Breakthrough in Test Procedures for Islanding Detection

New methods for Anti-Islanding Tests for Grid-tied Power Generator Equipment according to IEEE 1547 or DIN V VDE V 0126-1-1 or VDE-AR-N 4105 by Means of Simulated Impedance with REGATRON TC.ACS

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Overview

The standards DIN V VDE V 0126-1-1 [1] or VDE-AR-N 4105 [2] or IEEE 1547 provide strict regulations for power generating equipment feeding the public grid. The main aim is to harmonize all important technical specifications and to prevent safety risks at “islanding” conditions.
Up to now test methods using passive tuned circuits require a considerable effort both in terms of expensive components as also of work time. Power circuit simulation by REGATRON TC.ACS series allows for replacing lumped component R-L-C-circuits simply by “Simulated Impedance”. Furthermore the same TC.ACS device can be used to perform all necessary voltage and frequency tests based on the same test circuit, therefore the complete range of test requirements according to standard DIN V VDE V 0126-1-1 [1] or IEEE 1547 is being met with a fraction of expenditures both in time as in material.

Up-to-now Standard Test in Detail

With respect to frequency and voltage the standard DIN V VDE V 0126-1-1 [1] or VDE-AR-N 4105 [2] respectively defines limits, the violation of which power equipment need to detect and then disconnect from the grid. The device under test (DUT) has to disconnect from the grid autonomously within 0.1 second when voltages either fall below 80% or exceed 115% of the nominal voltage (UN). Also frequencies (f) below 47.5 Hz and above 51.5 Hz must result in disconnection within 0.1 second. Already today in many cases a grid simulator is used to confirm the fulfillment of these requirements.

Moreover the DIN/VDE standard states that an islanding condition must be reliably detected and a disconnection from the public low voltage system has to be executed within 5 seconds.

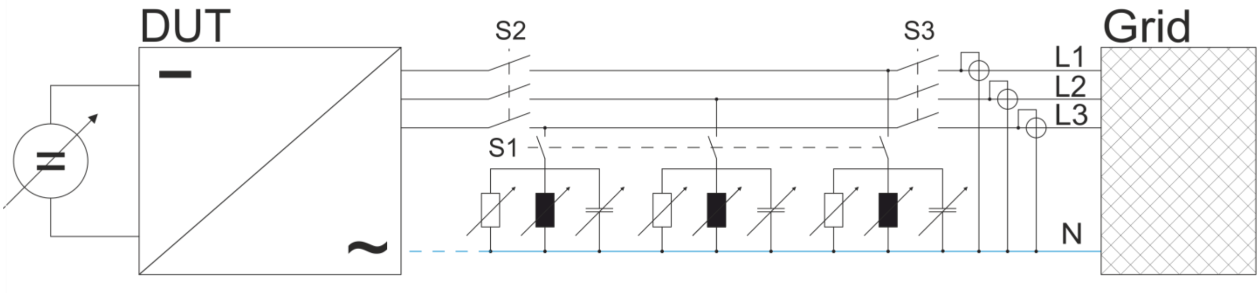


Figure 1: Test set-up for the detection of islanding operation according to VDE-AR-N 4105 [2]

In order to check the detection of islanding operation, R-L-C-circuits (see Figure 1) are connected in parallel to the DUT/grid. Each R-L-C-circuit is dimensioned to absorb the complete active and reactive power of the respective phase of the DUT. When the connection to the public system is being cut (S3), the DUT (a solar power inverter for example) has to separate from the public grid within 5 seconds. This test has to be run with P = 25%, 50% and 100% of the nominal power at the nominal frequency of ±0.1Hz and the nominal system voltage of ±3%. After each successful test run one parameter (L or C) is altered by approx. 1% within a range of approx. ±5% and the test run is repeated. Quite obviously, such a test is rather extensive with regards to material (different values of R, L and C with the corresponding ratings of voltage and current) and time. Although automated solutions are available, these are also material-consuming and expensive.

