Test Case 15

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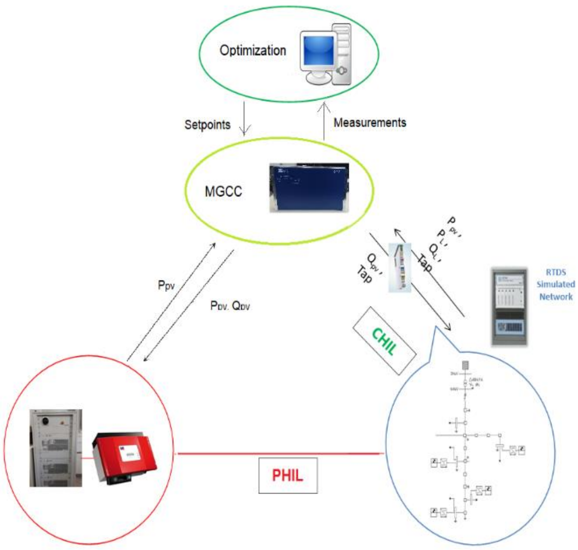
Name of the Test Case	Smart Grid Control Algorithm – optimal centralized Coordinated Voltage Control
Narrative	Distribution networks are becoming increasingly "smarter", as well as more complex, with the addition of power electronic devices, ICT, smart meters, and more. As a result, advanced control strategies to manage such networks are becoming necessary. An optimal centralized Coordinated Voltage Control (CVC) operates as a distribution management system. The algorithm manages all the devices of the network that are capable of regulating the voltage either directly (OLTCs), or through the injection of active/reactive power, such as Battery Energy Storage Systems (BESS) and Photovoltaic (PV) inverters. Management is based on the solution of an optimization problem, which minimizes a predefined objective function, subject to linear and non-linear constraints. A central controller is installed at substation level and is initialized with all the necessary static data of the network: network topology, admittance of lines and transformer, nominal power of DER units and storage systems, operating limits, tap change operations of the OLTC, etc. While it operates, it requests and receives real-time power measurements from the smart meters of loads and DER units, as well as the state of charge (SoC) of the storage systems and the current tap position of the OLTC. Using this dynamic data, it formulates the optimal power flow problem, whose objective function involves the minimization of voltage deviation of critical nodes from the nominal value, power losses of the lines and transformer, and tap change operations of the OLTC.
Function(s) under Investigation (*FuI*) "the referenced specification of a function realized (operationalized) by the object under investigation"	PV inverter's Q(U) control, OLTC controlling secondary voltage, MGCC behavior
Object under Investigation (*OuI*) "the component(s) (1..n) that are to be qualified by the test"	MicroGrid Central Controller (MGCC)
Domain under Investigation (*DuI*): "the relevant domains or sub-domains of test parameters and connectivity."	Electrical Power, ICT
Purpose of Investigation *(PoI)*	• Characterization and validation of the SuT

The test purpose in terms of Characterization, Verification, or Validation	• 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.	PV, OLTC, transformer, distribution line, upstream network impedance, MGCC
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.	Optimal centralized coordinated voltage control algorithm, Communication scheme
Test criteria *(TCR)* Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.	• OLTC behaviour according to reactive power levels • Inverter's effectiveness in participation in voltage regulation • Inverter's reaction to tap changes • BESS management effectiveness • Industrial MGCC behavior
Target Metrics *(TM)* Measures required to quantify each identified test criteria	1. When and how often the optimization converges. How fast and what is the solutions quality (suboptimal etc) 2. Voltage deviation of all the nodes from the nominal value, number of tap changes, network active power losses with and without the CVC algorithm 3. Estimation errors of voltage, active and reactive power 4. Ability of the BESS to provide voltage support (based on SoC) 5. Errors and failures and delays that the MGCC may introduce
Variability Attributes *(VA)* controllable or uncontrollable factors and the required variability; ref. to PoI.	• Load and RES Patterns (realistic, daily, annual variation) • Message exchange of MGCC using different protocols (Modbus, IEC 61850)
Quality Attributes *(QA)* threshold levels for test result quality as well as the definition of a decision rule such as pass/fail criteria.	1. Convergence of the optimization algorithm within some sec (validation) 2. All voltages are within ±5% of the nominal value (characterization) 3. Estimation quality characterized with a confidence of 95% (characterization)

