RLC-Load-Mode for TC.ACS

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1 Introduction

Regatron's new generation of AC / AC converters, called TC.ACS, enable not only grid simulation but also full current controlled operation.
This opens up the possibility to simulate various impedances. After measuring the voltage at the simulation port, the reference current can be calculated and controlled with the programmed R-L-C values. Thus, the desired impedance becomes visible on the simulation port. This new option is called RLC load mode.

Using ACSControl, 12 different topologies of RLC combinations can be independently adjusted for each phase. The control bandwidth is 1kHz.

Physical limitations will be shown in this document, especially the ones that occur at frequencies > 1kHz.

A practical example of an anti-islanding test, which is only one of many possible application examples, is shown. Using the RLC load mode, a standard-compliance test was successfully performed.

Since passive components are often used for this test, hardware effort and configuration time are massively reduced by the simulation of the R, L and C components.

2 Topologies

Twelve different topologies are available for the simulation (see Figure 1:).

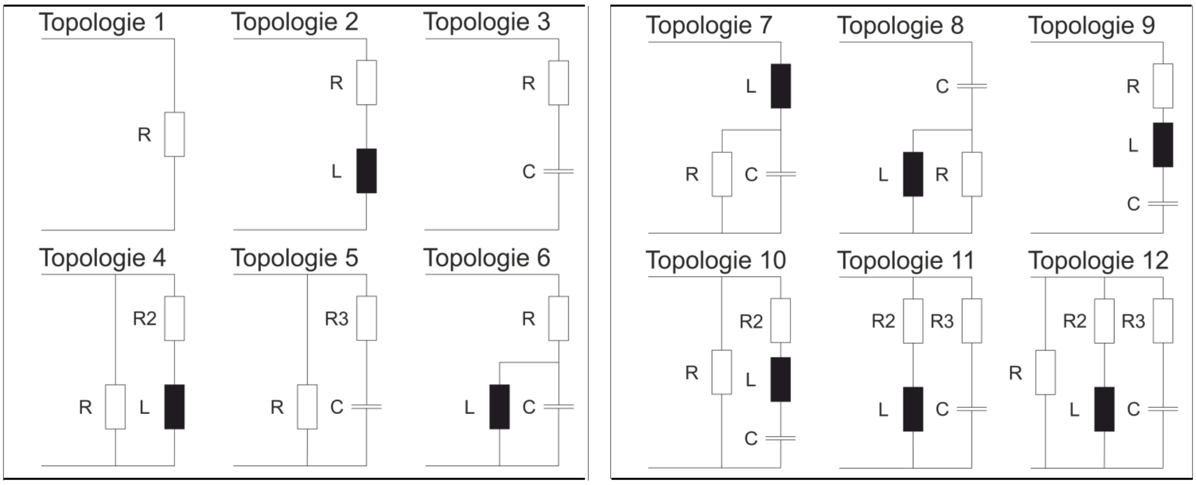

Figure 1: Overview of the available topologies

Each phase can be configured with different topologies or different values and these values can even be adjusted during operation (of course always within the specifications of TC.ACS (see 3 Limitations)).

Topology	Range of Values	Topology	Range of Values
Topology 1	R: 0.001 to 10000 Ω	Topology 7	R: 0.001 to 100 Ω L: 1u to 100mH C: 1u to 100mF
Topology 2	R: 0.01 to 100 Ω L: 1u to 1000mH	Topology 8	R: 0.1 to 100 Ω L: 1u to 50mH C: 1u to 50mF
Topology 3	R: 0.001 to 100 Ω C: 1u to 1000mF	Topology 9	R: 0.001 to 100 Ω L: 1u to 100mH C: 1u to 100mF
Topology 4	R: 0.1to 100 Ω R2: 0.1 to 100 Ω L: 1u to 1000mH	Topology 10	R: 1 to 50 Ω R2: 0.001 to 5 Ω L: 10u to 10mH C: 10u to 5mF
Topology 5	R: 0.001 to 100 Ω R3: 0.001 to 10 Ω C: 1u to 100mF	Topology 11	R2: 0.1 to 1 Ω R3: 0.001 to 1 Ω L: 1u to 50mH C: 1u to 10mF
Topology 6	R: 0.001 to 3.2 Ω L: 1u to 10mH C: 1u to 10mF	Topology 12	R: 1 to 100 Ω R2: 0.1 to 1 Ω R3: 0.2 to 1 Ω L: 10u to 50mH C: 10u to 10mF