The quality factor Q of the R-L-C-circuit must be 2 at least. The active power being absorbed by the circuit must not deviate from the active power fed by the power device for more than 3%. The following relationships apply:

$$L = \frac{{U_N}^2}{2\pi f P Q} \qquad C = \frac{PQ}{2\pi f {U_N}^2}$$

The test is set up as follows:

- Setting the inductivity, such that Q >/= 2
- Setting the capacity, such that the reactive power (P_Q) equals that of the DUT
- Setting the resistance, such that the active power equals that of the DUT
  (in the case of lumped components this active power is transformed into heat!)
- Closing S1, S2, S3 and starting the DUT, the corresponding active/reactive power builds up
- Opening S3 (→ islanding starts) and measuring the time until the DUT is turned off

State-of-the-art Solution Using Simulated R-L-C-Circuit

REGATRON offers unidirectional as well as bidirectional high-performance AC/DC power supplies in different ranges of power and voltage. Beside these DC series, the TC.ACS Grid Simulator series represents a full 4-quadrant AC/AC converter with excellent dynamics and power ranges of 0 to 30 kVA or 0 to 50 kVA respectively. By ingenious paralleling techniques, a system power up to 1 MVA is achievable. TC.ACS grid simulators may be run either in Grid Simulation mode, in R-L-C-Simulation mode or in a 3-phase Linear Amplifier mode specially designed for high speed HIL applications. In the current control mode, TC.ACS is able to generate a current, which dynamically changes according to the actual terminal voltage. By fast on-board computing techniques it is therefore possible to model complex impedance and simulate even R-L-C-circuits in real-time (see Figures 2 and 3).

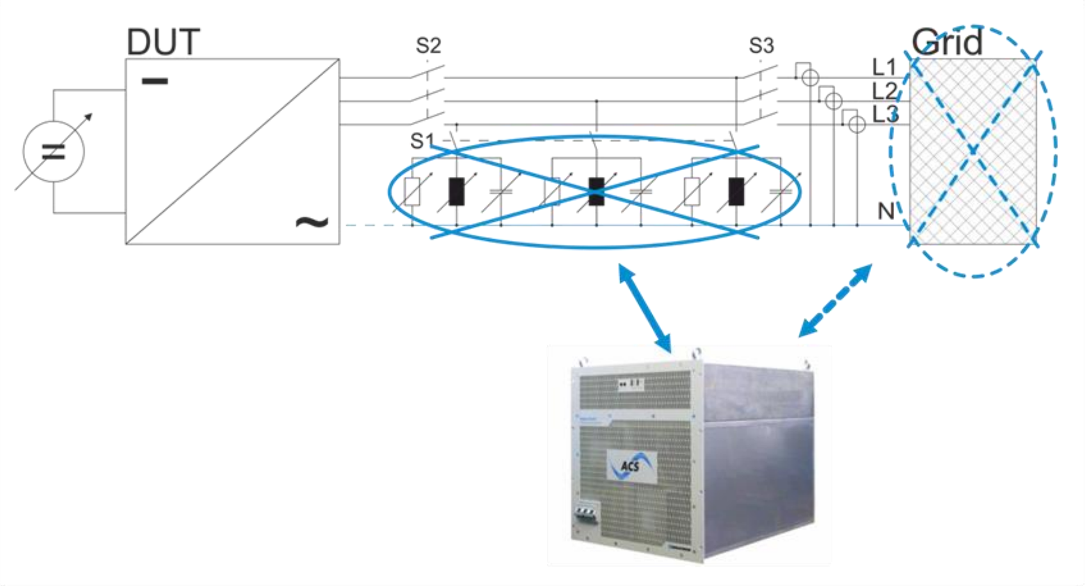


Figure 2: TC.ACS can be used to selectively simulate either the R-L-C-circuit or the public grid. This way both tests (detection of islanding and monitoring of voltage/frequency) can be carried out using the same circuitry.

In R-L-C-simulation mode the TC.ACS simulates the R-L-C tuned circuits based on pre-calculated values, while in grid simulation mode all voltage and frequency related tests easily may be performed. All relevant “component values” can be adapted in full operation. A special API programming interface allows even for automatic stepwise variation of parameters according to the standard VDE-AR-N 4105 [2]. It is obvious that the “Simulated Impedance Method” simplifies the detection of islanding conditions strongly.

