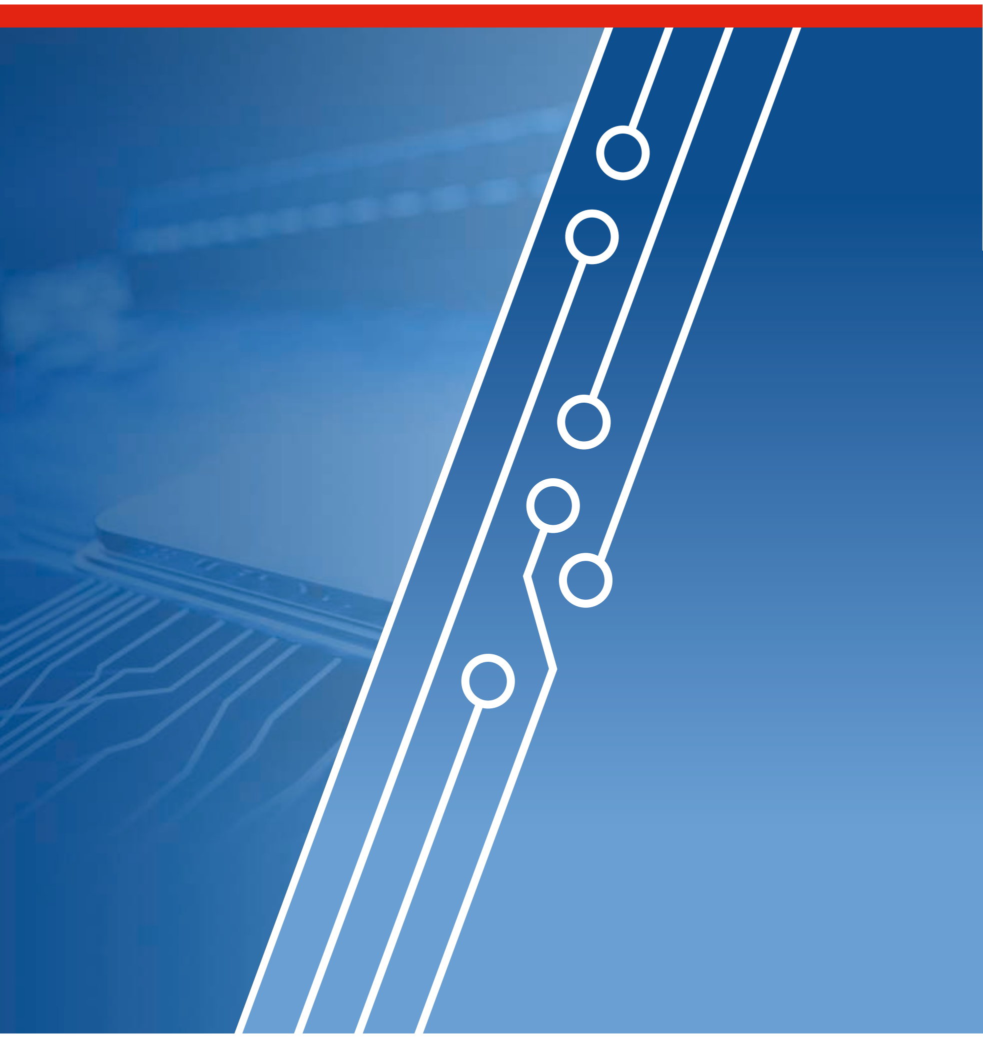

Elektro-Automatik

MANUAL

LIZENZFG

Function generator upgrade for PUx 10000 series

33100237_MA-Option-FG-PUx-Series-EN_01

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1. General

1.1 About this document

1.1.1 Retention and use

This document is to be kept in the vicinity of the equipment for future reference and explanation of the installation of the optional function generator for the in *1.1.3* listed series, as part of the purchase of the license. This document is to be delivered and kept with the equipment in case of change of location and/or user. The most recent issue of this document can be found online, on our website.

1.1.2 Copyright

Modification and partial or complete usage of this PDF document for other purposes as intended are forbidden and breach may lead to legal consequences.

1.1.3 Validity

This manual is valid for the product LIZENZFG that can be purchased as option for following series:

Series
EA-PU 10000
EA-PUL 10000
EA-PUB 10000

1.1.4 Symbols and warnings in this document

Warning and safety notices as well as general notices in this document are shown in a box with a symbol as follows:

	Symbol for general safety notices (instructions and damage protection bans) or important information for operation
	*Symbol for general notices*

1.2 Warranty

EA Elektro-Automatik guarantees the functional competence of the applied technology and the stated performance parameters. The warranty period begins with the delivery of free from defects equipment.

Terms of guarantee are included in the general terms and conditions (TOS) of EA Elektro-Automatik.

1.3 Limitation of liability

All statements and instructions in this manual are based on current norms and regulations, up-to-date technology and our long term knowledge and experience. The manufacturer accepts no liability for losses due to:

- Usage for purposes other than designed

1.4 Intended usage

The software based functionality called "function generator" (short: FG) is intended to be used only as described in this document which explain the basic functionality of the function generator. Implementation and remote control in custom software is described in an external programming guide which is delivered with the device on USB stick or available as download from our website.

1.5 Scope of delivery

After purchase of the optional accessory product LIZENZFG, a package will be delivered to the purchaser via e-mail or a direct download link and shall contain:

- This document as PDF
- An extended ModBus register list that includes all function generator related commands and adds to the general programming guide
- A firmware update file

1.6 Function generator overview

Depending on the type of device it's installed on, the upgrade will unlock a different number of functions which all together are considered as the function generator. A source, such as the power supplies of PU 10000 series, isn't technically able to discharge a battery and thus doesn't support the battery test functions. An electronic load from PUL 10000 series can't simulate a solar panel, because an electronic load is a sink. Only bidirectional devices, here from series PUB 10000, support all available functions. Overview of the available functions in this option:

		Can be unlocked on		
Function	**Abbr.**	**PUB 10000**	**PUL 10000**	**PU 10000**
Basic waves like rectangle, ramp, triangle (arbitrary generator)	-	✓	✓	✓
XY diagram (I-U only)	IU	✓	✓	✓
Fuel cell simulation	FC	✓	-	✓
Solar panel simulation (photovoltaics)	PV	✓	-	✓
Battery test - Discharging	-	✓	✓	-
Battery test - Charging	-	✓	-	-
Battery test - Combined	-	✓	-	-
Solar inverter simulation (MPP tracking)	MPPT	✓	✓	-

Further functions, which are partially based on PV, such as Sandia, are available in the software **EA Power Control** which also has optionally unlockable features, such as a function generator app. It includes the same functions as available on the device with this unlocked feature. In the user interfae it the would only configure and load the functions, but the function itself would run on the device. Other functions, which are not available in the device, would either completely run on the controlling PC or partially.

Overview of the additional functions in **EA Power Control** (Date: 12/2023, version 2.25):

		Can be used with		
Function	**Abbr.**	**PUB 10000**	**PUL 10000**	**PU 10000**
Automotive (LV123, LV124, LV148)	LV	✓(1	-	✓(1
Engine start curve simulation (DIN40839)	DIN	✓(1	✓(1	✓(1
Sandia	-	✓(1	-	✓(1

(1 Requires the unlocked function generator (FG) in the device

1.7 Installation

Following steps are intended for the process of purchase, installation and use of the option LIZENZFG:

1. Purchase of the license, either together with a device (one license per device is required) or later (requires to tell the serial number(s) of the device(s) for which licenses shall be acquired).
2. After the purchase, the package mentioned in *"1.5. Scope of delivery"* is delivered
3. Install a KE component firmware update, as delivered, on every device for which LIZENZFG has been purchased.
4. Restart the device once. The unlocked function generator should now be available.

1.8 How to use the function generator

Same as with all other functionality of the PUx 10000 series devices, the function generator is remotely controlled. This can be achieved using custom applications of any kind or our software **EA Power Control**. The programming guide, as included on USB stick with the device, together with this document shall describe how to use the function generator on a PUx 10000 device. Due to the function generator being an optional accessory for these series, it's not described in the user manuals of the three series. This document contains descriptions about the basic principle of the functions, at least if they require description.

2. The function generator

Reminder: there are standard wave functions such as rectangle or triangle which can be realized using the arbitrary generator. Others, such as PV, require to use the XY generator and there are even purely software based functions, like the battery test. All these are unlocked by the LIZENZFG option, but not every of the above listed function is supported by every device type. See *"1.6. Function generator overview"* for details.

2.1 General

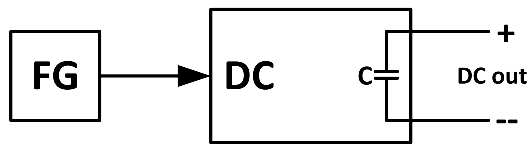
2.1.1 Limitations

The function generator is not accessible for remote control if resistance mode (R mode, also called UIR) is active.

