

# BATTERY CYCLE TOOL FOR R&S®NGU401, NGU201, NGM200 AND NGL200

## Products:

- ▶ R&S®NGU401
- ▶ R&S®NGU201
- ▶ R&S®NGM200
- ▶ R&S®NGL200
- ▶ R&S®NGU-K106
- ▶ R&S®NGM-K106

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<http://www.rohde-schwarz.com/appnote/1GP130>



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# 1 Overview

The application program of this application note provides a tool for cycling battery samples, using two-quadrant DC power supplies from Rohde & Schwarz. The batteries can be repeatedly charged and discharged while collecting information about open-circuit voltage, loaded voltage and internal resistance, depending on the charged and discharged capacity. The tool provides a variety of charts for displaying the collected data. It can be used for characterizing battery samples, as well as for creating battery models which can be used in the battery simulations of R&S®NGU201 and R&S®NGM200.

This tool is meant for the use by knowledgeable experts. The application note does not provide instructions on how to properly charge and discharge batteries.

## 2 Safety Instructions

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### **WARNING**

#### **Risk of fire**

Experimental charging of batteries poses the risk of fire.

- Do not leave the setup unattended.
  - Place batteries to be charged in a fire-proof containment.
  - Observe the rules and limits for charging, and the safety guidelines given for the respective battery types.
  - Make sure that the work space is equipped with fire and smoke detectors and fire extinguishers.
- 

## 3 Background

This tool requires DC power supplies with so-called "two-quadrant" operation which can source and sink current on positive output voltages. The devices supported by this application note, the special functions used and the function principle of the battery cycle tool are outlined below.

### **3.1 Source measure units R&S®NGU201 and R&S®NGU401**

Power Supplies R&S®NGU201 and R&S®NGU401, further herein below called "NGU", are source measure units with standard and high-speed logging capability of voltage and current.

R&S®NGU201 can be operated as power supply (positive output current) and load (negative output current) on positive voltages. R&S®NGU401 is a four-quadrant power supply, capable of sourcing and sinking currents with positive and negative output voltages.

## 3.2 Power supplies R&S®NGM201 and R&S®NGM202

Power Supplies R&S®NGM201 and R&S®NGM202, further herein below called “NGM”, are high-precision sources and sinks with standard and high-speed logging capability of voltage and current.

R&S®NGM201 provides one channel and R&S®NGM202 features two independent channels.

## 3.3 Power supplies R&S®NGL201 and R&S®NGL202

Power Supplies R&S®NGL201 and R&S®NGL202, further herein below called “NGL”, are high-precision sources and sinks with standard logging capability of voltage and current.

R&S®NGL201 provides one channel and R&S®NGL202 features two independent channels.

## 3.4 Arbitrary function

The arbitrary function in R&S® DC power supplies allows to specify variable source voltage and current setting as a function of time. [1] Value pairs of voltage and current are stored together with an associated dwell time. During the playback of the sequence, each pair is set in the output and maintained for the specified dwell time before the next pair of voltage and current values is set. The sequence starts when the respective channel is activated and, depending on the settings, is repeated cyclically or played only once. In the NGU the resolution for the dwell time is 0.1 ms, in the NGM the time resolution is 1 ms.

In manual control the arbitrary data is stored in an ASCII text file. The user interface provides an editor which allows to set up an arbitrary file on the touchscreen of the instrument. In remote control the data is uploaded from the controlling PC to the instrument via the remote-control interface, and stored into internal memory.

## 3.5 Battery simulation

For R&S®NGU201 and R&S®NGM200, optional battery simulations R&S®NGU-K106 and R&S®NGM-K106, respectively, are available. Channels with active battery simulation apply a certain open-circuit voltage and internal resistance depending on the state of charge (SoC). Both values can be specified in 1% steps of the SoC in a CSV (character-separated values) ASCII file.

The SoC is determined by integration of the current at the channel output, and by dividing the integral of the current by the value of the battery capacity which can be set in the user interface of the battery simulation.

The Battery simulation can be used to power a device instead of a battery, in order to reproducibly determine the behavior of the device depending on the state of charge of the battery.

# 4 Prerequisites

The following prerequisites have to be observed for a correct function of the application program.

## 4.1 Configuration of the NGU, NGM or NGL

No options are required for this application. Make sure to have the latest firmware version installed.

