Test Case 02

Author: Alexandros G.Paspatis, Alkistis Kontou Version: 2
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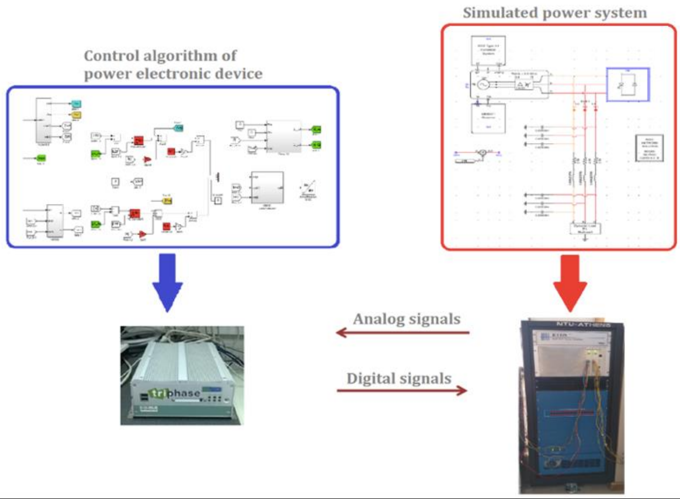
Name of the Test Case	Complying with the fault-ride-through (FRT) requirements in inverter-based droop-controlled microgrids
Narrative	An inverter-based microgrid is considered, with inverter-interfaced distributed energy resources (DERs) operating in parallel to feed the microgrid load. At some point, a network fault occurs, either inside the microgrid (when considering an islanded microgrid) or at the main grid (when considering a grid-connected microgrid). Through the control design of the inverter-interfaced distributed energy resources, power sharing is achieved between the multiple inverters during normal grid conditions. In this way, all inverters are equally stressed while the voltage and frequency of the microgrid are regulated close to their nominal values (droop control operation). Furthermore, when the network fault occurs, the inverters inject power according to the international standards to provide grid voltage support.
Function(s) under Investigation (*FuI*) “the referenced specification of a function realized (operationalized) by the object under investigation”	Power sharing in inverter-based microgrids and grid voltage support from inverters, during grid faults
Object under Investigation (*OuI*) "the component(s) (1..n) that are to be qualified by the test”	Inverter-interfaced distributed energy resources controllers
Domain under Investigation (*DuI*): “the relevant domains or sub-domains of test parameters and connectivity.”	Electrical Power
Purpose of Investigation *(PoI)* The test purpose in terms of Characterization, Verification, or Validation	• Transition to future smart-grids, where inverter-interfaced DERs provide multiple ancillary services • Characterization and validation of the SuT • Verification and validation of the OuI • Verification and validation of the FuT
System under Test (*SuT*): Systems, subsystems, components included in the test case or test setup.	An inverter-based microgrid consisting of multiple inverter-interfaced distributed energy resources (DERs), lines, loads, etc.
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and	A unified inverter controller that incorporates droop control and fault-ride-through techniques.

relevant interactions btw. OuI and SuT.	
<u>Test criteria</u> *(TCR)* Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.	Microgrid operation according to the designed control algorithm
Target Metrics *(TM)* Measures required to quantify each identified test criteria	1. Is power sharing achieved according to the droop control technique? 2. Is voltage support provided to the grid when grid faults occur according to the international standards?
Variability Attributes *(VA)* controllable or uncontrollable factors and the required variability; ref. to PoI.	1. Different microgrid loading 2. Different grid faults
Quality Attributes *(QA)* threshold levels for test result quality as well as the definition of a decision rule such as pass/fail criteria.	1. During the normal operation, the acceptable load voltages values should be inside the ±5% of the nominal voltage and the acceptable frequency values should be inside ±1% of the nominal frequency 2. Reactive power injection during grid faults, as a percentage of S_{max} 3. Inverter currents below their maximum threshold I_{max}

Qualification Strategy

The major ancillary services required from inverter-interfaced DERs during i) normal operation (droop control) and ii) during grid faulty operation (fault-ride-through) will be investigated through a single test where the inverters are equipped with the appropriate smart control algorithms.

Test Specification 02.01

Reference to Test Case	*02*
Title of Test	***Complying with the fault-ride-through (FRT) requirements while maintaining power sharing***
Test Rationale	*N/A*
Specific Test System (graphical)	

Target measures	*Inverter power injection, load voltage and frequency, inverter currents*
Input and output parameters	*Input:* • *Load* • *Inverter power injection set-points* • *Grid conditions* *Output:* • *Power, voltage, current and frequency measurements*
Test Design	1. *Operate multiple inverters in parallel* 2. *Perform a network fault when the microgrid operates either in islanded (non-interconnected) mode or in grid-connected mode* 3. *Save the experimental results*
Initial system state	• *Inverter controllers enabled* • *Hardware or simulated network and devices up and running* • *Computer displaying and saving data*
Evolution of system state and test signals	*The system goes from normal operation (operation close to nominal voltage and frequency) to operation under grid faults, to test the inverter control algorithms*
Other parameters	*N/A*
Temporal resolution	*N/A*
Source of uncertainty	*Impedance of load and lines, inverter sensors operation*
Suspension criteria / Stopping criteria	*Abnormal current/ power injections from inverters*

Mapping to Research Infrastructure

Experiment Specification 02.01.01

Reference to Test Specification	*02.01*
Title of Experiment	*Hardware-in-the-Loop for inverter controller validation in real conditions*
Research Infrastructure	Electric Energy Systems (ICCS-NTUA)
Experiment Realisation	Multiple inverters forming a microgrid, both through hardware setup and through simulated components in the RTDS
Experiment Setup (concrete lab equipment)	1. Real Time Digital Simulator (RTDS) 2. PC for RSCAD (UI of RTDS) 3. Hardware controller (Triphase) 4. Interfacing I/O cards
Experimental Design and Justification	• In RSCAD an inverter-based microgrid will be designed. The inverters will be simulated as controlled voltage sources to facilitate testing of the control scheme under faults. • FRT curve according to Grid Codes, will be used. • A hardware controller will be connected to RTDS to perform CHIL experiments and validate the control algorithm under real conditions.
Precision of equipment and measurement uncertainty	Software real-time measurements from RTDS, 50μs simulation step
Storage of experiment data	*Matlab files and Excel files*