Test Case 4

Author: A. Paspatis, A. Kontou, A. F. Cortés Borray, Julia Merino
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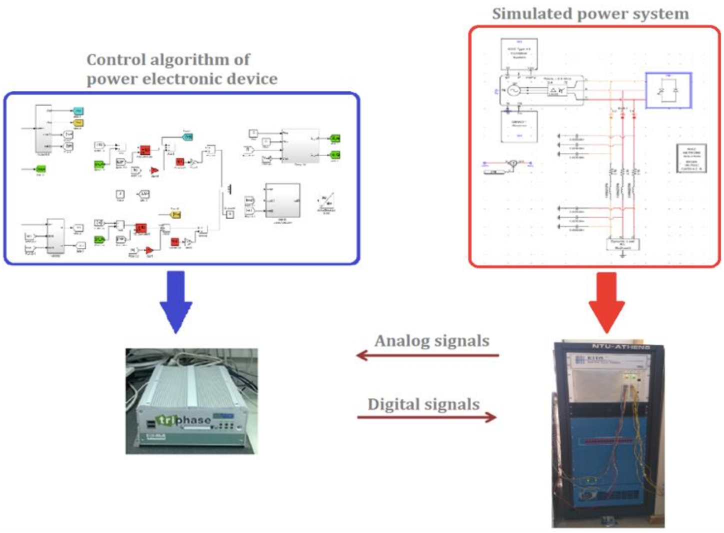
Name of the Test Case	Investigation of different voltage control techniques for inverter-interfaced DERs in microgrids
Narrative	A microgrid with inverter-interfaced distributed energy resources (DERs) is considered. In order to respect the system regulations and successfully feed the microgrid load, the voltage across the microgrid needs to be regulated close to its nominal value. Through the control design of the inverter-interfaced distributed energy resources, different control schemes are investigated. In particular i) master-slave voltage control, ii) conventional droop grid-forming control and iii) inverse droop grid-forming control.
Function(s) under Investigation (*FuI*) “the referenced specification of a function realized (operationalized) by the object under investigation”	Voltage regulation in a microgrid with inverter-interfaced DERs
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 Control systems
Purpose of Investigation *(PoI)* The test purpose in terms of Characterization, Verification, or Validation	Comparison of different voltage control schemes
System under Test (*SuT*): Systems, subsystems, components included in the test case or test setup.	A microgrid that hosts multiple inverter-interfaced distributed energy resources, lines, loads, etc.
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.	Different voltage control schemes to achieve microgrid load voltage regulation
Test criteria *(TCR)* Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output	Microgrid operation according to the designed control algorithm

measures.	
Target Metrics *(TM)* Measures required to quantify each identified test criteria	1. Voltage measured at the output of the inverter (Is proper voltage regulation achieved?) 2. Number of interruptions (Is continuity of service achieved after a sudden change in the demand and/or output of RES, or a generator outage?) 3. Overall performance (What are the advantages and disadvantages of each technique?)
Variability Attributes *(VA)* controllable or uncontrollable factors and the required variability; ref. to PoI.	1. Different microgrid loading 2. Different line impedance nature (i.e., resistive or inductive or complex)
Quality Attributes *(QA)* threshold levels for test result quality as well as pass/fail criteria.	Microgird voltages inside the ±5% of the nominal voltage / Successful

Qualification Strategy

The most common voltage control algorithms for inverter-based microgrids will be validated through three tests, one for each control technique, where the inverters forming the inverter-based microgrid will be equipped with the appropriate voltage control algorithm. Then, the results will be collected to perform the comparison between the different voltage control techniques.

Test Specification 4.01

Reference to Test Case	TC4
Title of Test	Performance of different voltage control techniques for inverter-interfaced DERs in microgrids
Test Rationale	This test will perform a comparison between different voltage control schemes that are widely used in inverter-based microgrids, i.e., master-slave control, conventional droop control and inverse droop control. Aiming to quantify the effectiveness of the aforementioned techniques, their pros & cons will be ultimately identified.
Specific Test System (graphical)	Laboratory setup 
Target measures	Microgrid voltages

Input and output parameters	*Input:* • *Level of unbalance of the load* • *Inverter power injection set-points and limits* • *DERs control parameters* • *Microgrid characteristics* *Output:* • *Microgrid voltages*
Test Design	1. *Operate multiple inverters in parallel* 2. *Perform load changes and observe voltage regulation (continuity of service)* 3. *Save the experimental results*
Initial system state	• *Inverter controllers enabled* • *Load disconnected* • *Grid voltages based on the nominal output values of the inverters* • *Hardware or simulated network and devices up and running* • *Power analyzer and computers displaying and saving data*
Evolution of system state and test signals	*The microgrid system is subjected to load variations (step changes)*
Other parameters	*N/A*
Temporal resolution	*At least 0.1 ms.*
Source of uncertainty	*Impedance of load and lines, inverter sensors operation*
Suspension criteria / Stopping criteria	*Abnormal current/ power injections from inverters or tripping of inverters*

Mapping to Research Infrastructure

Experiment Specification 4.01.01

Reference to Test Specification	*4.01*
Title of Experiment	Master-slave voltage control
Research Infrastructure	Electric Energy Systems Laboratory (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. Hardware controller (e.g., Three-phase real-time computer) 2. Simulated microgrid network and inverters in the RTDS 3. Optional: Hardware inverter (e.g., Three-phase inverter)
Experimental Design and Justification	Microgrid that hosts multiple inverter-interfaced DERs. At least one DER should operate in grid-forming mode and be the master unit, while the rest of the units can operate in grid-following mode as slaves.
Precision of equipment and measurement uncertainty	Software and power analyzer are of high precision, inverter sensing system may be of lower precision
Storage of experiment data	Power analyzer and computer memory

Experiment Specification 4.01.02

Reference to Test Specification	*4.01*
Title of Experiment	Conventional droop grid-forming control
Research Infrastructure	Electric Energy Systems Laboratory (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. Hardware controller (e.g., Three-phase real-time computer) 2. Simulated microgrid network and inverters in the RTDS 3. Optional: Hardware inverter (e.g., Three-phase inverter)
Experimental Design and Justification	Microgrid that hosts multiple inverter-interfaced DERs. All inverter-interfaced DERs are equipped with the conventional droop grid-forming control in order to regulate the microgrid voltage.
Precision of equipment and measurement uncertainty	Software and power analyzer are of high precision, inverter sensing system may be of lower precision
Storage of experiment data	Power analyzer and computer memory

Experiment Specification 4.01.03

Reference to Test Specification	*4.01*
Title of Experiment	Inverse droop grid-forming control
Research Infrastructure	Electric Energy Systems Laboratory (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. Hardware controller (e.g., Three-phase real-time computer) 2. Simulated microgrid network and inverters in the RTDS 3. Optional: Hardware inverter (e.g., Three-phase inverter)
Experimental Design and Justification	Microgrid that hosts multiple inverter-interfaced DERs. All inverter-interfaced DERs are equipped with the inverse droop grid-forming control in order to regulate the microgrid voltage.
Precision of equipment and measurement uncertainty	Software and power analyzer are of high precision, inverter sensing system may be of lower precision
Storage of experiment data	Power analyzer and computer memory