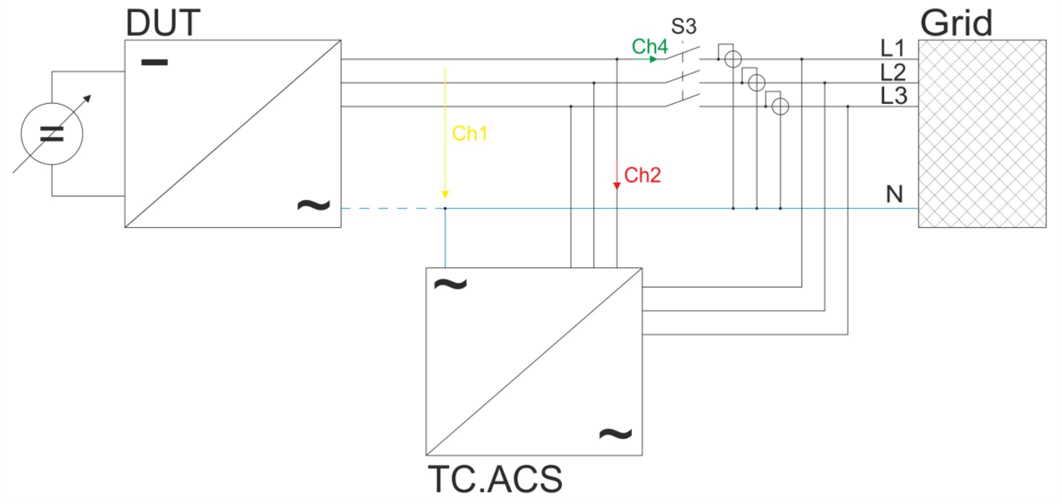


Figure 3: Test set-up using TC.ACS Impedance Simulation. For voltage and frequency related tests switch S3 stays open and the grid is being simulated by TC.ACS operated in Grid Simulator mode. For the detection of islanding switch S3 is closed, TC.ACS is operated in R-L-C-Simulation mode and the simulated R-L-C-circuits are adjusted in full operation. S3 is reopened again to test the DUT’s behavior while in islanding condition.

The use of TC.ACS in Grid Simulation mode and R-L-C-Simulation mode offers the following benefits:

- No need for a respectable component warehouse of high power R/L/C-components
- No need for a time consuming handling and recalibration of bulky and partly heavy circuit components
- Drastically simplified test circuitry
- No need for any tuning of real components and reconnecting at each test step
- Simple “component value entry” by enclosed software ACSControl
- Drastically reduced time requirements
- Simplification of tuned circuit alignment and variations in full operation

