

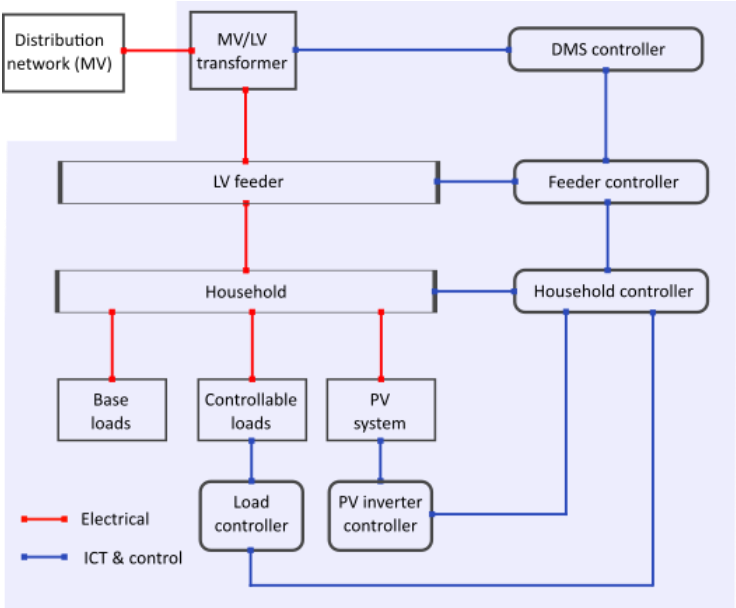
**Test Case 9**

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 Project: Erigrd 2.0

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Name of the Test Case	Evaluation of congestion management in distribution grid
<b>Narrative</b>	<p>The distribution network has been becoming congested because of the introduction of bi-directional power flow (due to the increasing penetration of DERs), unpredictable and increased power demands for consumption by the residential consumers (due to the introduction of new forms of loads such as Heat Pumps, EVs, etc.). As a result, the distribution network operators (DSOs) need to focus on the challenge of balancing power supply and demand. Congestion in the distribution network refers to an overvoltage at the connection points as well as overloading of the network components.</p> <p>On the one hand, to mitigate the network strains, conventionally DSOs focus mainly on network development by installing new cables and transformers to meet the increasing power flows. Nonetheless, the distribution loads are spread over large geographically areas and in a distributed manner, making the upgrade of the network more financially infeasible in a short term. Another alternative solution is to develop grid congestion management approaches so that the network infrastructure can be utilized in a better way. There are two types of congestion management methods namely direct as well as indirect. The former technique is realized by performing load curtailment, local generation reduction, network re-configuration, new installation of Battery Energy Storage System (BESS). In contrast, the latter approach focuses on solving the optimization of electricity cost with the constraints ensuring the transformers/feeders not to be overloaded.</p> <p>The direct congestion management method in this test includes two stages. The first stage consists of using a machine learning method, such as support vector machine, multi-class classification, decision tree, ANN..., in order to build congestion classification models. Once congestion is detected, it has to be labeled to one of the following statuses: normal, alert, emergency, and critical depending on the output of the trained models. In the second step, DSOs will use the congestion labeling to calculate the expected flexibility portfolio. With the expected procurement cost, the flexibility available in the feeders/households can be used to solve the congestion problem. After comparing the results with different conditions, the best setting for the congestion management can be chosen.</p> <p>On the other hand, an indirect congestion management needs to be based on an online learning technique to emulate the demand flexibility of a network. As for emulating the demand flexibility, the concept of price elasticity of demand can be</p>

