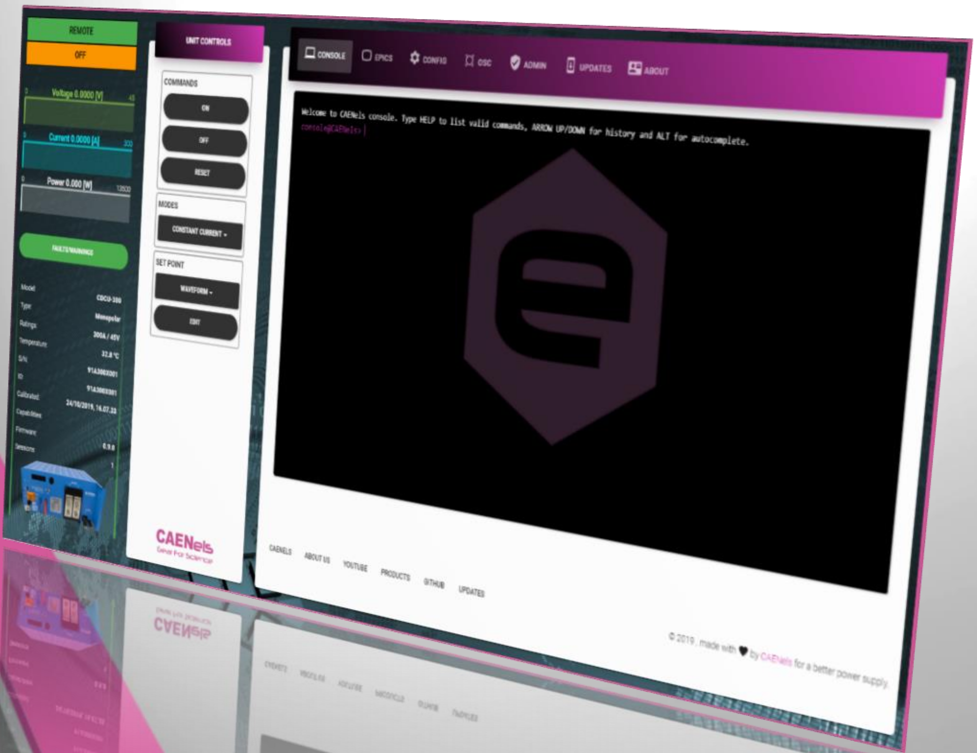
CDCU-100
CDCU-200
CDCU-300

Water-Cooled Unipolar DC/DC Converters

CAENels
Gear For Science

Remote Control Manual



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MAGNET POWER SUPPLY SYSTEMS

CAEN ELS s.r.l.
c/o AREA Science Park – Building Q1
S.S. 14 km 163,5 loc. Basovizza – 34149 Trieste (TS)
Italy

Registered office: *via Vetraia 11, 55049 – Viareggio (LU), Italy*

For technical assistance please refer to the following contact:

CAEN ELS s.r.l.
c/o AREA Science Park – Building Q1
S.S. 14 km 163,5 loc. Basovizza – 34149 Trieste (TS)
Italy
Mail: info@caenels.com
Web: www.caenels.com

Phone: +39 040 375 6610
Fax: +39 040 375 6611

Remote Control Manual – Models

This manual covers the following standard Power Supply models:

- **CDCU-100**
- **CDCU-200**
- **CDCU-300**

Table Of Contents

1. OVERVIEW 8

2. CAENELS DEVICE MANAGER 9

2.1 Searching for Connected Devices 10
2.2 Device Configuration 10

3. WEB SERVER 12

3.1 Main Windows 13
3.2 Fault Reset 14
3.3 Unit Controls 16
3.4 Regulation Mode 16
3.5 Set Point Control Modes 16
3.5.1 Normal Control Mode *16*
3.5.2 Waveform Control Mode *17*
3.6 EPICS IOC 19
3.7 Unit Configuration 21
3.7.1 Interlocks and Limits *22*
3.7.1.1 Limits 22
3.7.1.2 Regulation Fault 23
3.7.2 PID Values *24*
3.7.2.1 Save and Load pre-set PID configurations 25
3.7.3 Internal Memory *27*
3.7.4 NTP – Network Time Protocol *30*
3.8 Oscilloscope 32
3.8.1 Channels *33*
3.8.2 Basic *33*
3.9 Firmware Update & Support 35

4. SOFTWARE COMMANDS 36

4.1 Ethernet Interface 36
4.2 Command Syntax 37
4.3 Command Replies 38
4.4 Error Table 39
4.5 Command Table 41
4.6 Basic Commands 45
4.6.1 MON Command *45*
4.6.2 MOFF Command *46*
4.6.3 VER Command *47*
4.6.1 SN Command *48*
4.6.1 ID Command *49*
4.7 State, Faults and Warnings 50
4.7.1 MSTR Command *51*
4.7.1 MFTR Command *52*
4.7.2 MWRR Command *54*
4.7.3 MRESET Command *55*
4.8 Current and Voltage Setting/Reading 56
4.8.1 UPMODE Command *57*
4.8.2 MRI Command *59*
4.8.3 MRV Command *60*

4.8.4 LOOP Command ... *61*
4.8.5 MWI Command ... *62*
4.8.6 MWV Command ... *63*
4.8.7 MWIR Command ... *64*
4.8.8 MSRI Command ... *65*
4.8.9 MWVR Command ... *66*
4.8.10 MSRV Command ... *67*
4.9 GENERIC MONITORING PARAMETERS ... 68
4.9.1 MRT Command ... *68*
4.9.2 MRW Command ... *70*
4.9.3 MRP Command ... *71*
4.9.4 MRID Command ... *72*
4.10 SPECIAL COMMANDS ... 73
4.11 CONFIGURATION COMMANDS ... 73
4.11.1 MRG Command ... *76*
4.11.2 MWG Command ... *77*
4.11.1 MSAVE Command ... *79*
4.11.2 PASSWORD Command ... *80*
4.11.3 SETPSW Command ... *82*
4.12 ADVANCED FEATURES - WAVEFORM ... 83
4.12.1 WAVE:N_PERIODS: Command ... *85*
4.12.1 WAVE:POINTS Command ... *86*
4.12.1 WAVE:START Command ... *87*
4.12.1 WAVE:STOP Command ... *88*
4.13 ADVANCED FEATURES – POST-MORTEM ... 89
4.13.1 PMM:TRIG Command ... *90*
4.13.1 PMM:TIMESTAMP Command ... *91*
4.13.1 PMM Command ... *92*
4.13.2 PMM:READY Command ... *93*
4.13.3 PMM RESET Command ... *94*
4.14 ADDITIONAL FEATURES ... 95
4.14.1 Auto Shut-Down of Display ... *95*

Document Revisions

Revision	Date	Comment
1.0	January 8th, 2020	First Release
1.1	March 19th, 2020	Harmonic Suppressor command added

1. Overview

This manual covers the main information related to the dedicated high-level control and the low-level TCP/UDP raw commands for the CDCU power converters.

Section 2 covers in detail the CAEN ELS Device Manager software, which allows finding and identifying all the power units connected to the network, updating their Ethernet communication configuration and updating their firmware.

The integrated Web Server, which allows to easily control the power unit is described in Section 3.

The low-level ASCII-based TCP or UDP commands to remotely control and monitor the power converters are presented in Section 4.

2. CAENels Device Manager

The *"CAENels Device manager"* software can be used to detect:

- CAEN ELS devices described within this document and connected to the local network;
- Their network configuration;

The *"CAENels Device manager"* is available for Windows and Linux platform. The system requirements are:

1. Windows minimum system requirements:
   - Windows® XP or newer
   - Intel® or equivalent processor
   - 70 MB available HD space
   - Ethernet network card

2. Linux minimum system requirements:
   - Linux kernel 2.2.x or newer
   - Intel® or equivalent processor
   - 70 MB available HD space
   - Ethernet network card

2.1 Searching for Connected Devices

The following steps have to be performed in order to search of all CAEN ELS units connected to the local network:

- Install the *"CAENels Device manager"* software;
- Launch the software;
- Perform a scan to discover the connected device(s) – e.g. CDCU – by clicking the *"Scan"* button as indicated in **Figure 1**. If multiple network connections are available, it is possible to select the network(s) to be scanned in the *"Selected network interfaces"* window available under the "*Options*" menu. All the information about the selected devices are shown on the right side of the main window.

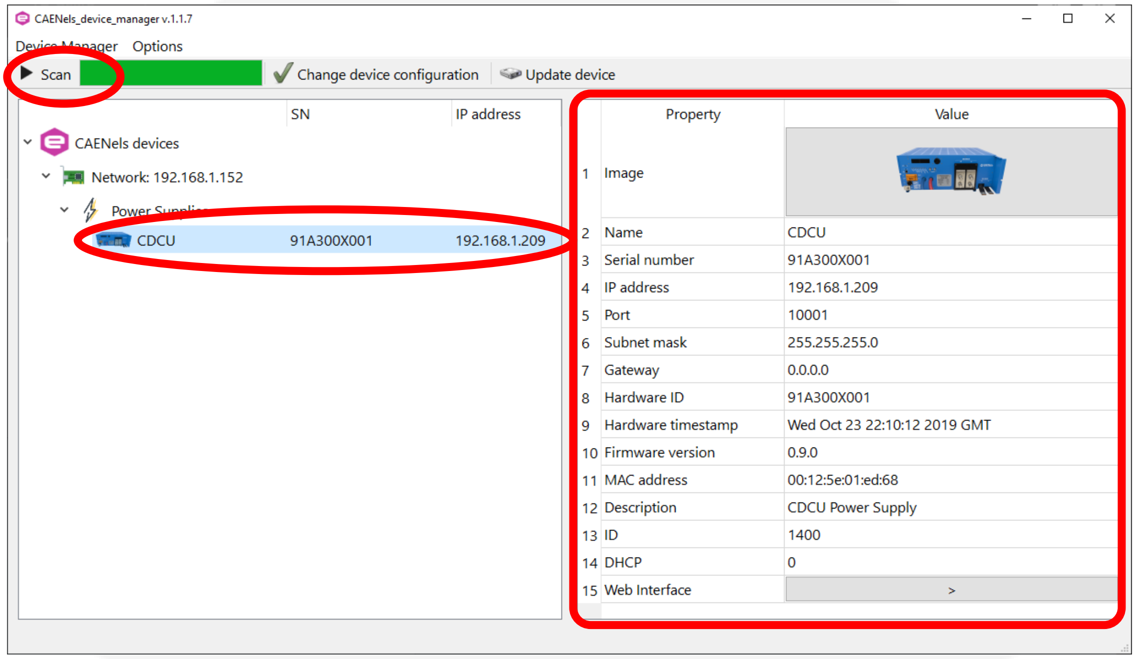


Figure 1: Device Manager - Main interface

Make sure that the firewall is not preventing communication between your computer and the unit(s). The "*CAENels Device manager*" uses **UDP port 30719** to find connected devices, so ensure that the UDP traffic is allowed in both directions on this port.

2.2 Device Configuration

The software allows also changing the Network configuration of the device(s) found on the local network.

In order to change the network configuration of the unit it is necessary to select the desired device and to click on the "*Change device configuration*" button in the main window as shown in **Figure 2**. The configurable Network options are:

- Device IP address;
- Subnet mask;
- Gateway.

To apply the changes on the device configuration it is necessary to edit the corresponding fields and then to click on the "*Save*" button. A screenshot of a sample device configuration is shown in the following picture:

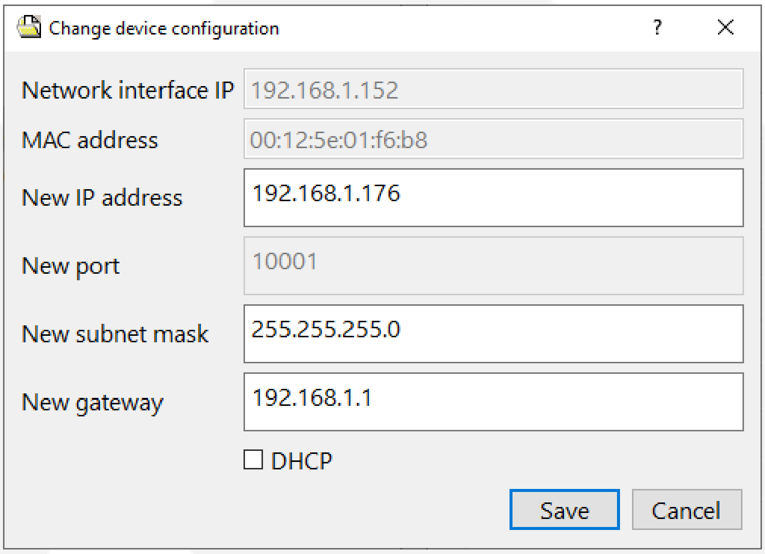


Figure 2: Device Manager - Change device configuration

3. Web Server

An on-board running Web Server allow to remotely control the main features of the CAEN ELS power converters using a Graphic User Interface (GUI).

In order to establish connection with a power converter, please be sure that the network configuration of the PC in use allows the connection to the module (same subnet of the power module). Then, it is necessary to type in the power supply IP address in the web browser in order to connect to it:

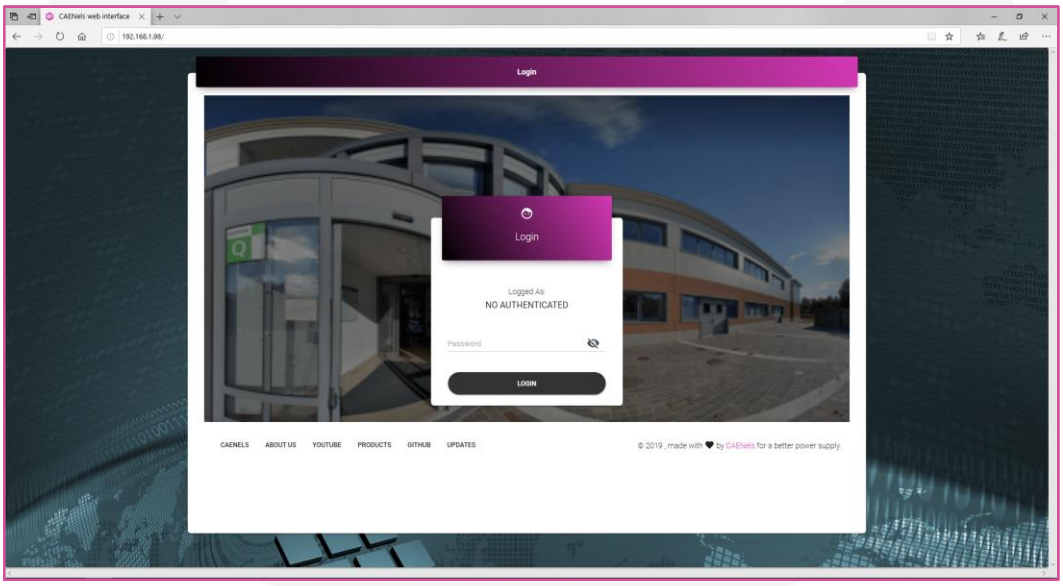


Figure 3: Web Server Login Page

When in the Login page as shown in **Figure 3**, set Password:

- “***user***”: for user privileges;
- “*ps-admin*”: for administrator privileges (unlock password-protected memory cells). Note: it is possible to change the default administrator password – please refer to the password section in the Software Commands chapter.

In either case, some cells are locked as these are factory-protected.