You can find an installer for the latest firmware version on the R&S® web site.

## 4.2 Requirements to controlling PC and software installation

The application program runs on PCs with Windows 10 operation system.

For the instrument remote control, the controlling PC must have a compatible VISA library installed. A free VISA library is available from the R&S® web site [2].

The application program requires .NET runtime 4.0 or higher. Make sure that .NET runtime 4.0 or higher is installed on the controlling PC. A compatible version 4.5 is available for download from [3]

The system partition of the hard disk must have approximately 800 Mbyte of free space to store the log data.

Copy installer “1GP130\_xyz.msi” to the local hard drive of the PC and start it. Follow the instructions on the screen.

## 4.3 Remote control connection

For remote control, either a USB connection, LAN connection or GPIB connection is required between the controlling PC and the NGM or NGL, respectively. GPIB can only be used with low sample rates of the fast log. See section 5.1.1 for details.

# 5 Test setup

Observe the following hints regarding the test setup to ensure proper operation of the application program.

## 5.1 Remote control

The following sections explain how the remote-control connection from the controlling PC to the instrument should be established.

### 5.1.1 Interfaces

R&S® instruments can usually be remote controlled via GPIB, LAN and USB. NGM additionally allows WLAN connection when option NGM-K102 is installed.

For the current task there are some prerequisites to observe, as the fast logging of NGU and NGM requires a certain minimum data rate, depending on the sample rate of the logging function.

The data rate of GPIB is sufficient only for the lower sample rates of the fast logging function. Therefore, GPIB is not recommended as connection to the instrument for this application.

The USB interface in the NGU and NGM supports two different USB classes. "CDC" emulates a serial interface via USB-to-serial converter and has the advantage of compatibility with older remote-control systems. The data rate of the "CDC" class is not sufficient for fast logging. Therefore "USB Class" in submenu "Device → Interfaces" has to be set to "TMC".

### 5.1.2 VISA ident strings

The NGU / NGM VISA ident string for USB has the format "USB0::0x0AAD::0x0197::3638.1234k02-123456::INSTR". The black digits and characters are invariant for all individuals of NGU and NGM, and specify interface type, manufacturer and instrument type. The violet digits are "8.4472" for NGM, and "9.3763" for NGU401 and NGU201. The blue digit specifies the instrument variant. It is "2" for NGM201 and NGU201, and "3" for NGM202 and NGU401. The green digits represent the serial number of the individual instrument. The type number and serial number are shown in menu item "Device → Device Information" on the instrument.

The ident string for the IP LAN connection to the NGM/NGL/NGP has the format "TCPIP0::aaa.bbb.ccc.ddd::inst0::INSTR". The black part is common for most instruments and for all NGU and NGM. The green part represents the IPv4 address which can be read with NGU or NGM in menu item "LAN" of sub-menu "Device → Interfaces → Network". "aaa" can have two or three digits. All other numbers in the string can have between one and three digits.

The "IP" button enters the template shown above in the resource combobox which then has to be completed with the actual IP address.

It is also possible to use the "Find" button (see below) for discovering the instruments on USB and GPIB interfaces and obtaining their VISA ident strings. The LAN interface is not searched with the "Find" button.

## 5.2 Connecting the DUT

Keep electric connections to the DUT as short as possible. When measuring very low currents, it may be advantageous to shield the DUT and the connections. Use the separate sense lines when large currents are expected. On the NGM202 the sense lines are only available on the channel connectors on the backplane. In this case you should consider to connect the DUT on the back side of the instrument.

Hum noise may be reduced when the low terminal is grounded. The NGU has a second low force terminal and a ground terminal on the front panel, which allow a convenient connection using the jumper supplied with the NGU. On the NGM a ground clamp is provided on the backplane.

# 6 User interface of the application software

## 6.1 Remote control tab

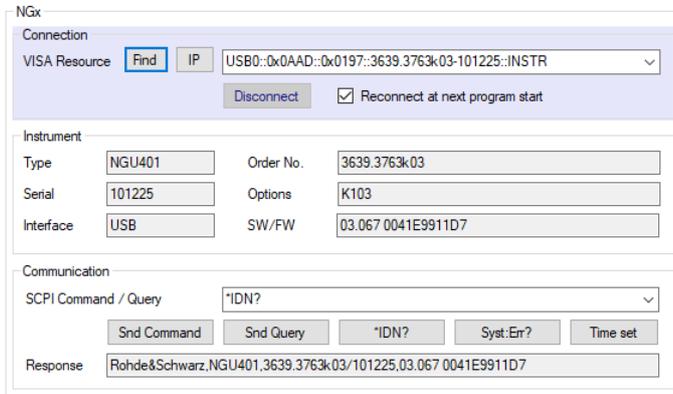


Figure 6-1 NGx field of the Remote Control tab

The remote-control tab allows configuration and test of the remote-control connection to the connected DC power supply or source measure unit.

