Test Case 10

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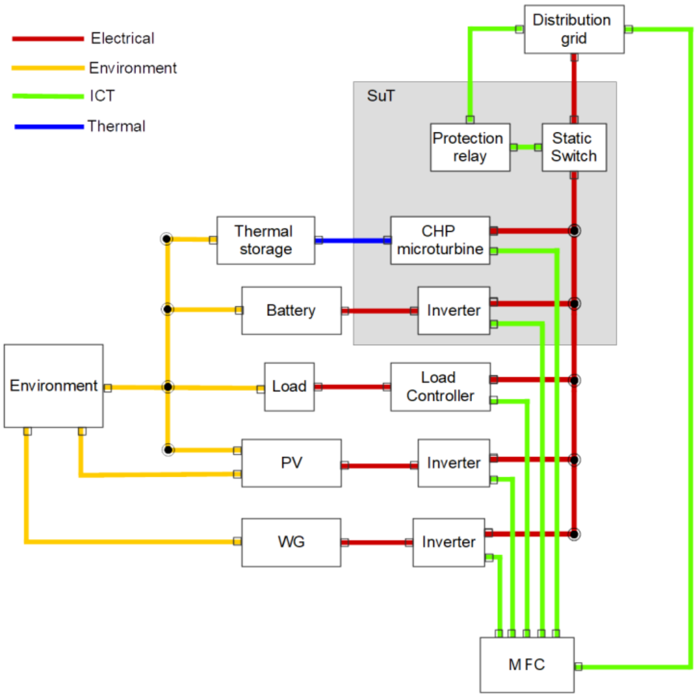
Name of the Test Case	Evaluation of secure transition from grid-connected to islanded operation: Uninterruptible Power Supply
Narrative Incl. use case and test objectives.	One of the functionalities that a microgrid should accommodate is its ability to automatically switch from grid-connected to islanded mode. The scope of this functionality is to isolate the microgrid's customers from the local distribution grid when in the latter some disturbances appear. The transition from grid-connected to islanded mode should be made in a seamless way in order to eliminate loss of power supply on the microgrid consumer's side (Uninterruptible Power Supply) and it is based on an automatic switch that disconnects the microgrid at the point of common coupling (PCC) as well as on at least one DER unit that has the ability to form the grid voltage once connection to the upstream grid is lost.
Function(s) under Investigation (*FuI*) "the referenced specification of a function realized (operationalized) by the object under investigation"	• Over/under voltage detection • Over/under frequency detection • ROCOF detection • Primary voltage control • Primary frequency control
Object under Investigation (*OuI*) "the component(s) (1..n) that are to be qualified by the test"	• Protection relay • Static Switch • DER inverters
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 Uninterruptible Power Supply capability

<table>
<tr>
<td>System under Test (SuT):
Systems, subsystems, components included in the test case or test setup.</td>
<td>



The main components and subsystems that are of interest for this TC are depicted in the above diagram and summarized below:

Protection Relay
Static Switch
CHP microturbines
Battery inverters
Communication channels

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<td>Functions under Test (FuT)
Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.</td>
<td>

Microgrid Frequency Controller (MFC)
Battery Management System
MPPT
Load control
SCADA
Energy Management System

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<tr>
<td>Test criteria (TCR)
Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.</td>
<td>

Frequency response
Voltage response

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<td>Target Metrics (TM)
Measures required to quantify each identified test criteria</td>
<td>

Maximum Voltage deviations
Maximum frequency deviations
Maximum ROCOF
Response/stabilization time

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	Variability Attributes *(VA)* controllable or uncontrollable factors and the required variability; ref. to PoI.	Fully Controllable attributes: • Protection relay parameters • Droop control parameters • Inverter control functionalities Partly Controllable attributes: • Load active/reactive power • Generator active/reactive power Uncontrollable attributes: • Solar irradiation • Wind speed • Ambient temperature • ICT and control delays