Table 1: Possible ranges of values of the topologies, based on numerics. There are further limitations due to oscillation tendencies, resolution and possible voltage and current ranges (see 3 Limitations).

The permissible value ranges of the elements of the topologies and the limitation to twelve possible topologies (see Table 1:) result from the finite arithmetic, since arbitrarily large / small values can't be used.

Furthermore, for configurations with capacitors always (small) series resistors should be defined, otherwise depending on the simulated network an infinitely large current set value would be necessary. Also with inductors a series resistor is necessary, since the offset of the voltage measurement would otherwise be integrated infinitely (e.g. a voltage offset of 213mV with a series resistor of 10mΩ will lead to an offset current of 21.3A, see also 3.5 Limitations by ADC resolution / Maximum output values).
For stability reasons, the ranges of values of the components to be simulated must partly be limited to additional minimum values for high frequencies (see 3.3 Limitations due to natural oscillations of TC.ACS).

The necessary damping resistances are to be selected depending on the structure and application (see 3.2 Oscillations caused by weak sources and 5 Practical example: Simulated anti-islanding test).

In ACSControl application software, the corresponding coefficients for the differential equation are calculated from the topology and its configured values and transferred to the firmware for the discrete calculation of the set values for the current.

3 Limitations

When operating in RLC load mode, some special cases must be considered to ensure smooth operation. Most restrictions are system-based and have no direct influence on the desired application.

3.1 Oscillations in Open Loop Operation

If no external voltage is present (open terminals), depending on the topology the system may tend to self-oscillate. This is because the simulated impedance resonates with the output filter, so even a small amount of disturbance (voltage measurement at open terminals) is sufficient to cause the system to oscillate at this frequency.

Solutions:

- Connect an external source to get a defined voltage.
- Increase the simulated damping resistance.
- Use the measuring filter for voltage measurement (see 3.2 Oscillations caused by weak sources) to blank out resonance points.

3.2 Oscillations caused by weak sources

There are configurations in which the DUT resonates with the filter capacity of TC.ACS. If the source is too weak or the cable impedance between DUT and TC.ACS is too high to keep the voltage of the DUT constant, oscillations can occur that can't be compensated by the current controller of TC.ACS due to the limited control bandwidth.

It is important that the control between voltage and load current remains stable under all circumstances (with the filter switched off) and is only dependent on the voltage V, not on the external load case.

For signals with frequency <1kHz applied to the simulation port, the simulation behaves as desired, but for frequencies >1kHz the influences of the filter board increase.

To attenuate high-frequency oscillations, a built-in 1st order filter can be activated in ACSControl. As a result, frequency components above the cut-off frequency of the filter (variably adjustable) are filtered out and are no longer amplified by the selected RLC configuration. However, frequencies that interact directly with the output filter can't be damped. This requires separate filter hardware on the simulation port of TC.ACS, such as a ADI-BOX (see

4 Influences when using an ADI-BOX).

It must be noted, however, that the measuring filter introduces an extra pole into the system. Therefore, the system may become unstable at the resonance point resulting from the selected impedance (depending on controller bandwidth, source impedance and filter frequency). Basically, the stiffer the source (DUT), the more stable the simulation.

Resistors up to approx. 1Ω can also be simulated up to 10kHz as pure resistance. Therefore, the RLC simulation can be used to ensure, by a suitably chosen damping resistor value, that the resonance between the impedance of the DUT and the output filter is attenuated. As a consequence, it is necessary to add a small attenuation resistance <1Ω in series with a capacitance to prevent these resonances introduced by external sources (see 5 Practical example: Simulated anti-islanding test)!

