CRYOGENIC SOFTWARE SUITE

USER MANUAL

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For Technical Support contact sales@cryogenic.co.uk.

Congratulations and thank you for purchasing a Cryogenic Limited instrument.

This manual describes how to use the software package provided with your equipment. It provides step by step instructions on how to configure and run each software module.

Each system delivered by Cryogenic Ltd is designed to suit custom requirements. Sections in this manual that are relative to hardware or software components that are not valid resources should be ignored.

Please read this document carefully before attempting to use the software, to familiarise yourself with features and safety issues.

CONTENTS

1. INTRODUCTION

The Cryogenic Software Suite is a software package specifically designed to control and monitor Cryogenic Limited equipment, to operate the installed software options and to run measurements.

The current version of the software has been developed in LabVIEW 2019 and requires a compatible version of the LabVIEW Run Time Engine and NI-DAQmx.

The Cryogenic Software Suite is provided as a compiled application. A separate set of folders is used to specify the various options installed and their configuration. These support files and their relative structure are essential for the correct operation of the application and should not be edited, moved or deleted.

FILE STRUCTURE

The software package consists of the main application, *Cryogenic Software Suite.exe*, and a set of folders - *Cryogenic Measurement System*, *Instruments*, *Measurements* and *Tools* - which reflect the internal software structure. Each of these folders may contain one or more subfolders, one for each option installed. Each subfolder will include a configuration file (*.ini) that details the settings required to correctly run the module and its corresponding hardware components, where present.

Please note that none of the configuration files should ever be edited, moved or deleted without consulting Cryogenic ltd.

Some Instruments and Measurements may also include a set of *Setup Files*, stored in a *Setup*s folder. These files define the set of parameters that characterise an experiment or a measurement range and type. Setup files can be edited and created by the user using the *Configuration Editor* tool.

STARTING THE SOFTWARE

Launching *Cryogenic Software Suite.exe* opens a Welcome Screen which loads the user interface *Main UI* and the application *Controller* (see Figure 1). The controller launches all configured *Instruments,* the software modules that drive the hardware components of the system. Each Instrument follows its own initialization procedure and the outcome is displayed on the Welcome Screen. If an instrument fails the initialization, the error is reported on the bottom right corner of the screen and in the main Error Console (see Error Console section). Once all Instruments are launched and initialized, the User Interface main sections are populated based on the installed options and their configurations.

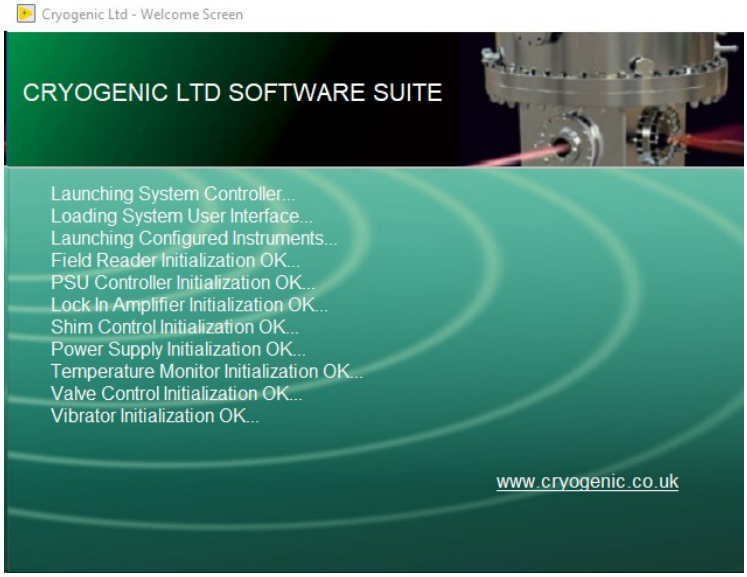

FIGURE 1 - WELCOME SCREEN

2. MAIN UI

The Main UI represents the main software interface. It is organised into 5 distinct subsections: the ***Options*** tree, the ***Variable Status*** tree, the ***Measurements & Tools*** and ***Instruments*** panes and the ***Status Bar***. The Instruments section can show up to 3 different instrument modules simultaneously. The Main UI can be customised from the *Cryogenic Measurement System* page of the *Configuration Editor* to automatically display the interfaces of specific modules at startup, by setting the values of *Default Measurement/Tool* and *Default Instrument* (see Main UI Configuration).

OPTIONS TREE

The Options tree provides a hierarchical list of the hardware and software components that form part of a specific system. Items are organised into four groups, also referred to as *nodes*: *Instruments*, *Measurements*, *Sequences* and *Tools*. When a module has been launched and is running, its name is displayed in italics.

Modules that directly control hardware are listed with the corresponding instrument's tag under the **Instruments** node. Instruments are always automatically launched at software startup and run in the background throughout the entire application. From the Options Tree the user has the possibility to control the behaviour of an instrument. Right-clicking a specific node opens a shortcut menu with the following options: *Initialise Instrument – Open in New Window – Run – Stop*.