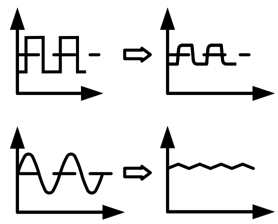
2.1.2 Principle

The device features a built-in function generator (short: FG), but the entire unit can't be considered as high power function generator, because its power stages are only post-connected to the FG. Primarily in source mode, the typical characteristics of a voltage and current source remain. Rise and fall times, caused by capacitor charge/discharge, affect the resulting signal on the DC terminal. While the FG is able to generate a sine wave with 10000 Hz, the device will never be able to follow the generated signal 1:1. Source and sink mode will slightly differ from each other regarding the results, while the sink mode will be generally better, because primarily focused on current.

Depiction of principle:



Effect of the output capacitance on functions:



The resulting wave on the DC terminal heavily depends on the frequency or period of the selected wave, its amplitude and also the voltage rating of the device. The effect of the capacities on the wave can be partially compensated. In source mode and when running voltage dynamics, on which the capacities have the biggest impact, it can help to put an additional load to the DC terminal in order to decrease rise and fall times. This extra load has a positive impact on periodic functions like rectangle or sine wave.

2.1.3 Resolution

Amplitudes generated by the arbitrary generator have an effective resolution of approx. 52428 steps between 0 and 100% of the rated range. If the amplitude is very low and the time long, the device would generate less steps and set multiple identical values after another, generating a staircase effect. It's furthermore not possible to generate every possible combination of time and a varying amplitude (slope).

2.2 Possible technical complications

Operation of switching mode power supplies as a voltage source can, when applying a function to the output voltage which changes quickly and in big steps, lead to damage of the output capacitors due to continuous charging/discharging which can cause overheating.

2.3 Method of operation

In order to understand how the function generator works and how the values interact, the following should be noted:

The device always works with the three set values U, I and P, also in function generator mode.

The selected function can be used on <u>one</u> set value, U or I, while the other two values are constant and have a limiting effect. Example: in sink mode, a source with 100 V is connected and the sine function applied to the current with an amplitude of 80 A and offset 80 A. The function generator would create a sine wave progression of current between 0 A (min) and 160 A (max), which will result in an input power between 0 W (min) and 16000 W (max). But in case the power would be limited to 12000 W the current would be limited to 120 A and if probed with an oscilloscope it could be viewed being truncated at 120 A and never reach the peak of 160 A.

For an even better understanding how the device works in dynamic operation read following:

⚠	• A PUB 10000 device also has an integrated electronic load, here called sink, which is supposed to discharge the capacities on the DC terminal of the device when running dynamic voltage changes in source mode, i.e higher voltage to lower voltage. This requires to define a certain current and power for sink mode. • The sink current, when being set to > 0 would load an external source, perhaps also discharge capacities in this source and thus this current setting has to be chosen carefully, because it also affects the necessary cross section of cables. Recommendation: set the current for sink mode to at least I_{Peak} of the resulting curve or higher.

Master-slave systems have further characteristics which have to be considered:

⚠	Additionally to the actual configuration of the function, global set value for voltage, current and power have to set correctly, the so-called “U/I/P limits”. These limits are transferred to all slave units of a master-slave system. It’s recommended to carefully configure them so the MS system can work as expected and the slave units wouldn’t impact the function run in a negative way and that instead the slave run along with the master and that even in highly dynamic operation the load is distributed equally between all units.

2.4 Selection, configuration and control of a function

Generally and a basic source for information about remote control of everything function generator related, refer to the external programming guide, as it’s delivered on USB stick with the device or is available as download from our website. The futhermore included ModBus register lists are the reference for every programmer, including those solely using SCPI or LabVIEW.

The programming guide also contains several examples for function generator access, partly in the ModBus section, partly in the SCPI section. Those can be adapted for every kind of programming environment and show how to select a function generator, how to configure a function and how to control it.

2.5 Basic wave functions (arbitrary generator)

Restrictions:

- With a PUB 10000 device, there is no preselection to which of both, source mode and sink mode, the function is applied; the settings decide whether it’s “source mode only”, “sink mode only” or a mixture of both
- When applying the function to the voltage, the device can only switch to and work in sink mode if the external voltage on the DC terminal is higher than the highest point (offset + amplitude) of the wave and the current setting for sink mode is not 0

Device series with display, such as PSI 10000, offer basic wave functions when manually using the function generator on the HMI which are not directly selectable in remote control, but can be realized using the **arbitrary generator** the same way as those models do it internally.

2.5.1 Overview

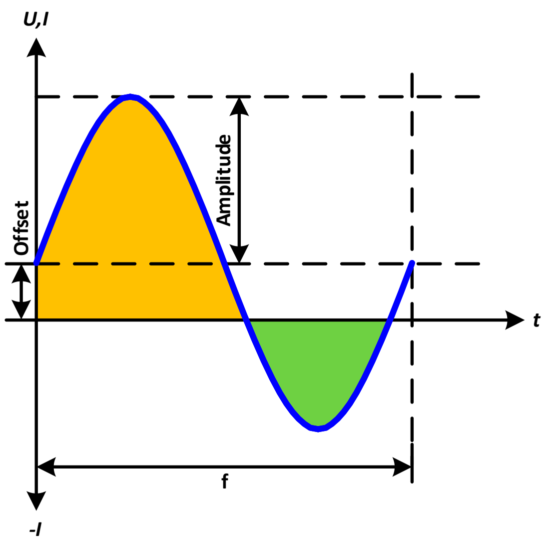
Base wave	Required sequence points	Description
Sinus	1	One sequence point, using all 8 available parameters, generates a partial, full or several periods of a sine wave. There is minimum ratio between time and frequency, as well as between start frequency and end frequency, in case they’re different.
Rectangle	4	One sequence point each for pulse, pause, rise and fall
Triangle / Sawtooth	2	One sequence point each for rise and fall. Optionally can a third one put a waiting time between two repetitions.
Ramp	2 or 3	At least two sequence points, of which one generates the actual ramp, no matter if up or down. The second one is used to have a waiting time after reaching the ramp end, so the function wouldn’t stop.
DIN40839	5	See the DIN paper or the depiction below. One sequence point for each part of the curve.
Trapezoid	4	See below

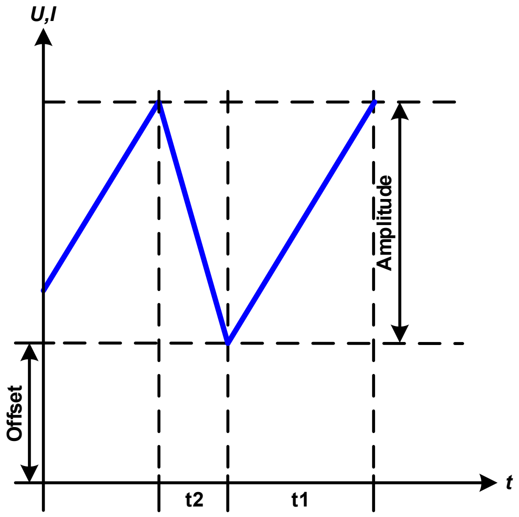
2.5.2 Sequence points

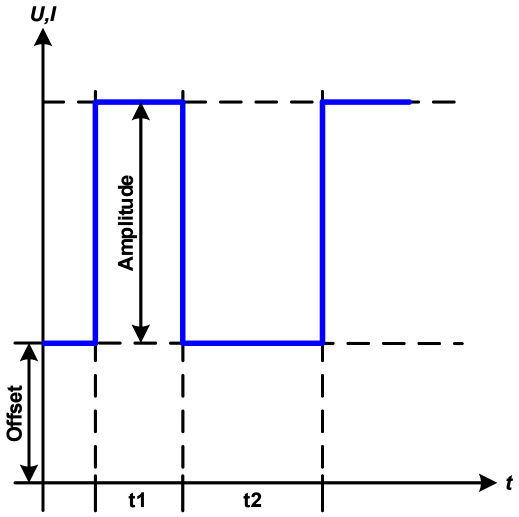
The arbitrary generator is based on 99 sequence points with 8 parameters, comprised of 16 registers each, starting at address 900:

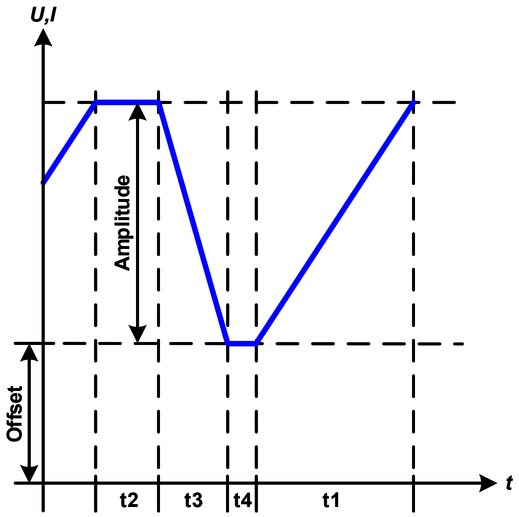
Parameter acc. to register list	Phys. unit	Alternative name	Adjustment range	Notes
Us/Is(AC)	V, A	AC amplitude	0...50% U_{Nom} or I_{Nom}	Defines the amplitude of the AC part of the generated wave, between start and end of the sequence point. These two values are only used for sine wave generation and can be left 0 for other waves.
Ue/Ie(AC)	V, A	AC amplitude	0...50% U_{Nom} or I_{Nom}	
fs(1/T)	Hz	Frequency start	1...10000	Defines the frequency of the AC part of the generated wave, between start and end of the sequence point. These two values are only used for sine wave generation and can be left 0 for other waves.
fe(1/T)	Hz	Frequency end	1...10000	
Angle	°	Start angle	0...359	Start angle of a sine wave generation per period. If the rest of the generated wave is complete and also ends at the expected angle depends on the time value of the sequence point and also the frequency setting.
Us/Is(DC)	V, A	Offset (for AC) DC start	0...100% U_{Nom} or I_{Nom}	With a sine wave, these define the Y axis offset, which is also the baseline of the curve, as it shall be from start to end of the sequence point. With other functions, these define whether the DC part is horizontal or falling/rising.
Ue/Ie(DC)	V, A	Offset (for AC) DC end	0...100% U_{Nom} or I_{Nom}	
Sequence time	µs	Period time	10...36,000,000,000	For a sine wave, the sequence point time matters less, but it should match the frequency or time of a period. With this time you can select whether to generate one wave or several per sequence point. Usually, it would be set up to generate one wave and then repeat infinitely. For all other wave types, the 10 µs to 10 h are the effective range per sequence point, so that with 99 points a very long can be covered already.

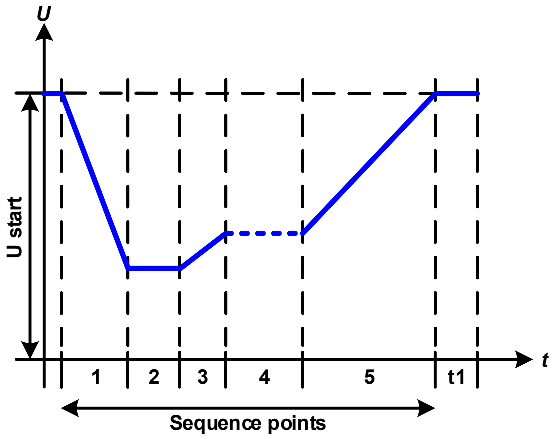
2.5.3 About the basic wave functions

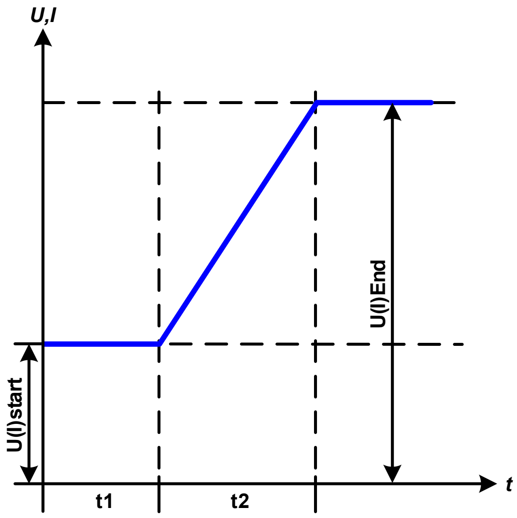
Sine wave	Application and result
	A sine wave signal is generated and applied to the selected set value, for instance the current ("I" mode, register 852). Depending on the adjusted parameters, a bidirectional device (PUB 10000) could apply the wave either solely to sink mode or to source mode, but also to both with automatic switchover at zero point. The scheme on the left depicts the "mixed mode" run (yellow = source mode active, green = sink mode active). While the amplitude is always an absolute value, the offset can be positive or negative (I mode only). For calculating the maximum power the current amplitude and the offset value have to be added. Example: a voltage of 100 V is set. The parameters for the sin(I) function shall generate an amplitude of 80 A and an offset of +50 A. The resulting maximum power when reaching the highest point of the sine wave then is (80 A + 50 A) * 100 V = 13000 W for the source part and when reaching the lowest point (sink part) it will be (50.A - 80 A) * 100 V = -3000 W. Other device types, which are either source or sink, can only work in the positive range of the Y axis, the 1st quadrant.

Triangle / Sawtooth	Application and result
 	Offset and amplitude result from the parameters **DC start** and **DC end**, while the offset shifts the signal on the Y axis. Two sequence points are required, one for the rising edge, one for the falling. A triangular wave signal for use on the current or voltage is generated. The positive and negative slope times can be set independently via the sequence points's time. The sum of the intervals t1 and t2 determines the cycle or period time and its reciprocal is the frequency. Example: a frequency of 10 Hz is required and would lead to periodic duration of 100 ms. This 100 ms can be freely allocated to t1 and t2, e.g. 50 ms:50 ms (isosceles triangle). In order to achieve a sawtooth shaped wave, time t2 would be set to the smallest values to achieve a vertical ramp-down.

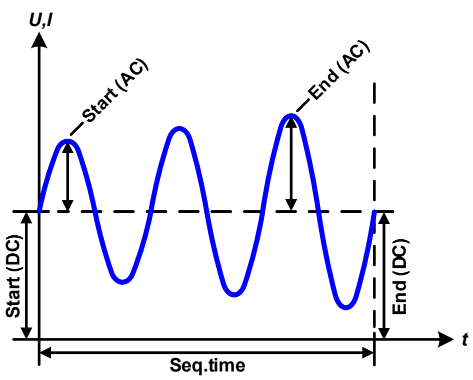
Rectangle	Application and result
 	Offset and amplitude result from the parameters **DC start** and **DC end**, while the offset shifts the signal on the Y axis. Four sequence points are required, though two would suffice, one for the upper level and for the lower. The device would simply jump between both. However, it's recommended to define the rising and falling edges also as sequence points, then with the lowest time value (10 µs). A rectangular or square wave signal for use on the current or voltage is generated. The intervals t1 and t2 define how long the value of the amplitude (pulse) and how long the value of the offset (pause) are effective. Intervals t1 and t2 can be used to define a duty cycle. The sum of t1 and t2 gives the period and its reciprocal the frequency. Example: a rectangular wave signal of 25 Hz and a duty cycle of 80% are required. The sum of t1 and t2, the period, is 1/25 Hz = 40 ms. For a duty cycle of 80% the pulse time (t1) is 40 ms*0.8 = 32 ms and the pause time (t2) is 8 ms

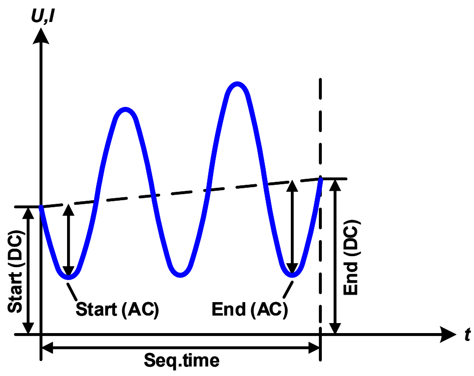
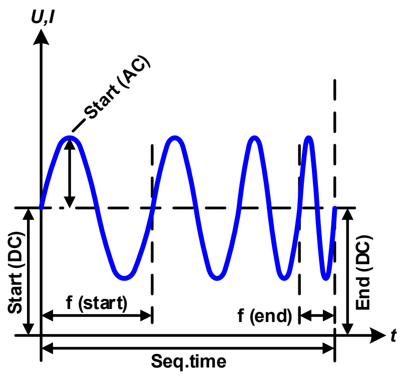
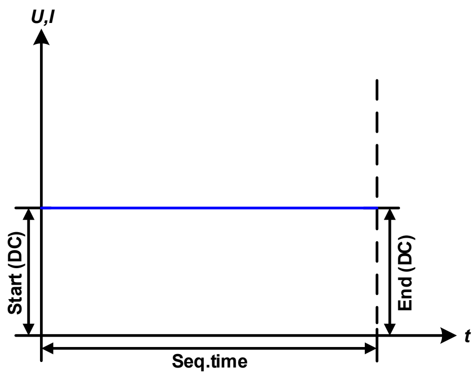
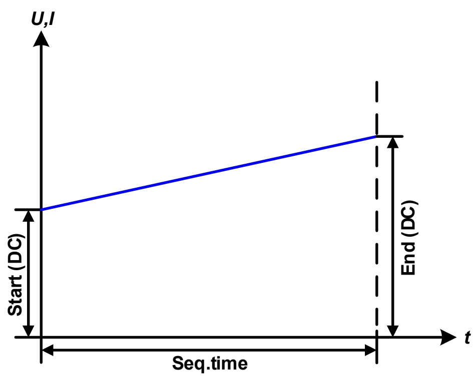
Trapezoid	Application and result
 	Offset and amplitude result from the parameters **DC start** and **DC end**, while the offset shifts the signal on the Y axis. A trapezoid is a special form of a rectangle. Four sequence points are required. Same as with other functions the generated signal can be applied to the set value of voltage (U mode) or to the current (I mode). The slopes of the trapezium can be varied by adjusting the times for rise and fall separately. The periodic duration and repetition frequency are the result of the four adjustable time values. With suitable settings the trapezium can be deformed to two triangular or two rectangular pulses. It has, therefore, universal use.