Solutions:

- Select a correspondingly large impedance at the resonance point.
- When using the 1st order filter in ACSControl, select a correspondingly large impedance at the resulting resonance point.
- Change the filter cutoff frequency.
- Reduce the gain of the i1 controller by reducing the parameter Kp.
- Select a source with a sufficiently high short-circuit current.

3.3 Limitations due to natural oscillations of TC.ACS

Due to a resonance point of the line filter, TC.ACS is not able to simulate an impedance of <0.5Ω@6.2kHz. RLC load mode amplifies this resonance and the device oscillates at this frequency.

Solutions:

- Select correspondingly high impedance @6.2kHz.
- Activate the 1st order filter in ACSControl (filter cutoff frequency approx. 500-2000Hz)
- Reduce the gain of the i1 controller by reducing the parameter Kp.

3.4 Power Feedforward

When operating as a sink, fast and big load steps can only be fed back into the grid with the aid of the power feed forward. If this is not the case, an error message "Overvoltage DC" will be indicated. Depending on the DUT, the power feedforward must be activated accordingly.

3.5 Limitations by ADC resolution / Maximum output values

Another limitation is the maximum resolution of the ADC for measuring the signals. For example, simulating 1kΩ at 10V voltage at the simulation port would give a current of 1mA, which is below the minimum resolution of 147mA. The same applies analogously to the voltage measurement with a minimum resolution of 213mV.

4 Influences when using an ADI-BOX

When using the first generation RL load mode, a filter configuration called ADI-BOX was used to stabilize the system. This is a parallel connection of a 300µH choke L_{ADI} and a 5Ω resistor R_{ADI} per phase, to filter disturbances that could destabilize the system.

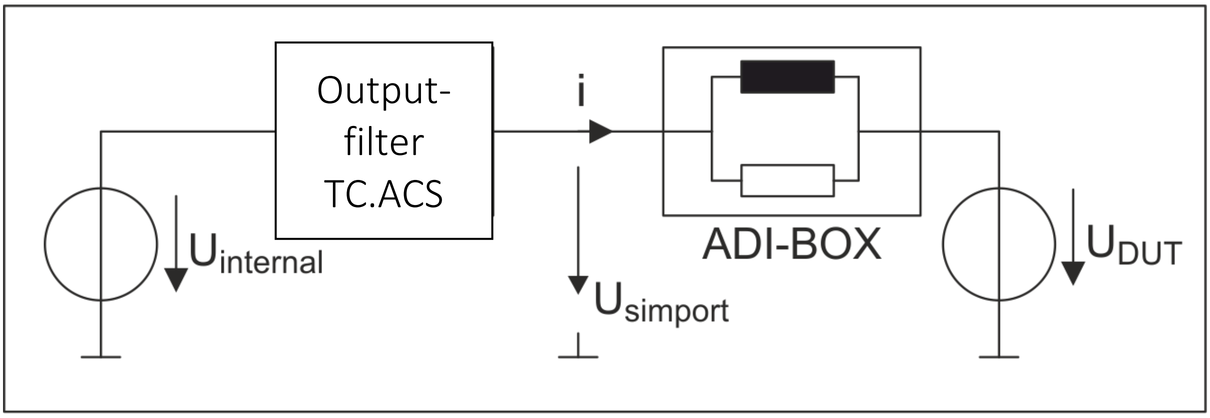

Figure 2: Schematic representation of the RLC load mode when using an ADI-BOX.

Figure 3: clearly shows that the simulated impedance in the simulation of a 1Ω R load with connected ADI-BOX only shows the desired behavior up to approx. 100Hz. At frequencies >100Hz, the influence of the ADI-BOX becomes larger and the impedance, due to the inductance in the ADI-BOX, becomes higher than the set value. The zero at about 18 kHz is smoothed a little in reality due to the neglect of the attenuation in the calculation.