The **Measurements** node lists all available configured measurements. The run-time shortcut menu allows the user to run the measurement without displaying its user interface, to run it in a new pop up window

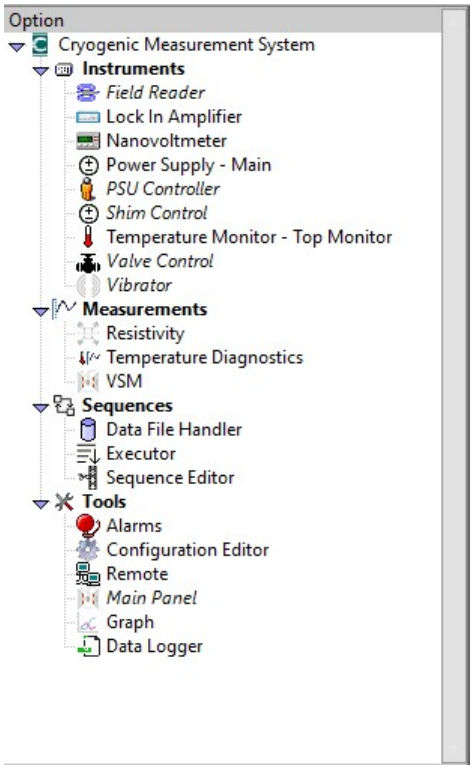

FIGURE 2 – OPTIONS TREE

(*Open In New Window*), or to edit its configuration. Differently from Instruments, Measurements are launched by the user on demand.

Under the **Sequences** node are listed the modules that run and execute sequences of measurements and log full scans and results. Similarly to Measurements, Sequences options are only launched on user's demand. Right-clicking a node gives access to a similar menu to the one for the Measurements nodes.

The last set of options is listed under the **Tools** node. Refer to the corresponding items section for a description of their use and functionality.

VARIABLE STATUS TREE

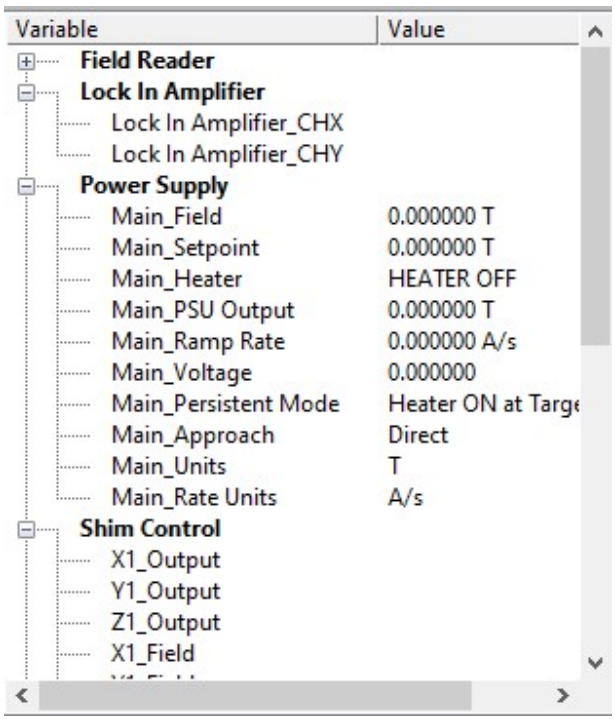

FIGURE 3 - VARIABLE STATUS TREE

The *Variable Status Tree* gives an overall representation of a system's status by listing the main parameters monitored by each instrument and their current value.

Parameters are grouped by instrument and listed under the corresponding instrument's tag. The instruments nodes can be expanded or contracted, to show or hide variables of interest. The Variable Status tree allows a user to quickly inspect several parameters at once, without having to display all UIs.

STATUS BAR

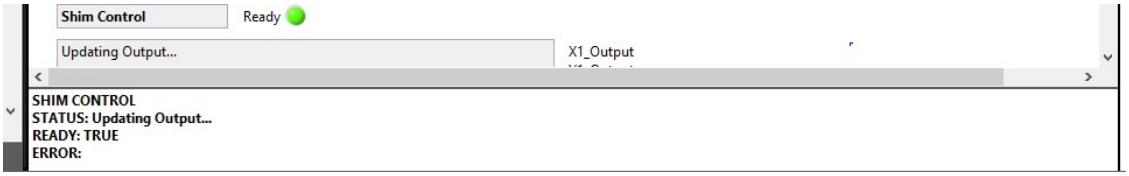

FIGURE 4 - STATUS BAR

The *Status Bar* shows a summary of a measurement's or instrument's status by displaying a description of its current *status*, *error* and *ready* flag. Selecting an instrument or measurement on the *Options Tree* brings up the status for that specific node. The information displayed is refreshed every 5 seconds.

MEASUREMENTS AND TOOLS SECTION

This section is normally the main focus of the software user interface. It can display one module at a time from the *Measurements*, *Sequences* or *Tools* groups. The drop down menu at the top of the pane is populated at start-up with the full list of valid options from the three categories. After selecting a module, its UI is open and the module is launched.

A different option can be selected at any time from the drop down menu. The previously selected module continues execution in the background, while the new one is displayed and launched, if not already running.

INSTRUMENTS SECTION

This section consists of three different panes that can be used to simultaneously display the user interfaces of up to 3 different instruments. Three separate drop-down menus are used to select what module to display in each section. Instruments run in the background throughout the entire application execution, even when their front panel is not displayed on the main UI.