DIN40839	Application and result
	Offset and amplitude result from the parameters **DC start** and **DC end**, while the offset shifts the signal on the Y axis. This function is typically run on the voltage, even on sinks (PUL 10000), which would then use CV mode. If the function is set up to run in source mode of a bidirectional device (PUB 10000), the built-in load function acts as a sink and ensures the quick output voltage drop as required for some parts of the curve, allowing the output voltage progress as defined in the norm paper. The curve conforms to test impulse 4 of the DIN. With suitable settings, other test impulses can be simulated. If the curve part in sequence point 4 should contain a sine wave instead, then an AC amplitude could simply be integrated for point 4. The global start (and end) voltage is adjustable as parameter set value of voltage. It does no modify the voltage settings in the single sequence points, but it should match the start voltage setting (U start) of sequence point 1.

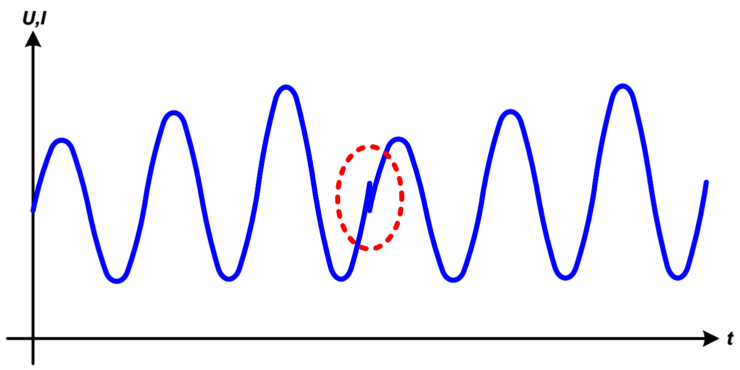
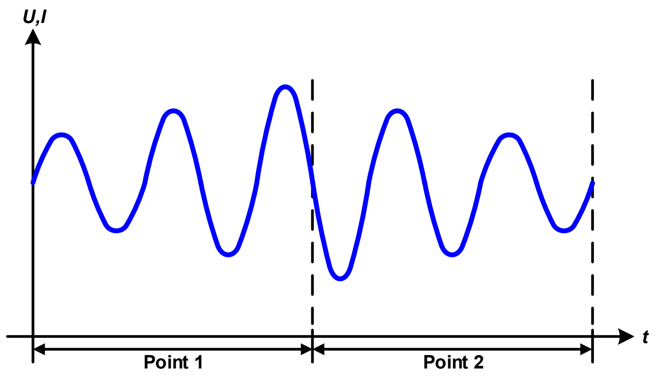
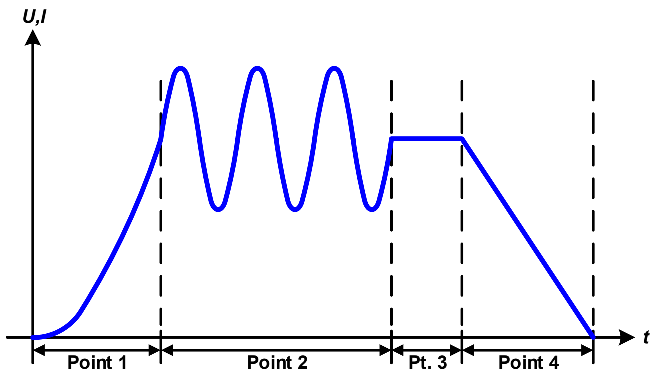
Ramp	Application and result
	Offset and amplitude result from the parameters **DC start** and **DC end**, while the offset shifts the signal on the Y axis. It would require two or three sequence points. One would generate a rising or falling ramp between the start and end values over time t2. Another would create a delay with its time (t1) before the ramp starts. The ramp function can run once and then stops at the end value. To have a repeating ramp, the Trapezoid function would have to be used instead. A third sequence point can be added to have the function not stop at the ramp end and drop the output voltage or current, but to remain there for up to 10 h. If more time is needed, further sequence points of 96 remaining could be added. Important to consider are the static values of U or I which define the start level before the ramp generation. It's recommended that the corresponding static set value is set equal to value **DC start**. That unless the load at the DC terminal of the device is a power supply in source mode and shall not be provided with a voltage before the actual start of the ramp (time t1). Or the external source shall not be loaded yet with a current. In that case the static value should be set to zero.

2.5.4 More about the arbitrary generator

Schematic diagrams	Applications and results
	**Example 1:** Focusing 1 cycle of 1 sequence point: The DC values at start and end are the same but those of the amplitude aren't. The end value is higher than the start value so the amplitude increases with each new half sine wave continuously over the sequence point time. This, of course, only if time and frequency allow for multiple waves to be created. For instance, with f=1 Hz and time = 3 s, three full waves would be generated, if the angle is 0°, and reciprocally the same for f=3 s and time=1 s.

Schematic diagrams	Applications and results
	**Example 2:** Focusing 1 cycle of 1 sequence point: The values Start(DC) and End(DC) aren't equal, as well as the AC Start(AC) and End(AC) values aren't. In both cases the end value is higher so that offset increases over time, but also the amplitude. Additionally, the first sine wave starts with a negative half wave because the angle has been set to 180°. The start angle can be shifted at will in steps of 1° between 0° and 359°.
	**Example 3:** Focusing 1 cycle of 1 sequence point: Similar to example 1 but with a different end frequency. Here this is shown as higher than the start frequency. This impacts the period of the sine waves such that each new wave will be shorter over the total span of the sequence time.
	**Example 4:** Focusing 1 cycle of 1 sequence point: Similar to example 1 but with a start and end frequency of 0 Hz. Without a frequency, no sine wave part (AC) will be generated and only the DC settings will be effective. A ramp with a horizontal progression would result.
	**Example 5:** Focusing 1 cycle of 1 sequence point: Similar to example 1 but with a start and end frequency of 0 Hz. Without a frequency no sine wave part (AC) will be generated and only the DC settings will be effective. Here the DC start and end values are unequal and a steadily increasing ramp would result.

By linking together a number of differently configured sequence points, complex progressions can be created:

Schematic diagrams	Applications and results
	**Example 6** Focusing 2 cycles of 1 sequence point: One sequence point, configured as in example 2, is run. Since the settings define that the end offset (DC) is higher than the start, the second run will revert to the same start level as the first, regardless of the signal level at the end of the first run. This can produce a discontinuity in the total progression (marked in red) which may only be compensated with a careful choice of settings.
	**Example 7** Focusing 1 cycle of 2 sequence points: Two sequence points run consecutively. The first one generates a sine wave with increasing amplitude, the second one with a decreasing amplitude. Together they produce a progression as shown to the left. In order to ensure that the wave peak in the middle occurs only once, the first sequence point must end with a positive half wave and the second one start with a negative half wave as shown in the diagram.
	**Example 8** Focusing 1 cycle of 4 sequence points: Point 1: 1/4th sine wave (angle = 270°) Point 2: Three sine waves (ratio of frequency to time is 1:3) Point 3: Horizontal ramp (f = 0) Point 4: Falling ramp (f = 0)

2.6 Simple photovoltaics simulation (XY generator)

Though it's basically the same as running an IU function, there is a dedicated PV mode for the XY generator. The PV curve is either a UI or IU, depending how you put it into an XY diagram, but since the voltage of a solar panel depends on the current load, the current is the leading physical value, so we consider it as UI curve. This mode allows to adjust an irradiance or irradiation value during the simulation which wouldn't be available in the standard IU mode. The table data of the precalculated curve would simply be loaded into the device. The device could also calculate the curve on its own, but then it would require to use a different way via several commands related to extended PV simulation according to EN50530 where you would directly access the technical solar panel parameters.