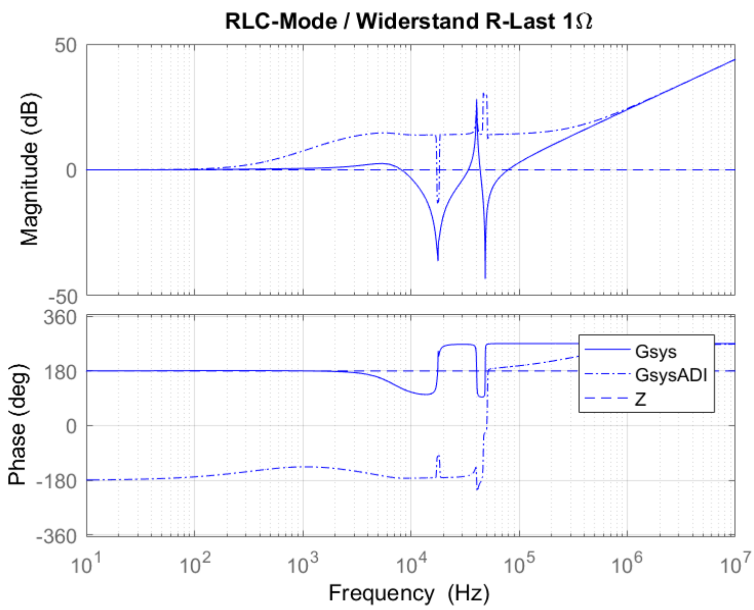

Figure 3: Influence of the ADI-BOX (dashed line) on the simulated impedance compared to the case without ADI-BOX (solid) and a passive, optimal R-load in the case of 1Ω (dashed).

Large deviations exist in particular in the simulation of C loads, since the inductance of the ADI-BOX forms an LC filter with the simulated capacitance with a corresponding resonance frequency of $f_r \approx \frac{1}{2\pi\sqrt{L_A(C_{SIM})}}$. For higher frequencies, the circuit is no longer capacitive but inductive (see Figure 4:)

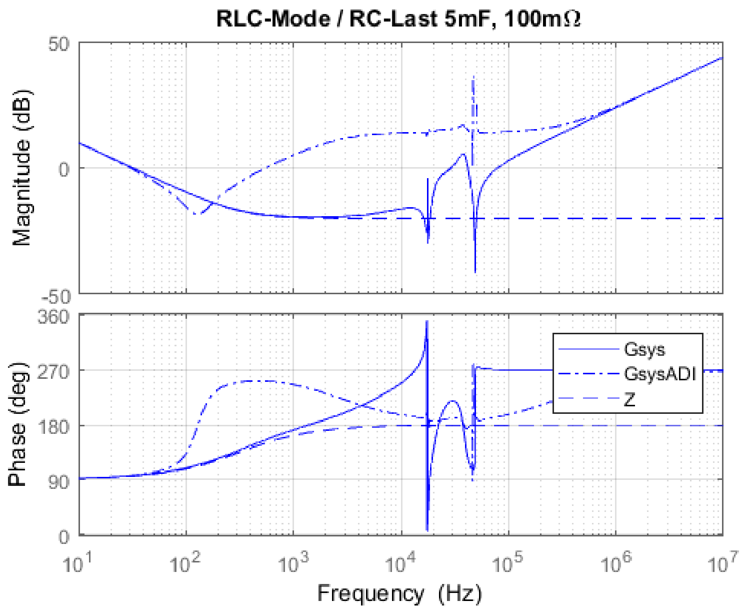

Figure 4: Influence of the ADI-BOX (dashed line) on the simulated impedance compared to the case without ADI-BOX (solid) and a passive, optimal RC load in the case 5mF, 100mΩ (dashed).

5 Practical example: Simulated anti-islanding test

The benefit of the RLC load mode is shown in a practical example.

Regenerative power supplies must be subjected to a so-called anti-islanding test in accordance with DIN VDE 0126-1-1 [2] to ensure that the device recognizes and switches off an island condition.