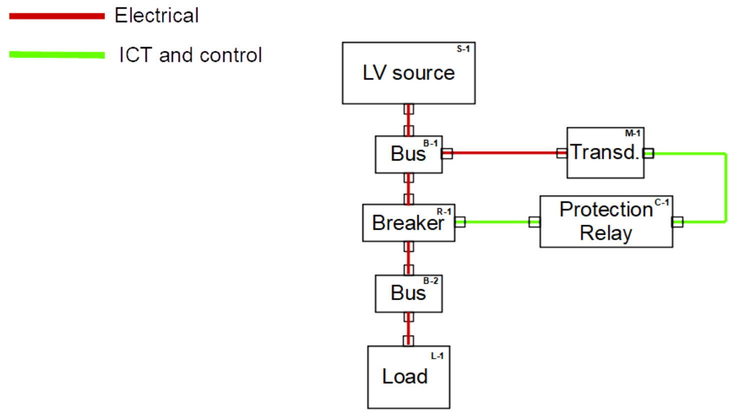
	Quality Attributes *(QA)*
	threshold levels for test result quality as well as pass/fail criteria.
		• Sampling time of signals (frequency, voltages): <1ms
		• Resolution:
		  o frequency 0.05Hz,
		  o voltage 0.005 pu
		• Points of measurement:
		  o Frequency: at least 1 (at the point of common coupling)
		  o Voltage: 1 point for each resource connected at their electrical output

Qualification Strategy

In order to meet the specific PoI, which is the evaluation of the microgrid's capability of UPS, three test specifications are required:
-One test is related to the protection equipment and its effective detection of disturbances in the upstream distribution grid. This test ensures that the combination of the protection relay and the static switch can adequately disconnect the microgrid when frequency disturbances appear. This test examines the response of the protection subsystem for various kinds of disturbances including over/underfrequency and increased ROCOF.
-The second test is related to the protection subsystem and its ability to detect voltage disturbances. The reason why this functionality is addressed separately than the frequency test is the different requirements in the test system topology. In the voltage test, specifically, the detailed microgrid topology is considered since it can affect the voltage level at the Point of Common Coupling.
-The third test is related to the response of the grid-supporting voltage source inverters of the microgrid after the disconnection. In principle, the test aims to assess the capability of these resources to maintain a voltage/frequency deviation within specific limits thanks to the primary control. The test is conducted under different initial conditions depending on the event that activates the protection equipment (for example, over/underfrequency).

Test Specification 10.01

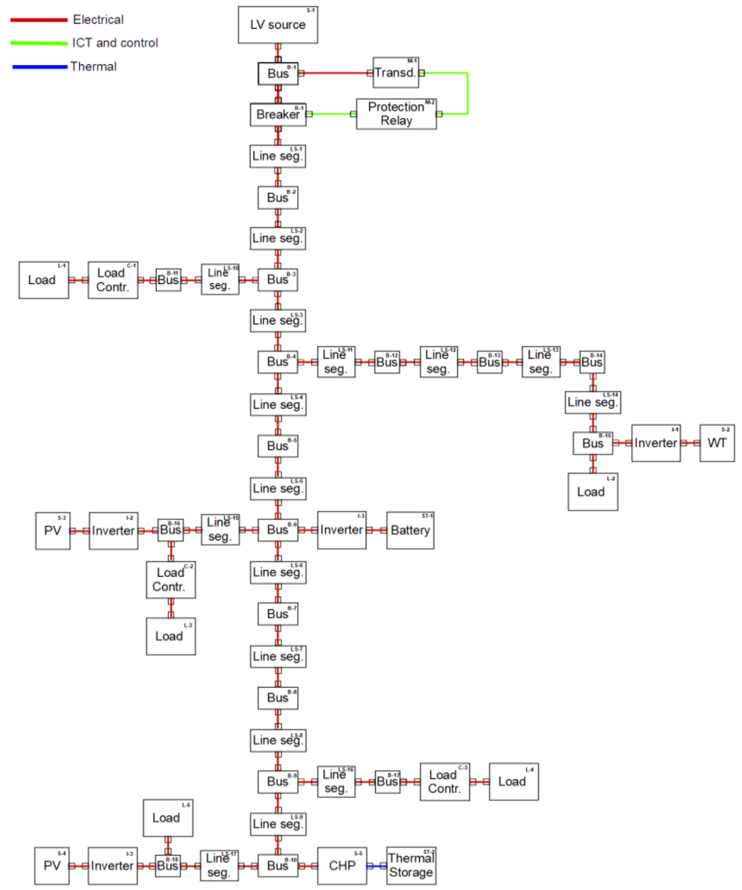
Reference to Test Case	TC10
Title of Test	Response of protection subsystem to various kinds of frequency disturbances
Test Rationale	This test is necessary in order to verify the protection relay's capability of detecting the specified disturbances as well as to verify that the response time of the static switch in disconnecting the