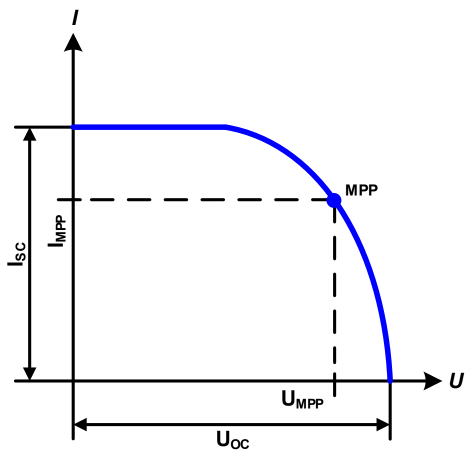
The external calculation of a simple PV curve is based on four corner parameters of the solar panel:

- the short-circuit current (I_{SC}), which is the maximum current that a panel can deliver at almost 0 V
- the open circuit voltage (U_{OC}), which almost reaches its maximum value even in low light situations
- the maximum power point (MPP), at which the panel can provide the maximum output power, defined by U_{MPP} and I_{MPP}

The voltage of the MPP (here: U_{MPP}) lies typically 20% below U_{OC}, the current of the MPP (here: I_{MPP}) lies typically 10% below I_{SC}. In case there are no definite values for the simulated solar cell available, **Impp** and **Umpp** can be set to these typical values. The device limits the I_{MPP} value to I_{SC} as upper limit, the same applies to U_{MPP} and U_{OC}.

The maximum of 4096 in the look-up table (LUT) of the XY generator is defined to stretch over 0-125% rated value, in this case the rated voltage of the device. However, the device cannot measure up to 125% of its rated voltage. As as source (PUB 10000, PU 10000), it can only generate voltages up to 102% and as a sink (PUL 10000) it would accept external voltages up to 110% and above that switch off with OVP alarm.

The effectively usable range is hence considered as 0-100%, which results in effective 3277 LUT values. Should the open circuit voltage of the simulated solar panel be significantly lower than the rated voltage, let's say 50%, not only the number of values to calculate reduces, but also the resolution.

<table>
<tr><th>PV curve</th><th>Application and result</th></tr>
<tr><td>
</td><td>The device, as a source, will supply a voltage between 0 V and the voltage set value which here should be equal to U_{OC}. According to the diagram, the current limit, as picked from the IU table, would be 0 or close to it. When then loading the voltage with any current between 0 A and the rated device current, the voltage would collapse and another current limit would be picked from the IU table, allowing a certain current at a certain voltage.

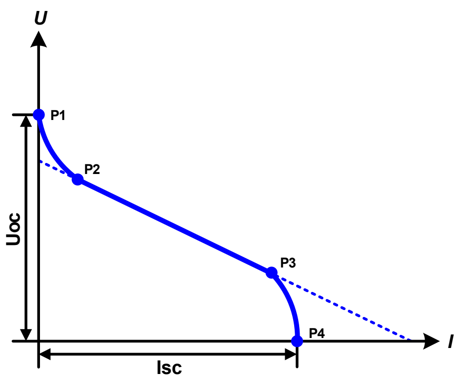
With a U_{OC} of, let's say, 50% of the rated device voltage it would require to calculate approx. 1638 current values and to load them into the device after the XY generator has been selected for PV mode. This is due to the current being equivalent to the

While the simulation is running, the user can see from the actual values (voltage, current, power) of the DC output, where the operating point of the power supply, i. e. of the simulated solar panel currently is. The additionally adjustable Irradiance is a factor to the current (Y axis) and is adjustable between 0% and 100% in 1% steps. It helps to simulate different light situations from darkness (no power output) to the minimal amount of light that is required to have the panel provide full power.

100% irradiation value, however, is always scaled for the rated current of the device. It means, with a 480 A model and when the simulated panel shall have an ISC of 300 A, the range for the irradiance isn't scaled to match the 300 A.</td></tr>
</table>

2.7 Fuel cell simulation (XY generator)

The XY generator mode "FC" stands for fuel cell and is used to simulate the characteristics of such a source. This is achieved by loading XY table data into the device that represent the calculated FC curve. The device cannot calculate the curve itself.

<table>
<tr><th>Schematic diagram:</th><th>Application and result:</th></tr>
<tr><td>
</td><td>The scheme to the left shows an example fuel cell voltage curve which would gradually sink when loaded. It can be recognized that this curve is actually a UI curve and since the device can only accept IU table data, the values to load would have to transposed.

The principle of using the IU data is the same as with the PV curve simulation. See "2.6. Simple photovoltaics simulation (XY generator)".

The voltage limit at P1 would be defined by setting the voltage set value of the device to the required level of U_{OC}.</td></tr>
</table>

2.8 Extended PV function according to EN 50530

This extended PV table function according to norm EN 50530 is used to simulate solar panels in order to test and rate solar inverters. It's also based on the XY generator, same as the simple PV table function from *2.6*, but offers more specific tests and evaluations due to more adjustable parameters, which are also accessible while the simulation runs.

The device can, however, only calculate and run a PV curve. Evaluation of a solar inverter, as described in the norm paper, is only possible with our software **EA Power Control**. It will, amongst other result data, determine the inverter's efficiency.

The impact of the parameters on the PV curve and the simulation is described in the norm paper of EN 50530, which users can refer to in case more detailed description is required. This section only deals about configuration and control of the PV simulation.

2.8.1 Differences to the basic PV function

The extended PV function has four additional or different characteristics compared to the simple PV function:

- The simulation distinguishes between a single test run and an automatic test run, called day trend, which is based upon a user-defined curve built from up to 100,000 points
- There are two invariable and one variable panel technologies available to choose from
- There are more parameters available to adjust during runtime
- It allows for data recording during runtime

2.8.2 Technologies and technology parameters

When configuring the PV simulation it's required to select the solar panel technology to simulate. The technologies **cSI** and **Thin film** are invariable in their parameters, while technology **Manual** (default) is variable in all parameters, but within specific limits. This allows for the variation of the simulation and when copying the fixed parameter values from **cSi** or **Thin film** to **Manual**, it even enables their variation as well.

One advantage of the invariable technologies is that their technology parameters are automatically set to their defined defaults in the configuration procedure.

Overview of the technology parameters used in the PV curve calculation and their defaults:

Parameter acc. to register list	ModBus address	Name	Manual (Default value)	cSI	Thin film	Unit
FFu	12034	Fill factor for voltage	>0...1 (0.8)	0.8	0.72	-
FFi	12036	Fill factor for current	>0...1 (0.9)	0.9	0.8	-
Cu	12042	Scaling factor for U_{OC} (1	>0...1 (0.08593)	0.08593	0.08419	-
Cr	12044	Scaling factor for U_{OC} (1	>0...1 (0.000109)	0.000109	0.0001476	m²/W
Cg	12046	Scaling factor for U_{OC} (1	>0...1 (0.002514)	0.002514	0.001252	W/m²
α	12038	Temperature coefficient for I_{SC} (2	>0...1 (0.0004)	0.0004	0.0002	1/°C
β	12040	Temperature coefficient for U_{OC} (1	-1...<0 (-0.004)	-0.004	-0.002	1/°C

(1 Uoc = Open circuit voltage of a solar panel
(2 Isc = Short-circuit current (=max. current) of a solar panel

2.8.3 Simulation mode

Apart from the panel technology there is also a simulation mode to select. Four options:

Mode acc. to register 12001	Other name	Description
Umpp/Impp (0x0002)	U/I	Controllable simulation. During time and depending on a selectable input mode, either the voltage (U_{MPP}, in V) and current (I_{MPP}, in A) in the maximum power point (MPP) are variable or the open circuit voltage (U_{OC}, in V) and the short-circuit current (I_{SC},in A) of the simulated panel. The purpose of this mode is to directly shift the MPP into various directions.
Irradiation / temperature (0x0001)	E/T	Controllable simulation. During runtime, the irradiation (E, in W/m²) and surface temperature (T, in °C) of the simulated solar panel are adjustable. This also impacts the curve and the resulting MPP. The purpose of this mode is to analyze the impact of temperature and/or irradiation on the performance of a solar panel.
Daily trend Umpp/Impp (0x0004)	DAY U/I	Automatic simulation run, processing a day trend curve consisting of up to 100,000 points defined by values for U_{MPP}, I_{MPP} and time.
Daily trend irradiation/temp. (0x0003)	DAY E/T	Automatic simulation run, processing a day trend curve consisting of up to 100,000 points defined by values for irradiation, temperature and time.