Enter the VISA resource string of the power supply as described in section 5.1.2 into the Visa Resource text box.

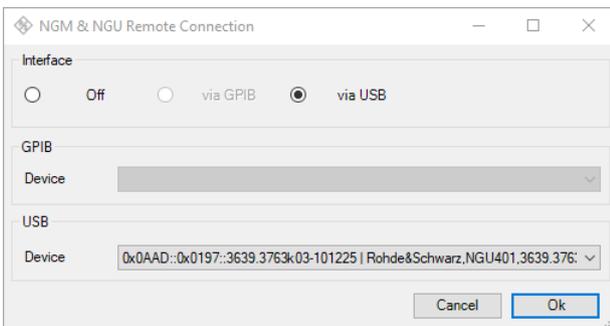


Figure 6-2 Remote connection window

Clicking the “Find” button starts a search on the USB and GPIB interfaces and displays found NGU or NGM instruments in a new remote connection window (Figure 6-2 Remote connection window. If multiple devices are detected, one on each interface can be selected in the comboboxes showing the resource strings, and the interface to be used can be selected with the radio buttons on top.

Clicking the “IP” button enters the resource string template for IP connections into the resource combobox.

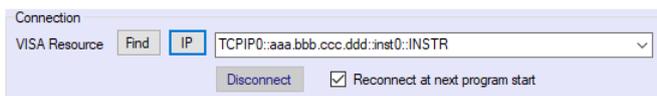


Figure 6-3 Resource string template for IP connections

Enter the actual IP address of the DC power supply in the places marked with “aaa.bbb.ccc.ddd”. The IP address can be read from the “Interfaces → Network” sub-menu of the device menu.

Any resource which has been connected successfully in the past, is stored with the settings of the user interface and appears in the resource combobox after the next start of the program. If “Reconnect at next program start” is checked, the instrument which has been connected last before closing the application will

be reconnected when it is started next time. If required, the “Disconnect” button can be used to end an existing remote control connection.

The “Instrument” groupbox shows information about the instrument which has been successfully connected last.

The function of the remote connection can be checked with the buttons in the “Communication” groupbox. It is recommended to check the remote-control connection before starting a battery cycling operation.

“Snd Command” sends a SCPI command entered in the “SCPI Command / Query” combobox to the instrument.

“Snd Query” sends a SCPI command entered in the “SCPI Command / Query” combobox to the instrument, reads the response from the interface and displays it in the “Response” textbox.

The “SCPI Command / Query” combobox remembers the last 20 commands which have been sent successfully. To send one of these commands again, open the combobox using the small arrow on the right side, and select the desired command before clicking the “Snd Command” or “Snd Query” button, respectively.

“\*IDN?” displays the identification string returned from the instrument in the response textbox.

Note: It is recommended to execute the “\*IDN?” function before proceeding with the battery cycling setup. This ensures that the instrument can be reached by remote control. Based on the identity reported by the instrument, appropriate controls are enabled in the sweep tab, if supported by the type of the connected power supply.

“Syst:Err?” reads one entry from the error queue and displays it in the response textbox. The error queue can be regarded as a first-in-first-out buffer to which SCPI errors caused by remote commands are written by the instrument and picked up by the “SYST:ERR?” command.

“Time set” sets the real-time clock of the instrument to that of the controlling PC.

The “Working Folder” textbox displays the path of the working folder on the controlling PC used by the application program. This folder contains a file “trace.log” where error messages from the application program are written, and a file “settings.sup” memorizing the settings of the user interface at the time the application program was terminated last time. The “Open” button opens a file explorer in the application folder.



Figure 6-4 Environment field of the Remote Control tab

The “Data Folder” Combobox displays the path of the data folder on the controlling PC used by the application program. This folder is the target for log data from the NGM or NGL. Initially the data folder is the same as the working folder, but a different location can be selected by clicking the “...” button.