Each sub-pane can be expanded or contracted by dragging the splitter bars on top of the instrument's name up and down the screen.

FIGURE 5 - INSTRUMENTS UI SECTION

MAIN UI CONFIGURATION

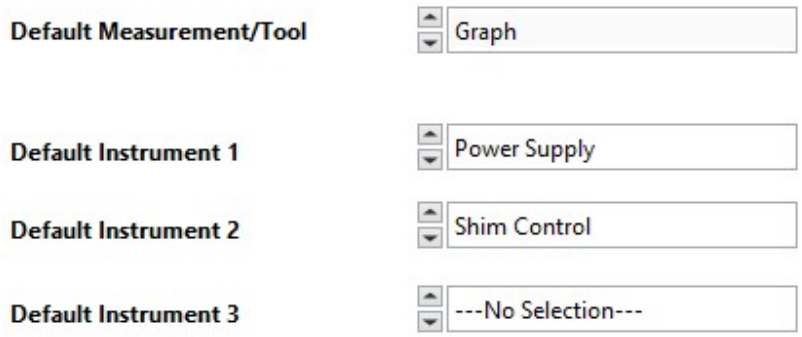

FIGURE 6 - MAIN UI CONFIGURATION

The default Measurements, Tools and Instruments displayed on the Main UI at start-up can be configured from the *Cryogenic Measurement System* option of the Configuration Editor. The list of the software modules that can be inserted in each of the 4 sections of the main user interface is automatically populated with valid options for each system. The *Default Instruments* refer to the 3 sub windows of the *Instruments* section, listed from top to bottom.

3. INSTRUMENTS

INTRODUCTION

Instruments are automatically launched at application start-up. The main settings that define the communication protocol or that relate to the instrument specific hardware are stored in *configuration files* (*.ini). Software settings are saved to *setup files*. An instrument can only have one configuration file but multiple setup files, which are stored in the *Setup* folder in the Instrument's root directory. The name of the default setup, loaded when the instrument is launched, is saved to the instrument's configuration.

POWER SUPPLY

INTRODUCTION

The *Power Supply* module controls the range of Cryogenic Limited power supplies. It allows the user to ramp a magnet to field, define field dependent ramp rates, set persistent mode, detect a magnet quench, pause or prevent ramping in case of magnet overheating.

When the VI is launched, the power supply is initialised and configured. The initialisation procedure configures the magnet dependent critical parameters saved in the instrument's configuration, such as the *Gauss/Amps* constant, the *Maximum Current* and the *Voltage Limit*. If the magnet is fitted with a persistent switch, the *Switch Heater Voltage* is also configured at this stage. The software also sends a full status update request, to establish current output, voltage, heater status and the value of the persistent field.

If an error occurs during initialisation, the message *'Initialization failed'* is shown on the VI status bar. The *Sweep* button is disabled and the power supply cannot be operated. A more detailed description of the error is shown in both the Balloon Error Engine and the Error Console (see Error Console section). Errors at initialisation are normally caused by incorrect settings of the serial parameters or the power supply's constants, such as maximum current or voltage limit (see Power Supply Configuration).

FIGURE 7 - POWER SUPPLY INITIALISATION ERROR

If no errors are encountered and the initialisation is successful, the display shows *'Power Supply Ready'* and the software is ready to control the instrument. When not ramping, the power supply software is idle. Output current and voltage are regularly updated and the software keeps monitoring for quenches.

POWER SUPPLY UI

The Power Supply UI is shown in Figure 8 – Power Supply UI. The indicators on the left hand side display the current *Status*, while the *Control* settings to start a ramp are positioned on the right.

The *Status* section displays the value of the **Magnet Field**, the **Voltage**, the actual power supply **Output**, the **Ramp Rate** in use and the **Switch Heater** status. If the magnet is in persistent mode, i.e. the switch is closed and the magnet is in its superconducting state, the value of *Magnet Field* might differ from the one shown in *Output*, which indicates the current in the leads.

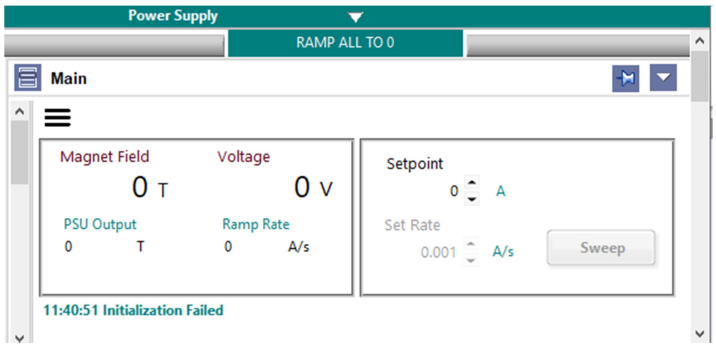

FIGURE 8 – POWER SUPPLY UI

Switch Heater indicates the status of the persistent mode switch heater. Its value can vary between "*HEATER ON*", "*HEATER OFF*" or "*HEATER OFF @ B*". This last option refers to the case where the Heater has been switched off with the magnet at field (persistent mode).