2.8.4 Day trend

The so-called day trend is a special simulation mode for long-term tests. It processes a curve consisting of up to 100,000 user-definable points. For every processed point on that day trend curve, the PV curve is calculated anew. Every point is defined by 3 values of which one is the dwell time. When defining long dwell times the day trend curve can be supported by an interpolation feature (see *"2.8.5. Interpolation"*) which can be optionally activated. It will calculate and set intermediate points between two succeeding curve points. Hence it should be considered to run the day trend with or without interpolation.

The day curve points have to be loaded into the device before the actual simulation start. Those points are not stored inside the device. During the simulation run, such as with all simulation modes, data can be recorded and later read from the device (see *"2.8.6. Data recording"*).

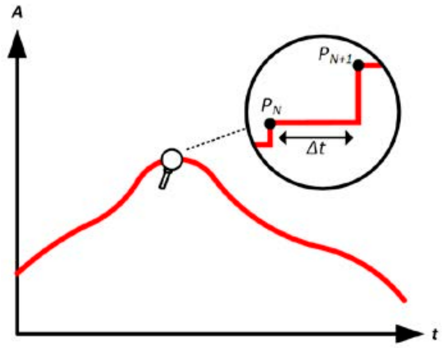
Parameter acc. register 12010	Phys. unit	Range	Description
Index	-	1...100,000	Number of the day trend curve point, as user-defined by the three values below. Should be written continuously from index 1
E / U-MPP	W/m², V	0...1500	Irradiation as factor on the MPP or direct MPP voltage, depending on the mode
Temp. δ/ I-MPP	°C, A	-40...+80	Solar panel surface temperature or direct MPP current, depending on the mode
Δt	ms	500...1,800,000	Dwell time of the day trend curve point or „time between two points"

2.8.5 Interpolation

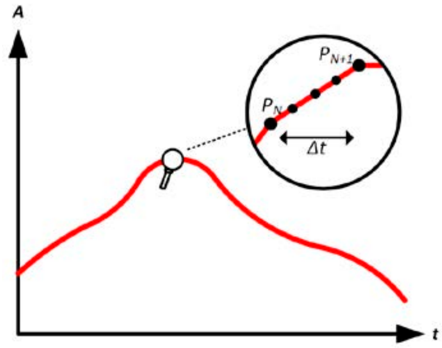
The interpolation feature can calculate and set intermediate steps when running the PV function in day trend mode, i. e. **DAY E/T** or **DAY U/I**. The calculation is always done between to succeeding points on the day trend curve. The dwell time of every curve point is adjustable between 500 and 1,800,000 milliseconds (see above, format of the day trend data file). While there are no extra points calculated when using the minimum time of 500 ms, following applies to higher dwell time definitions:

- The number of intermediate steps is determined from the dwell time and spread as equally as possible, where any of the steps can have its own dwell time between 500 and 999 ms
- The intermediate steps also respect the slope between the current and the next day trend curve point and thus every step also includes a corresponding value alteration

Visualization:



Without interpolation - the curve results in steps



With interpolation - the curve remains linear

An example: the dwell time of the 3450th curve point is defined as 3 minutes, which is 180 seconds. There will be 180 / 0.5 -1 = 359 intermediate steps calculated and set until reaching the 3451st point. In mode DAY U/I the MPP voltage changes from 75 V to 80 V and the MPP current changes from 18 A to 19 A. When calculated, this would mean a ΔU/Δt of 27.7 mV/s and a ΔI/Δt of 5.5 mA/s. Depending on the device in use, such small steps in voltage or current may not be doable. However, the device would try to set the first intermediate step with 75.0138 V and 18.0027 A.

2.8.6 Data recording

There is the option (register 12018) to record data during the simulation run, in any simulation mode. The data can read be via digital interface, which even allows reading while the simulation is still running. As long as the simulation is running, the device will record one data set every 100 ms into an internal buffer. This interval is not adjustable. The max. number of data sets, here also called indexes, is 576,000. This results in a max. record time of 16 hours. The indexes are internally counted with every new record (register 12022). When reaching the max. number, the index will restart from 1, overwriting former data. Every index will contain 6 values.

Since remote control allows to read the recorded data during simulation run and in case of simulations running longer than 16 hours, clever index polling and early data fetch can avoid data loss due to the counter reaching the buffer end. After all data has been read, the buffer can be purged, if needed (register 12019).

What is recorded? Independently from the selected simulation and as long as the simulation runs, every 100 ms a new record containing these six values is stored, which can be read via register 12024:

- Actual voltage (U_act) -> should be identical to U_{MPP}, if the MPP has been reached
- Actual current (I_act) -> should be identical to I_{MPP}, if the MPP has been reached
- Actual voltage (P_act) -> should be identical to P_{MPP}, if the MPP has been reached
- Voltage in the MPP, as calculated, copy from register 12002
- Current in the MPP, as calculated, copy from register 12003
- Power in the MPP, as calculated, copy from register 12004

2.8.7 Controlling the simulation

Simulation control in terms of start and stop is done using a dedicated register (12000) which would at least be used to start, because with the day trend modes the simulation would stop automatically when reaching the end of the curve. Together with the simulation stop the data recording would also stop.

2.8.7.1 Stop criteria

Besides an expected and automatic stop at the end or a manually triggered one, the simulation run could unintentionally stop due to several reasons:

1. A type of alarm, such as PF, OVP, OCP or OPP occurred, which would switch the DC terminal off.

2. A user event occurred whose action has been defined as **Alarm**, which would switch the DC terminal off.

Situation 2 can be avoided by carefully setting up other parameters, unrelated to the function generator.

2.8.8 Test analysis

After the simulation has stopped, recorded data can be read via any of the digital interfaces, of course only if data recording has been activated as part of the configuration. Activating the data recording feature during the simulation run is, however, still possible in remote control. Via digital interface there is the option to read any portion of the data, which will also have an impact on the time required to read the data.

The data can later be used to visualize, analyze and determine characteristics of the simulated solar panel and also of the solar inverter which is usually used as load when running such tests. More details can be found in the standard paper.

2.9 Battery test function

⚠	The battery test function is only a feature to test batteries. The device has no battery management system included. It means, that there is no monitoring of single battery cells. Dead cells cannot be detected and in case there is at least one dead cell in a battery when being charged or discharged by the device, the battery could be destroyed. External battery management hardware and software might be required.

The purpose of the battery test function is to charge and discharge various battery types in industrial product tests or laboratory applications. Users must be aware that not every device type can cover all battery test functions. An electronic load (PUL 10000) can only discharge a battery, while a power supply (PU 10000) can only charge it. Only a bidirectional device (PUB 10000) can cover everything. Test modes overview:

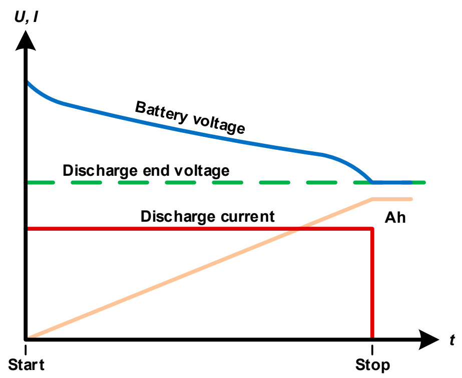
Mode name acc. to register list	Other name	Description	Supported by		
			PU	PUL	PUB
Battery discharge test (static)	**Static discharge**	Discharges a battery with a static, i. .e. fixed current that cannot be changed while the test runs	-	✓	✓
Battery discharge test (dynamic)	**Dynamic discharge**	Discharges a battery with a pulsing current that alternates between two configured levels. These levels can also not be changed while the test runs.	-	✓	✓
Battery charge test (static)	**Static charge**	Charges a battery with a static current until the charging end voltage has been reached. That current cannot be changed while the test runs.	✓	-	✓
Battery dynamic test	**Dynamic test**	Combines static charge and discharge, with a user-defined resting time between to test phases	-	-	✓

In **Static discharge** mode which by default runs in constant current (CC) regulation, the settings for power (register 11502) or resistance (register 11504) can also let the device run the function in constant power (CP) or constant resistance (CR). Like with the normal operation of the device, the set values determine what regulation mode (CC, CP, CR) will be in effect. If, for example, CP operation is projected, the set value of current should be set to maximum and resistance mode should be turned off, so that both don't interfere. For a projected CR operation it's similar. Current and power should then be set to maximum.