3.1 Main Windows

The web server main window is presented below:

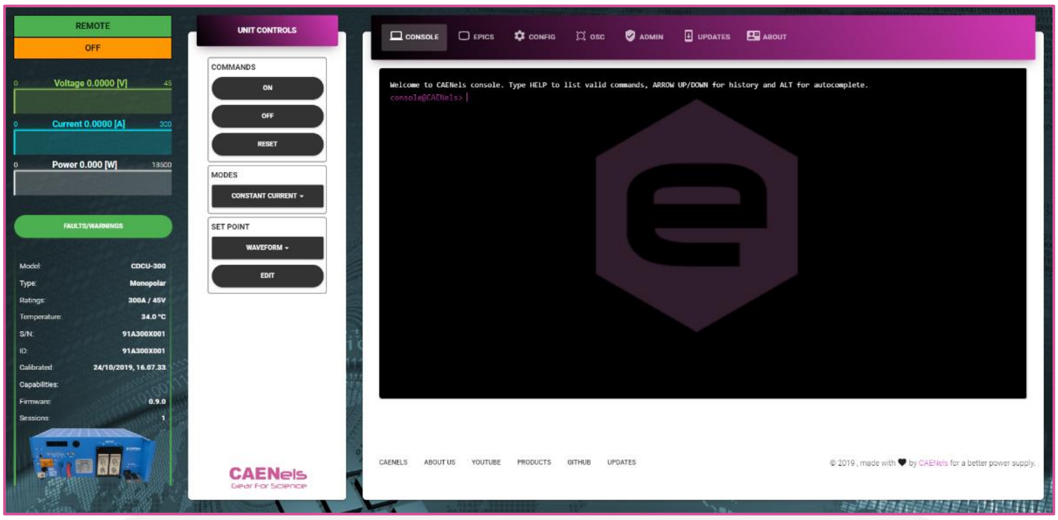


Figure 4: Web Server – Main Window

The “CONSOLE” tab can be used to send commands to the power units (please refer to Section 4 for the supported commands). In addition, by typing “clear”, it is possible to reset the console. The key ‘AltGr’ can be used to display the command auto-completion tips.

On the left side, power supply information are reported:

Figure 5: Web Server – Main Window Information

- **Unit Controls:** allows to Switch ON/OFF the unit and to Reset its status register (in case of a fault);

- **Regulation Mode:** allows to select the mode of operation. The regulation mode can be changed only when the unit is switched OFF;

- **Voltage/Current Set section:** this section allows to set the Voltage (for the "*Constant Voltage*" mode) or Current (for the "*Constant Current*" mode) setpoint. To apply a setpoint it is necessary to click on the *Ramp* or *Set* button. The *Ramp* button performs a ramp to the selected setpoint according to the set slew-rate, otherwise the *Set* button applies directly the selected setpoint;

- **General Information:** shows some information regarding the connected unit – e.g. the power converter model and its serial number;

- **Unit Status:** shows some information regarding the output status, the temperature values, the leakage current, the unit control mode – i.e. local or remote - and the fault status. By clicking on the fault status indicator, it is possible to access the detailed fault status windows;

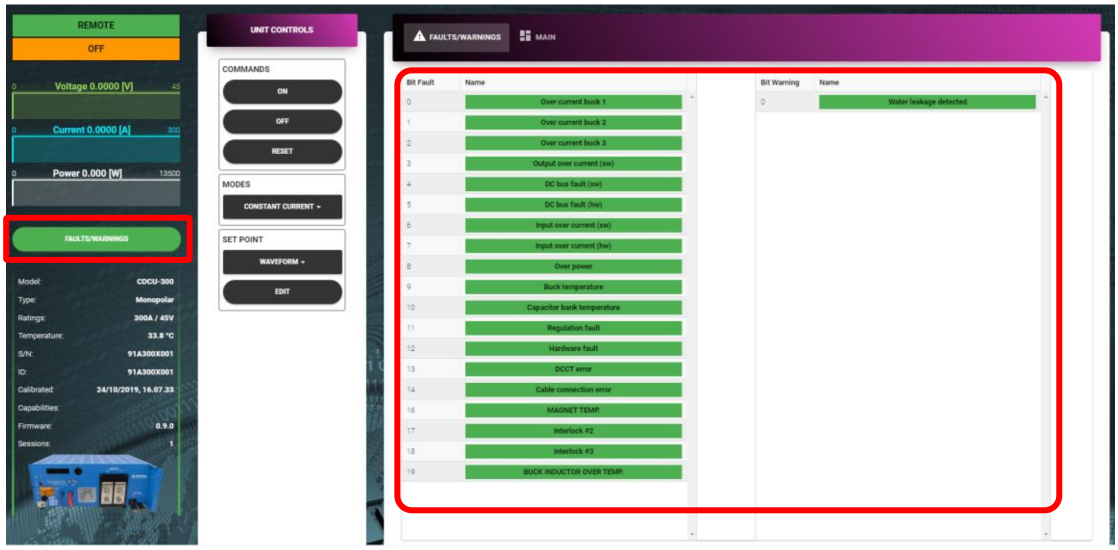
- **Output Monitor:** indicates the actual output voltage, output current and output power.

3.2 Fault Reset

A detailed description of the possible fault conditions of the power converter can be found in the CDCU User's manual.

If a fault condition arises, the "FAULTS/WARNINGS" green button turns to red, otherwise in the case of a warning condition (without faults) the button turns to orange.

To understand the nature of the fault, it is possible to click on the red "FAULTS/WARNINGS" button and the web interface will show the fault(s) and warning(s) details.



In order to reset the fault and thus to turn the power supply on again, the following steps need to be performed:

1. Remove the fault cause - e.g. solve the external interlock cause;
2. Click on the RESET button;
3. Turn ON the power supply.

3.3 Unit Controls

The “UNIT CONTROLS” section allows turning the module ON/OFF and to reset eventual faults (when the “FAULTS/WARNINGS” button is red). Please refer to Section 4.7 for further information on faults list.

3.4 Regulation Mode

The “MODES” window allows to select between two different control modes:

- Constant Current (CC): the module set-point is in [A];
- Constant Voltage (CV): the module set-point is in [V].

3.5 Set Point Control Modes

The CDCU power converters by CAEN ELS may be controlled in different ways:

- Normal: single set point;
- Waveform: pre-stored and custom waveforms generation.

In the following sections these two modes are discussed.

3.5.1 Normal Control Mode

In this control mode the user can set a single set point. In order to do so, just type the desired value in [A] or [V] (depending on CV or CC mode) and click “APPLY”:

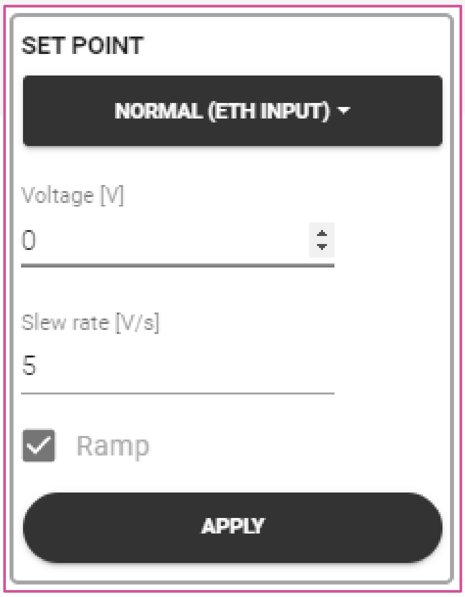


Figure 6: SET POINT – NORMAL

If the "Ramp" checkbox is selected, the module will apply a specific A/s or V/s ramping to the setpoint (it may be changed by changing the Slew Rate value in **Figure 6**).

3.5.2 Waveform Control Mode

An embedded waveform generator may be used for set-points generation. The arbitrary waveform generator uses a DMA (Direct Memory Access) module to reproduce the waveform setpoints which are stored in a physical memory, thus avoiding the latency time TCP or even UDP protocols would bring.

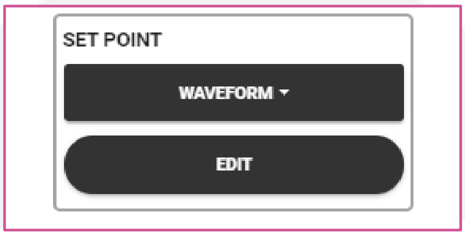


Figure 7: SET POINT – WAVEFORM

By clicking "EDIT" (**Figure 7**) the user can select between 4 different waveform types:

- SINE Wave;
- SQUARE Wave;
- TRIANGULAR Wave;
- CUSTOM Wave.

Once the waveform is selected, it is possible to edit it by acting on gain, offset and other parameters:

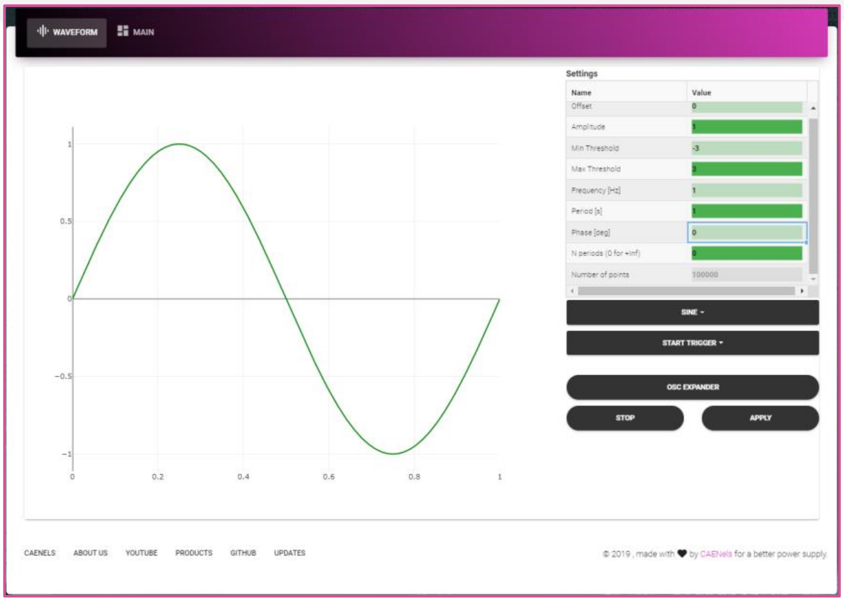


Figure 8: Sine Wave Generation

The "OSC EXPANDER" option can be used in order to see both the waveform window and the embedded oscilloscope window at the same time and also to have access to the PID settings in order to modify in real-time the dynamic behaviour of the output.

3.6 EPICS IOC

An on-board EPICS IOC server is running on each power converter and the main window is shown in **Figure 9**. The “Protocols” tab shows the current EPICS server settings:

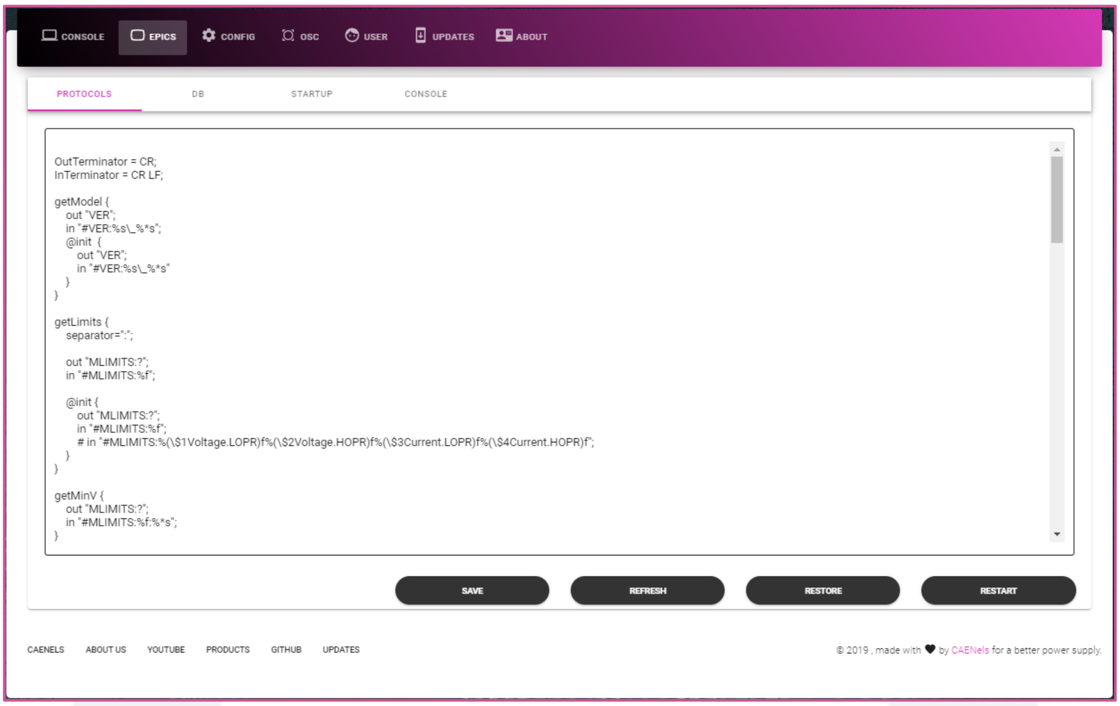


Figure 9: EPICS - Main Window

EPICS PV (Process Variables) can be changed on the “DB” tab (**Figure 10**):

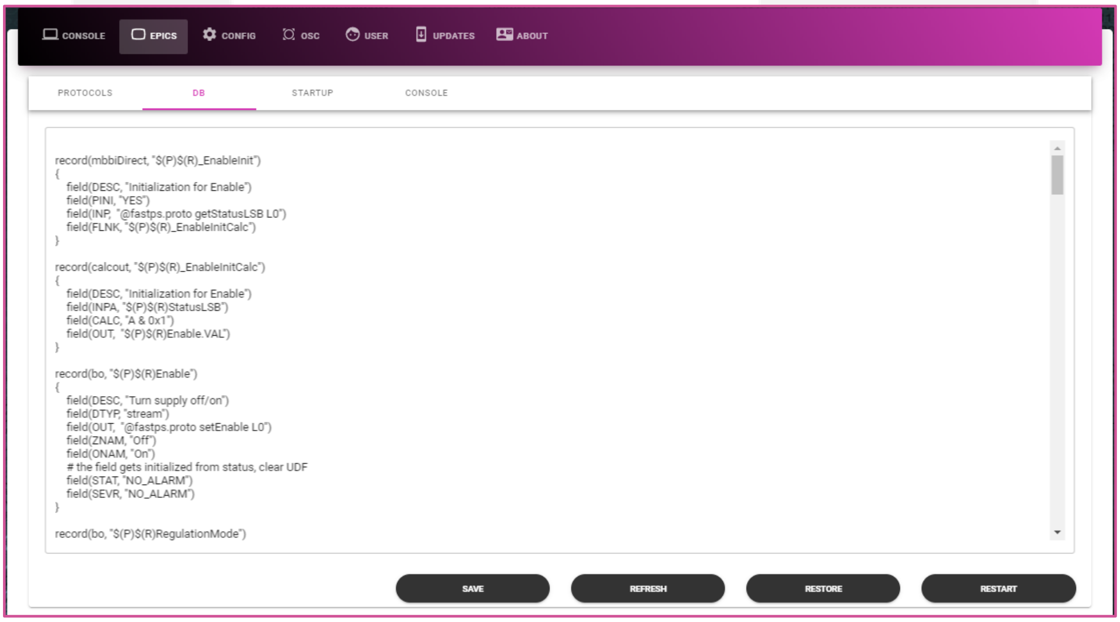


Figure 10: EPICS - DB

After the editing has been performed, click “SAVE” to store the current configuration.