Voltage is the voltage seen by the power supply across its terminals, which is the sum of the voltage drop on the leads and the induced voltage due to current changing in the coil during a ramp.

The *Control* section contains the parameters that define a ramp: **Setpoint**, **Set Rate** and the **Sweep** button to start a ramp.

Units for current/field and rate are set from the *Control* section but also applied to the *Status* indicators on the right. For example, changing the units of *Setpoint* updates both *Magnet Field* and *PSU Output* to the values in the new units, and the same applies to the units in *Set Rate* and *Ramp Rate*.

The message box under the *Status* and *Control* sections provides updates each time a new target or ramp rate is selected and during the different phases of a ramp operation.

QUICK ACCESS MENU

The sandwich menu on top of the *Status* section opens the *Quick Access* collapsible panel from where the user can view or modify the ramp settings from the *Setup* in use. Any changes made in this section are not saved to the current *Setup* and are lost once the power supply module or the whole application is restarted. Refer to the configuration section for more details.

Synchronise PSU allows synchronisation between two or more power supplies when going in or out of persistent mode.

Persistent Mode controls the behaviour of the switch at the end of a ramp, with options to keep the Heater ON, switch the Heater OFF and ramp the leads to 0, or switch the Heater OFF while keeping current in the leads.

Ramp Rate Mode sets whether the ramp rates are automatically set by the software, or by the user. Possible choices are ***Follow Ramp Rate Table***, ***Limit by Table*** or ***Set Manually***.

Ramp Rate Table shows the ramp rates for the different ranges of field.

Target Approach sets the way the final target is reached, with the options being ***Direct, Overshoot, Degaussing*** or ***Cycling***. Selecting one of these methods enables or disables the relevant settings. Please refer to the configuration section for details.

The method for *Target Approach* (see below) is indicated next to the *Quick Access* sandwich menu.

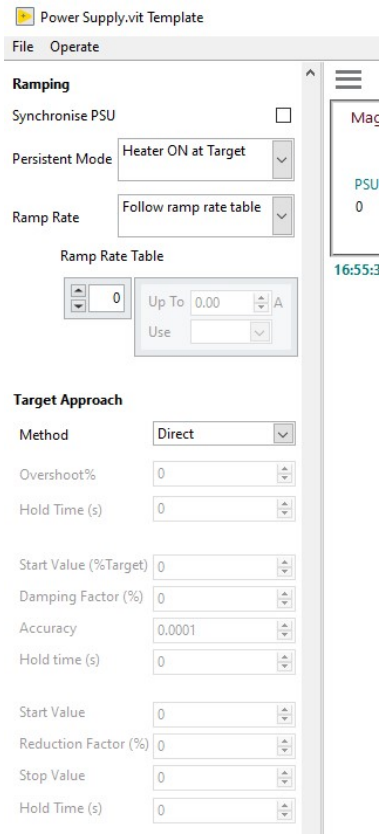

FIGURE 9 – POWER SUPPLY QUICK SETTINGS

SETTING A NEW FIELD

Enter the desired field value in *Setpoint*, slecting first the units among **Amps (A), Tesla (T)** or **Gauss (G)**. Please note that a *Setpoint* higher than the maximum current or field is ignored. Configure a rate value by adjusting *Set Rate* and its corresponding units to **A/s**, **Tesla/s**, **Tesla/min** or **Tesla/h**. *Set rate* is only enabled if **Ramp Rate Mode** is set to *Set Manually (ignore table)*, while the displayed units can be changed also when a ramp rate table is being used. Enter a ramp rate value in the **A/s** control and click **Set Rate** to send this value to the power supply. Some power supplies will have a different set of available ramp rates, therefore the value in this box will be overwritten with the closest available value for that specific model. When choosing a ramp rate value bear in mind that the magnet in its superconducting state is a pure inductance and the voltage induced across the coil is directly proportional to the ramp rate. Too large an induced voltage could cause the magnet to quench.

Click *Sweep* to start a ramp. The message '*Ramping Magnet to XX.XX Tesla (Amps)*'. is displayed in the message box, followed by the *Time To Target,* the estimated time for the power supply to reach its final target, based on current output and ramp rate (or ramp rate table, where defined). This estimate does not keep into account the time to ramp the leads or to open or close the persistent switch. While ramping, the *Sweep* button is replaced by the *Abort* button. When Abort is pressed, the ramp is halted, the power supply paused and the message '*Ramp Aborted*' is displayed. A new ramp can be started by selecting Sweep again as previously described. Once the target has been reached, the message '*Target Reached*' is shown and the software returns to its idle state.

If the system is fitted with a ***persistent switch***, the software sets the heater on before starting the ramp. If the magnet is already in persistent mode, the leads are first ramped to the current in the magnet. The message '*Ramping Leads to Magnet Current…*' is shown during this phase. Once the current in the leads matches the current in the magnet, or if the magnet is at zero field, the software switches the power supply heater on and waits either until the switch temperature has reached the configured *open temperature* or for a fixed amount of time, depending on whether a switch thermometer is available and is being monitored (see the Power Supply Configuration). During this time '*Waiting for Switch Transition*' is displayed in the message box. Once the switch transition is complete, the ramp starts as described earlier.