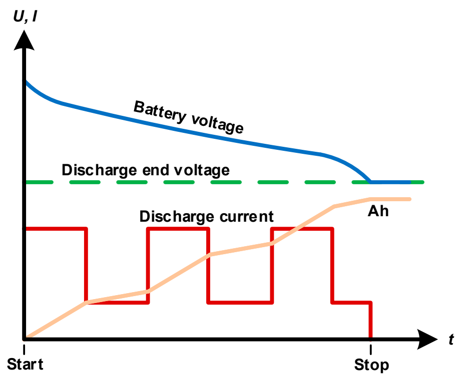
For **Dynamic discharge** mode there is also a power setting (register 11522), but it can't be used to run the dynamic battery test function in pulsed power mode or at least the result would not be as expected. It's recommended to always adjust the power value according to the test parameters, so it doesn't interfere with the pulsed current.

!	*When discharging with high currents and in dynamic mode, it may happen that the battery voltage shortly drops below the discharge end voltage (U_{DV}) threshold and the test will unintentionally stop. Here it's recommended to adjust U_{DV} accordingly.*

Graphical depiction of both discharging modes:



Static discharge

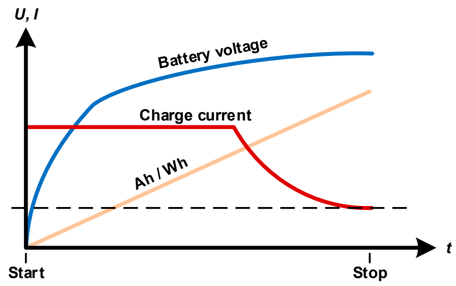


Dynamic discharge

The **Static charge** basically follows the charging profile used for lead-acid batteries. The battery is charged with a constant current until it either reaches the specified charging end voltage or charging end time, or when the charging current falls below the specified charging end current threshold.

The fourth mode is called **Dynamic test** and combines **Static discharge** with **Static charge** in one flow. Due to the combined charging and discharging phases in this test mode, it's only available with bidirectional power supplies, here PUB 10000 series.

The same parameters as for the single test parts are available, plus some extra for the flow. You can, for example, select what comes first, charge or discharge (register 11581). There is also an option to cycle the test, i. e. repeat 1 to 999 times or infinitely (register 11584) and you can define a resting period (register 11582) which elapses before the next cycle.



Static charge

2.9.1 Settings for the static discharge mode

The following parameters are required for the **Static discharge** test and must be configured:

Parameter acc. to register list	Register	Description
Max. current	11500	Maximum discharge current (in Ampere)
Max. power	11502	Maximum discharge power (in Watt)
Max. resistance	11504	Maximum discharge resistance (in Ohm), activates resistance mode, if ≠ 0
Discharge (end) voltage	11506	Threshold (in Volt) where the discharge process shall stop
Max. capacity to discharge	11508	Max. battery capacity to discharge, after which the test can stop automatically. This is optional, so that also more capacity could be consumed than what's adjustable with this value.
Max. discharge time	11510	Max. test time in format HH:MM:SS, after which the test can stop automatically. This is optional, so that test could also be longer than what's adjustable with this value.
Action upon reaching the max. discharge capacity	11512	Defines an action that can either stop the test or generate a message in battery test status register 11544 upon reaching the max. consumed capacity as given by register 11508
Action upon reaching the max. discharge time	11513	Defines an action that can either stop the test or generate a message in battery test status register 11544 upon reaching the max. test time as given by register 11510

2.9.2 Settings for the dynamic discharge mode

The following parameters are required for the **Dynamic discharge** test and must be configured:

Parameter acc. to register list	Register	Description
Current level 1	11514	Upper resp. lower current setting (in Ampere) for pulsed operation (the higher value of both is automatically used as upper level)
Current level 2	11516	
Max. power	11502	Maximum discharge power (in Watt)
Time of current level 1	11518	t1 = Time (in seconds) for the upper level of the pulsed current (pulse)
Time of current level 2	11520	t2 = Time (in seconds) for the lower level of the pulsed current (pause)
Discharge (end) voltage	11524	Threshold (in Volt) where the discharge process shall stop
Max. capacity to discharge	11526	Max. battery capacity (in Ah) to discharge, after which the test can stop automatically. This is optional, so that also more capacity could be consumed than what's adjustable with this value.
Max. discharge time	11528	Max. test time in format HH:MM:SS, after which the test can stop automatically. This is optional, so that test could also be longer than what's adjustable with this value.
Action upon reaching the max. discharge capacity	11530	Defines an action that can either stop the test or generate a message in battery test status register 11544 upon reaching the max. consumed capacity as given by register 11526
Action upon reaching the max. discharge time	11531	Defines an action that can either stop the test or generate a message in battery test status register 11544 upon reaching the max. test time as given by register 11528

2.9.3 Settings for the static charge mode

The following parameters are required for the **Static charge** test and must be configured:

Parameter acc. to register list	Register	Description
Max. voltage	11545	Charging voltage (in Volt)
Charge current	11547	Maximum charging current (in Ampere)
Charge end current	11551	Current threshold (in Ampere) below which the charging would stop
Max. capacity to charge	11553	Max. battery capacity (in Ah) to charge, after which the test can stop automatically. This is optional, so that also more capacity could be supplied than what's adjustable with this value.
Max. charge time	11555	Max. test time in format HH:MM:SS, after which the test can stop automatically. This is optional, so that test could also be longer than what's adjustable with this value.
Action upon reaching the max. charge capacity	11557	Defines an action that can either stop the test or generate a message in battery test status register 11544 upon reaching the max. supplied capacity as given by register 11508
Action upon reaching the max. charge time	11558	Defines an action that can either stop the test or generate a message in battery test status register 11544 upon reaching the max. test time as given by register 11510

2.9.4 Settings for the dynamic test mode

The following parameters are required for the **Dynamic test** and must be configured:

Parameter acc. to register list	Register	Description
Charge voltage	11559	Charging voltage (in Volt), for the charging phase.
Charge current	11561	Static charging current (in Ampere), for the charging phase.
Charge end current	11565	Threshold (in Ampere) below which the charging phase would end.
Charge duration	11567	Duration of the charging part (max. 10 h).
Discharge current	11569	Static discharging current (in Ampere).
Discharge end voltage	11571	Threshold (in Volt) upon which the discharging part would end.
Discharge duration	11573	Duration of the discharging part.
Max. charge/discharge capacity	11575	Max. total battery capacity (in Ah) to charge/discharge, after which the test can stop automatically. This is optional, so that also more capacity could be supplied or consumed than what's adjustable with this value.
Max. time	11577	Max. test time in format HH:MM:SS, after which the test can stop automatically. This is optional, so that test could also be longer than the max. 10 h which can be set up here, whereas both phases each can already 10 h.
Action upon reaching the max. capacity	11579	Defines an action that can either stop the test or generate a message in battery test status register 11544 upon reaching the max. supplied capacity as given by register 11575.
Action upon reaching the max. charge time	11580	Defines an action that can either stop the test or generate a message in battery test status register 11544 upon reaching the max. test time as given by register 11577.
Start with discharging or charging phase	11581	Determines whether the test starts with charging or discharging.
Pause time between operations	11582	Time to rest/pause the test before the next phase.
Cycles	11584	Number of cycles to run the complete test (0 = infinite cycles or 1...999).

Basic running scheme of the dynamic test:

1. After the test start, in the first test phase the battery is either charged or discharged, as defined.
2. As soon as any test phase end condition is reached, the test would continue in the next test phase with the opposite test mode, so that it would always alternate between charge and discharge phases.
3. The test would either stop upon reaching a defined time limit or upon reaching a defined capacity limit, whatever comes first, or by a device alarm or interaction (manual ore remotely controlled stop). It means, it could theoretically run infinitely.

4. Rules:
   - One test cycles is always a combination of 1 charge and 1 discharge phase
   - Every phase has its own duration setting, which cannot be overruled. It means, there is always a max. time per test phase
   - In case of a device alarm, the test is stopped, not halted. It means, it cannot be continued after the alarm is cleared.

2.9.5 Battery test status

During and after a battery test run, several statuses can be read:

Status acc. to register list	Register	Description
Time at end of test	11540	No matter what battery test mode has been run, this can be read after the test stop and sums up the total test time (HH:MM:SS.MS)
Status	11544	Readable anytime, it shall represent various test statuses, such as if the test has stopped and has been successful or not, or when still running, in what phase. The current test phase is informative for the dynamic test mode.

2.9.6 Battery test control

By command, the battery test must be selected and later, after configuration, started. Stop by command is optional.

Parameter acc. to register list	Register	Description
Mode selection	11535	Being the first register to address, it selects the battery test mode
Start/stop	11532	Starts the battery test which includes some plausibility tests and in case they were OK, continues the test as planned. Otherwise, the test would stop after a few seconds, with an error status in register 11544. Can also be used to stop the test early.

As long as the test is running, all register involved in the test configuration, will be locked against write access. Together with other status registers (505, 511) and the actual values, the unit controlling the device battery testing device can record data in parallel, as part of a test documentation.