Note: The selected file location has to support the data rate and access speed required for the fast logging operation. “Jumps” in the IV diagram may be due to missing portions of fast log traces, caused by inappropriate storage media.

The “Open” button opens a file explorer in the data folder.

The combobox on bottom of the window shows the last 64 messages on the remote-control interface in use. While the combobox is closed, it shows the last message. To see the last 64 messages, click on the arrow on the right side.

## 6.2 Settings tab

The controls in the settings tab allow to configure all aspects of the battery cycling. The tab is divided into different fields for charge and discharge operation, global settings and control. The parameters of these fields are explained in more detail below.

### 6.2.1 Save / recall charge and discharge settings

All parameters of the settings tab can be saved to a file and recalled later. Use the “Save As ...” and “Load” buttons in the “Charge / Discharge Settings” field.



Figure 6-5 Charge / Discharge Settings field of the Settings tab

### 6.2.2 Global field

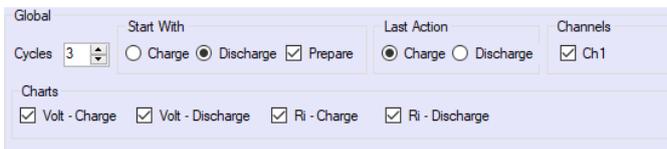


Figure 6-6 Global field of the settings tab

The settings in the global field define the overall parameters of the cycling operation.

The “Cycles” numeric input control allows to set the number of charge-discharge cycles which are carried out automatically.

The “Start with” group box allows to define whether charging or discharging will be the first complete operation.

If the state of charge of the battery under test is unknown, the “Prepare” checkbox causes the tool to bring it into a defined state before the cycling is started. If the first operation of the cycling is charging, the battery is prepared by discharge to the limits set in the “Discharge” field before the first complete charging operation is started. If the first operation of the cycling is discharge, the battery is prepared by charging it with the specified method before the first complete discharging operation is started.

The “Last Action” choice allows to leave the batteries under test in a defined condition after cycling has ended. The usually recommended choice is “Charge” because it allows the batteries to store them in fully-charged state.

For the two-channel devices NGL202 and NGM202 the “Channels” checkboxes allow to select one of the channels or both for the cycling operation.

All settings on this tab can be stored to a file and recalled later using the “Save As ...” and “Load...” buttons. This allows to collect individual settings for different battery types and switch between them quickly.

## 6.2.3 Charge field

Charge

OC Voltage 4.500 V (maximum voltage at the battery when the current is below the specified limit)

CC 0.000 A  Pulsed 0.500 A 4.0 s, 0.250 A 1.0 s

Charge End Criterion (Choose at least one)

Check voltage under charge  Check open circuit voltage

Voltage 4.199 V  Volt. Plateau 0.000 mV  Neg. Delta V 0.000 mV  Low Voltage 0.200 V  Capacity 0.100 Ah  Time Limit 4.000 h

0.0 s 10.0 s

Pause 10.0 s

After End Criterion has been Reached

Stop Charging  CC 0.066 A up to 0.000 V

CV 4.200 V down to 0.100 A  CC 0.044 A for 3333 s

Figure 6-7 Charge field of the settings tab

### 6.2.3.1 Charge methods

Charging can be done with constant current and pulsed current. For both methods the open-circuit voltage of the power supply can be set. The internal resistance can only be determined with pulsed charging. For this reason, a battery model can only be created from pulsed charge data.

Charging with pulsed current allows to determine the open-circuit voltage and internal resistance besides the voltage under charge which is usually considerably higher than the open-circuit voltage. The pulsed charging method switches between a high charge current and a lower current. The open-circuit voltage is extrapolated from the difference of the voltages and the difference of the currents. The internal resistance is calculated from the difference between voltage under charge and open-circuit voltage, and from the higher charge current.

### 6.2.3.2 Charge-end criteria

To serve the needs of different battery chemistries, various configurable charge-end criteria are supported. At least one criterion has to be selected by ticking the respective checkbox. Multiple criteria may be selected. In this case the charging is ended when any of the selected criteria has been reached.

With pulsed charging method, all criteria related to voltage can be applied either to the voltage under charge or to the (extrapolated) open-circuit voltage.