QUENCH

A magnet quench denotes a transition of the magnet wire from its superconducting state to a resistive normal state. The SMS power supply is fitted with an automatic quench protection circuit which shuts down the power supply immediately whenever a combination of increasing voltage with falling current is detected. A quench can be detected while not ramping and while ramping down, as well as when ramping up.

If the power supply detects a quench during a ramp, the software displays the message *Magnet Quench at XX.XX Tesla (Amps)* and the *Sweep* button is replaced by the **Reset** button. *Reset* needs to be pressed to restore communication with the instrument. Following a quench, the power supply can no longer be operated, neither manually nor from the software. After acknowledging the quench with *Reset*, *t*he message *Magnet Quench - Restart Power Supply and Software* is displayed to warn that the power supply must be power cycled to fully clear the quench message and restore its normal functionality. It is also advisable to restart the power supply software.

POWER SUPPLY CONFIGURATION

The *Power Supply Configuration* is accessed through the *Configuration Editor* module, which can be loaded from the *Options Tree* in the software Main UI.

! ***Please consult Cryogenic Limited before altering any of the settings below***

GENERAL SETTINGS

This section covers some of the most basic settings of the power supply module.

Enabled sets whether the module is included in the main software or ignored.

Power Supply Name is a label that identifies the specific instrument under the *Power Supply* group in the Options Tree. Although this field can be left empty, adding a name is necessary to distinguish different units in systems where more than one power supply is present.

Model indicates the list of supported power supply makes and models. A unit from the Cryogenic Ltd's range is shown as SMSXXXC(-H), where XXX indicates the power supply's maximum current output rating. The model number is used to display only the available rates in the ramp rate table, as different sets of ramp rates are defined for different output ratings (see section *0 Ramping*).

Reversibility indicates if a power supply is *unipolar* or *bipolar*.

Units indicates the default units for output and setpoint used by the power supply instrument each time this module is started or Initialised. Options are **Tesla** or **Amps**.

Voltage Limit sets the maximum voltage output (in Volts) the Power Supply should deliver.

Low Field Option enables, where supported, the low current option, a 350mA reversible current source with 20bit resolution.

COMMUNICATION

This section contains the instrument communication settings.

Interface currently supports **USB** (which covers also RS232) or **Ethernet**. If *USB*, all serial parameters (**USB COM Address, Baud Rate**, **Data Bits**, **Parity**, **Flow Control** and **Stop Bits**) need to be set. If the right COM port is not listed in the drop down menu, click **Refresh** to update the list. If the interface is *Ethernet*, both **IP Address** and **Remote Port** need to be configured.

Termination Character is the decimal representation of the termination character used in Read operations. Power supplies from the SMS range can issue responses of one or more ASCII lines, depending on the query, with each line terminated by a CRLF sequence (\r\n). In firmware versions 7 and above, an extra termination character can be defined, which is appended at the end of the power supply's multiline message. This termination character can be configured from the power supply's keypad, and it defaults to decimal 19 (0x13). Leave this parameter blank for SMS firmware versions that do not support the extra termination character.

MAGNET SETTINGS

This section contains magnet specific settings.

T/A is the Coil Constant, field to current conversion factor for the specific magnet expressed as Tesla over Amps.

Inductance is the inductance of the coil in Henry.

Cooling indicates whether the system is Cryogen Free or Liquid.

Max Current (A) is the magnet maximum current value in Amps.

Max Field (T) is the magnet maximum field value in Tesla.

Max Rate is the fastest energisation rate at which the magnet can be operated and is expressed in A/s. This parameter is also the fastest rate at which the power supply would be ramped down in the event of a *temperature warning* (see section 0).

PERSISTENT SWITCH

This section lists the set of parameters that determine the behaviour of the power supply module when a persistent mode switch is fitted.

Switch Indicates whether the system is currently fitted with a Persistent Mode Switch. Selecting **Fitted** enables the configuration of the remaining parameters in this section.

Switch Voltage (V) is the voltage that the power supply needs to apply to the persistent mode switch heater in order to drive the switch normal once in its superconducting state.

Lead Rate A/s is the rate at which the current in the leads is increased or decreased when the persistent mode switch heater is off. This value is typically higher than the magnet ramp rate as there are no induced voltages generated by the current in the coil.

Switch Heater off after (s) indicates the time the software waits at the end of a ramp, before switching the heater off. This delay should be used to ensure the magnet has been fully charged to the target before entering persistent mode. This is particular relevant for magnet with a large inductance. This setting only applies when the software is configured to automatically set persistent mode at the end of each ramp, i.e. when either *Heater OFF at Target, leads to 0*, or *Heater OFF at Target, leads at target* is selected in the instrument's setup.

Switch Thermometer is the name of the thermometer used to monitor the temperature of the switch. This list is automatically populated with the names of the temperature sensors being monitored by a temperature monitor. If the desired thermometer is not listed, the name of the sensor can be manually typed in. Leave blank if a thermometer is not fitted.

Switch Open T (K) defines the temperature above which the switch becomes non-superconducting or open. This setting is only valid if a *Switch Thermometer* has been fitted.