2.10 MPP tracking function

MPP stands for the maximum power point (see principle view to the right) on the power curve of solar panels. Solar inverters, when connected to such panels, constantly track this MPP once it has been found. Since this requires to sink energy as a consumer, like the inverter is one, this function can only be run on device types with sink mode, specifically electronic loads and bidirectional power supplies.

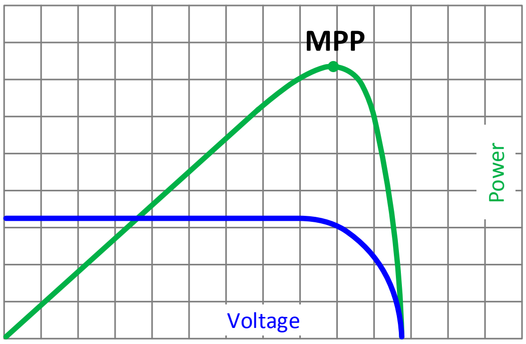


Figure 2 -.PV voltage curve (blue) and PV power curve (green) in an XY diagram

The device imitates the solar inverter behavior. It can be used to test even huge solar panels without having to connect a real solar inverter device which also requires to have a load connected to its AC output. Furthermore, all MPP tracking related parameters of the device can be adjusted and it's thus more flexible than an inverter with its limited DC input range.

For evaluation and analysis purposes, the device can also record measured data, i. e. DC terminal related values such as actual voltage, current or power, and provides them for reading via digital interface.

The MPP tracking function offers **four modes**.

2.10.1 Mode MPP1

This mode is also called "Find MPP". It's the simplest option to have the device find the MPP of a connected solar panel. It requires to set only three parameters. Value U_{OC} is necessary, because it helps to find the MPP quicker as if the device would start at 0 V or maximum voltage. Actually, it would start at a voltage level slightly above the open circuit voltage (U_{OC}).

The short-circuit current (I_{SC}) is used as a upper limit for the current, so the device would not try to draw more current than the panel is specified for. Following parameters would be configured for tracking mode **MPP1**:

Parameter acc. to register list	Register	Description
Uoc (Setup)	11000	Open circuit voltage of the solar panel or array to which the device is connected. This parameter can be found in the technical specifications of the panel.
Isc (Setup)	11001	Short-circuit current of the solar panel or array to which the device is connected. This parameter can be found in the technical specifications of the panel.
Interval (Setup)	11013	Interval between two attempts to find the MPP

Application and result:

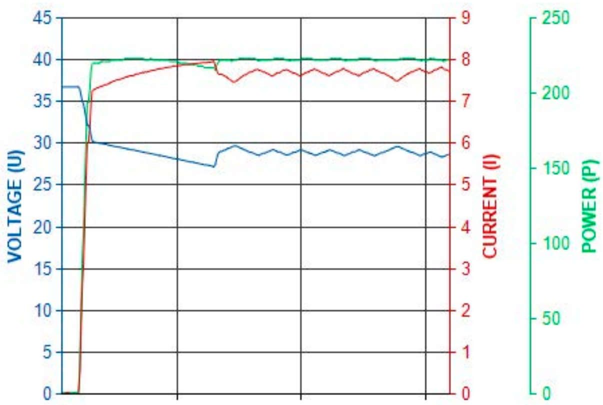
After the three parameters have been set, the function can be started. For MPPT control see below. As soon as the MPP has been found, the function will stop and switch off the DC terminal. The acquired MPP values of voltage (U_{MPP}), current (I_{MPP}) and power (P_{MPP}) would then be available for readout.

The time of a function run depends on the parameter Δt. Even with the minimum setting of 5 ms one run usually takes already a few seconds.

2.10.2 Mode MPP2

This mode tracks the MPP, so it's closest to the operation of a real solar inverter. Once the MPP is found, the function wouldn't stop, but try to track the MPP permanently. Due to the nature of solar panels this can only be done below the level of the MPP. As soon as this point is reached, the voltage starts to sink further and so does the actual power. The additional parameter **Delta P** defines how much the power may fall before the direction is reversed and the voltage starts to rise again until the load reaches the MPP. The result are zigzag shaped curves of both, voltage and current.

Typical curves are shown in the picture to the right. For the example the **Delta P** was set to a quite small value, so the power curve looks almost linear. With a small **Delta P** the load would always track close to the MPP.



Following parameters would be configured for tracking mode **MPP2**:

Parameter acc. to register list	Register	Description
Uoc (Setup)	11000	Open circuit voltage of the solar panel or array to which the device is connected. This parameter can be found in the technical specifications of the panel.
Isc (Setup)	11001	Short-circuit current of the solar panel or array to which the device is connected. This parameter can be found in the technical specifications of the panel.
Interval (Setup)	11013	Interval between two attempts to find the MPP
Delta P (Setup)	11006	Tracking/regulation tolerance below the MPP

2.10.3 Mode MPP3

Also called "fast track", this mode is very similar to mode MPP2, but without the initial step which is used to find the actual MPP, because mode MPP3 would directly jump to the power point defined by user input (U_{MPP}, P_{MPP}). In case the MPP values of the equipment under test are known, this can save a lot of time in repetitive tests. The rest of the function run is the same as with MPP2 mode. During and after the function, the least acquired MPP values of voltage (U_{MPP}), current (I_{MPP}) and power (P_{MPP}) are available for readout.

Following parameters would be configured for tracking mode **MPP3**:

Parameter acc. to register list	Register	Description
Uoc (Setup)	11000	Open circuit voltage of the solar panel or array to which the device is connected. This parameter can be found in the technical specifications of the panel.
Isc (Setup)	11001	Short-circuit current of the solar panel or array to which the device is connected. This parameter can be found in the technical specifications of the panel.
Umpp (Setup)	11003	Voltage in the MPP of the solar panel or array to which the device is connected. This parameter should be stated in the technical specifications of the panel. Alternatively, it could be calculated from I_{MPP} and P_{MPP}.
Pmpp (Setup)	11005	Power in the MPP of a real or simulated solar panel or array the device is connected to. This parameter should be stated in the technical specifications of the panel. Alternatively, it could be calculated from U_{MPP} and I_{MPP}.
Interval (Setup)	11013	Interval between two attempts to find the MPP
Delta P (Setup)	11006	Tracking/regulation tolerance below the MPP

2.10.4 Mode MPP4

This mode is different to the others, because it does not track automatically. It rather offers the choice to define and load a user curve of up to 100 points of voltage values, which would then processed point by point by the device while it measures current and power and at the end would return the results in up to 100 sets of acquired data (actual values of voltage, current, power). Start and end point can be adjusted as well. Parameter Δt defines the time between two points and the function run can be repeated up to 65535 times. Once the function stops at the end or due to manual interrupt, the DC terminal is switched off and the measured data will become available for read. Furthermore, the acquired set of data with the highest actual power, typically representing the MPP, will be available in extra registers for readout.

Following parameters would be configured for tracking mode **MPP4**:

Parameter acc. to register list	Register	Description
Start	11014	Start point for the run of x out of 100 subsequent points
End	11015	End point for the run of x out of 100 subsequent points
Repetitions	11016	Number of repetitions for the run from Start to End
Interval (Setup)	11013	Time before the next point
User curve (MPP4) voltage values	11100 - 11199	Up to 100 voltage values (U_{MPP}) can be loaded which should build a consequential curve.

As a result of running through the voltage value curve, following data can be read after the test stop:

Parameter acc. to register list	Register	Description
User curve (MPP4) results	11200 - 11499	Up to 100 data sets cons, matching the up to 100 voltage points on the loaded curve. In case the curve run is repeated, as defined by Repetitions, the results will be overwritten by the next run. There is no time to read the results in between two runs. In order to lose no data, it's better to configure only one run per test, read the data afterwards and to start the test again.

2.10.5 Control and status

For MPP tracking test control and status, which is readable during and after the test, following is available:

Parameter acc. to register list	Register	Description
Start/Stop	11010	Starts the test for the selected MPP tracking mode anytime. Test modes MPP1 and MPP4 are expected to stop automatically, while modes MPP2 and MPP3 would never stop automatically, so this command is used.
Finished (Function status for MPP1/4)	11011	Status for modes MPP1 and MPP4 when they're finished. Can be used to determine when the result analysis can begin.
Error during function	11012	General error flag, no particular error code
Umpp (Result)	11007	When read after the test is finished, it's would represent the voltage in tracked MPP, except for mode MPP3 which isn't supposed to find the MPP
Impp (Result)	11008	When read after the test is finished, it's would represent the current in tracked MPP, except for mode MPP3 which isn't supposed to find the MPP
Pmpp (Result)	11009	When read after the test is finished, it's would represent the power in tracked MPP, except for mode MPP3 which isn't supposed to find the MPP

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