	microgrid is below a specified threshold.
Specific Test System (graphical)	 The above setup allows the evaluation of the frequency protection function with only one load in place of a detailed microgrid since frequency deviations are due to larger-scale disturbances in the transmission system.
Target measures	• Δf_{max}<±0.5Hz • $ROCOF_{max}$ <1Hz/s • Response time (Relay and Switch) <0.5s
Input and output parameters	Input parameters • Frequency • Load consumption • Relay state Output parameters • Breaker state • Load voltage
Test Design	The test is conducted into three distinct steps each of which tackles one frequency threshold (i.e., 50.5Hz, 49.5Hz, and ±1Hz/s). It is presumed that in between these steps the relay is reset to its initial state in order to allow for the detection of the next disturbance.
Initial system state	• The source frequency is within the operating limits i.e., 49.5Hz < f < 50.5Hz, and –1Hz/s < ROCOF <+1Hz/s). • The breaker (static switch) is closed, and therefore the load is supplied. • The protection relay is reset to its normal (initial) state
Evolution of system state and test signals	• The LV source frequency is monitored and, controlled in order to increase stepwise to the maximum allowable value of 50.5Hz. The time of this activation limit is recorded. • The protection relay detects the disturbance and activates a disconnection of the static switch. • The static switch disconnects the load from the LV source. The load voltage is monitored in order to detect the disconnection time and calculate the response time of the system. • The relay is reset and the static switch reconnects the load to the source. • The LV source is controlled to change its frequency stepwise to 49.5Hz. The time of this activation limit is recorded. • The protection relay detects the disturbance and activates a disconnection of the static switch.

	• The static switch disconnects the load from the LV source. The load voltage is monitored in order to detect the disconnection time and calculate the response time of the system. • The relay is again reset and the static switch reconnects the load to the source. • The LV source is controlled to change its frequency gradually upwards or downwards with a ROCOF equal to 1Hz/s. The time of this activation limit is recorded. • The protection relay detects the disturbance and activates a disconnection of the static switch. • The static switch disconnects the load from the LV source. The load voltage is monitored in order to detect the disconnection time and calculate the response time of the system.
Other parameters	N/A
Temporal resolution	A sampling time of <1ms is required for the accurate measurement of the protection time response
Source of uncertainty	Uncertainties that may appear in this test are due to the precision of the various instruments used to measure the voltage/frequency responses. Additional uncertainties may be introduced by the communication channel delays between the protection relay and the static switch.
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, if the frequency variations are well above the specified limits (i.e., 0.1Hz and 0.1Hz/s) the test should be discarded and repeated with the appropriate values.

Test Specification 10.02

Reference to Test Case	TC10
Title of Test	Response of protection subsystem to various kinds of voltage disturbances
Test Rationale	This test is an extension of TS10.01 in the sense that the protection subsystem is tested in terms of voltage limits. Due to the fact that the voltage at the PCC is determined by the local configuration of the microgrid, a detailed microgrid topology is used instead of one lumped load.