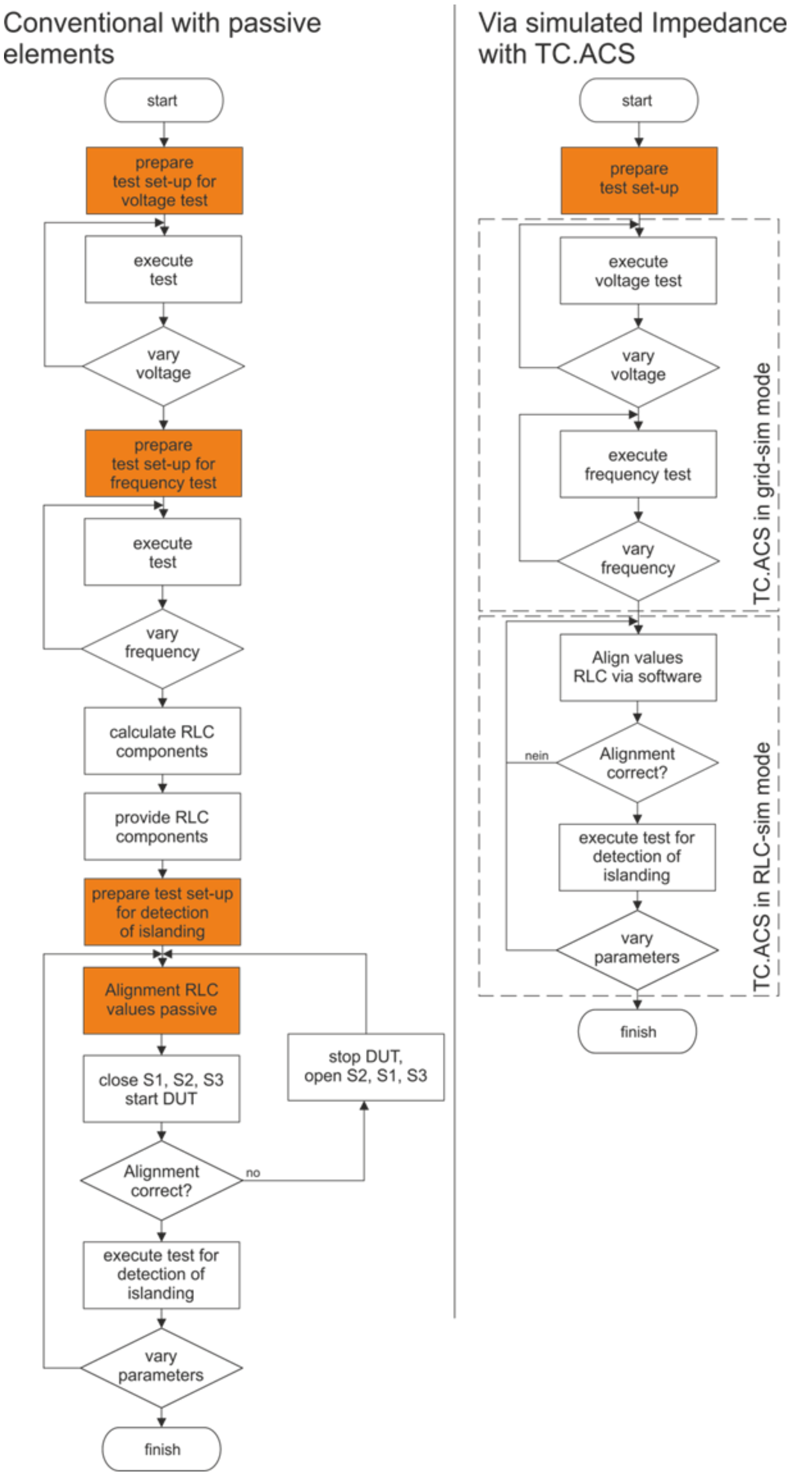


Figure 4: Flowcharts of the test sequences according to DIN/VDE regulations. On the left the conventional approach is shown with passive elements and on the right the same test using the integrated solution. The steps highlighted orange are those which require the most effort in work and material.

With the described test set-up it is possible to apply both single-phase as well as multi-phase blackouts to the DUT, as required by the standard. In the single-phase case an R-L-C-system is simulated only on one phase, while on the others an off-load operation is programmed.

Use Case: Testing a DC/AC Converter for the Detection of Islanding

In order to demonstrate the capability of the R-L-C-circuit simulation, a REGATRON TC.GSS is operated in regenerative mode with a nominal power of 5 kW per phase (this is the DUT working as “Solar-inverter”). The tuned circuits are simulated by TC.ACS with the values given in Table 1. As a driving DC power source (e.g. a “Solar Array Simulation”) a further TC.GSS is being used.

Topology	Topology no. 12 (see figure 7)
R	12.6 Ω
C	900 µF
L	11.22 mH
R2	0.1 Ω
R3	0.4 Ω
Q	3
Cut-off frequency of voltage measurement	500 Hz

Table 1: Values for testing the detection of islanding condition

Cutting the grid by S3, the circuit shows a flawless perpetuation of the islanding operation by the TC.ACS in the RLC-circuit-simulation mode. The DUT detects the islanding in turn and breaks off well within the defined period of time (see Figure 5). The values of the R-L-C-circuit can be varied during operation in order to meet the required tolerances.