The following criteria are available:

- **Voltage:** The selected voltage surpasses the specified limit.
- **Voltage Plateau:** The selected voltage does not change more than the specified difference within the specified time.
- **Negative Delta V:** The selected voltage drops from the maximum reached by more than the specified difference.
- **Low Voltage:** The selected voltage stays below the specified threshold for more than the specified time (cell short circuit)
- **Capacity:** Charging is stopped when the specified capacity has been charged.
- **Time Limit:** Charging is stopped at the specified time limit after it has been started.

With many battery chemistries it is difficult to exactly determine the “full” state-of-charge from measured properties. Therefore the charge-end criteria serve the purpose of protecting the battery from overcharge, but the battery capacity can be determined more precisely from the discharge process.

### 6.2.3.3 Top-up charging

After the end criterion for the main charging process has been reached, an additional top-up charging process can be appended, for example at a lower charge current. Three methods are available:

- Constant voltage down to a specified charge current.
- Constant current up to a specified voltage threshold.
- Constant current for a specified duration.

### 6.2.3.4 Pauses

After the main charging process and after top-up charging, pauses can be inserted to allow for chemical relaxation processes or adaptation of the inner cell temperature to the surrounding temperature.

## 6.2.4 Discharge field

The screenshot shows a software interface for configuring a discharge test. It is divided into two main sections: 'Discharge' and 'Pause'.  
In the 'Discharge' section, there are two radio buttons: 'CC' (Constant Current) and 'Pulsed'. The 'Pulsed' option is selected. Next to 'CC' is a numeric input field with '0.000' and the unit 'A'. Next to 'Pulsed' is a numeric input field with '0.500' and the unit 'A'. To the right of the 'Pulsed' current field are two more numeric input fields: '4.0' with the unit 's' and '1.0' with the unit 's', representing pulse duration and pause duration respectively. Below these are two radio buttons: 'Check loaded voltage' and 'Check open circuit voltage'. The 'Check open circuit voltage' option is selected. To the left of these radio buttons is a numeric input field with '3.200' and the unit 'V', representing the end voltage.  
Below the 'Discharge' section is a 'Pause' section with a numeric input field containing '10.0' and the unit 's'.

Figure 6-8 Discharge field of the settings tab

Discharging can be performed with constant current or pulsed operation. Note that the internal resistance can only be determined with pulsed operation. For this reason a battery model can only be created from pulsed discharge data.

The discharge current can be set for each of the two alternatives. For the pulsed discharge operation, the duration of the load and the duration of the interval without load can be configured.

Discharge end criterion can be the loaded voltage, measured at the end of each load period, or the open-circuit voltage, measured at the end of each period without load.

## 6.2.5 Control field

The buttons in this field allow to start and stop the cycling operation. It is also possible to pause the operation and resume it at a later time at the same stage. During the pause the outputs of the power supplies are disabled.

## 6.3 Dashboard tab

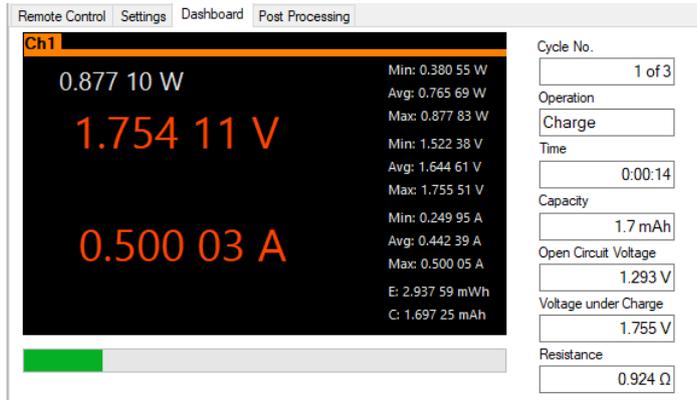


Figure 6-9 Channel display of the dashboard tab

While the cycling is running, the dashboard tab shows an overview over its state. Instantaneous voltage, current and power are shown in the style of a channel display on the instrument, together with minimum, maximum and average of power, voltage and current as well as energy and charge. The statistics are reset at the start of each new charge or discharge operation.

The fields on the right-hand side of the channel display give more information on the state of the cycling, plus calculated values like internal resistance.

For convenience, the control field is also available on the dashboard tab.