<table>
<tr><td>Specific Test System
(graphical)</td><td>


The above test system is based on the LV distribution network benchmark application example by CIGRE[1]</td></tr>
<tr><td>Target measures</td><td>

- ΔV_{max}=+15% to -20% of nominal voltage
- Response time (Relay and Switch) <0.5s
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<tr><td>Input and output parameters</td><td>Input parameters

- Voltage at PCC
- Power flow at PCC
- Relay state

Output parameters

- Breaker state
- Voltage at PCC
</td></tr>
<tr><td>Test Design</td><td>The test is conducted into two distinct steps each of which tackles one voltage threshold (i.e., +15% (265V) and -20% (184V). It is presumed that in between these steps the relay is reset to its normal state in order to allow for the detection of the next disturbance.</td></tr>
<tr><td>Initial system state</td><td>

- The source and the microgrid are operated in a way that leads to a voltage at the PCC within the protection limits i.e., $184V< V_{pcc} < 265V$.
- The breaker (static switch) is closed, therefore the microgrid exchanges power with the grid (voltage source).
- The protection relay is reset to its normal state
</td></tr>
<tr><td>Evolution of system state and test signals</td><td>

- At first the voltage at the PCC should be within the protection limits and the microgrid should be connected to the grid (LV source) and exchange power.
- Either the LV source or some of the microgrid units should
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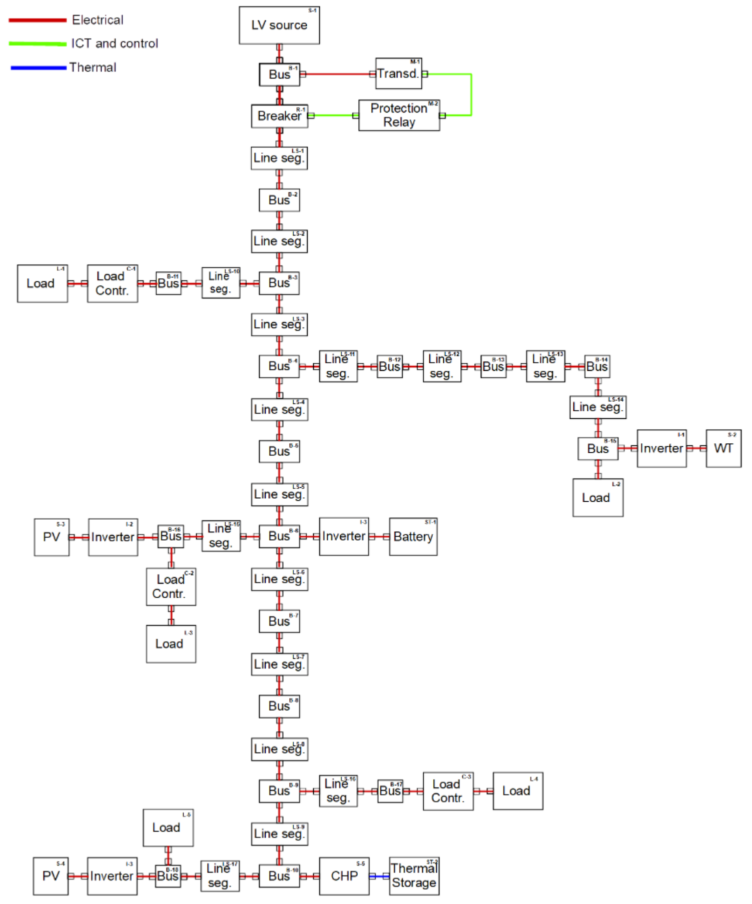
	be controlled in a way that allows the voltage at the PCC to increase towards the upper limit (15%). The time that the voltage crosses the limit is recorded. • The protection relay detects the disturbance and activates a disconnection of the static switch. • The static switch disconnects the microgrid from the LV source. The PCC voltage is monitored in order to detect the disconnection time and calculate the response time of the protection system. • The relay is reset and the static switch reconnects the microgrid to the source. • Either the LV source or some of the microgrid units should be controlled in a way that allows the voltage at the PCC to decrease towards the lower limit (-20%). The time that the voltage crosses the limit is recorded. • The protection relay detects the disturbance and activates a disconnection of the static switch. • The static switch disconnects the load from the LV source. The PCC voltage is monitored in order to detect the disconnection time and calculate the response time of the system.
Other parameters	N/A
Temporal resolution	A sampling time of <1ms is required for the accurate measurement of the protection time response
Source of uncertainty	Uncertainties may arise due to the precision of the various instruments used to measure the voltage responses. Additional uncertainties may be introduced by the communication channel delays between the protection relay and the static switch, as well as from the operation of the microgrid units that are subject to: • 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.