EPICS startup configuration can be changed in the "STARTUP" window (**Figure 11**):

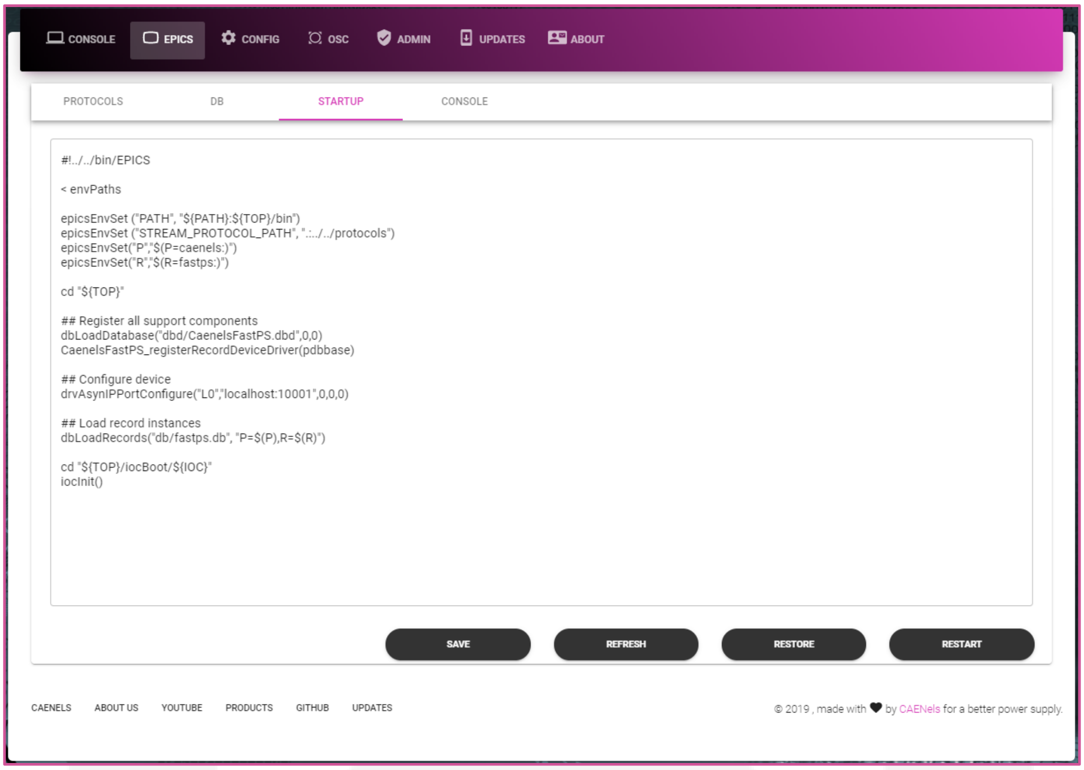


Figure 11: EPICS – STARTUP

In the "EPICS-CONSOLE" window the EPICS-supported commands may be typed in order to get command replies (e.g. by typing "dbl" the power source will reply with the current EPICS-IOC configuration of records and variables) as in **Figure 12**:

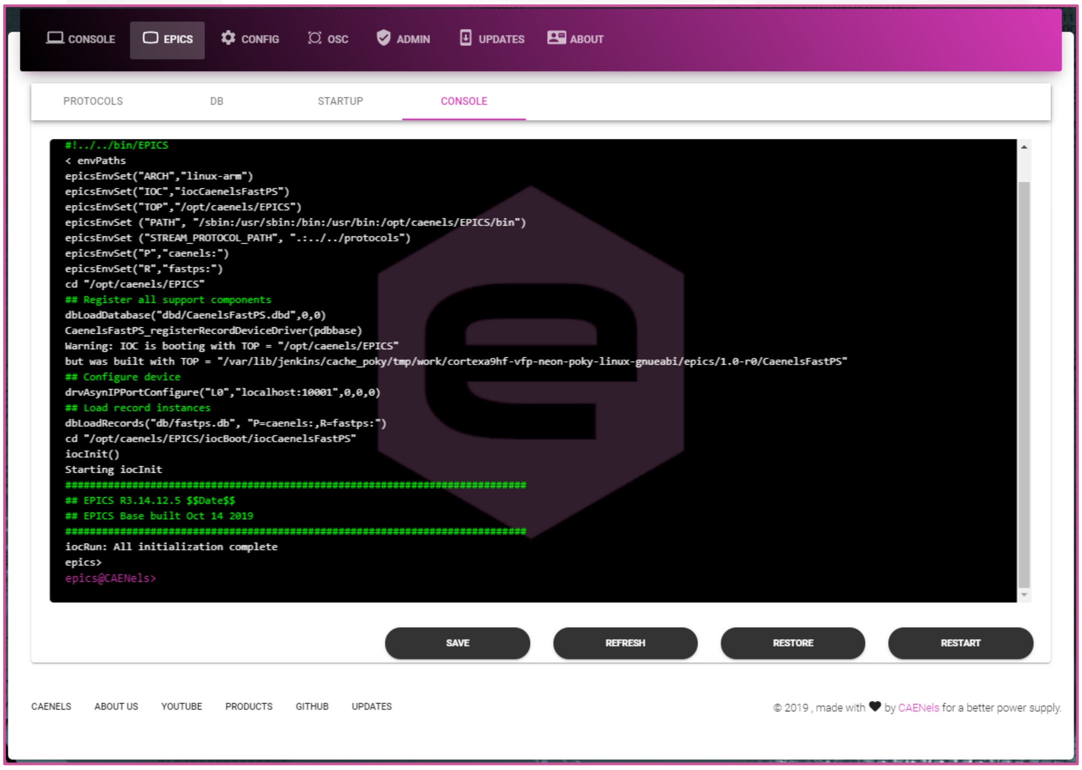


Figure 12: EPICS – CONSOLE

3.7 Unit Configuration

By clicking on the "CONFIG" button on the main Toolbar it is possible to display the configuration Window, where it is possible to configure the converter. Several fields are password-protected. Please remember to set "Ps-admin" as the password at login in order to have administrator privileges.

The "CONFIG" window is presented below:

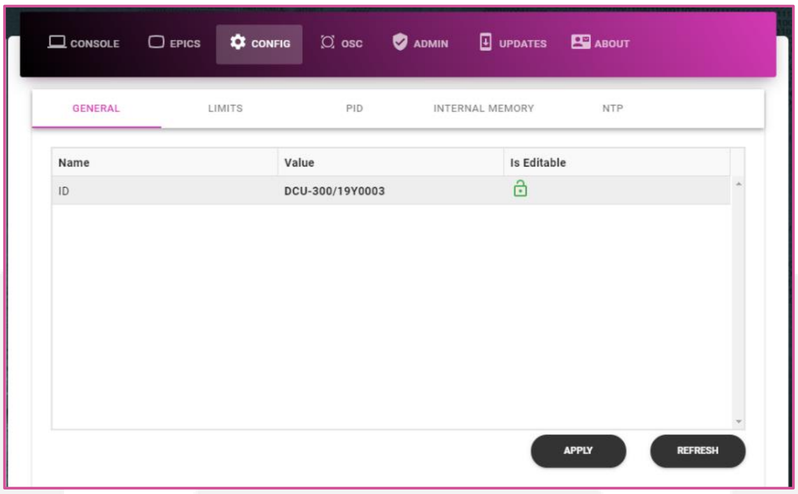


Figure 13: Web Server – General Section

- **GENERAL** tab**:** shows the serial number of the module;
- **LIMITS** tab**:** from this tab the user can perform the following operations.
  - display and edit the names, direction, status (enabled or disabled) and intervention time of the available external interlocks;
  - visualize and edit the module limits (which generate a fault condition) – e.g. the maximum allowable temperature, min DC-link voltage, Leakage current limit, etc.
- **PID** tab**:** from this tab it is possible to edit the PID regulator parameters – i.e. proportional, derivative and integral terms;
- **INTERNAL MEMORY** tab**:** in this tab the user can display, edit and save the content of the internal memory of the power unit;
- **NTP** tab**:** in this tab the user can configure the NTP (Network Time Protocol) configuration.

3.7.1 Interlocks and Limits

The “LIMITS” window is divided into 2 sub-windows:

- Limits;
- Regulation Fault.

These sub-windows are explained in the following paragraphs.

3.7.1.1 *Limits*

Under the “LIMITS” section, different important parameters are listed as the maximum allowed Buck temperature. It is strongly recommended not to change such values as shown in **Figure 14**.

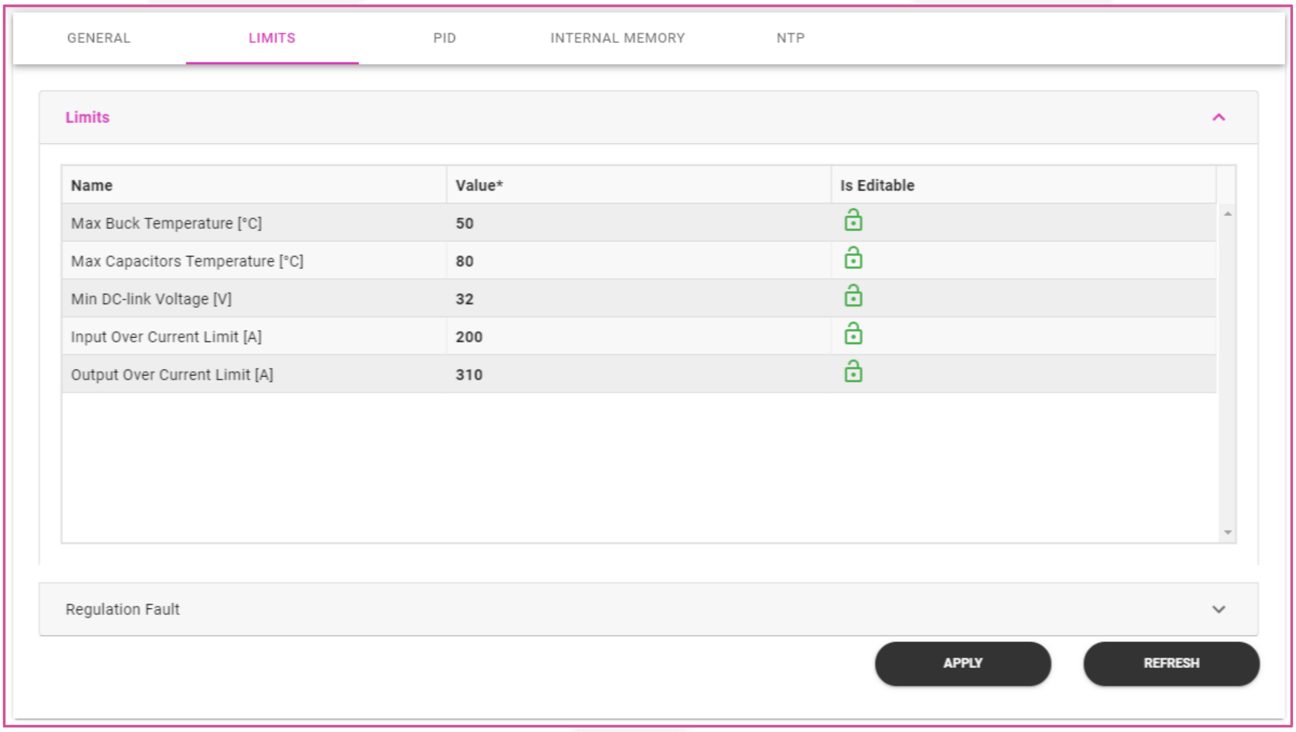


Figure 14: Web Server – Limits Section

3.7.1.2 *Regulation Fault*

Whenever a power converter is not able to reach a set point, voltage one or current one, depending on the set regulation mode, a “Regulation Fault” will appear.

E.g.: if the user sets a 15-A set-point on a 2-Ohm load and the maximum voltage output is 20 V, a “Regulation Fault” will appear as soon as the power source senses that it is impossible to reach the set-point.

Under the “Regulation Fault” section the following limits are listed:

- *Current Regulation Fault Limit*: maximum difference between the current set-point and the current that can be reached;
- *Voltage Regulation Fault Limit*: maximum difference between the voltage set-point and the voltage that can be reached;
- *Regulation Fault Intervention Time*: maximum time allowed to reach the set-point.

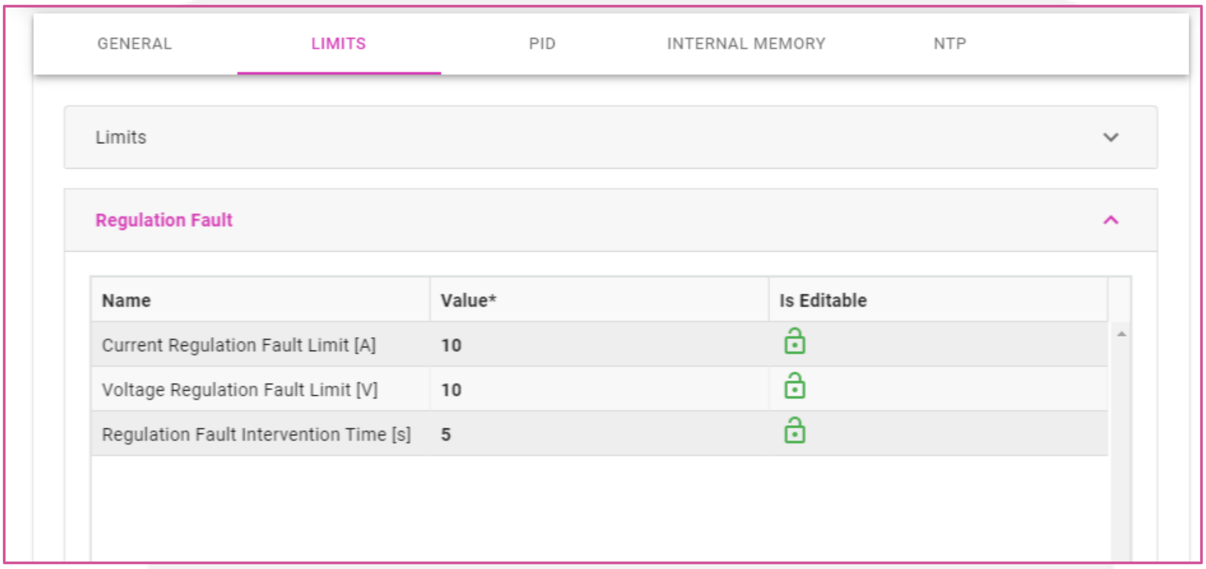


Figure 15: Web Server – Regulation Fault Section

In this case also it is recommended not to change the default factory values. However, this may be useful in specific applications (e.g., high inductive loads with high time constants which can take a long time to get to stationary state).

3.7.2 PID Values

CAEN ELS power converters run a state-of-the-art completely digital control loop instead of the more common analog one based on hardware components.

The PID regulator is implemented directly in the FPGA logic, thus allowing for very fast dynamics with the possibility of configuring the Proportional, Integrative and Derivative parameters to adapt the response of the power unit on the specific connected load.

PID parameters are found in the "CONFIG" Window under the "PID" section:

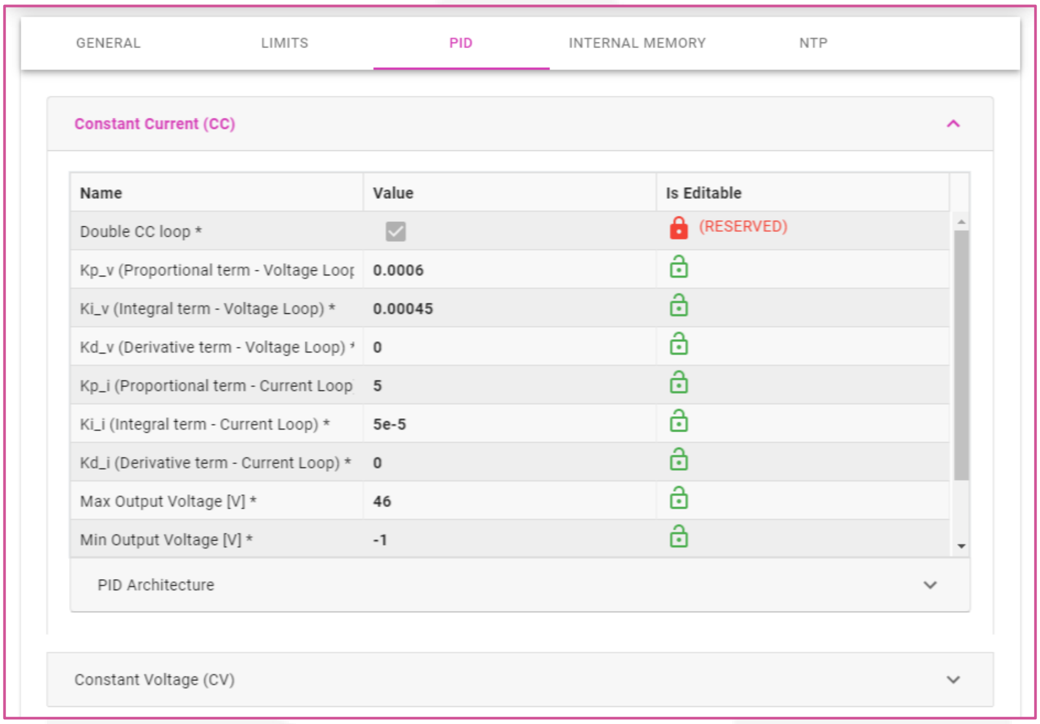


Figure 16: Web Server – PID section

PID parameters can be set separately for output current control (Constant Current, CC) mode and for output voltage control (Constant Voltage, CV) mode. In the same window it is possible to display the PID architecture as shown in **Figure 17**. Please note that for CC control, both current and voltage loops are involved, while for CV control only the voltage loop is enabled.