## 6.4 Post-processing tab

The post-processing tab allows to open log files from previous cycling operations for further processing. It is possible to display charts of various values versus charged or discharged capacity, or versus number of executed cycles. Furthermore, it is possible to generate a battery model for use with the battery simulation of R&S®NGU201 and R&S®NGM200 (see section 3.5).

An existing log file can be opened using the “Browse ...” button on top of the tab. The combobox holds path names of previously opened log files for quick access. Files with path names starting with “...\” are located in the data folder which can be selected on the Remote Control tab.



Figure 6-10 Log file selection in the post-processing tab

## 6.4.1 Charts

The 'Charts' field contains the following items:

- Voltage - Charge: Cycles 1 2 3 . Show
- OC Voltage - Charge: Cycles 1 2 3 . Show
- Voltage - Discharge: Cycles 1 2 3 . Show
- OC Voltage - Discharge: Cycles 1 2 3 . Show
- Ri - Charge: Cycles 1 2 3 . Show
- Ri - Discharge: Cycles 1 2 3 . Show
- Capacity - Cycles:  Discharge  Charge Show
- Ri - Charge Cycles:  @ 95 %  @ 50 %  @ 5 % SoC
- Determine capacity from:  Discharge  Charge Show
- Ri - Discharge Cycles:  @ 95 %  @ 50 %  @ 5 % SoC Show

Figure 6-11 Charts field of the post-processing tab

The first six charts plot voltages or internal resistances versus charged or discharged capacity, respectively. The central buttons allow to select the cycles from which traces should be generated in the chart. If you click one of these buttons, a selection window will open.

The 'Cycle selection window' contains the following items:

- All Cycles
- 1
- 2
- 3
- 4
- Apply to all
- Cancel
- Ok

Figure 6-12 Cycle selection window

The selection window shows one checkbox for each available cycle. The “All Cycles” checkbox toggles all of them at the same time. “Apply to all” copies the selection to the other charts. When the selection has been made and the “Ok” button is clicked, the selection is shown on the buttons. For each selected cycle the respective number appears. Deselected cycles are marked with periods “.”.

The seventh chart shows discharged and / or charged capacity versus cycles. If a large number of cycles is available, this allows to investigate aging effects of the batteries under test. The same is the case with the charges which show the internal resistance during discharge or charge versus the number of cycles. In each chart a maximum of three traces plot the internal resistance at configurable SoCs.

Figure 6-1 shows a selection of charts which can be generated with the functionality of the post-processing tab.