Test Specification 10.03

Reference to Test Case	TC10
Title of Test	Primary frequency and voltage response after disconnection
Test Rationale	Once the protection system intervenes to isolate the microgrid, the local DER controllers (voltage and frequency droop) react to the imbalance and try to stabilize the microgrid operation. The specific test aims at characterizing the simultaneous ability of the DER units (i.e., battery storage and CHP) to stabilize the voltage and frequency.

Specific Test System (graphical)	 In this TS the selected test system is the same with TS10.02 and is based on the LV distribution network benchmark application example by CIGRE[1]
Target measures	• ΔV_{max}=+15% to -20% of nominal voltage • Δf_{max}<±1Hz • $ROCOF_{max}$ <2Hz/s • Response time (frequency/voltage stabilization) <5s
Input and output parameters	Input parameters • Solar irradiance • Wind speed • Ambient temperature • Load consumption • Breaker state Output parameters • Frequency • Voltages
Test Design	The test considers one power imbalance that is caused from the disconnection of the breaker and the loss of power exchange to/from the grid. This imbalance will result in activation of the droop controllers and the possible subsequent stabilization. The same test will have to be repeated several times for five (5) different initial conditions depending on the type of disturbance.
Initial system state	There are five possible initial states for the system in terms of frequency and voltage values. All five of them, however, require that initially the microgrid is connected to the grid and that both the voltage at PCC and the frequency are within allowable limits.

	Once these conditions are met, each one of the five disturbances should be generated through the LV source.
Evolution of system state and test signals	1. The microgrid is running in parallel with the LV source with which exchanges some power 2. The LV source frequency is monitored and controlled in order to increase stepwise to the maximum allowable value of 50.5Hz. The time of this activation limit is recorded 3. The protection relay detects the disturbance and activates a disconnection of the static switch 4. The static switch disconnects the microgrid from the LV source 5. The frequency at the PCC and the Voltage at multiple points of the microgrid are monitored in order to estimate the response time from the protection activation to the new steady-state 6. The relay is reset and the static switch reconnects the load to the source 7. Step 2 is repeated with the frequency setting at 49.5Hz 8. Steps 3-6 are repeated 9. Step 2 is repeated with the frequency setting at ROCOF=1Hz/s 10. Steps 3-6 are repeated 11. Either the LV source or some of the microgrids units should be controlled in a way that allows the voltage at the PCC to increase towards the upper limit (15%). The time that the voltage crosses the limit is recorded. 12. The protection relay detects the disturbance and activates a disconnection of the static switch 13. The static switch disconnects the microgrid from the LV source 14. Frequency at the PCC and Voltage at multiple points of the microgrid are monitored in order to estimate the response time from the protection activation to the new steady-state 15. The relay is reset and the static switch reconnects the microgrid to the source 16. Either the LV source or some of the microgrids units should be controlled in a way that allows the voltage at the PCC to increase towards the lower limit (-20%). The time that the voltage crosses the limit is recorded. 17. The protection relay detects the disturbance and activates a disconnection of the static switch 18. The static switch disconnects the microgrid from the LV source 19. Frequency at the PCC and Voltage at multiple points of the microgrid are monitored in order to estimate the response time from the protection activation to the new steady-state
Other parameters	N/A
Temporal resolution	A sampling time of <1ms is required for the accurate measurement of the total system response
Source of uncertainty	Uncertainties that may arise due to the precision of the various instruments used to measure the voltage responses. Additional uncertainties may be introduced by the communication channel delays between the protection relay and the static switch, as well as from the operation of the microgrid units that are subject to: • Environmental conditions • Consumers' demand • Grid parameters variability i.e., resistance/inductance ratio
Suspension criteria / Stopping	The test should be suspended and restarted if one of the quality

criteria	attributes described in the TC is not met.

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