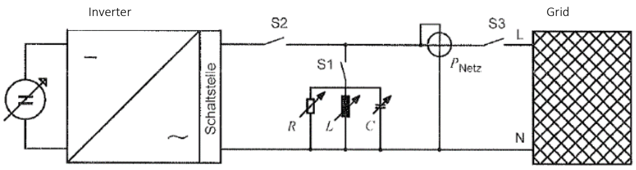

Figure 5: Test circuit according to standard DIN, VDE 0126-1-1 [2]

For this purpose, a resonant circuit is connected in parallel to the test object / network, which must be adjusted as follows:

- Adjust the inductance so that Q> 2
- Set the capacity so that PQ (Reactive Power) of the resonant circuit is equal to the reactive power of the DUT.
- Set the resistance so that the active power of the resonant circuit is equal to the active power of the DUT.
- Subsequently, S1, S2, S3 are closed and the DUT is turned on, so that the corresponding active / reactive power flows.
- S3 is opened and the time until the DUT switches off is measured.
- After each successful test, one parameter (L or C) is changed by approx. 1% in the total range of approx. ± 5% and the test is repeated.

The entire test procedure is carried out at P = 25%, 50%, 100% of the nominal power and at nominal frequency ± 0.1 Hz and ± 3% of the nominal voltage.

For such applications, a TC.ACS in RLC load mode and a TC.ACS in grid simulation mode are predestined, since the adaptation and finely graded change of the R-L-C values are very easy to perform.

For the test setup two regenerative AC / DC converters with anti-islanding detection (TC.GSS) are used (see Figure 6:).

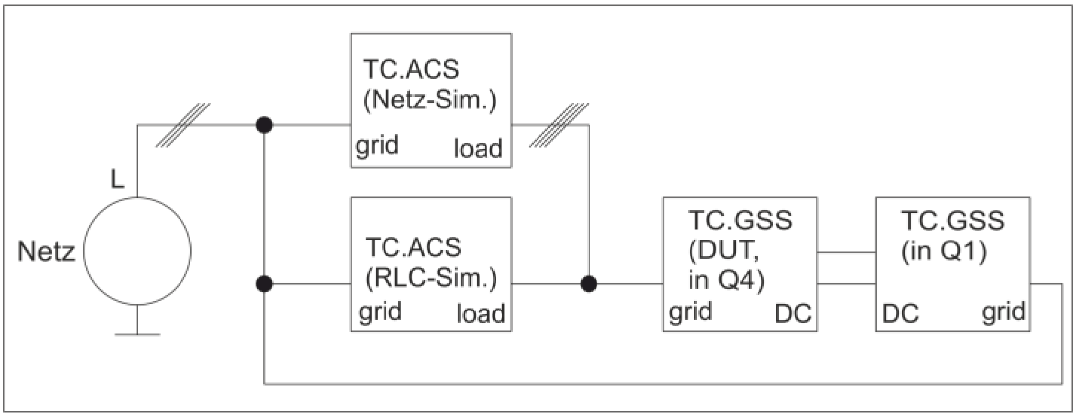

Figure 6: Test setup Anti-Islanding-Test

For the load simulation, following settings are made in RLC load mode:
Topology No. 12, P = 5kW (per phase), U_{GRID} = 230V_{RMS}, Q = 3 (formulas acc. to [2]).

$$L = \frac{U_{GRID}^2}{2\pi f * P * Q} = 11.22mH$$
$$C = \frac{P * Q}{2\pi f * U_{GRID}^2} = 900\mu F$$
$$R = \frac{U_{GRID}^2}{P} = 10.6\Omega$$
$$R2 = 0.1\Omega, \qquad R3 = 0.4\Omega$$

Further, the 1st order filter with a cutoff frequency of 500 Hz is selected.

R2 and R3 are chosen so that the numerics work properly and stability is ensured (see also 3.2 Oscillations caused by weak sources). R3 must be chosen large enough that R3 dampens the oscillations of the grid impedance.
The quality factor of the damped resonant circuit derives from the following equation:
$Q = 2\pi \frac{W}{V}$, where
W = stored energy at the beginning of a period of oscillation,
V = loss energy within one period.