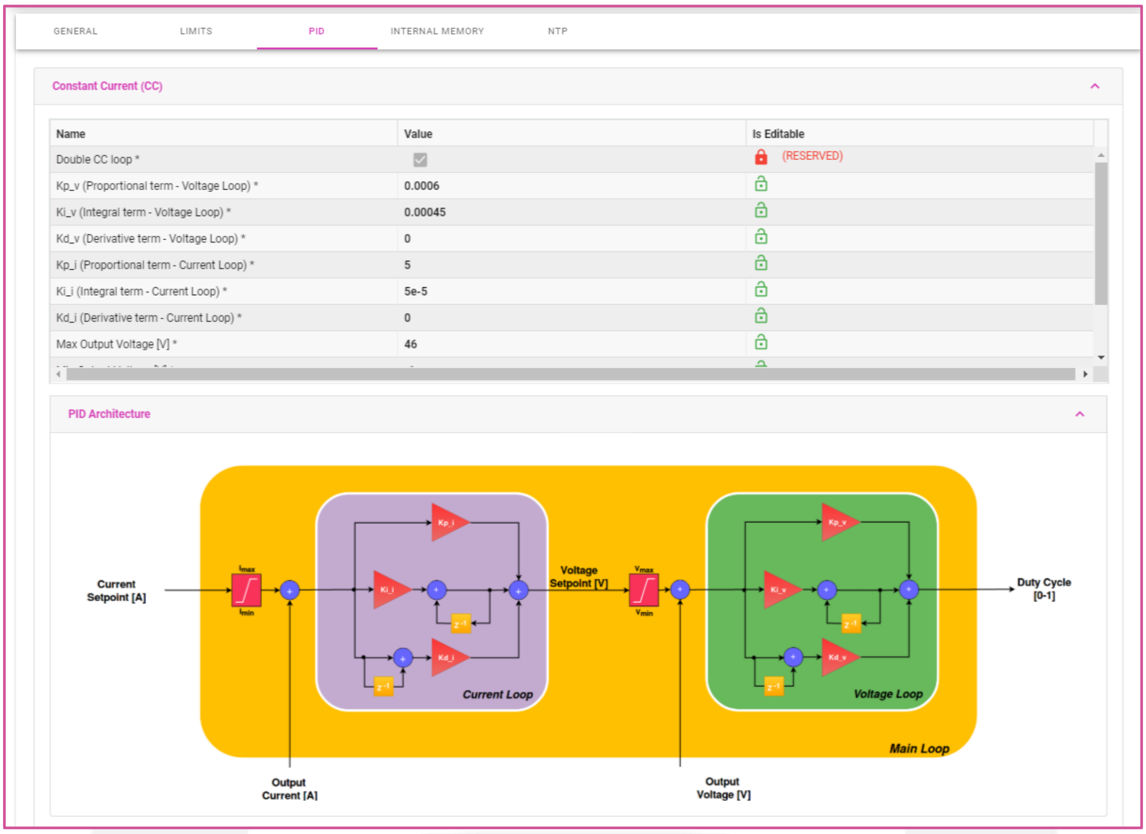


Figure 17: Web Server – PID section (CC) and PID architecture

3.7.2.1 *Save and Load pre-set PID configurations*

PID configurations can be exported as **.cpid** files. To export a PID configuration, please click on the "Export" button:

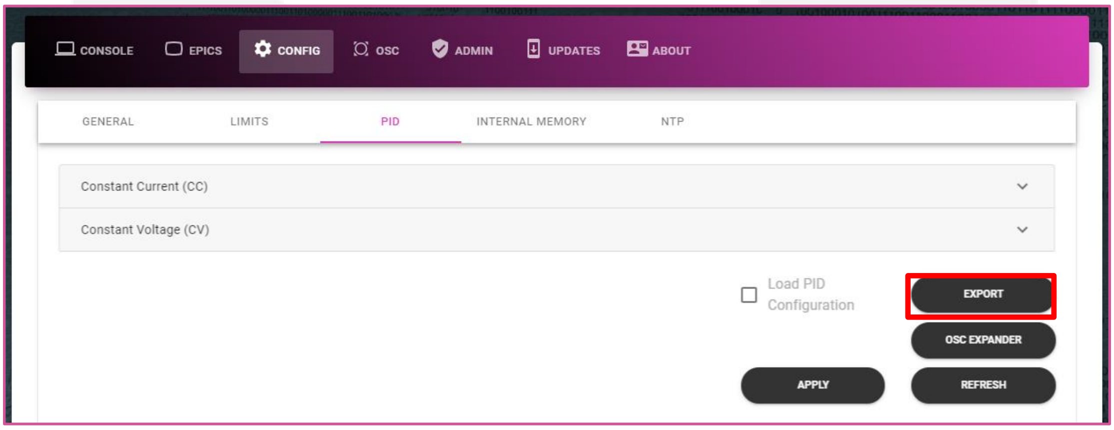


Figure 18: Web Server – export/save PID settings

<u>It is recommended to save the file using a name which refers to the load in use and/or to the dynamic behaviour achieved.</u>

To use a stored configuration, select the "Load PID Configuration" option and drag & drop the **.cpid** file in the reserved space:

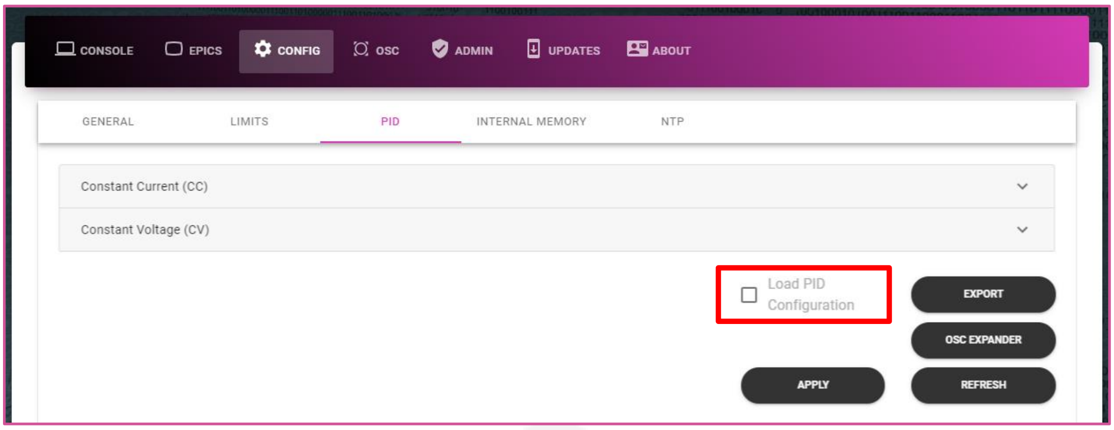


Figure 19: Web Server – import/load PID settings

<u>Once the configuration is selected, it is automatically stored and saved into the power converter by clicking "APPLY"</u>.

3.7.3 Internal Memory

All the internal parameters of the power converter are listed in the "Internal Memory" tab:

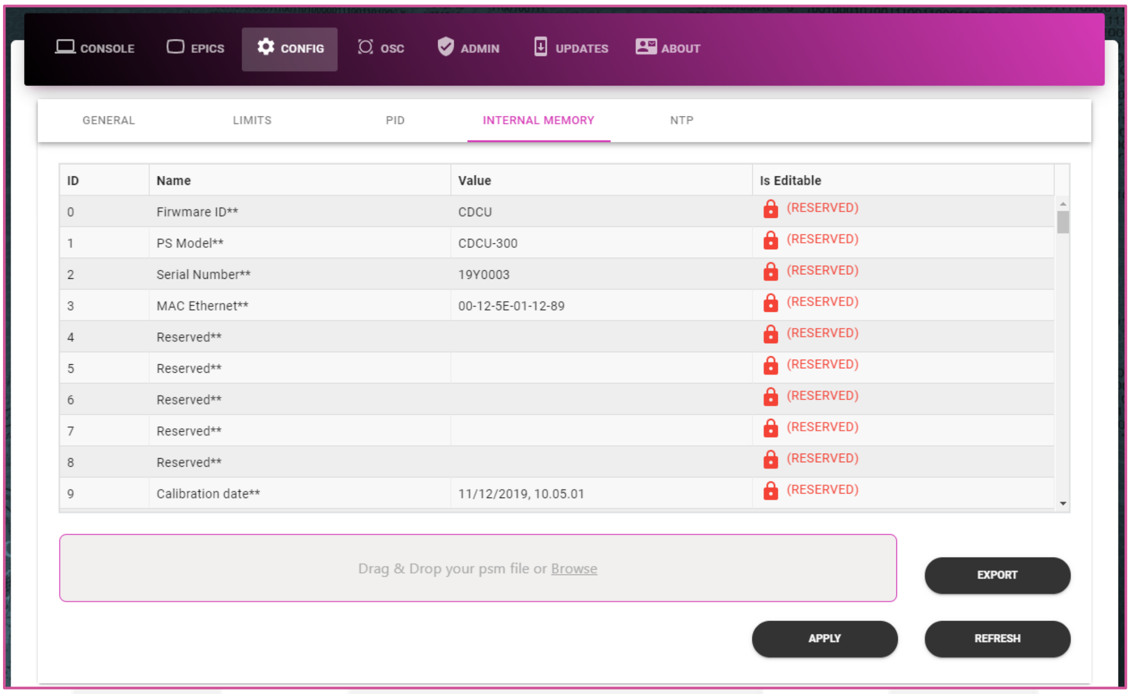


Figure 20: Web Server – Internal Memory

The internal parameters can be changed by using the "Value" field. It is necessary to click on the "APPLY" button in order to apply the changes.

By clicking the "EXPORT" button, a **.psm** file can be exported in order to save the internal memory parameter status. The **.psm** file can be also imported, using the drag & drop area (purple framed rectangle as seen in **Figure 20**). To apply the imported **.psm** file it is necessary to click on the "APPLY" button. Please note that several parameters are password-protected and the parameters can be changed only depending on the user's privileges level.

Parameter #	Access Privileges	Parameter Name
0	Read Only	Firmware ID
1	Read Only	PS Model
2	Read Only	Serial Number
3	Read Only	MAC Ethernet
4-8	/	Reserved
9	Read Only	Calibration date
10	Read Only	Current Calibration Parameter a
11	Read Only	Current Calibration Parameter b
12	Read Only	Current Calibration Parameter c
13	Read Only	Current Calibration Parameter d
14	Read Only	Voltage Calibration Parameter a
15	Read Only	Voltage Calibration Parameter b
16	Read Only	Voltage Calibration Parameter c
17	Read Only	Voltage Calibration Parameter d
18	Read Only	DC Bus Calibration Parameter a
19	Read Only	DC Bus Calibration Parameter b
20	Read Only	DC Bus AC Calibration Parameter a
21	Read Only	DC Bus AC Calibration Parameter b
22	Read Only	DAC Iset Calibration Parameter a
23	Read Only	DAC Iset Calibration Parameter b
24	Read Only	DAC Iout Calibration Parameter a
25	Read Only	DAC Iout Calibration Parameter b
26	Read Only	Input Current Calibration Parameter a
27	Read Only	Input Current Calibration Parameter b
28-29	/	Reserved
30	Admin	Module ID
31	Admin	Default Current Slew Rate [A/s]
32	Admin	Default Voltage Slew Rate V [V/s]
33-34	/	Reserved
35	Admin	TFT shutdown timeout [minutes] – 0 to disable the timeout
36	Admin	Feed Forward [0-disable; 1-enable]
37-39	/	Reserved
40	Admin	PID CC: Kp_v
41	Admin	PID CC: Ki_v
42	Admin	PID CC: Kd_v
43	Admin	PID CC: Kp_i
44	Admin	PID CC: Ki_i
45	Admin	PID CC: Kd_i
46	Admin	PID CC: Max Voltage [V]
47	Admin	PID CC: Min Voltage [V]

48	Admin	PID CC: Max Current [A]
49	Admin	PID CC: Min Current [A]
50	Admin	PID CC Mode: [-1-single, 2-double]
51-55	/	Reserved
56	Admin	NAK Error Code Description (0-disable, 1-enable)
57-59	/	Reserved
60	Admin	PID CV: Kp_i
61	Admin	PID CV: Ki_i
62	Admin	PID CV: Kd_i
63	Admin	PID CV: Kp_v
64	Admin	PID CV: Ki_v
65	Admin	PID CV: Kd_v
66	Admin	PID CV: Max Current [A]
67	Admin	PID CV: Min Current [A]
68	Admin	PID CV: Max Voltage [V]
69	Admin	PID CV: Min Voltage [V]
70-74	/	Reserved
75	Admin	Max Capacitors Temperature [°C]
76-81	/	Reserved
82	Admin	Max Buck Temperature [°C]
83	Admin	Min DC-Bus Voltage [V]
84-85	/	Reserved
86	Admin	Current Regulation Fault Limit [A]
87	Admin	Voltage Regulation Fault Limit [A]
88	Admin	Regulation Fault Intervention Time [s]
89	Admin	Input Overcurrent Limit [A]
90	Read only	Interlock Enable Mask
91	Read only	Interlock Activation Level Mask
92	Read only	Interlock #1 intervention time [ms] – fixed to 1000 ms
93	Read only	Interlock #1 name – fixed to External Magnet Temperature
94	Read only	Interlock #2 intervention time [ms] – fixed to 1000 ms
95	Read only	Interlock #2 name - fixed to Ext. Interlock #1
96	Read only	Interlock #3 intervention time [ms] – fixed to 1000 ms
97	Read only	Interlock #3 name - fixed to Ext. Interlock #3
98	Read only	Interlock #4 intervention time [ms] – fixed to 1000 ms
99	Read only	Interlock #4 name – fixed to Buck Inductor Over-Temperature
100	Read only	Output Over-Current [V]
101-119	/	Reserved
120	Read only	Harmonic Suppressor filter – a_0 coefficient
121	Read only	Harmonic Suppressor filter– a_1 coefficient
122	Read only	Harmonic Suppressor filter – b_0 coefficient

123	Read only	Harmonic Suppressor filter – b_1 coefficient
124	Read only	Harmonic Suppressor filter – b_2 coefficient
125	Read only	Harmonic Suppressor filter – Decimation
126	Read only	Harmonic Suppressor filter – Delay Taps (1 tap = 10 µs)
127	Read only	Harmonic Suppressor filter – Gain
128	Read only	Harmonic Suppressor filter – Duty Cycle Variation Limit
129	Read only	Harmonic Suppressor filter – Enable

Table 1: Memory Parameters of the CDCU power units

3.7.4 NTP – Network Time Protocol

The Network Time Protocol (NTP) is an Internet protocol intended for the synchronization of the system under Coordinated Universal Time - UTC.