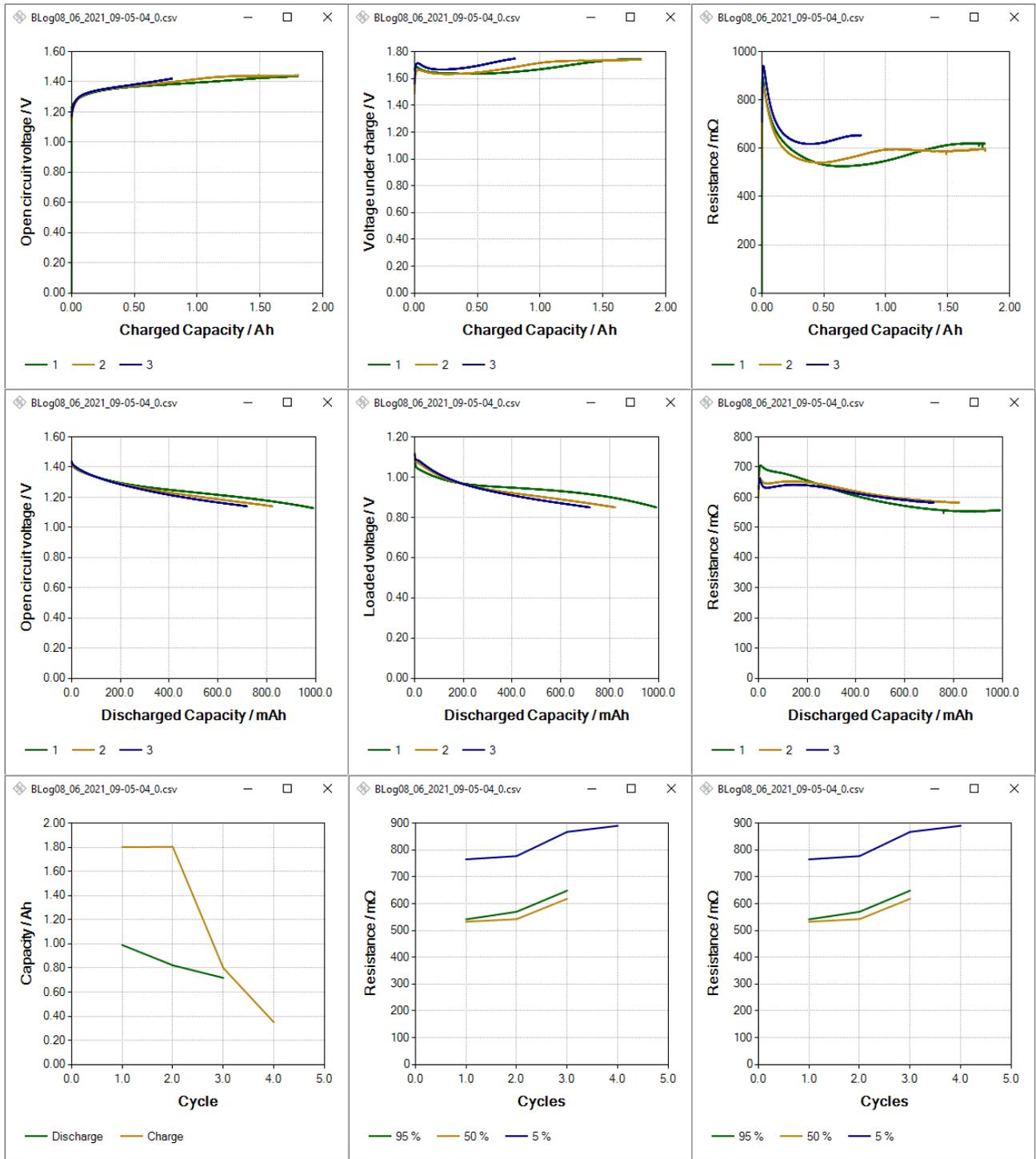


Figure 6-13 Charts generated from the post-processing tab

## 6.4.2 Battery model

The “Create Battery Model” field allows to turn logging data from battery cycling into a battery model which can be used on the battery simulation of R&S®NGU201 and R&S®NGM200.

```
Device:  
Format:BATTERY  
Capacity:0.822  
#InitialSoC:100  
#CurrentLimitEndOfDischarge:0.001  
#CurrentLimitRegularCharge:3.010  
#CurrentLimitEndOfCharge:3.010  
SoC;Voltage;Resistance  
0:1.141;0.582  
1:1.143;0.582  
2:1.144;0.582  
3:1.147;0.583  
4:1.148;0.584  
5:1.150;0.583  
6:1.152;0.584  
7:1.154;0.585  
8:1.155;0.585  
9:1.157;0.585  
10:1.158;0.585  
11:1.160;0.586  
12:1.162;0.587
```

Figure 6-14 Battery model field of the post-processing tab

Select the cycle number and whether the model should be created from charge or discharge data.

Since the battery model specifies open-circuit voltage and internal resistance depending on the state of charge, the battery capacity corresponding to 100% SoC has to be determined for the respective cycle. For a battery model generated from discharge data, the battery capacity is always determined also from the discharge data of the same cycle. For a battery model generated from charge data, it is possible to select whether the battery capacity should also be determined from the charge data, or instead from the discharge data of the same cycle.

After clicking the “Create” button, a file selector opens for entering the file name of the battery model file. Subsequently, all data is calculated, the file is written, and the contents of the file can be viewed in the textbox below the controls.

# 7 Literature

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# 8 Ordering Information

Designation	Type	Order No.
Two-quadrant source measure unit	R&S®NGU201	3639.3763.02
Four-quadrant source measure unit	R&S®NGU401	3639.3763.03
Power Supply	R&S®NGM201	3638.4472.02
Power Supply	R&S®NGM202	3638.4472.03
Power Supply	R&S®NGL201	3638.3376.02
Power Supply	R&S®NGL202	3638.3376.03
Battery Simulation (R&S®NGU201 only)	R&S®NGU-K106	3663.0625.02
Battery Simulation for R&S®NGM200 Power Supplies	R&S®NGM-K106	3636.6626.02

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Application Note | Battery Cycle Tool for R&S@NGU401, NGU201,  
NGM200 and NGL200

Data without tolerance limits is not binding | Subject to change

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