

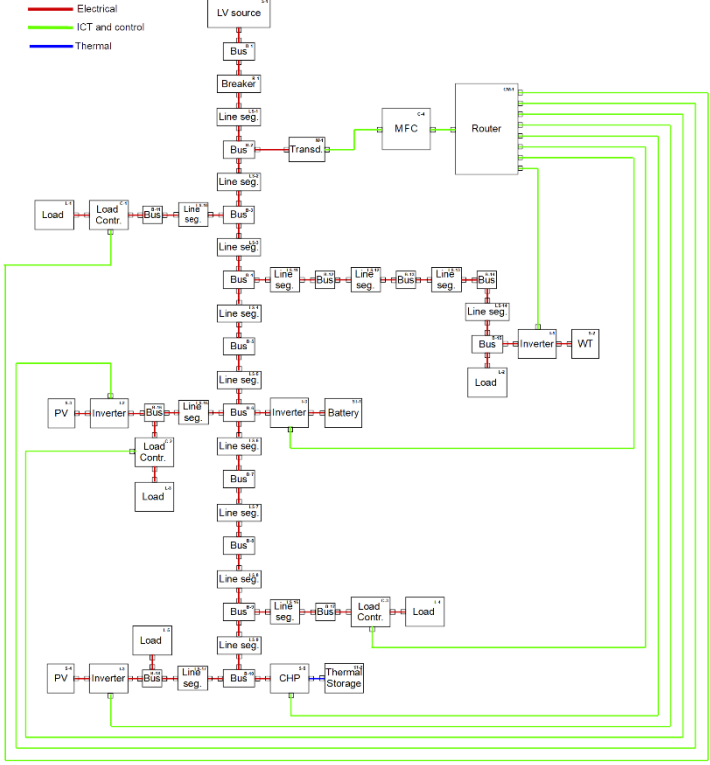|	
System under Test (*SuT*): Systems, subsystems, components included in the test case or test setup.	 The main components and subsystems that are of interest for this TC are depicted in the above diagram and summarized below: • Microgrid Frequency Controller (MFC) • Load Controllers • CHP microturbines • Battery inverters • RES inverters • Communication channels
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.	• Battery Management System (BMS) • Maximum Power Point Tracker (MPPT) • Inverter control (Grid Forming, Grid Following, Grid Supporting) • CHP control (Heat or Power Priority) • Load control • Supervisory Control and Data Acquisition (SCADA) • Energy Management System (EMS) • Local droop control • Local inertia control
Test criteria *(TCR)* Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.	• Frequency response
Target Metrics *(TM)* Measures required to quantify each	• Frequency Restoration time • Steady-state frequency deviation (after restoration)

identified test criteria	• Frequency oscillations damping factor (trumpet curve) • Remaining reserves (power/energy) • DERs curtailment • Loads curtailment
Variability Attributes *(VA)* controllable or uncontrollable factors and the required variability; ref. to PoI.	Fully Controllable attributes: • Grid topology • Droop control parameters • Inverters control functionalities Partly Controllable attributes: • Loads active/reactive power • Generators active/reactive power Uncontrollable attributes: • Solar irradiation • Wind speed • Ambient temperature • ICT and control delays

Quality Attributes *(QA)*
threshold levels for test result quality as well as pass/fail criteria.
	• Sampling time of signals (frequency and power flows): 100ms
	• Resolution:
	    ○ frequency 0.05Hz,
	    ○ power 0.01 pu
	• Points of measurement:
	    ○ Frequency: at least 1 (at the point of common coupling)
	    ○ Power: 1 point for each resource connected at their electrical output
	• Size of imbalance disturbance: >20%
	• Environmental conditions:
	    ○ Enough solar irradiation and wind speed so that the combined RES portfolio produces at least 20% of its maximum power
	• State of Charge: between 35% and 90%
	• Load: at least 20%

Qualification Strategy

The selected PoI can be tackled by one Test Specification only in which only some input variables or system parameters need be changed over the test repetitions in order to achieve the desired results. In other words, aspects such as the main grid topology remain unchanged except for small reconfigurations. In our TC this topology is selected to be a LV distribution grid. Also, in order to validate the frequency response of the

islanded microgrid, no specific tests are prerequisite to determine parameters and variable values necessary to conduct the main test.

Test Specification TC6.TS1

Reference to Test Case	TC6
Title of Test	Validation of islanded microgrid ability to restore frequency deviations in a stable manner
Test Rationale	This test allows us to validate the ability of core components of the microgrid to effectively respond and tackle imbalances that result in frequency deviations. These core components include the MFC, the DER units that provide reserves as well as communication parts that can influence the stability of the control due to time delays.
Specific Test System (graphical)	 The above test system is based on the LV distribution network benchmark application example by CIGRE[1]
Target measures	• Restoration time <120s • Steady-state deviation: <0.1Hz • Reserves' availability: >20% • DERs curtailment: <30% • Loads curtailment: <5%
Input and output parameters	Input parameters • Solar irradiance • Wind speed • Ambient temperature • Load consumption • Breaker state Output parameters • Frequency • State-of-Charge • Power of Reserves

Test Design	The test considers several consecutive imbalances and frequency deviations. This is needed to sufficiently evaluate the capability of the frequency control system to cope with these incidents. It is possible that the initial state of the microgrid grid-connected with the exchange of power with the utility grid. At the beginning of the test the circuit breaker can be opened to isolate the microgrid and cause a disturbance in the power balance.
Initial system state	- The circuit breaker at the PCC is open. Alternatively, it can be opened right after the start of the test as a potential disturbance source. - The combination of the RES units should provide at least 20% of their nominal power. - The consumption of the loads should be at least 20% of the maximum consumption. - The battery SOC should be between 40 and 60% - The imbalance should be under 5%.
Evolution of system state and test signals	- The microgrid starts in islanded mode or in grid-connected mode. - Firstly, the system is sufficiently balanced so that a small number of reserves (ideally zero) are implemented and the frequency is nominal (50Hz). - One imbalance emerges which leads to significant frequency deviation and the consequent activation of a large part of reserves. - Subsequent disturbances emerge either before or after the restoration of frequency to its nominal value.
Other parameters	N/A
Temporal resolution	Monitoring quantities should have a maximum sampling time of 0.1s.
Source of uncertainty	- Environmental conditions - Consumers' demand - Grid parameters variability i.e., resistance/inductance ratio
Suspension criteria / Stopping criteria	The test should be suspended and restarted if one of the quality attributes described in the TC is not met. Also, suspension may be due to deviation from the desired initial conditions described above.

[1]CIGRE. Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources; CIGRE Task Force C6.04.02; CIGRE: Paris, France, 2009

Mapping to Research Infrastructure

Our final goal of the mapping step is to produce as many as possible among a number of different testing approaches. These approaches include: pure simulation of the system either as a monolithic or as a co-simulation approach. Real-time simulation, primarily in the form of CHIL (PHIL is also possible). Purely physical implementation where a mock-up of the benchmark grid is used in laboratory environment.