In such architecture the power converter acts as client and an NTP server must be available in order to achieve synchronization.

The NTP server can run locally on the PC in use (in this case several guides online can be found, depending on the used OS) or can be reached by Internet (e.g. refer to pool.ntp.org).

Once the IP of the NTP server is known, just insert it in the NTP window on the CAEN ELS web server as shown in **Figure 21**:

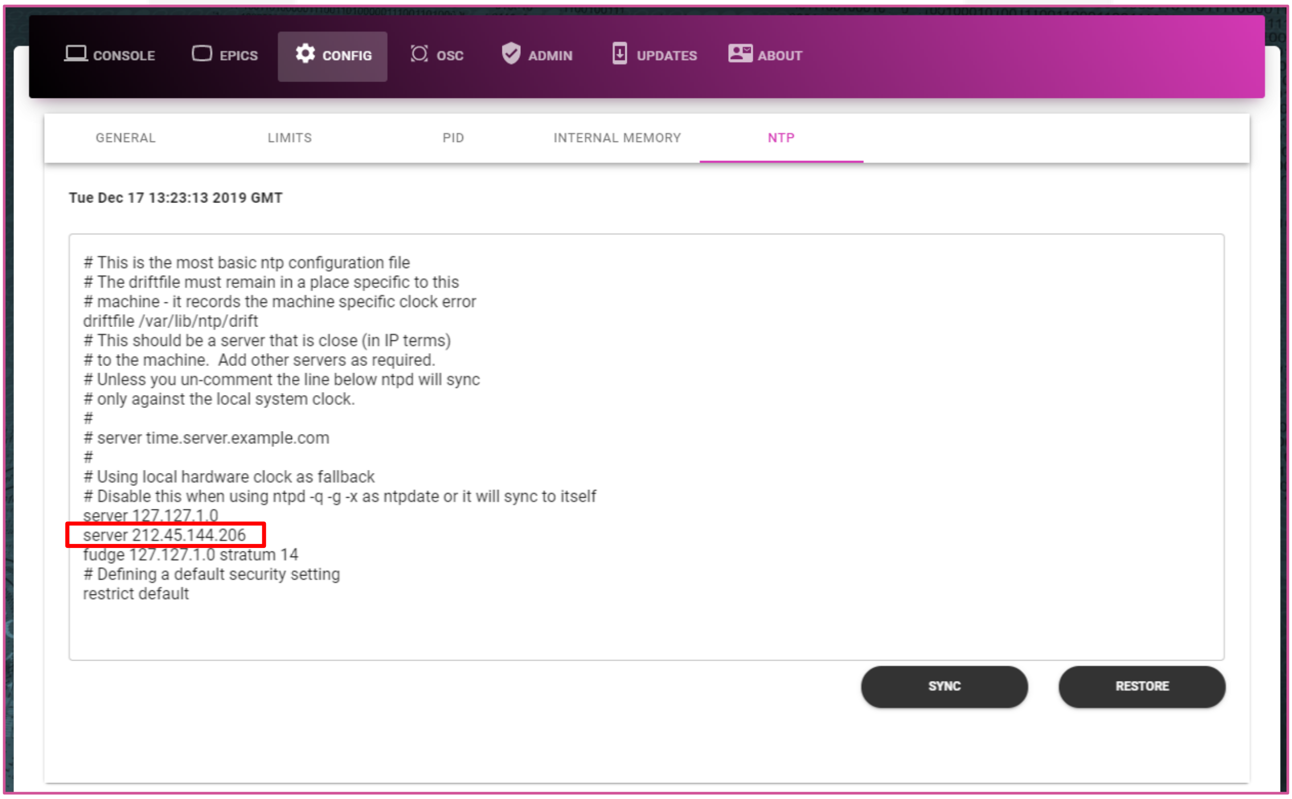


Figure 21: Web Server – NTP Server

When the configuration has been set, click “SYNC” in order to synchronize the power module to the NTP server.

The synchronization can be useful to display the EPICS events in the universal time format.

Note: please be sure that the gateway is configured correctly in order to access to the NTP server.

3.8 Oscilloscope

The embedded Web Server also allows accessing the on-board oscilloscope, plotting in real time, via DMA (Direct Memory Access), the acquired readbacks (such as the current/voltage setpoints, or current/voltage readouts):

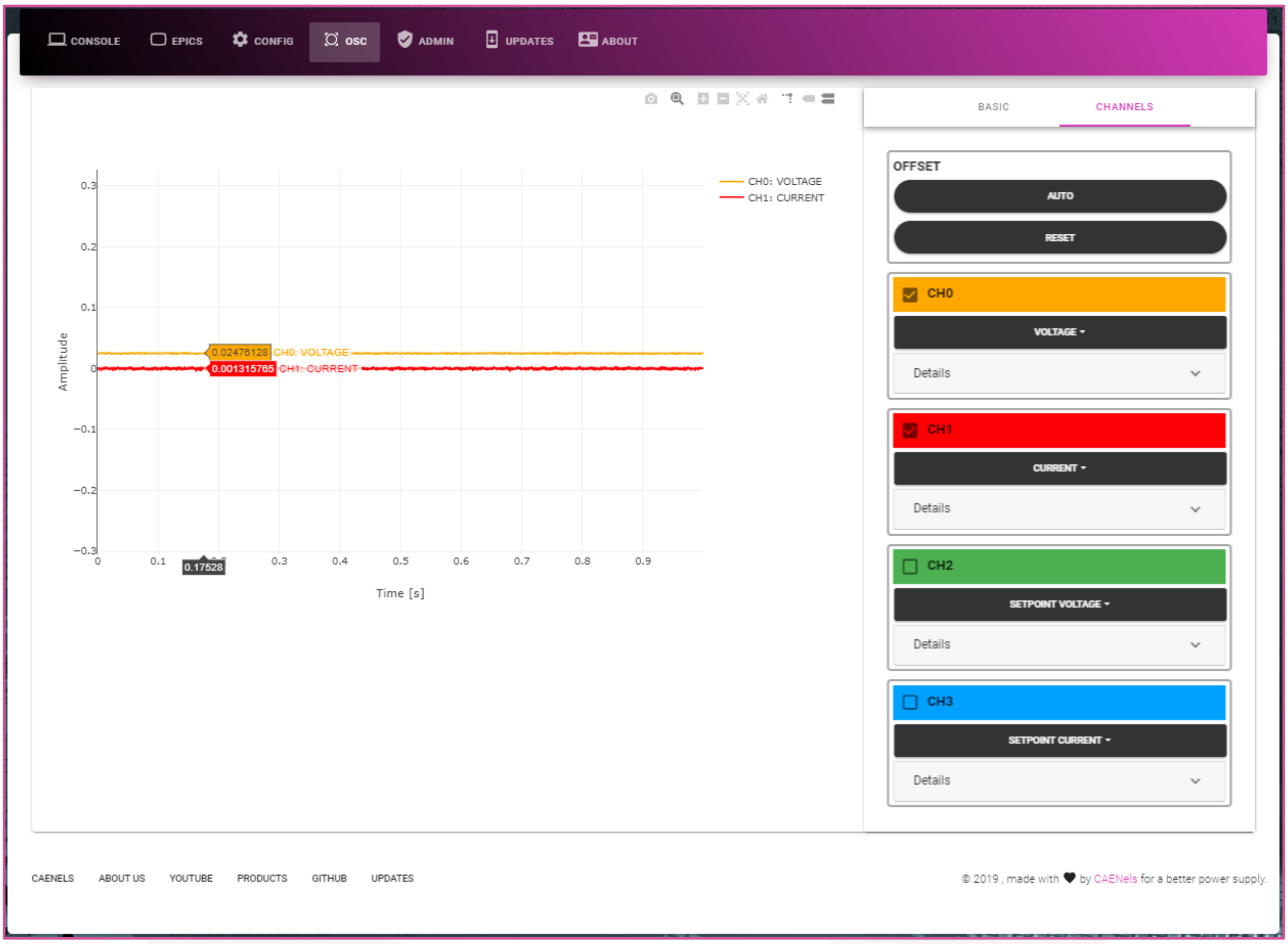


Figure 22: Web Server – Embedded Oscilloscope

Several icons can be found above the oscilloscope main plot area, as shown in **Figure 23**:

Figure 23: Web Server – Embedded Oscilloscope – zooming features

These icons present at the top of this window provide different features (from left to right):

- Save the actual plot as a **.png** file;
- Zoom (creating a zoom region with mouse cursor);
- Zoom In;

- Zoom Out;
- Auto-scale;
- Reset Axes;
- Toggle Spike Lines (it correlates X and Y points for an easier oscilloscope reading);
- Show Closest Data (shows time, value per each channel when passing on the channels plotting with the mouse cursor);
- Compare Data (shows valueCH1,…,valueCHn, time when passing on the channels plotting with mouse cursor).

On the upright corner in **Figure 22** two tabs are present: “BASIC” and “CHANNELS”, here below discussed.

3.8.1 Channels

The on-board embedded Oscilloscope allows plotting up to 4 values, to be decided from the following options (selectable from the “CHANNELS” tab):

- Current set-point;
- Voltage set-point;
- Current readout actual values;
- Voltage readout actual values.

In addition, two offset functions are available by clicking on the related widgets:

- AUTO: sets all the channels to zero;
- RESET: resets the real values for each channel.

3.8.2 Basic

In this tab (“BASIC”) the user can set different values and parameters related to the oscilloscope operation and the triggering options:

Figure 24: Web Server – Embedded Oscilloscope – BASIC window

Four different operation modes are available from the "MODE" window:

- AUTO: continuous real-time plotting;
- NORM: used in trigger mode, the oscilloscope waits to be triggered and then updates the plot at each trigger;
- SINGLE: used in trigger mode, the oscilloscope waits to be triggered and then updates the plot only at the first trigger condition;
- STOP: stops plotting.

The "HORIZONTAL" window allows changing the time-width of the oscilloscope plotting – i.e. horizontal scale.

The "TRIGGER" window is used to edit all the values related to trigger modes NORM and SINGLE:

- SOURCE (CH1, CH2, CH3 or CH4): selects the trigger signal source;
- EDGE (POS, NEG, BOTH): select the triggering edge;
- Level: selects the trigger level on the vertical scale;
- Position: selects the trigger horizontal position in the time window.

3.9 Firmware Update & Support

The "UPDATES" and "ABOUT" tabs provide additional support and information to end-users such as firmware updates and connection to the CAEN ELS website as well as listed contacts for maintenance of power converters when required.

In order to update the firmware of the unit, please follow the simple instructions reported in **Figure 25**. Once the **.updt** file has been dropped, the power source will automatically start the update procedure.

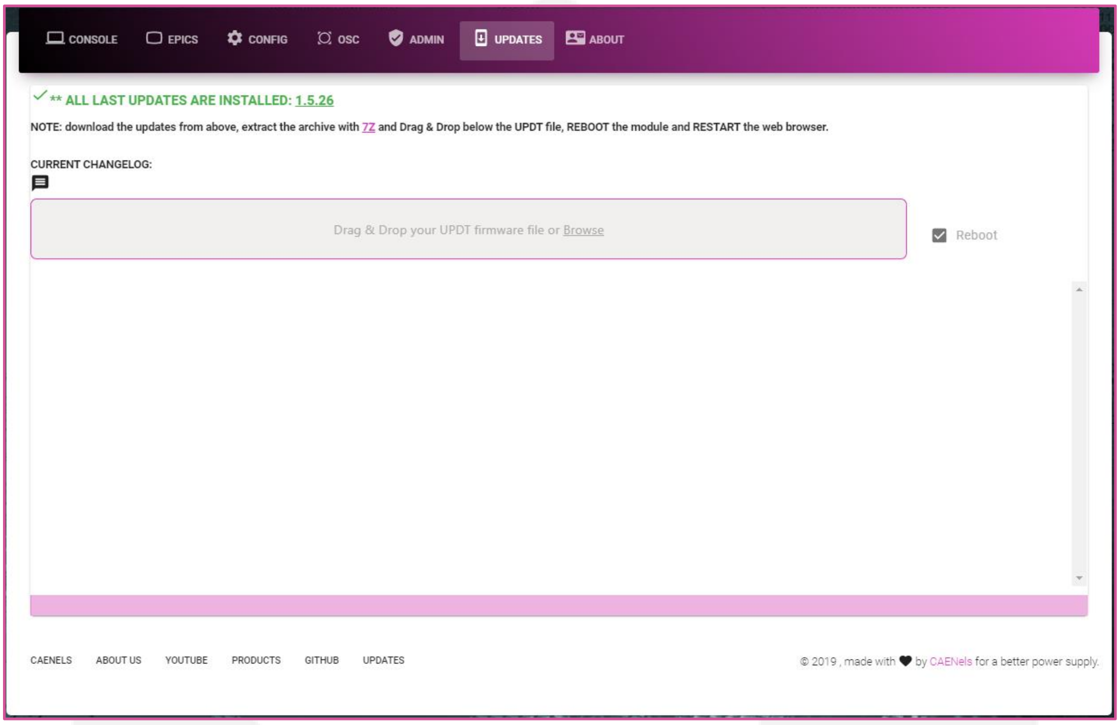


Figure 25: Web Server – "UPDATES"

4. Software Commands

This chapter describes the basic TCP/IP or UDP/IP software commands used for controlling, configuring and monitoring the power converter.

4.1 Ethernet Interface

The device is shipped with default IP address, subnet mask, and gateway and TCP-IP or UDP-IP communication port:

Parameter	Factory Value
IP address	192.168.0.10
Subnet mask	255.255.255.0
Gateway	192.168.0.1
TCP/IP or UDP/IP port	10001

Table 2: Default Ethernet Settings

4.2 Command Syntax

Commands must be sent in ASCII format and are composed by a *"command field"* and one, two or more *"parameter field(s)"*, separated by a colon (*"**:**"*). The number of *"parameter fields"* depends on the specific command. Commands are **NOT case sensitive** and therefore the command string can be sent either using uppercase or lowercase characters (conversion to uppercase characters is performed internally). Each command must be terminated with the termination sequence. The protocol supports two termination sequences:

- *"carriage return"* termination char "**\r**" (*"0x0D"* in hexadecimal notation or commonly CR) or
- "*carriage return\line feed*" sequence "**\r\n**" ("*0x0D 0x0A"* in hexadecimal notation or commonly CRLF).

Command Example:

MWI:20.5580\r or ***MWI:20.5580\r\n***

- ***"MWI"*** is the command field;
- ***":"*** is the parameter's separation character;
- ***"20.5580"*** is the first parameter field;
- ***"\r"*** or ***"\r\n"*** are the termination sequences of the command.

In the following command description, the ***"\r"*** termination char is used, but it can be always replaced with the termination sequence ***"\r\n"***.

Commands are processed one at a time; therefore, **user must wait for a response from the unit before sending the next command**.

All the responses from the power module are in upper case and are terminated with the same *"carriage return\line feed"* sequence ("**\r\n**"), *"0x0D 0x0A"* in hexadecimal notation or commonly CRLF.

MWI:10.5875\r\n →

← **#ACK\r\n**

or:

MWI:10.5875\r →

← **#ACK\r\n**

4.3 Command Replies

The reply from the module depends on the given command. In general, the command can be grouped in two categories: Write commands and Read commands.

For **write commands** there are two specific replies that indicate that the command has been correctly elaborated or not. Those replies are hereafter presented:

- **A**c**K**nowledge ("***#AK***") indicates that the command is valid and it was correctly elaborated by the device:

#AK\r\n

- ***"#AK"*** is the **A**c**K**nowledged response to a valid command;
- ***"\r\n"*** is the termination sequence of the reply.