	<p>considered. Accordingly, demand flexibility during all time-periods of a day shall be treated as a commodity that can be substituted or complemented to each other.</p> <p>The objective of this Test Case is to evaluate different congestion management methods in distribution grid under the circumstance of high penetration of DERs and other active loads such as EVs, HPs ...</p>
<b>Function(s) under Investigation (FuI)</b> "the referenced specification of a function realized (operationalized) by the object under investigation"	Congestion management of the DMS controller <ul style="list-style-type: none"> <li>▪ Direct approach: mitigating congestions by curtailment of load and local generation and by influencing the voltage level at the secondary side of a MV/LV transformer</li> <li>▪ Indirect approach: motivating individual prosumers with dynamic prices through intermediate market entities such as aggregators and retailers. DSOs also incentivize customers by providing compensations for their load reduction when needed to solve network congestions.</li> </ul>
<b>Object under Investigation (Oul)</b> "the component(s) (1..n) that are to be qualified by the test"	<ul style="list-style-type: none"> <li>• DMS controller</li> </ul>
<b>Domain under Investigation (Dul):</b> "the relevant domains or sub-domains of test parameters and connectivity."	<ul style="list-style-type: none"> <li>• Electrical domains</li> <li>• Control and ICT domain</li> </ul>
<b>Purpose of Investigation (Pol)</b> The test purpose in terms of Characterization, Verification, or Validation	<ul style="list-style-type: none"> <li>• Characterization and comparison of different congestion management methods.</li> </ul>
<b>System under Test (SuT):</b> Systems, subsystems, components included in the test case or test setup.	<p>In electric power domain:</p> <ul style="list-style-type: none"> <li>• DMS controller</li> <li>• DER (PV system)</li> <li>• Household appliances</li> <li>• Distribution transformer</li> <li>• Aggregator/consumer/prosumer controllers</li> <li>• Household controllers</li> <li>• Household appliance controllers</li> <li>• DER controllers</li> </ul> <p>In ICT domain:</p> <ul style="list-style-type: none"> <li>• Communication network</li> </ul>

	
<p><b>Functions under Test (FuT)</b> Functions relevant to the operation of the system under test, including FuT and relevant interactions btw. Oul and SuT.</p>	<ul style="list-style-type: none"> <li>• DMS congestion management functionality</li> <li>• DER power output control</li> <li>• Household appliances control of the aggregator/consumer/prosumer controller</li> <li>• Communication via ICT</li> </ul>
<p><b>Test criteria (TCR)</b> Formulation of criteria for each Pol based on properties of SuT; encompasses properties of test signals and output measures.</p>	<ul style="list-style-type: none"> <li>• Performance of the congestion management algorithm under realistic conditions</li> <li>• The transformer and feeders should not be overloaded</li> <li>• Reduction in the cost of flexibility procurement</li> </ul>
<p><b>Target Metrics (TM)</b> Measures required to quantify each identified test criteria</p>	<ul style="list-style-type: none"> <li>• Accuracy of congestion prediction</li> <li>• Transformer overloading/loss of transformer life/Hot spot temperature of the transformer/transformer loss</li> <li>• Feeder overloading</li> <li>• Cost of congestion management</li> <li>• DER power curtailment</li> <li>• Household voltage profiles</li> <li>• Flexibility procured by DSO</li> <li>• Reduction in peak demand</li> </ul>
<p><b>Variability Attributes (VA)</b> controllable or uncontrollable factors and the required variability; ref. to Pol.</p>	<ul style="list-style-type: none"> <li>• Household consumption profiles</li> <li>• DER generation (weather condition)</li> <li>• Packet loss</li> <li>• Communication delay</li> </ul>
<p><b>Quality Attributes (QA)</b> threshold levels for test result quality as well as pass/fail criteria.</p>	<ul style="list-style-type: none"> <li>• Transformers/feeders are not overloaded</li> <li>• Voltage deviation within <math>\pm 10\%</math> (typically for LV networks)</li> </ul>