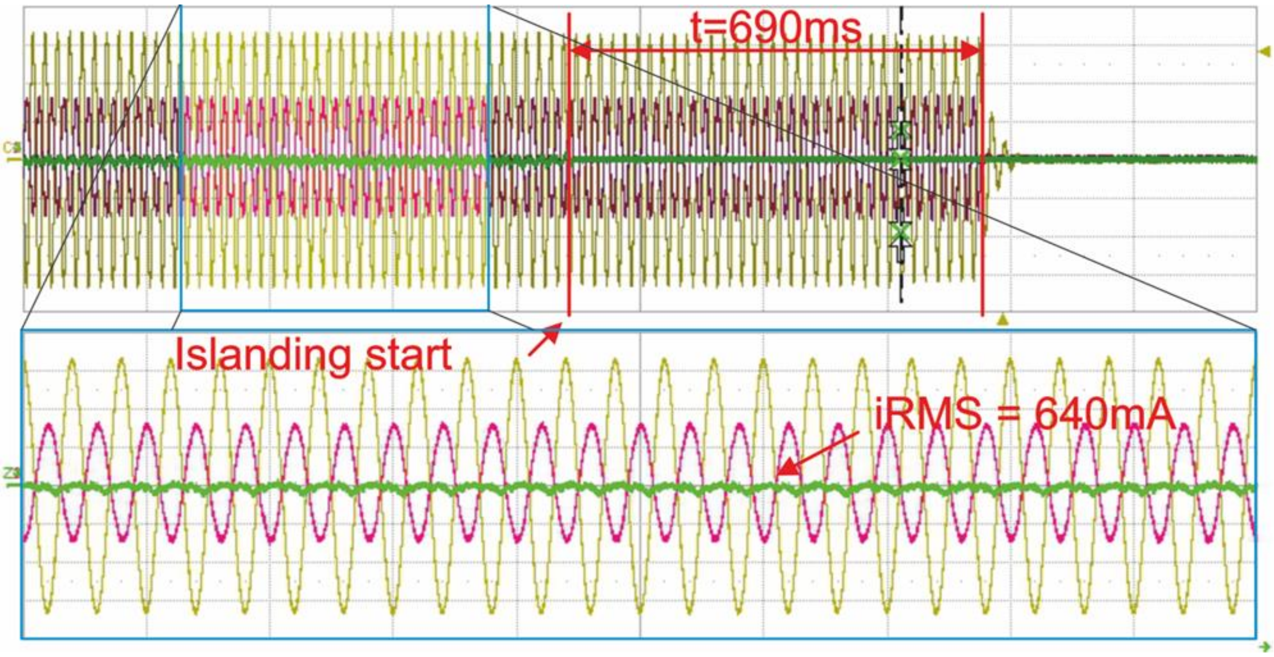
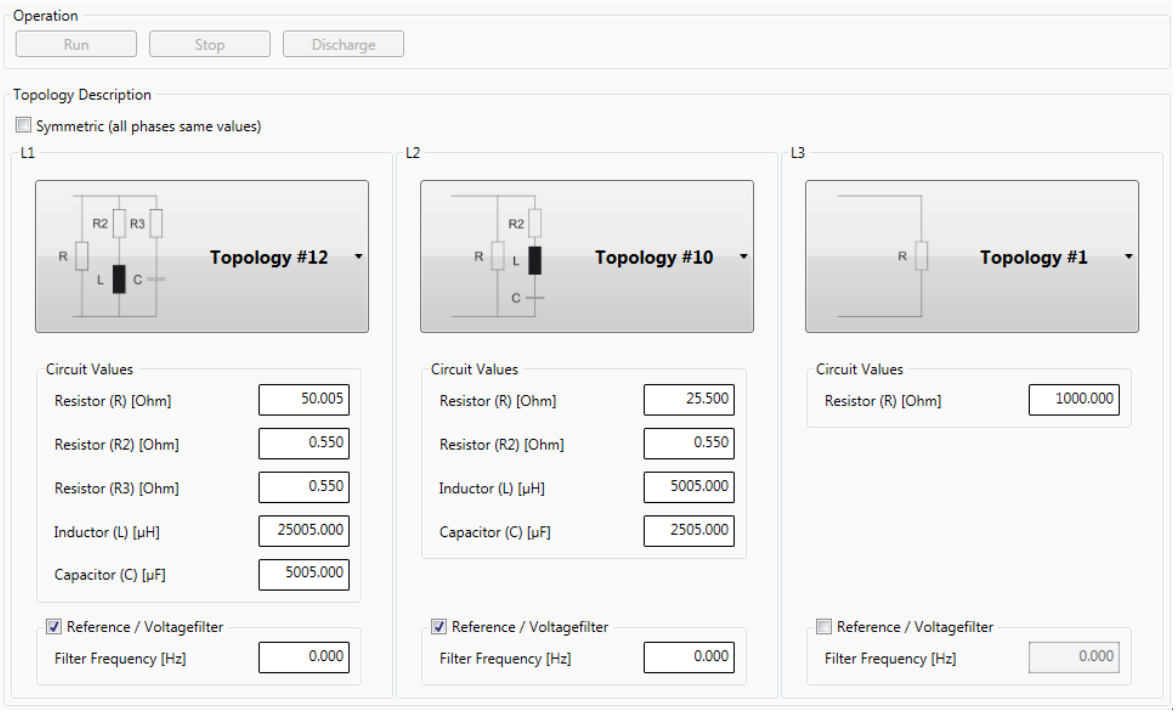