- **N**ot **A**c**K**nowledge (*"**#NAK**"*) indicates that the command is either not valid or that it was not accepted by the device; the *"NAK"* reply is followed by an *"error code"* field, which can be used to determine the cause of the error (see the List of the Error Codes appendix, section 4.4, for a detailed list of all possible error codes):

#NAK:01\r\n

- ***"#NAK"*** is the **N**ot **A**c**K**nowledged response to an invalid command;
- ***":"*** is the parameter's separation character;
- ***"01"*** is the error code,
- ***"\r\n"*** is the termination sequence of the reply.

If the "Error Code Description" is Enabled (please refer to the internal memory table), then the Error Code Description is added to the error code description and to the NAK reply has the following format:

#NAK:01 Unknown Command\r\n

- ***"#NAK"*** is the **N**ot **A**c**K**nowledged response to an invalid command;
- ***":"*** is the parameter's separation character;
- ***"01"*** is the error code, followed by a space and the Error Code Description;
- ***"\r\n"*** is the termination sequence of the reply.

In the following command description, the NAK reply without Error Code Description is used, but the Error Code Description mode can be always enabled using the proper field in the internal memory.

For **read commands**, the replies are generally formed by an echo string, followed by the corresponding read value. The echo string is preceded by the hash character (“**#**”) and the echo is separated from the “**:**” separation character.

Some examples are hereafter shown:

MRI:?\r →

← **#MRI:12.8875\r\n**

or:

MWI:?\r →

← **#MWI:10.9850\r\n**

or:

MRG:90\r →

← **#MRG:90:0x2\r\n**

- the read commands are highlighted in **blue**;
- the echo string is highlighted in **green**;
- the read value is in **purple**;
- the termination char is highlighted in **red**.

For more detailed information about the single command please refer to the specific command section.

4.4 Error Table

The list of error codes returned with the ***#NAK*** reply and their description are hereafter shown:

Error Number	Description
01	Unknown Command
02	Unknown Parameter
03	Index Out of Range
04	Not Enough Arguments
05	Privilege Level Requirement not met
06	Save Error
07	Invalid Password
08	Module in fault
09	Module already on
10	Set-point is out of hardware bounds
11	Set-point is out of software limits
12	Set-point is not a number
13	Module is off

14	Slew rate out of limits
15	Device is set in local mode, cannot modify values from remote interface while in this state"
16	Module is NOT currently generating a waveform
17	Module is currently generating a waveform
18	Device is not set in local mode, cannot modify values from local interface while in this state
19	Loop mode already set to desired value
20	Loop mode is not the same that uses the variable required to change
21	Module is not in normal update mode
22	Float mode already set to desired value
23	Reserved
24	Reserved
25	Reserved
26	Waveform error
27	Cannot open the required file
28	Cannot change set point because the module is inverting polarity
29	Cannot write waveform data
30	Reserved
31	Cannot set options for socket used by oscilloscope
32	Cannot change settings because in parallel slave mode
33	Reserved
34	Reserved
35	Reserved
36	The required feature is not available
37	UDP buffer overflow
38	Cannot apply the setting because the module is in WAIT FOR OFF state
39	Reserved
40	Reserved
41	Reserved
42	Reserved
43	DHCP is enabled
44	Post mortem monitor not ready
99	Unknown error

Table 3: NAK Error code table

4.5 Command Table

The list of commands used within the communication protocol and the corresponding syntax is hereafter presented as well as a description of each command purpose and any special requirements related to the specific command.

The basic commands are summarized in Table 4. For the advanced commands (such as Waveform generation and Post Mortem monitor), please refer to the relative sections.

Command	Read/ Write	Parameter #1	Parameter #2	Detailed description	Reply value
ID	R	“?”	/	Return the module ID	Module Identification
LOOP	W R	“I” or “V” “?”	/ /	Set the power module loop mode Query for the power supply loop mode	“AK” or “NAK” Loop mode (“I” or “V”)
MFTR	R	“?”	/	Read module internal fault register	Internal fault register (Hex representation)
MOFF	W	/	/	Turn the module OFF	“AK” or “NAK”
MON	W	/	/	Turn on the module	“AK” or “NAK”
MRESET	W	/	/	Reset the module status/fault/warning registers	“AK” or “NAK”
MRG	R	Parameter field number	“?”	Read the given parameter field	Field content (ASCII)
MRI	R	“?”	/	Read output current value	Output read current
MRP	R	“?”	/	Read DC-Bus Voltage	DC-Bus voltage read
MRT	R	“?”	/	Read Temperature [°C]	Temperature read
MRV	R	“?”	/	Read output voltage value	Output read voltage
MRW	R	“?”	/	Read output power	ASCII indicating the output read power

MSAVE	W	/	/	Save the used parameter in the non-volatile memory	"AK" or "NAK"
MSRI	W R	I Ramp Slew rate "?"	/ /	Set the I ramp slew rate [A/s] (ASCII) Query for the I ramp slew-rate	"AK" or "NAK" Current ramp slew-rate
MSRV	W R	I Ramp Slew rate "?"	/ /	Set the I ramp slew rate [V/s] (ASCII) Query for the I ramp slew-rate	"AK" or "NAK" Voltage ramp slew-rate
MSTR	R	"?"	/	Read module internal status register	Internal status register (Hex representation)
MWG	W	Parameter field number	Value in ASCII	Write to the given parameter field	"AK" or "NAK"
MWI	W R	I Setpoint "?"	/ /	Set the new current setpoint (ASCII) Query for the last applied current setpoint	"AK" or "NAK" Current setpoint
MWIR	W R	I Setpoint "?"	/ /	Go to the given setpoint with a ramp Query for the last accepted final ramp setpoint	"AK" or "NAK" Final current setpoint
MWRR	R	"?"	/	Read module internal warning register	Internal warning register (Hex representation)
MWV	W R	V Setpoint "?"	/ /	Set the new voltage setpoint (ASCII) Query for the last applied setpoint	"AK" or "NAK" Voltage setpoint
MWVR	W R	V Setpoint "?"	/ /	Go to the given setpoint with a ramp Query for the last accepted final ramp setpoint	"AK" or "NAK" Final voltage setpoint
PASSWORD	W R	Password word "?"	/	Set the password word (ASCII) Query for the actual user privileges	"AK" or "NAK" User privileges (ASCII representation)
SETPSW	W	Set Custom Password word	/	Set the custom password word (ASCII)	"AK" or "NAK"
SN	R	"?"	/	Return the module Serial Number	Serial Number

UPMODE	W	Update mode	/	Set the update mode (NORMAL – WAVEFORM)	“AK” or “NAK”
	R	“?”	/	Query for the current update mode	ASCII indicating the current update mode
VER	R	“?”	/	Return the module model and installed firmware version	Module model and firmware version

Table 4: Commands overview table

4.6 Basic Commands

In the following section are described the basic commands that allows to control the power unit and to monitor its status.

4.6.1 MON Command

The ***MON*** (Module ON) command is intended to turn ON the module output driver, thus enabling the output current terminals and allowing the power supply to regulate and feed current or voltage to the connected load.

After the reception of an “MON” command, the power supply automatically sets output current to 0 A or 0 V (depending if the module is set in constant current or constant voltage mode).

Replies from the power converter to a ***MON*** command are in the form “***#AK*\r\n**” – when the command is correctly executed - or “***#NAK:****xx*\r\n**”, when the command cannot be executed, with “*xx*” indicating the error code. The complete list of the error codes is shown in the

Error Table**.** Sending a ***MON*** command when the module output is already enabled generates a non-acknowledgment response.

Examples:

MON command example:

MON\r →

← **#AK\r\n**

MON command example when the module is already enabled (09 code):

MON\r →

← **#NAK:09\r\n**

4.6.2 MOFF Command

The ***MOFF*** (Module OFF) command is intended to turn OFF the module output driver, thus disabling the output terminals.

The ***MOFF*** command automatically sets output current to 0A or 0V with a ramp before disabling the output drivers (the unit goes from the state ON to the state Wait for Off). This is done in order to ovoid output overshoots (especially in constant current regulation mode). The slew-rate of the ramp is factory defined. The output drivers are disabled once the power unit reaches zero current output (so the Finite State Machine – i.e. FSM – goes from the “Wait for Off” state to “OFF” state). Once the unit is in the “Wait for Off” state, it is possible to force the transition to the “OFF” state by sending another OFF command (without waiting for the condition where the output current reaches zero). The FSM is hereafter shown:

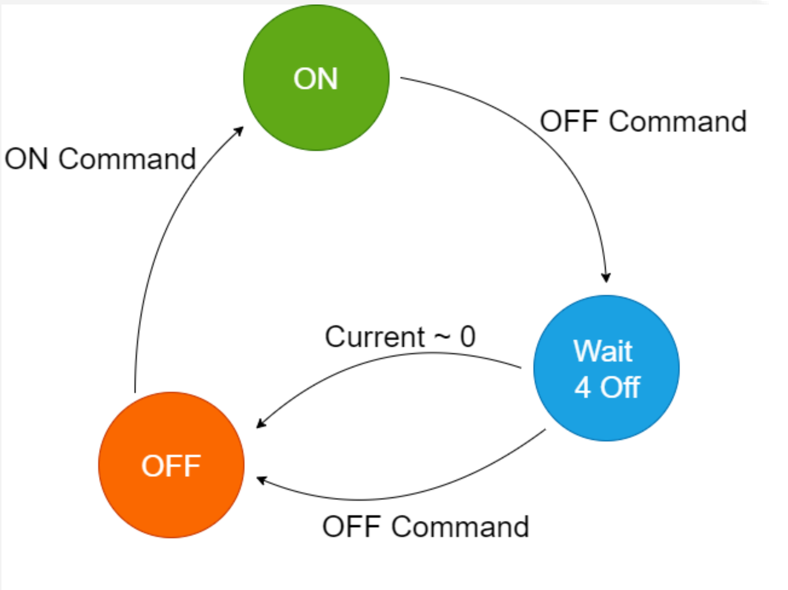


Figure 26: OFF State Machine

Replies from the unit to a ***MOFF*** command are in the form “***#AK\r\n***” – when the command is correctly executed - or “***#NAK:xx\r\n***”, when the command cannot be executed, with “*xx*” indicating the error code.

Examples:

MOFF command example:

MOFF\r ⟶

⟵ **#AK\r\n**

MOFF command example when the module is in local mode:

MOFF\r ⟶

⟵ **#NAK:15\r\n**

4.6.3 VER Command

The ***VER*** command returns the information regarding the model and the current installed firmware version.

The response to the ***VER*** command is in the following format:

#VER:ps_model:fw_version\r\n

where "***#VER***" is the echo string, "***ps_model***" is the power converter model and "***fw_version***" is the current firmware version. The echo, model and firmware information are separated by "**:**" character and the string is terminated with the standard "***\r\n***" character sequence.

Example:

VER command example:

VER:?\r →

← **#VER:CDCU-200:0.9.01\r\n**

4.6.1 SN Command

The ***SN*** command returns the information regarding the model and the serial number.

The response to the ***SN*** command is in the following format:

#SN:ps_model:serial_number\r\n

where "***#SN***" is the echo string, "***ps_model***" is the power converter model and "***serial_number***" is the power converter serial number. The echo, model and serial information are separated by "**:**" character and the string is terminated with the standard "***\r\n***" character sequence.

Example:

SN command example:

SN:?*\r* →

← **#SN:CDCU-200:19Y0001*\r\n***

4.6.1 ID Command

The ***ID*** command returns the identification of the power converter (which correspond to the internal parameter field #30).

The response to the ***ID*** command is in the following format:

#ID:identification\r\n

Example:

SN command example:

SN:?\r →

← **#SN:MAGNET_33A\r\n**

4.7 State, Faults and Warnings

In this section are described the command related to the status, faults and warnings of the unit and how to reset their status.

4.7.1 MSTR Command

The ***MSTR*** command returns the value of the power supply internal status register. The response to the ***MSTR*** command is in the following format:

#MSTR:status_reg\r\n

where "***#MSTR***" is the echo string and "***status_reg***" is the hexadecimal representation of the internal status register. The internal status register has 32 bits and so its representation is composed by 8 hexadecimal values.

The ***MSTR*** command, being a reading command, returns a response in any module condition.

Example:

MSTR command example:

MSTR:?\r →

← **#MSTR:00000012\r\n**

In this example the value 00000012 (hex) means that the bit [1] and bit[4] are high.

The following table shows the CDCU internal fault register structure:

Bit #	Bit name	Description
[1:0]	Power Supply State	Indicates power supply state (please refer to the FSM on **Figure 26**): 00 – OFF 01 – ON 11 – Wait for Off
[2]	Fault bit	This bit indicates that a fault occurred; use MFTR function, to display the fault register. This is a latch bit and so once set, it can be reset only with the reset command.
[3]	Warning bit	This bit indicates that a warning occurred; use MWRR function, to display the warning register. This is a latch bit and so once set, it can be reset only with the reset command.
[4]	Loop Mode	Indicates the power supply loop mode: 0 – Current Mode 1 – Voltage Mode
[5]	Reserved	/
[6]	Local mode	Indicates if the power unit is in the local mode of operation (1) or not (0). In the local mode of operation (that can be set from the local interface on the front panel) the ON/OFF and set operation are allowed only from the local menu and are not allowed from the remote interface.
[8:7]	Reserved	/
[9]	Setpoint source mode	Indicates the setpoint source mode: 0 – Normal, 1 – Waveform (reproduce waveform points)
[31:10]	Reserved	/

Table 5: CDCU Status Register structure

4.7.1 MFTR Command

The ***MFTR*** command returns the value of the power supply internal fault register. The response to the ***MFTR*** command is in the following format:

 # MFTR:fault_reg\r\n

where "***#MFTR***" is the echo string and "***fault_reg***" is the hexadecimal representation of the internal fault register. The internal fault register has 32 bits and so its representation is composed by 8 hexadecimal values.

The ***MFTR*** command, being a reading command, returns a response in any module condition.

Example:

MFTR command example:

MFTR:?*\r* →

← **#MFTR:00000010*\r\n***

The following table shows the CDCU internal fault register structure:

Bit #	Bit name
[0]	Buck 1 Over-Current
[1]	Buck 2 Over-Current
[2]	Buck 3 Over-Current.
[3]	Output Over-Current
[4]	DC-Bus Fault
[5]	DC-Bus Hardware Fault
[6]	Input Over-Current
[7]	Input HW Over-Current
[8]	Over-Power
[9]	Buck Over-Temperature
[10]	Cap. Bank Over-Temperature
[11]	Regulation fault
[12]	Hardware Fault
[13]	DCCT Fault
[14]	Cable connection Fault
[15]	Reserved
[16]	External Magnet Temperature
[17]	External Interlock 2
[18]	External Interlock 3

[19]	Buck Inductor Over-Temperature
[31-20]	Reserved

Table 6: CDCU Fault Register structure

For the detailed information regarding the fault registers, please refer to the CDCU User's manual.

4.7.2 MWRR Command

The ***MWRR*** command returns the value of the power supply internal warning register. The response to the ***MWRR*** command is in the following format:

 # MWRR:warning_reg\r\n

where "***#MWRR***" is the echo string and "***warning_reg***" is the hexadecimal representation of the internal warning register. The internal warning register has 32 bits and so its representation is composed by 8 hexadecimal values.

The ***MWRR*** command, being a reading command, returns a response in any module condition.

Example:

MWRR command example:

MWRR:?\r →

← **#MWRR:00000001\r\n**

The following table shows the CDCU internal warning register structure:

Bit #	Bit name
[0]	Water leakage Warning
[31:1]	Reserved

Table 7: CDCU Warning Register structure

4.7.3 MRESET Command

The ***MRESET*** command has to be used in order to perform a complete reset of the module fault and warning registers. This is needed, for example, to enable the channel output again after a fault condition has been reached.

Before sending the ***MRESET*** command to the power supply it is important to remove the fault/warning presence, or the power supply will instantly get a new fault/warning issue. After an ***MRESET*** command with reply in the form "***#AK\r\n***", the power supply can be turned on again.