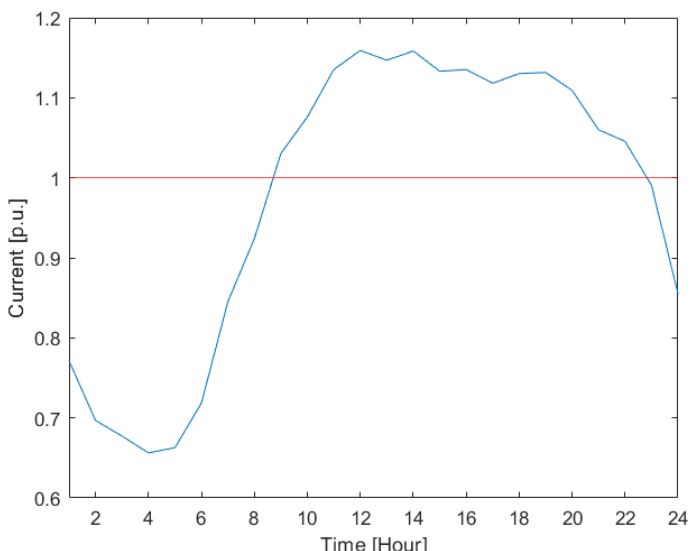
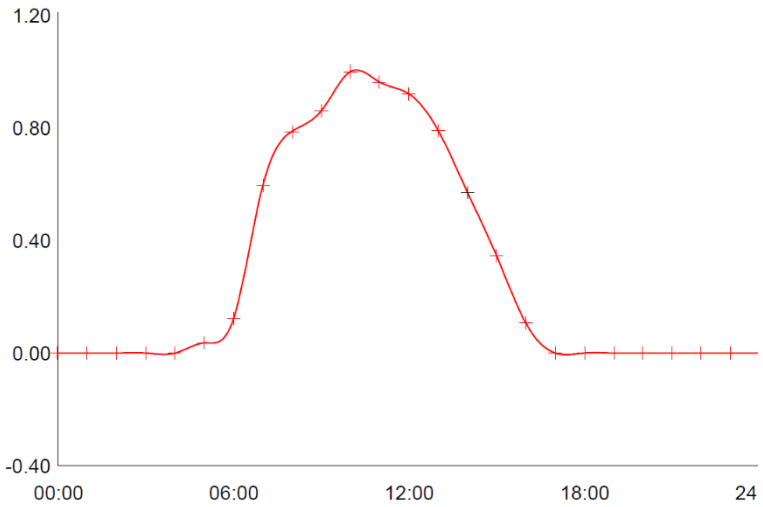
- Reduction in DER power curtailment