Figure 5: Behavior of the R-L-C-Simulation during an islanding detection test. 690ms after the start of the islanding the DUT shuts off.
Ch1 (yellow): Voltage L1-N at the input of the DUT
Ch2 (red): Current L1 at the output of the RLC-simulator TC.ACS
Ch4 (green): Current through S3 (current into the grid). In operating state the RMS-current into the grid is approx. 640mA and hence <3% of the nominal power.

Simple Use of the Enclosed Software

Both RLCSim and GridSim modes are operated by the software ACSControl, which is included in the scope of delivery. In the GridSim mode a large variety of voltage patterns can be generated by the resident function generator.
In RLCSim mode the parameter values are set by a user interface (see Figure 6). Subsequently, a circuit analysis is performed creating a set of differential equations running in real-time onboard of TC.ACS. By this, phase currents are dynamically computed as a function of the relative phase voltage.



☐ Symmetric (all phases same values)

L1: Topology #12

Circuit Values
Resistor (R) [Ohm] 50.005
Resistor (R2) [Ohm] 0.550
Resistor (R3) [Ohm] 0.550
Inductor (L) [µH] 25005.000
Capacitor (C) [µF] 5005.000

☑ Reference / Voltagefilter
Filter Frequency [Hz] 0.000

L2: Topology #10

Circuit Values
Resistor (R) [Ohm] 25.500
Resistor (R2) [Ohm] 0.550
Inductor (L) [µH] 5005.000
Capacitor (C) [µF] 2505.000

☑ Reference / Voltagefilter
Filter Frequency [Hz] 0.000

L3: Topology #1

Circuit Values
Resistor (R) [Ohm] 1000.000

☐ Reference / Voltagefilter
Filter Frequency [Hz] 0.000

Figure 6: Graphical interface of ACSControl software: The R-L-C-topology can be set per phase.

An adjustable low pass filter restricts the bandwidth of the voltage measurement, this helps to suppress unwanted resonances within the simulation chain. At the same time voltage pulses are attenuated, preventing undesirably high currents. Moreover, an application programming interface (API) provides the possibility to access the individual parameters. Thus for instance the simulated load can variably be set via step functions, an important feature when configuring automated test sequences.

Additional Areas of Application for the RLC-Simulation

In addition to the described parallel resonant circuit above, currently further topologies are available for the simulation of complex impedance, see figure 7 below.

The RLC simulation allows for definition of a wide variety of complex AC loads ranging from purely inductive to purely capacitive in a high kVA area. Also cos-φ steps are possible in order to test phase shifters. Such tests are feasible not only in the 3-phase-grid, but also for each individual phase.

One-phase to three-phase loads can easily be simulated observing the TC.ACS device specifications. AC load simulation is very helpful for R+D work, AC network/grid definition and device testing as well as for educational purposes. Moreover, the API allows for dynamic parameter variation, opening up the way to programmable load variation, an indispensable topic for network analysis and dynamic AC device testing.

Testing devices with switch-mode output together with TC.ACS RLC-Simulation needs sometimes a special care. Due to the complex impedance of TC.ACS output structure, unwanted AC noise may cause interference. In such cases additional filtering (i.e. notch filters) will suppress the unwanted modulation frequency. By this technique, even switch mode equipment can be tested easily in a RLC-Simulation environment.