Replies from the unit to a ***MRESET*** command are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code).

Examples:

MRESET command example:

MRESET\r →

← **#AK\r\n**

MRESET command example when the module is in local mode:

MRESET\r →

← **#NAK:15\r\n**

4.8 Current and Voltage Setting/Reading

In this section, specific commands to set or to read the value of the current and/or voltage are discussed.

4.8.1 UPMODE Command

The ***UPMODE*** command can be used in order to select the update mode of the set-point. There are two possible mode of operation:

- **NORMAL** – in this mode of operation the power unit works in the standard update mode. The direct set-point or ramp commands are received using the standard Ethernet communication and they are applied immediately when the command is received. The analog input signal is ignored.
- **WAVEFORM –** in this mode of operation the power unit can reproduce the preloaded waveform. When the unit is set in waveform mode, the remote commands are not accepted.

To set the update mode of operation the following commands has to be used:

UPMODE:mode\r\n

where "***mode***" is a string indicating the mode of operation:

- "**NORMAL**" for normal update mode,
- "**WAVEFORM**" for waveform input update mode.

Replies from the unit to a ***UPMODE*** set are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:**xx**\r\n***", when the command cannot be executed ("*xx*" is the error code).

To read the current used loop mode of operation the query command: "***UPMODE:?***" has to be used. The response to the "***UPMODE:?***" query command is in the following format:

#UPMODE:mode \r\n

where "***#UPMODE***" is the echo string, "***mode***" is a string indicating the currently used update mode.

The update mode is also visible in the status register (bit [9]). For further information, please see the MSTR command.

Examples:

UPMODE example to set the update mode to analog:

UPMODE:NORMAL\r →

← **#AK\r\n**

UPMODE query example when the module is in normal mode:

UPMODE:?\r →

← **#UPDMODE: NORMAL\r\n**

4.8.2 MRI Command

The ***MRI*** command returns the readback value of the power supply actual output current.

Replies from the power supply to this command are in the following format:

#MRI:current_value\r\n

where "***#MRI***" is the echo string, "***current_value***" is the output current value readback in Ampere [A].

Example:

MRI command example:

MRI:?\r →

← **#MRI:22.123456\r\n**

4.8.3 MRV Command

The ***MRV*** command returns the readback value of the power supply actual output voltage.

Replies from the power supply to this command are in the following format:

#MRV:voltage_value\r\n

where "***#MRV***" is the echo string, "***voltage_value***" is the output voltage value readback in Volts [V].

Example:

MRV command example:

MRV:?\r →

← **#MRV:10.123456\r\n**

4.8.4 LOOP Command

The ***LOOP*** command can be used in order to select the mode of loop control of the CDCU power unit. There are two possible modes of operation:

- Constant Current (C.C.),
- Constant Voltage (C.V.).

To set the mode of operation the following commands has to be used:

LOOP:mode\r\n

where "***mode***" is a single char indicating the mode of operation:

- "**I**" for Constant Current (c.c.) mode and
- "**V**" for Constant Voltage (c.c.) mode.

Replies from the unit to a ***LOOP*** set are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code). The two modes of operation can be changed only when the module is turned OFF.

To read the current used loop mode of operation the query command: "***LOOP:?***" has to be used. The response to the "***LOOP:?***" query command is in the following format:

#LOOP:mode \r\n

where "***#LOOP***" is the echo string, "***mode***" is a single character indicating the loop mode ("***I***" for constant current mode and "***V***" for constant voltage mode).

Examples:

LOOP set example to set the constant current mode:

LOOP:I\r →

← **#AK\r\n**

LOOP set example when the module is ON:

LOOP:V\r →

← **#NAK:09\r\n**

LOOP query example when the module is in constant voltage (C.V.) mode:

LOOP:?\r →

← **#LOOP:V\r\n**

4.8.5 MWI Command

The ***MWI*** command can be used to set the output current value when the module is in the constant current mode (see ***LOOP*** Command). This command is usually needed when running feedback-related applications and for small changes in the output current.

The use of this command is alternative to the MWIR Command (ramping current command), which is advised for regular use.

This command has the following format:

MWI:current_setpoint\r\n

where "***current_setpoint***" is the desired current set-point expressed in Ampere [A].

Replies from the module to a ***MWI*** set are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code).

To read last applied current setpoint the query command: "***MWI:?***" has to be used. The response to this query command is in the following format:

#MWI:current_setpoint\r\n

where "***#MWI***" is the echo string, "***current_setpoint***" is the last applied current setpoint expressed in Ampere [A].

Examples:

MWI set example, with current setpoint +10.52 A:

MWI:10.52\r →

← **#AK\r\n**

MWI set example when the module is OFF:

MWI:10.52\r →

← **#NAK:13\r\n**

MWI query example:

MWI:?\r →

← **#MWI:1.52\r\n**

4.8.6 MWV Command

The ***MWV*** command can be used to set the output voltage value when the constant voltage mode is used (see ***LOOP*** Command). The use of this command is alternative to the ***MWVR*** Command (ramping voltage command).

This command has the following format:

MWV:voltage_setpoint\r\n

where "***voltage_setpoint***" is the desired voltage set-point expressed in Volts [V].

Replies from the unit to a ***MWV*** set are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code).

To read last applied voltage setpoint the query command: "***MWV:?***" has to be used. The response to this query command is in the following format:

#MWV:voltage_setpoint \r\n

where "***#MWV***" is the echo string, "***voltage_setpoint***" is the last applied voltage setpoint expressed in Volts [V].

Examples:

MWV set example, with voltage setpoint +10.525 V:

MWV:10.525\r →

← **#AK\r\n**

MWV set example when the module is OFF:

MWV:10.525\r →

← **#NAK:13\r\n**

MWV query example:

MWV:?\r →

← **#MWV:10.525\r\n**

4.8.7 MWIR Command

The ***MWIR*** command can be used to perform a ramp to the given current setpoint. This command can be used when the constant current mode is selected (see ***LOOP*** Command).

The use of this command is alternative to the ***MWI*** Command**.** The difference between the ***MWI*** command and the ***MWIR*** command is that the first one generates a direct change in output current characterized by the PID regulator parameters (the command is ideally suited for small output current changes and feedback purposes) while the second one makes the power supply go from the previous to the actual current value performing a ramp, defined by a slew-rate in [A/s].

The default value of the slew-rate is stored in the parameter table and it can be read and modified using the ***MSRI*** command.

To dynamically change the current slew-rate value it is possible using the ***MSRI*** Command. This command has the following format:

MWIR:final_ramp_setpoint\r\n

where "***final_ramp_setpoint***" is the final current value expressed in Ampere [A] to which the power unit will ramp with the defined slew-rate.

Replies from the power unit to a ***MWIR*** set are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code).

To read the selected final ramp setpoint, the query command: "***MWIR:?***" has to be used. The response to this query command is in the following format:

#MWIR:final_ramp_setpoint\r\n

where "***#MWIR***" is the echo string and "***final_ramp_setpoint***" is the final ramp setpoint expressed in Ampere [A].

Examples:

MWIR set example, with final ramp setpoint +10.5 A:

MWIR:10.5\r →

← **#AK\r\n**

MWIR set example when the module is OFF:

MWIR:10.5\r →

← **#NAK:13\r\n**

MWIR query example:

MWIR:?\r →

← **#MWIR:10.5\r\n**

4.8.8 MSRI Command

The ***MSRI*** command can be used to dynamically change the value of the current ramp slew-rate. The default slew-rate, used at start-up of the unit, is the value stored in the parameters table.

This command has the following format:

MSRI:slew_rate\r\n

where "***slew_rate***" is slew-rate for the current ramp expressed in Ampere per second [A/s].

Replies from the power converter to a ***MSRI*** set are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:****xx****\r\n***", when the command cannot be executed ("*xx*" is the error code).

To read the current used slew-rate for the current ramp, the query command: "***MSRI:?***" has to be used. The response to this query command is in the following format:

#MSRI:slew_rate\r\n

where "***#MSRI***" is the echo string and "***slew_rate***" is the slew-rate value used for the current ramp expressed in Ampere per second [A/s].

Examples:

MSRI example, to set the current slew-rate to 10 A/s:

MSRI:10\r →

← **#AK\r\n**

MSRI query example:

MSRI:?\r →

← **#MSRI:10\r\n**

4.8.9 MWVR Command

The ***MWVR*** command can be used to perform a ramp to the given voltage setpoint. This command can be used, when the constant voltage mode is selected (see ***LOOP*** Command).

The use of this command is alternative to the ***MWV*** Command**.** The difference between the ***MWV*** command and the ***MWVR*** command is that the first one generates a direct change in output voltage characterized by the PID regulator parameters while the second one makes the power supply go from the previous to the actual current value performing a ramp, defined by a slew-rate in [V/s].

To dynamically change the slew-rate value it is possible to use the ***MSRV*** Command.

This command has the following format:

MWVR:final_ramp_setpoint\r\n

where "***final_ramp_setpoint***" is the final voltage value expressed in Volts [V] to which the power unit will ramp with the defined slew-rate.

Replies from the power unit to a ***MWVR*** set are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:****xx***\r\n***", when the command cannot be executed ("*xx*" is the error code).

To read the selected final ramp setpoint, the query command: "***MWVR:?***" has to be used. The response to this query command is in the following format:

#MWVR:final_ramp_setpoint\r\n

where "***#MWVR***" is the echo string and "***final_ramp_setpoint***" is the final ramp setpoint expressed in Volts [V].

Examples:

MWVR set example, with final ramp setpoint +15.2 A:

MWVR:15.2\r →

← **#AK\r\n**

MWVR query example:

MWVR:?\r →

← **#MWIR:15.2\r\n**

4.8.10 MSRV Command

The ***MSRV*** command can be used to dynamically change the value of the voltage ramp slew-rate. The default slew-rate, used at start-up of the unit, is the value stored in the parameters table.

This command has the following format:

MSRV:slew_rate\r\n

where "***slew_rate***" is slew-rate for the voltage ramp expressed in Volts per second [V/s].

Replies from the unit to a ***MSRV*** set are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code).

To read the current used slew-rate for the voltage ramp, the query command: "***MSRV:?***" has to be used. The response to this query command is in the following format:

#MSRV:slew_rate\r\n

where "***#MSRV***" is the echo string and "***slew_rate***" is the slew-rate value used for the voltage ramp expressed in Volts per second [V/s].

Examples:

MSRV example, to set the current slew-rate to 10 V/s:

MSRV:10\r →

← **#AK\r\n**

MSRV query example:

MSRV:?\r →

← **#MSRV:10\r\n**

4.9 Generic Monitoring Parameters

This section describes some generic parameters that can be monitored through dedicated instructions (e.g. temperatures, estimated active power applied to the connected load and so on).

4.9.1 MRT Command

The ***MRT*** command returns the maximum temperature readout of the internal sensors (Buck, Capacitor Bank and Carrier Temperature). The response to the ***MRT*** command is in the following format:

#MRT:temperature\r\n

where "***#MRT***" is the echo string and "***temperature***" is the temperature value expressed in Celsius [°C]. The ***MRT*** command, being a reading command, returns a response in any module condition.

Example:

MRT command example:

MRT:?\r →

← **#MRT:37.4\r\n**

The same command can be also used to read each internal temperature sensor. In such case the internal temperature sensor can be read using the command

The same command can be also used to read each internal temperature sensor. In such case the command format is the following: "***#MRT:x:?\r\n***", where "*x*" is the number of the temperature sensor, which are shown in the following table:

Number#	Temperature Sensor Position
1	Buck
2	Capacitor Bank
3	ADC and Shunt
4	Carrier board

Table 8: Temperature Sensor Number

The response to this query command is in the following format:

#MRT:x:temperature\r\n

Example:

Specific MRT command example (that returns the internal buck temperature):

MRT:1:?\r →

← **#MRT:1:32.5\r\n**

4.9.2 MRW Command

The ***MRW*** command returns the actual value of the estimated active power applied to the connected load.

The response to the ***MRW*** command is in the following format:

#MRW:active_power\r\n

where "***#MRW***" is the echo string and "***active_power***" is the output active power readback expressed in Watts [W], estimated as the product of the output voltage and output current readbacks. The ***MRW*** command, being a reading command, returns a response in any module condition.

Example:

MRW command example:

MRW:?\r →

← **#MRW:100.4542\r\n**

4.9.3 MRP Command

The ***MRP*** command returns the readback value of the DC-Bus voltage. The response to the ***MRP*** command is in the following format:

#MRP:bus_voltage\r\n

where "***#MRP***" is the echo string and "***bus_voltage***" is the DC-Bus voltage, expressed in Volts [V].

The ***MRP*** command, being a reading command, returns a response in any module condition.

Example:

MRP command example:

MRP:?\r →

← **#MRP:60.07\r\n**

4.9.4 MRID Command

The ***MRID*** command returns the module identification name string. This description is useful in case that there are numerous units installed and it is possible to give a description for each unit (for example the name of the load on which the unit is connected). This information is also displayed on the local display.

The response to the ***MRID*** command is in the following format:

#MRID:fast_ps_identification\r\n

where "***#MRID***" is the echo string and "***fast_ps_identification***" is the module identification string. The identification string is stored in the parameters table and so it is possible to change it using the MWG command.

Example:

MRID example with the module identification "SkewMag1.3":

MRID\r →

← **#MRID:SKEWMAG1.3\r\n**

4.10 Special Commands

This section describes special commands that are specific for each different power supply.

4.11 Configuration Commands

In the following section are described the software commands that allow to read, set and store the working parameters of the power supply unit. MRG Command and MWG Command allow reading or modifying the working parameters. The write-access to several parameters is password protected and certain parameters are read only and so it is not possible to modify them. To change the password privileges, use the ***PASSWORD*** Command. In order to save the parameter on the on-board non-volatile memory, the MSAVE Command has to be used.