Switch Closed T (K) defines the temperature below which the switch becomes superconducting or closed. This setting is only valid if a *Switch Thermometer* has been fitted.

Switch Transition Time (s) applies to liquid Helium systems that are not fitted with a superconducting switch thermometer and for which the transition is estimated to occur after a specific amount of time. It defines the time interval required for the switch to become resistive (or superconducting) after the heater has been switched on (or off).

SETUPS

Default Setup indicates the setup that is used at software start-up or Initialisation (see next section). The drop down list shows all available setups for the specific power supply.

POWER SUPPLY SETUPS

A Setup contains details on how the power supply will operate at run time. Use *Setup Name* in *General* settings to assign a name to the setup and select the right instrument type in *Model.*

RAMPING

This section contains the settings that define how a ramp is performed.

Synchronise PSU manages synchronisation between two or more magnets, when setting persistent mode, by ensuring all switches are in the same status at all times, i.e. either all open or all closed. The software works in sync among all power supplies that have this option enabled. A magnet is only ramped once all other magnets are also not in persistent mode, i.e. their switches are open. Vice versa, a magnet is only put into persistent mode once all other magnets have been ramped and their switches are also ready to be closed. This option works best when all PSUs are ramped simultaneously through a sequence.

Persistent Mode controls the behaviour of the switch at the end of a ramp, with options to keep the Heater ON, switch the Heater OFF and ramp the leads to 0, or switch the Heater OFF while keeping current in the leads.

Ramp Rate Mode sets whether the ramp rates are automatically set by the software, or by the user. Possible choices are ***Follow Ramp Rate Table***, ***Limit by Table*** or ***Set Manually***. While with the first option the rate for a specific field is set to the value from the table for the corresponding field range, with the second option the user has the possibility to use any rate that is slower than (below) the corresponding value in the table for that specific field range.

Ramp Rate Table allows the user to define a range of fields where a particular ramp rate will be used and it allows the automatic provision of rates while the magnet is being ramped through varying field. As a general rule when configuring the table, it might be safe to use faster ramp rates at lower field values, however the rate should progressively slow down as the maximum field value is approached, in order to reduce the risk of quenching the magnet.

The ramp rate at row *n* in the table is used for current ranging between the value of '**Up To**' at entry *n-1* and the value at entry *n*. The rates available in the dropdown menu '**Use**' depend on the model of power supply.

! *When setting up the ramp rate table, ensure that the field specification in the last entry in the table includes the maximum field value.*

WARNINGS

This section allows the user to configure the safety features that prevent driving current through a warm magnet and that pause a ramp if overheating occurs.

Figure 10 illustrates the flowchart of the algorithms.

Magnet Thermometer indicates the name of the sensor used to monitor the magnet temperature. The list is automatically populated with the names of sensors currently monitored by the temperature monitor module in the application. A sensor name can also be typed in directly if the required thermometer is not shown.

The list under *Magnet Thermometer* defines the magnet temperature limits as a function of field. These limits are defined as highest allowed temperatures for the magnet during a ramp and while idle. The value of **Max T (Ramp)** on each line is the maximum temperature the magnet can reach between **Field** on the same line and *Field* in the previous line (or 0, for the very first element of the table), with all field values expressed in the *Units* set in the configuration.

If overheating occurs during a ramp, and the final field target is higher than the actual field in the magnet, the power supply is automatically paused and the message '*Magnet Too Warm - Ramping Paused*' is displayed. The ramp is only resumed when the temperature drops below a delta - **Min Drop(K)** - of the value of *Max T (Ramp)* for the current field range. Once a ramp is resumed, overheating of the magnet can potentially reoccur, and so would the process of pausing/resuming a ramp. To prevent the system from entering instability, the software only allows 3 attempts. At the 4th over-heating episode, the magnet is ramped to 0. As an extra precaution, the magnet is also de-energised if the temperature does not decrease within 5 minutes of an overheating episode.

If the magnet is at field, but not being ramped, the software will initiate a ramp to 0 as soon as the magnet temperature rises above the value of **Max T (Idle)** for the current field range.