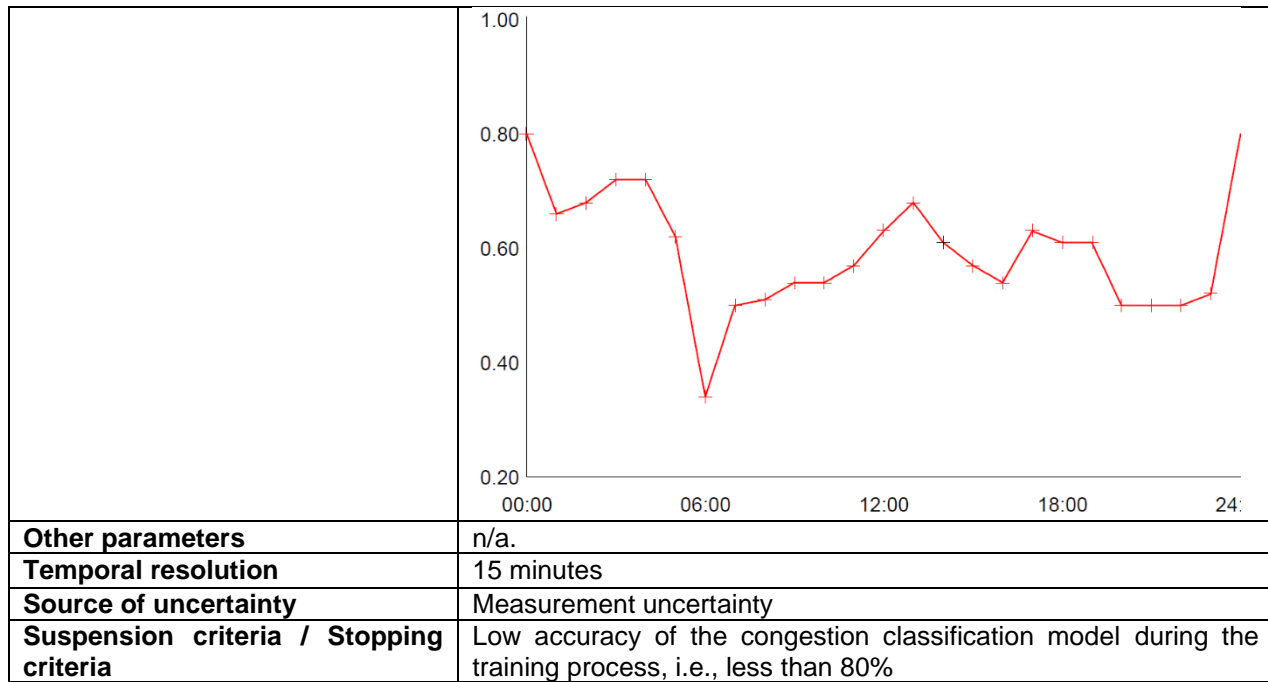
## Qualification Strategy

The test case is split in two TSs: one to characterize the direct method, one to characterize the indirect method. Then, the results will be analysed to compare the performances of the two methods. For the TSs, either a pure simulation or a co-simulation will be performed.