The complete list of the configuration parameters, their field index and the access privileges are hereafter shown

Parameter #	Access Privileges	Parameter Name
0	Read Only	Firmware ID
1	Read Only	PS Model
2	Read Only	Serial Number
3	Read Only	MAC Ethernet
4-8	/	Reserved
9	Read Only	Calibration date
10	Read Only	Current Calibration Parameter a
11	Read Only	Current Calibration Parameter b
12	Read Only	Current Calibration Parameter c
13	Read Only	Current Calibration Parameter d
14	Read Only	Voltage Calibration Parameter a
15	Read Only	Voltage Calibration Parameter b
16	Read Only	Voltage Calibration Parameter c
17	Read Only	Voltage Calibration Parameter d
18	Read Only	DC Bus Calibration Parameter a
19	Read Only	DC Bus Calibration Parameter b
20	Read Only	DC Bus AC Calibration Parameter a
21	Read Only	DC Bus AC Calibration Parameter b

22	Read Only	DAC Iset Calibration Parameter a
23	Read Only	DAC Iset Calibration Parameter b
24	Read Only	DAC Iout Calibration Parameter a
25	Read Only	DAC Iout Calibration Parameter b
26	Read Only	Input Current Calibration Parameter a
27	Read Only	Input Current Calibration Parameter b
28-29	/	Reserved
30	Admin	Module ID
31	Admin	Default Current Slew Rate [A/s]
32	Admin	Default Voltage Slew Rate V [V/s]
33-34	/	Reserved
35	Admin	TFT shutdown timeout [minutes] – 0 to disable the timeout
36	Admin	Feed Forward [0-disable; 1-enable]
37-39	/	Reserved
40	Admin	PID CC: Kp_v
41	Admin	PID CC: Ki_v
42	Admin	PID CC: Kd_v
43	Admin	PID CC: Kp_i
44	Admin	PID CC: Ki_i
45	Admin	PID CC: Kd_i
46	Admin	PID CC: Max Voltage [V]
47	Admin	PID CC: Min Voltage [V]
48	Admin	PID CC: Max Current [A]
49	Admin	PID CC: Min Current [A]
50	Admin	PID CC Mode: [-1-single, 2-double]
51-55	/	Reserved
56	Admin	NAK Error Code Description (0-DISABLE, 1-ENABLE)
57-59	/	Reserved
60	Admin	PID CV: Kp_i
61	Admin	PID CV: Ki_i
62	Admin	PID CV: Kd_i
63	Admin	PID CV: Kp_v
64	Admin	PID CV: Ki_v
65	Admin	PID CV: Kd_v
66	Admin	PID CV: Max Current [A]

67	Admin	PID CV: Min Current [A]
68	Admin	PID CV: Max Voltage [V]
69	Admin	PID CV: Min Voltage [V]
70-74	/	Reserved
75	Admin	Max Capacitors Temperature [°C]
76-81	/	Reserved
82	Admin	Max Buck Temperature [°C]
83	Admin	Min DC-Bus Voltage [V]
84-85	/	Reserved
86	Admin	Current Regulation Fault Limit [A]
87	Admin	Voltage Regulation Fault Limit [A]
88	Admin	Regulation Fault Intervention Time [s]
89	Admin	Input Overcurrent Limit [A]
90	Read only	Interlock Enable Mask
91	Read only	Interlock Activation Level Mask
92	Read only	Interlock #1 intervention time [ms] – fixed to 1000 ms
93	Read only	Interlock #1 name – fixed to External Magnet Temperature
94	Read only	Interlock #2 intervention time [ms] – fixed to 1000 ms
95	Read only	Interlock #2 name - fixed to Ext. Interlock #1
96	Read only	Interlock #3 intervention time [ms] – fixed to 1000 ms
97	Read only	Interlock #3 name - fixed to Ext. Interlock #3
98	Read only	Interlock #4 intervention time [ms] – fixed to 1000 ms
99	Read only	Interlock #4 name – fixed to Buck Inductor Over-Temp.
100	Read only	Output Over-Current [V]
101-119	/	Reserved
120	Read only	Harmonic Suppressor filter – a_0 coefficient
121	Read only	Harmonic Suppressor filter– a_1 coefficient
122	Read only	Harmonic Suppressor filter – b_0 coefficient
123	Read only	Harmonic Suppressor filter – b_1 coefficient
124	Read only	Harmonic Suppressor filter – b_2 coefficient
125	Read only	Harmonic Suppressor filter – Decimation
126	Read only	Harmonic Suppressor filter – Delay Taps (1 tap = 10 µs)
127	Read only	Harmonic Suppressor filter – Gain
128	Read only	Harmonic Suppressor filter – Duty Cycle Variation Limit
129	Read only	Harmonic Suppressor filter – Enable

Table 9: Parameters table

4.11.1 MRG Command

The ***MRG*** command returns the value stored in the given parameter number. The correct form for the reading request is as follow:

MRG:parameter_index:?\r\n

where "***parameter_index***" is the index of the parameter to be read. The response to the ***MRG*** command is in the following format:

#MRG:parameter_index:parameter_value\r\n

where "***#MRG***" is the echo string, "***parameter_index***" is the parameter's index and "***parameter_value***" is the parameter caption. The unit replies with "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code) – for example if the given parameter is out of the permitted range.

Examples:

MRG example of the CDCU Model (parameter #1):

MRG:1:?\r →

← **#MRG:1:FAST-PS 2020-400\r\n**

MRG example of read a not valid parameter's index (parameter # -1):

MRG:-1\r →

← **#NAK:03\r\n**

4.11.2 MWG Command

The ***MWG*** command lets users write a desired value in the given parameters index.

MWG:parameter_index:parameter_value\r\n

where "***parameter_index***" is the parameter's index and "***parameter_value***" is the content to be written.

Replies from the power unit to a ***MWG*** write are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code).

After a ***MWG*** command the values are immediately applied, but they are not stored in the internal memory. To store the modified parameters in the non-volatile internal memory it is necessary to use the

MSAVE Command.

Examples:

MWG example of the Module ID (parameter #30)

MWG:30:MAGNET A\r →

← **#AK \r\n**

MWG write example to the read-only field #1 (PS Model):

MWG:1:MAGNET A\r →

← **#NAK:05\r\n**

4.11.1 MSAVE Command

The ***MSAVE*** command can be used store the parameter fields in the non-volatile internal memory. If the parameter fields are not saved, they will be lost at power-off of the power supply.

Replies from the power modules to a ***MSAVE*** are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("***xx***" is the error code).

Example:

MSAVE example:

MSAVE*\r* →

← **#AK *\r\n***

4.11.2 PASSWORD Command

The ***PASSWORD*** command can be used to unlock or lock the access to the protected parameter fields.

Several parameters are protected in order not to let inexperienced users to change some power supply parameters that might compromise the correct operation of the power module. See the **Parameters table** for a detailed list of the parameter fields (parameters with *Admin* access privileges are password protected; parameters with *Read Only* access privileges cannot be modified).

The correct format for this command is as follows:

PASSWORD:password_word\r\n

where "***password_word***" is the password to lock or unlock the protected parameter fields, that can be:

- "***PS-ADMIN***" to receive the *Admin* access privileges and unlock the protected parameter fields;
- "***USER***" to return to *User* access privileges and lock the protected parameters fields.

Replies from the unit to a ***PASSWORD*** command are in the form "***#AK\r\n***" – when the command is accepted - or "***#NAK:xx\r\n***", when the command is not accepted ("*xx*" is the error code). When a wrong password word is received, the unit replies with a "***#NAK:07\r\n***" (error code 07 – invalid password) and locks the protected parameter fields.

To read the current privileges level the following query command can be used: "***PASSWORD:?***". The response to this query command is in the following format:

#PASSWORD:privileges_level\r\n

where "***#PASSWORD***" is the echo string and "***privileges_level***" is the string indicating the privileges level.

The privileges level "***ADMIN***" indicates that the user is able to modify the protected parameter fields, otherwise "***USER***" indicates that the uses is able to modify only the not protected parameter fields.

The password to unlock password-protected cells is:
PS-ADMIN

Note: if a wrong password is inserted, then the privileges are set to user.

Examples:

PASSWORD example of correct password word (unlock the protected cells):

PASSWORD:PS-ADMIN\r →

← **#AK \r\n**

PASSWORD example of correct password word (lock the protected cells):

PASSWORD:USER\r →

← **#AK \r\n**

PASSWORD example of wrong password word:

PASSWORD:CAENELS\r →

← **#NAK:07 \r\n**

PASSWORD access level query:

PASSWORD:?\r →

← **#PASSWORD:ADMIN\r\n**

4.11.3 SETPSW Command

The ***SETPSW*** command can be used to change the default Admin password. To change the password, it is necessary to have Amin privileges and then it is possible to customize the password using the following command:

SETPSW:password_word\r\n

where "***password_word***" is the new password that replaces the default one.

Replies from the unit to a ***SETPSW*** command are in the form "***#AK\r\n***" – when the command is accepted - or "***#NAK:xx\r\n***", when the command is not accepted ("***xx***" is the error code).

ATTENTION: once modified, the default password is overwritten and it will NOT be valid anymore. If the password is forgotten it is necessary to contact CAEN ELS directly, indicating the MAC Address of the unit in order to receive the command word to restore the default password.

4.12 Advanced Features - Waveform

With the CDCU unit is also possible to reproduce a pre-loaded waveform on the power supply output. If the loop mode is set to CC (Constant Current) then the waveform is reproduced as a current, otherwise, if the loop mode is set to CV (Constant Voltage), the waveform is reproduced as voltage.

The update rate of the waveform point is equal to the PWM period – e.g. 10 microseconds - and so to 100 kHz.

To set the module in Waveform mode it is necessary to use the

UPMODE Command.

4.12.1 WAVE:N_PERIODS: Command

The ***WAVE:N_PERIODS:*** command is used to set the number of periods the waveform needs to be reproduced. The maximum number that can be set is 2^{32} -1 (32 bit unsigned integer). By setting “0”, the waveform is reproduced with an infinite number of periods. The execution of the Waveform can be stopped with **WAVE:STOP** command.

Replies from the power modules to a ***WAVE:N_PERIODS:*** are in the form “***#AK\r\n***” – when the command is correctly executed - or “***#NAK:xx\r\n***”, when the command cannot be executed (“***xx***” is the error code).

To read the set waveform periods number, the following query command can be used: “***WAVE:N_PERIODS:TRIG:?***”. The response to this query command is in the following format:

#WAVE:N_PERIODS:periods\r\n

where “***#WAVE:N_PERIODS***” is the echo string and “***periods***” is the number of set periods.

Example:

WAVE:N_PERIODS example:

WAVE:N_PERIODS:5\r →

← **#AK \r\n**

4.12.1 WAVE:POINTS Command

The ***WAVE:POINTS*** command is used to load the waveform points into the module. The minimum number of points is 100 and the maximum 500'000.

Note: The update rate of the waveform execution is 100 kHz and so the time resolution between the loaded points is of 10 µs.

The ***WAVE:POINTS*** command format is the following:

WAVE:POINTS:point_0:point_1:point_2:……… :point_last\r\n

where the waveform points are directly passed in float form [A or V, depending over the loop mode], separated by ":".

Replies to this command are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("***xx***" is the error code).

Example:

WAVE:POINTS example:

WAVE:POINTS:1.1:0.543:…:3.42\r

#AK \r\n

4.12.1 WAVE:START Command

The ***WAVE:START*** command is used to start the waveform generation. If a fixed number of periods is set, the module will reproduce the selected number of period and then the output will remain fixed on the last generated output. If infinite number of periods is set (0), then the module will continue to reproduce the waveform until waveform stop command is set.

Replies from the power modules to a ***WAVE: START*** are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("***xx***" is the error code).

Example:

WAVE:START example:

WAVE:START*\r* →

← **#AK *\r\n***

4.12.1 WAVE:STOP Command

The ***WAVE:STOP*** command is used to stop the waveform generation.

Replies from the power modules to a ***WAVE: STOP*** are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("***xx***" is the error code).

Example:

WAVE:STOP example:

WAVE:STOP\r →

← **#AK \r\n**

4.13 Advanced Features – Post-Mortem

The CDCU power unit allows acquiring post-mortem data in order to analyze them and have more information on the behavior of the power converter before and after a fault condition happened.

The post mortem logic is formed by a circular buffer, in which are stored the voltage, current and current setpoint data. **The length of the circular buffer is fixed to 10s and the sampling frequency is fixed to 100us.**

In the post mortem block it is possible also define the position of the fault trigger position and so to define how many samples has to be acquired after the fault condition. The default value of the fault trigger is 0s and so the whole window (10s) is related to the values after the fault condition. For example, if the fault trigger position is 4s then the first part of the window (4s) are related to the acquisition before the fault and the second part of the window (10s-4s = 6s) is related to the acquisition after the fault conduction happened.

4.13.1 PMM:TRIG Command

The ***PMM:TRIG*** command is used to set the fault trigger position in the acquisition window and it is expressed in seconds. The default value of the fault trigger is 0s and so the whole window (10s) is related to the values after the fault condition. For example, if the fault trigger position is set to 4 (4 seconds) then the first part of the windows is filled with the samples before the fault condition and the second part of the window (6s) is filled with the samples after the fault condition.

The correct format for this command is as follows:

PMM:TRIG:trig_position\r\n

where "***trig_position***" is the fault trigger position inside the acquisition window expressed in seconds (accepted values are in the range [0s – 10s]).

Replies from the unit to a ***PMM:TRIG*** command are in the form "***#AK\r\n***" – when the command is accepted - or "***#NAK:****xx****r\n***", when the command is not accepted ("*xx*" is the error code).

To read the set trigger position, the following query command can be used: "***PMM:TRIG:?***". The response to this query command is in the following format:

#PMM:TRIG:trig_position\r\n

where "***#PMM:TRIG***" is the echo string and "***trig_position***" is the fault trigger position setting.

Examples:

PMM:TRIG set example (4 indicates 4 seconds):

PMM:TRIG:4\r →

← **#AK \r\n**

PMM:TRIG query example:

PMM:TRIG:?\r →

← **#PMM:TRIG:4\r\n**

4.13.1 PMM:TIMESTAMP Command

The ***PMM:TIMESTAMP*** command returns the timestamp of the first captured sample in the acquisition window (if available). The correct form for the reading request is as follow:

PMM:TIMESTAMP:?\r\n

The response to the ***PMM:TIMESTAMP*** command is in the following format:

#PMM:TIMESTAMP:date_time\r\n

where "***#PMM:TIMESTAMP***" is the echo string and "***date_time***" is the date time relative to the first sample in the acquisition window expressed in Greenwich Mean Time (for example: FRI DEC 13 13:21:51 2019 GMT). The timestamp is related to the NTP configuration: if the NTP is not configured correctly, then the system will return the internal timestamp, which is not synchronized with the GMT.

The unit replies with "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code) – for example if the acquisition is not completed.

Replies from the unit to a ***PMM:TRIG*** command are in the form "***#AK\r\n***" – when the command is accepted - or "***#NAK:xx\r\n***", when the command is not accepted ("*xx*" is the error code).

Example:

PMM:TIMESTAMP query:

PMM:TIMESTAMP:?\r →

← **#PMM:TIMESTAMP:FRI DEC 13 13:21:51 2019 GMT\r\n**

4.13.1 PMM Command

The ***PMM*** command returns the samples contained in the acquisition buffer. The samples can be read only when a fault event happened and so the acquisition buffer is full. To monitor the status of the acquisition buffer the function PMM:READY Command has to be used.

To get the samples from the acquisition buffer it is necessary to use the following command:

PMM:x:?\r\n

where "x" is the acquisition buffer channel. The available acquisition buffer channels are:

Number#	Acquisition Buffer Channel
0	Voltage
1	Current
2	Setpoint Current

Table 10: Acquisition buffer channels

The response to the ***PMM*** command is in the following format:

#PMM:0:sample_1:sample2:sample3:………:sample100.001\r\n

where "***#PMM***" is the echo string, "**0**" is the requested acquisition buffer channel, followed by the ***samples*** that are separated by ":". In total 100.001 samples are returned (10 seconds with the sampling rate of 100 us).

The unit replies with "***#NAK:xx*\r\n**", when the command cannot be executed ("*xx*" is the error code) – for example if the fault trigger does not occurred and so the buffer is not filled.

4.13.2 PMM:READY Command

The ***PMM:READY*** command returns the status of the acquisition buffer. When this flag is high indicates that the acquisition buffer was filled and it is ready to be read (with the PMM Command). The format of the command is the following:

PMM:READY:?\r\n

The response to the ***PMM:READY*** command is in the following format:

#PMM:READY:status\r\n

where "***#PMM:READY***" is the echo string and "***status***" is the ready status, that can be 1 in case that the buffer is ready to be read or 0 if the buffer is not ready.

Example:

PMM:READY query:

PMM:READY:?\r →

← **#PMM:READY:1\r\n**

4.13.3 PMM RESET Command

The ***PMM:RESET*** command can be used to rearm the acquisition buffer once the trigger event happened.

Replies from the unit to a ***PMM:RESET*** command are in the form "***#AK\r\n***" – when the command is correctly executed - or "***#NAK:xx\r\n***", when the command cannot be executed ("*xx*" is the error code).

Examples:

PMM:RESET command example:

PMM:RESET\r →

← **#AK\r\n**

4.14 Additional Features

This section is intended to collect different and peculiar features of CAEN ELS power supplies.

4.14.1 Auto Shut-Down of Display

CAEN ELS power supplies, by default, perform an automatic turn-off of the front panel display in order to preserve the life-time of the TFT display itself. The timeout time can be changed by modifying the value of the field #35 of the power supply memory (refer to the **Parameters table**).

By default, the display will shut off after 30 minutes of no-operation by the user. A simple operation (rotate, click) on the front panel navigation switch will wake the display up again.