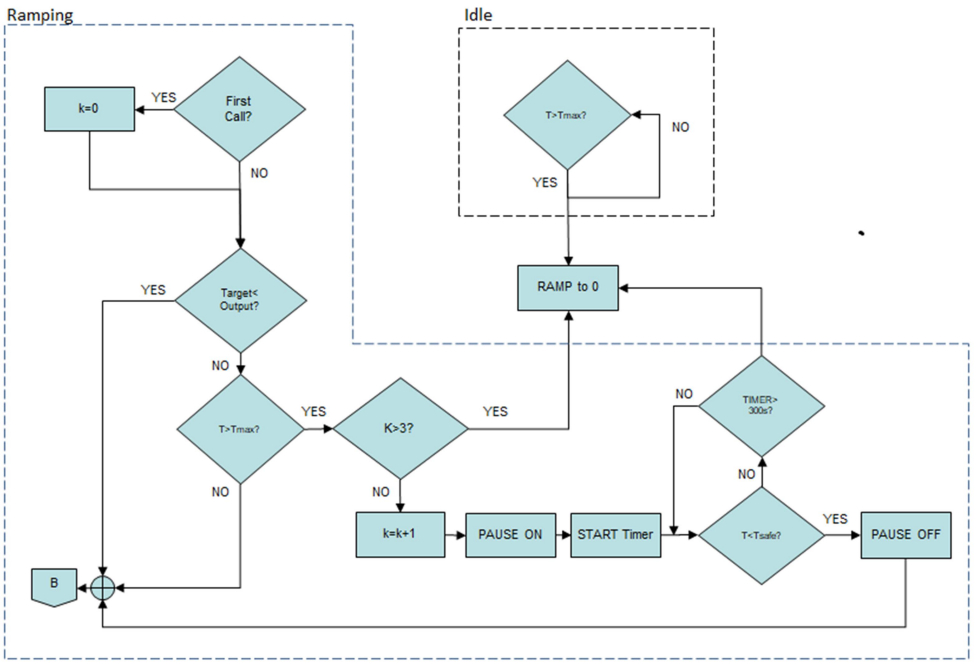

FIGURE 10 - MAGNET TEMPERATURE WARNINGS FLOWCHART

TARGET APPROACH

This section defines the software procedure to reach the final target. Four different methods are possible - **Direct**, **Overshoot**, **Cycling**, **Degaussing** - and can be chosen from the **Method** drop down list. Diagrams of the algorithms are presented in Figure 11.

Direct implements a standard ramp, where the magnet is ramped straight to its final target.

With **Overshoot**, the magnet is ramped to an initial setpoint higher than the desired target, held at this value for a predefined interval, and then ramped down to its final target. The amount by which to exceed the target is set as a percentage of the target itself in **Overshoot %**. The length of time the magnet is held at the *Overshoot* value is set in seconds with **Hold Time (s)**.

To improve field stabilisation, the target can be reached after allowing for **Cycling** of the field around the final target. The parameters to set are **Start Value** (expressed as % of final target), **Damping Factor (%)**, **Accuracy** (minimum absolute value to reach, expressed in the same units in use for the target) and **Hold Time (s)** (see Figure 11).

When **Degaussing** is enabled the software sets an initial magnetic field (**Start Value (%Target)**) and subsequently sets and holds intermediate targets of alternating polarity, which are reduced in amplitude over time by the **Damping Factor (%)**. The magnet sits at each intermediate target for **Hold Time(s)** seconds and the process continues until the intermediate target is less than (or equal to) the minimum field value **Stop Value** (absolute value expressed in the same units in use for the target). At this point the magnet is finally ramped to 0.