Alternatively, the Q-factor can also be extracted from the transfer function
(see Figure 7:), where:

$$Q = \frac{f_0}{f_2 - f_1}$$

and f_2, f_1 are the points where the impedance is reduced to $\frac{1}{\sqrt{2}} = -3dB$ relative to the point f_0.

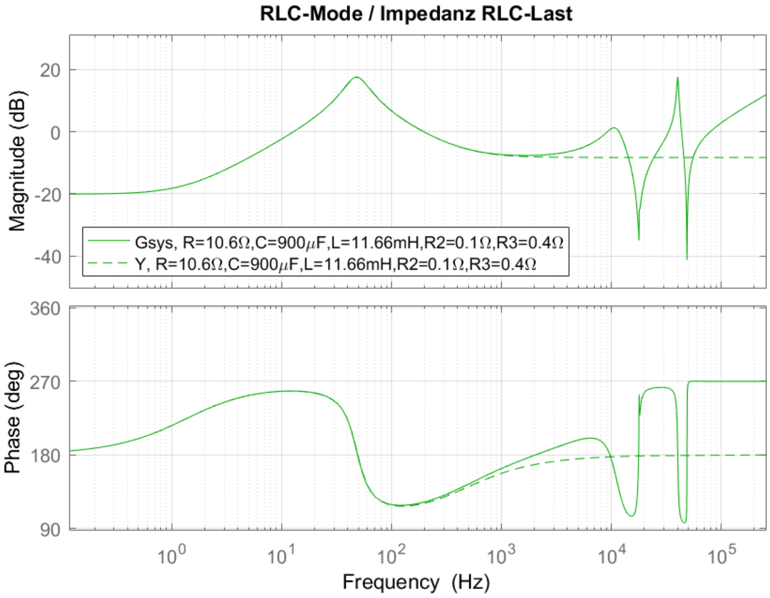

Figure 7: Transfer function of the simulated RLC impedance. Dashed would be a real, passive impedance, solid is the effectively simulated RLC load-mode impedance. Relevant is the range around 50Hz.

Figure 8: shows the test procedure after switching off the grid simulator until the island operation is detected by TC.GSS.

Figure 8: Behavior with RLC simulation in the Anti-Islanding test. At t = -645ms the grid simulator is switched off, after 645ms the DUT switches off with islanding detection. Ch1 (yellow): Voltage L1-N at the input of TC.GSS, Ch2 (red): Current L1 of simulated RLC load with TC.ACS, Ch4 (green): Current supplied from the grid simulator. RMS-value of current through the grid simulator is at 600mA when on, which equals to <3% of the test power of 5kW

6 Summary

With standard control parameters for the current controller, the RLC load mode can be used successfully and a control bandwidth of 1 kHz can be achieved in the required operating cases.

However, there are some limitations to the operation:

- Depending on the programmed impedance, the RLC load mode oscillates at open loop operation, as resonances can be excited internally.
- External sources interact directly with the output filter of TC.ACS and can only be conditionally influenced for frequencies above the controller bandwidth. Alternatively, external additional filters (option ADI-BOX) can be used, but these severely limit the scope of the RLC load mode.
- Resonances by weak sources can be damped by correspondingly simulated damping resistors.
- An optional digital cut-off filter with variable cut-off frequency can blank out unwanted resonance points for the calculation of the current setpoint, but can lead to an unstable system due to the additional pole in some circumstances.
- The value range of the possible impedances is limited by numerics, but all realistic values can be simulated.
- It may be necessary to activate the power feedforward.
- The minimum resolution of the measurement and the maximum continuous current limit the value ranges depending on the voltage and frequency at the simulation port.

7 References

[1] LGF Elektrotechnik GmbH, «E-Mail from 14.03.2017: "Datenblätter / freigaben LGF140815-02, LGF140120-02",» 2017.

[2] DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE, «Selbsttätige Schaltstelle zwischen netzparallelen und Eigenerzeugungsanlage und dem öffentlichen Netzspannungsnetz,» VDE Verlag GmbH, Berlin, 2006.

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