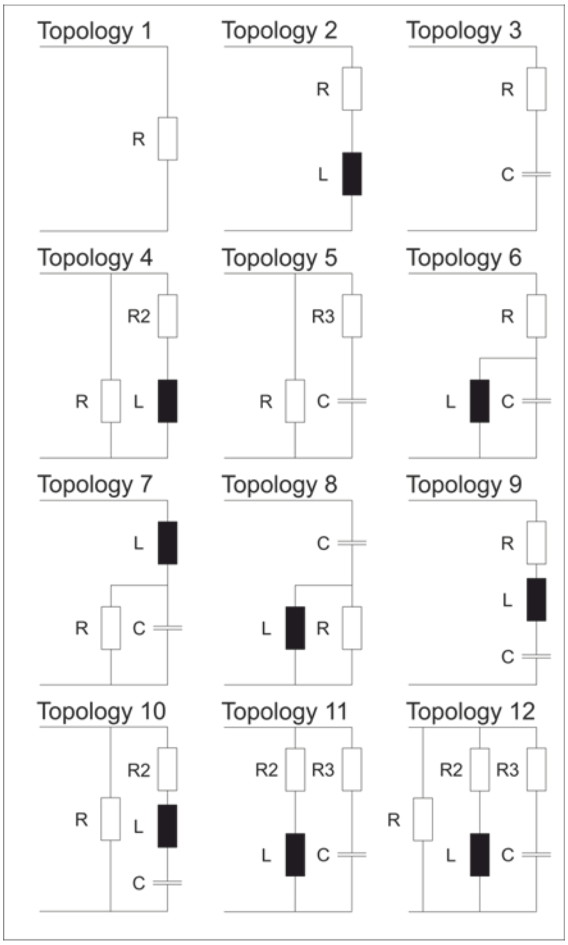


Figure 7: Overview of the RLC-topologies currently available. These can be simulated according to the system limits of the TC.ACS.

Constraints of the Simulation

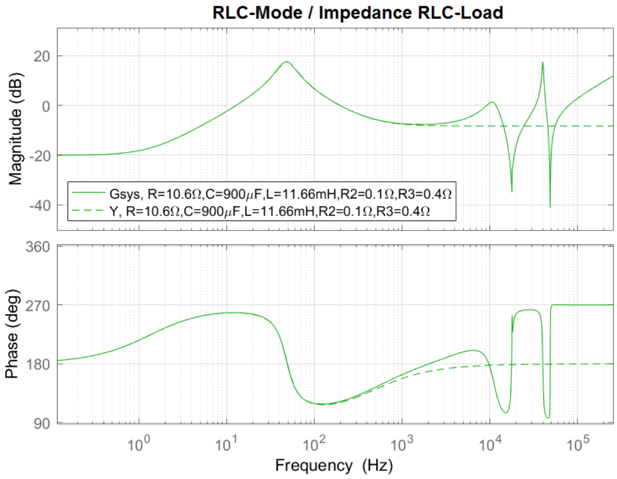


Figure 8: Comparison of the simulated (continuous) and the real (dotted) impedance according to the topology 12 of the RLC-operation with the following values: R=10.6Ω, C=900µF, L=11.66mH, R2=0.1Ω, R3=0.4Ω.
The influence of the TC.ACS output filter is clearly visible in the frequency range > 1kHz.

In the frequency range below 1 kHz there are only small local deviances between the real and the computed impedance due to measuring tolerances and nonlinearities in the control circuit. However, these are comparable to tolerances of real components. By adjustment of the component values it is possible at any time to tune the values such that the test requirements are met.

Sources

[1] DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE. DIN V VDE V 0126-1-1:2013-08 Selbsttätige Schaltstelle zwischen einer netzparallelen und Eigenerzeugungsanlage und dem öffentlichen Netzspannungsnetz.

[2] DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE. VDE-VR-N 4105:2011-08 Erzeugungsanlagen am Niederspannungsnetz - Technische Mindestanforderungen für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Niederspannungsnetz.

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