## Test Specification TC9.TS01

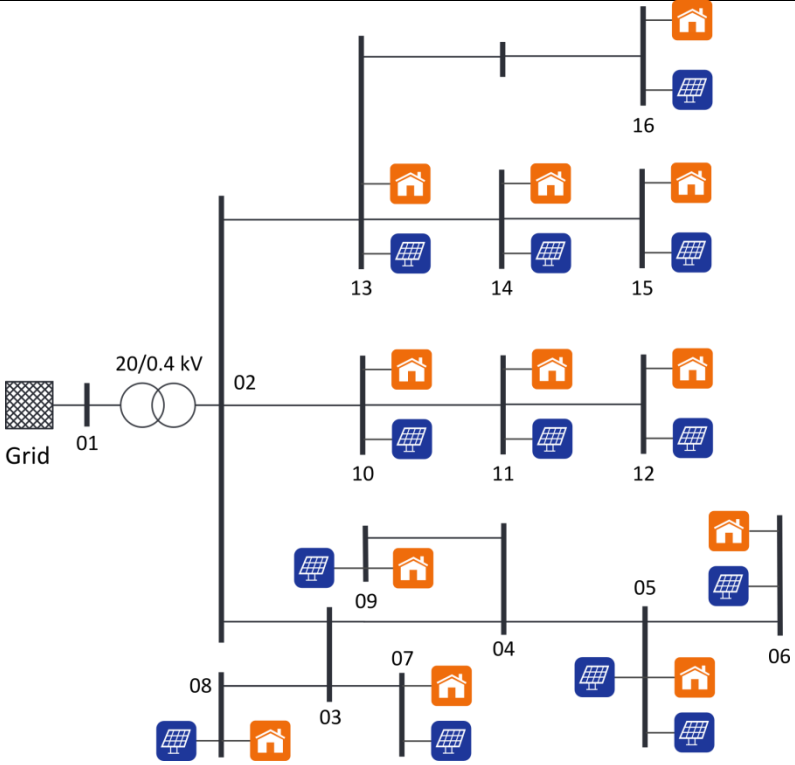
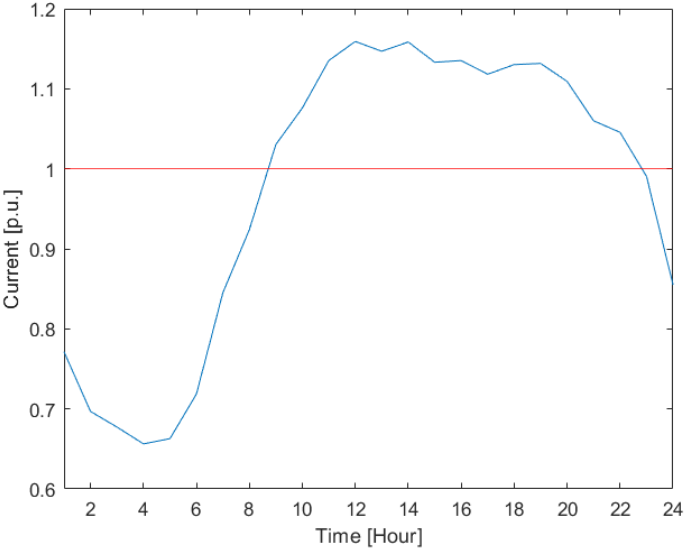
<b>Reference to Test Case</b>	TC9
<b>Title of Test</b>	Characterisation of direct method
<b>Test Rationale</b>	The goal of this Test is to evaluate the performance of a direct congestion management method. The results of the developed congestion forecasting model will be compared to the actual values to assess its accuracy. Afterwards, the efficiency of the method will be evaluated in terms of target metrics specified in the Test Case description.
<b>Specific Test System</b> (graphical)	<p>The Test System includes a LV (0.4 kV) network with realistic data provided by a local utility company. This network consists of three feeders with various loads and PV systems connected along the feeders.</p>
<b>Target measures</b>	Voltages, currents of all grid components.
<b>Input and output parameters</b>	Weather conditions (hence DER production), grid topology, household load profiles, controllable generation production
<b>Test Design</b>	<ul style="list-style-type: none"> <li>• Initialize the simulation, achieving a steady state condition;</li> <li>• Keep the simulation running with the feeding load and generation profiles in order to create several congestion conditions (peak of load or peak of generation) over the whole simulation run</li> <li>• Evaluate the results of the test in terms of transformer</li> </ul>