Qualification Strategy

The PoI will be met through a single test system where the MGCC will optimally control the voltages of a distribution network, while simultaneously minimizing power losses and tap change operations of the transformer's on-load tap changer (OLTC). This will be accomplished with a central controller that receives real-time measurements from key nodes of the network (under normal operation), solves an optimization problem, and dispatches set-points to controllable devices located in the network, such as the OLTC, inverters of DER units and storage systems. The experimental setup will be a combined CHIL and PHIL to validate the performance in real conditions.

Test Specification TC15.01

Reference to Test Case	*15*
Title of Test	*Validation of Coordinated Voltage Control algorithm based on combined CHIL and PHIL test*
Test Rationale	*To validate the successful operation of the system when using hierarchical control and the effective implementation of the communication scheme when using hardware MicroGrid Central Controller in real conditions*
Specific Test System (graphical)	
Target measures	• *Active and reactive power of loads* • *Active and reactive power of PVs and BESS* • *SoC of BESS* • *Tap position of the OLTC* • *Bus voltages*
Input and output parameters	*Input to CVC:* • *Active and reactive power of loads* • *Active power of PVs* • *SoC of BESS* • *Tap position of the OLTC* *Output of the CVC:* • *Active and reactive power of the BESS* • *Reactive power of the PV Inverters* • *Tap position of the OLTC*
Test Design	1. *Initialization of the voltage control algorithm* 2. *Reception of input parameters from the network via the MGCC* 3. *Solution of the optimization problem* 4. *Dispatch of optimal set points to the voltage regulating devices via the MGCC* 5. *Save the simulation results for each iteration* 6. *Repeat steps 2 to 5 in pre-configured intervals*

Initial system state	– *Power system in steady-state* – *Controller up and running* – *Communications established* – *OLTC Controller up and running* – *DERStorage Controller up and running* – *DERGen Controller up and running* – *Optimal power flow solution achieved*
Evolution of system state and test signals	*Mitigation of voltage deviations*
Other parameters	*N/A*
Temporal resolution	*N/A*
Source of uncertainty	*Convergence of the optimization algorithm, communication Interfaces and delays*
Suspension criteria / Stopping criteria	*Communication failures, abnormal system conditions*

Mapping to Research Infrastructure

Experiment Specification TC15.01.01

Reference to Test Specification	*15.01*
Title of Experiment	*Combined Control and Power Hardware-in-the-Loop simulation for testing Smart grid control algorithm*
Research Infrastructure	Electric Energy Systems Laboratory (ICCS-NTUA)
Experiment Realisation	Smart grid control algorithm for optimal operation of distribution network with voltage regulating assets and DERS. Hardware MGCC for implementation of industrial communication scheme and hardware inverter for validation in real conditions.
Experiment Setup (concrete lab equipment)	• Simulated distribution network in RTDS • PV inverter (SMA) • PV simulator (Regatron) • Spitzenberger and Spies Linear Amplifier • External central controller (ControlHUT) (SEL MGCC) • Communication card • I/O interfacing cards • Computer
Experimental Design and Justification	A low voltage residential network will be designed in RTDS. The network will consist of OLTC, BESS, DERs and loads. The CVC algorithm running on a computer will manage all the devices of the network that are capable of regulating the voltage. The MGCC will communicate with the PC to send network measurements and receive assets' setpoints. Additionally, a hardware PV inverter will be connected with RTDS to validate the algorithm and the communication scheme in 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*