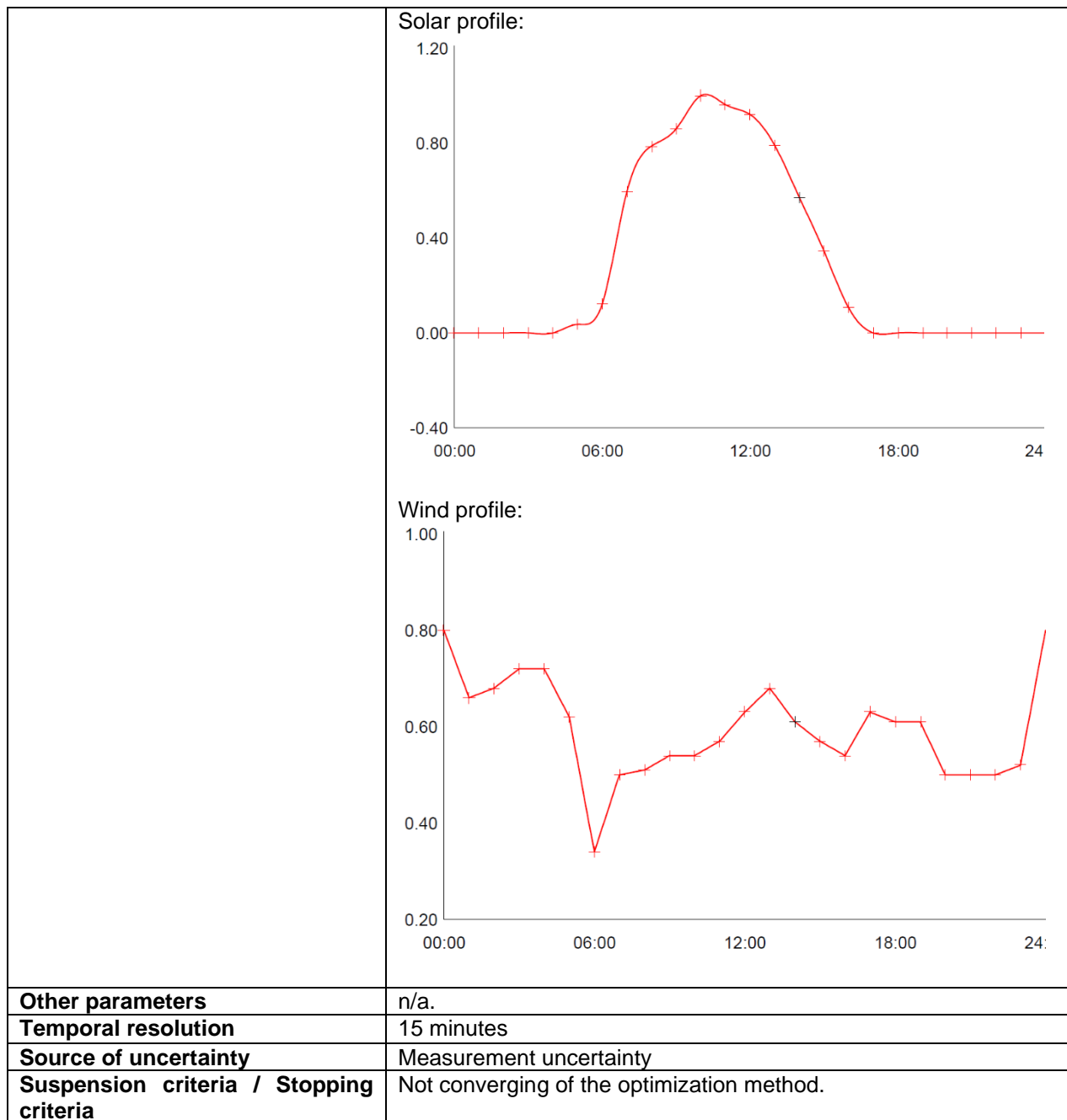
	<p>loading power, flexibility procured by the DSO, and procurement cost in two cases with and without the congestion management functionality in the DMS controller</p> <ul style="list-style-type: none"> <li>Reinitialize the simulation and repeat the test with different congestion condition.</li> </ul>
<b>Initial system state</b>	Transformer and feeders loading in permissible ranges.
<b>Evolution of system state and test signals</b>	<p>The evolution of the congestion at the MV/LV transformer is illustrated in the figure below:</p>  <p>The evolution of the system state is shown in the figures below:</p> <p>Solar profile:</p>  <p>Wind profile:</p>



### Test Specification TC9.TS02

<b>Reference to Test Case</b>	TC9
<b>Title of Test</b>	Characterisation of indirect method
<b>Test Rationale</b>	The goal of this Test is to evaluate the performance of the indirect method considering the impact of the communication latency and packet losses on a LV grid congestion management.
<b>Specific Test System</b> (graphical)	The Test System includes a LV (0.4 kV) network with realistic data provided by a local utility company. This network consists of three feeders with various loads and PV systems connected along the feeders.

	 <p>In addition to the above network, a market model is also developed.</p>
<b>Target measures</b>	Voltages, currents of all grid components and grid services cost.
<b>Input and output parameters</b>	Weather condition (hence DER production), grid topology, household load profiles, controllable generation production
<b>Test Design</b>	Initialize the simulation; achieve a steady state condition; trigger a congestion condition (peak of load or peak of generation); evaluate the response of the DMS controller; reinitialize the simulation and repeat the test with different congestion condition and the baseline.
<b>Initial system state</b>	Transformer and feeders loading in permissible ranges.
<b>Evolution of system state and test signals</b>	<p>The evolution of the congestion at the MV/LV transformer is illustrated in the figure below:</p>  <p>The evolution of the system state is shown in the figures below:</p>



### Mapping to Research Infrastructure

#### Experiment Specification TC9.TS01.ES01

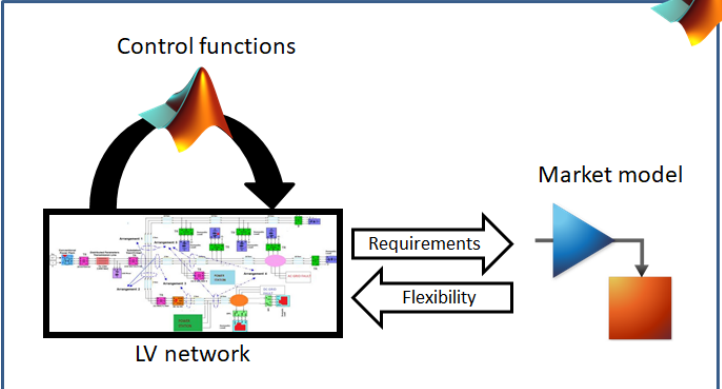
<b>Reference to Test Specification</b>	TC9.TS01
<b>Title of Experiment</b>	<i>Co-simulation for performance evaluation of direct congestion management method</i>
<b>Research Infrastructure</b>	CEA
<b>Experiment Realisation</b>	<p>The experiment is realized by performing a co-simulation setup between PowerFactory and Matlab using Mosaik as a master algorithm.</p> <p>The congestion management functionality and all the neces-</p>



	sary control functions are modeled in Matlab. A realistic LV network with high penetration of PV systems is implemented in PowerFactory and is run in QuasiDynamic mode.
<b>Experiment Setup</b> (concrete lab equipment)	
<b>Experimental Design and Justification</b>	<ul style="list-style-type: none"> <li>All the load consumption and PV generations will be varied following different pre-defined profiles to create congestion issues in order to evaluate the performance of the designed congestion management function.</li> </ul>
<b>Precision of equipment and measurement uncertainty</b>	<ul style="list-style-type: none"> <li>N/a</li> </ul>
<b>Storage of experiment data</b>	<ul style="list-style-type: none"> <li><i>hdf5 or csv files</i></li> </ul>

### Experiment Specification TC9.TS02.ES02

<b>Reference to Test Specification</b>	TC9.TS02
<b>Title of Experiment</b>	<i>Simulation for performance evaluation of indirect congestion management method</i>
<b>Research Infrastructure</b>	RSE
<b>Experiment Realisation</b>	<p>The experiment is realized by performing a simulation in Matlab.</p> <p>All the necessary control functions are modeled with a script in Matlab. The local services market model is developed in Simulink and a realistic LV network with high penetration of PV systems is implemented in SimPowerSystem using phasor models. All the simulation components are managed by a master algorithm which setup all the experiment configurations (input, models parameters, etc.).</p>
<b>Experiment Setup</b> (concrete lab equipment)	The whole experiment is performed in Matlab environment. In particular, the local services market model is developed in Simulink, the LV network model in SimPowerSystem while the

	<p>control functions of the components are .m file integrated with SimPowerSystem.</p> <p>In order to validate the indirect congestion management, the flexibility provided by the local services market should be enough to avoid grid congestions.</p> 
<b>Experimental Design and Justification</b>	All the load consumption and PV generations will be varied following different pre-defined profiles (see TC24.TS02) to create congestion issues in order to evaluate the flexibility provided by the local services market.
<b>Precision of equipment and measurement uncertainty</b>	Since the experiment is a simulation, this is not available.
<b>Storage of experiment data</b>	All variable states are saved in a .mat file with a time-step of 15 minutes.