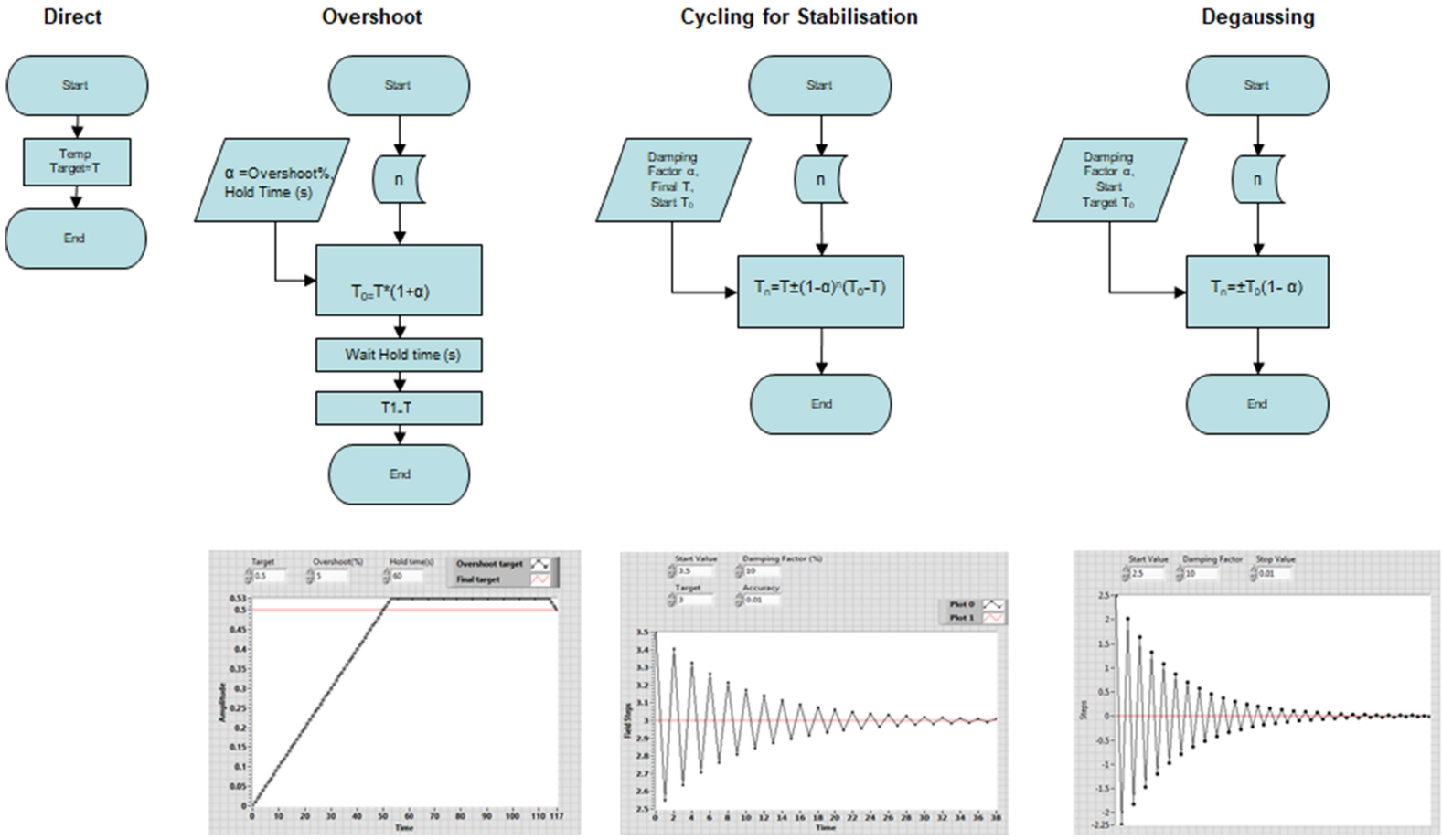

FIGURE 11 - METHODS FOR TARGET APPROACH

List Of Power Supply Status Messages

Communication error

Error on serial communication

Connection Lost

Communication with power supply has been lost

Emergency Shutdown: ramping leads...
Emergency Shutdown: ramping Magnet to 0
Emergency Shutdown: Target Reached

These messages are issued when the software has launched an emergency shutdown procedure, following magnet overheating. If the magnet is in persistent mode the first message will be issued while the leads are being ramped. The next message is shown while the magnet is being de-energised and the last one once the procedure is complete

Holding at current target...

Indicates that the magnet is being held at the current target. This message is issued when a hold time is configured for the current approach method

Initialising

Power supply is being initialised

Initialization Complete

Initialization complete and successful

Initialization Failed

Power supply failed to initialize

Magnet Quench at XX.XX Amps/Tesla

The power supply has detected a quench

Magnet Quench - Restart Power Supply and Software

The *Reset* button has been pressed after a quench message was displayed. The power supply needs to be power cycled and the software restarted

Magnet Too Warm

The temperature on the Magnet thermometer is above the limit. Ramping is not permitted

Magnet Too Warm - Ramping Paused

The Magnet temperature is higher than the maximum value allowed for the current field. Ramping has been paused

New rate set xx.xxx

Confirmation message displayed when a new ramp rate is set

Power Supply Ready

Power supply idle, no errors are reported, ready to ramp

Ramp Aborted

The user has selected Abort, or magnet overheating has triggered the Abort procedure

Ramping leads to 0

The power supply is bringing the current in the leads to 0, having already ramped the magnet and switched the heater off

Ramping leads to Magnet Current

The power supply is ramping the leads to the current in the magnet, in preparation for switching the heater on and setting a new field in the magnet

Ramping Magnet to xx.xx Amps|Tesla - Time To Target hh:mm:ss

Standard message during a ramp. See '*Time To Target'* entry for details on the time string format

Ramp Rate mode changed to: "Follow ramp rate table"
Ramp Rate mode changed to: "Set manually, limit by ramp rate table"
Ramp Rate mode changed to: "Set manually (ignore table)"
These messages are displayed whenever the ramp rate mode is changed

Ramp rate units changed

Issued when the units of the ramp rate have been changed in the software

Resuming Ramp

This message is displayed each time a ramp is resumed after being paused due to overheating

Setting a new field

Indicates the software has initiated the procedure to set a new field

Shutting Down

Indicates that the power supply module has been correctly stopped and the module has followed a shutdown procedure (any pending ramp has been aborted and power supply paused)

Starting Leads Ramp

Indicates that the power supply has started ramping and the current is only flowing through the leads

Starting Ramp

Indicates that the power supply has started ramping and the current is flowing though the magnet

Switch temperature readings not valid. Ramping is disabled

Switch sensor fault with magnet idle

Heater Switched Off/Heater Switched On

Issued when the heater is switched off or on

Target Reached

The power supply has reached its final target

Time To Target X hours Y minutes Z seconds

Estimate of the total time to reach the final target from the current field. It includes the time to reach intermediate targets if the Approach is not Direct, but it does not keep into account the time to ramp the leads. X, Y and Z are integers.

Units Changed toTesla/Amps

Units of target, magnet field and output have been changed

Waiting at Field

Indicates that the magnet is being held at the current target before the heater is switched off and the leads are ramped to 0

Waiting for Controller

The power supply has been configured to wait for completion of a pre-ramp action on another power supply before a ramp. This message indicates that the power supply module is waiting for the PSU Controller to give the go ahead.

Waiting for Switch Transition

Heater has been switched on or off and the software is waiting for the change of state

Unable to acquire temperatures. Magnet ramping disabled

The power supply module cannot access magnet and switch temperatures. This message can indicate that the Temperature Monitor is still completing initialization or has failed to initialize

SHIM CONTROL

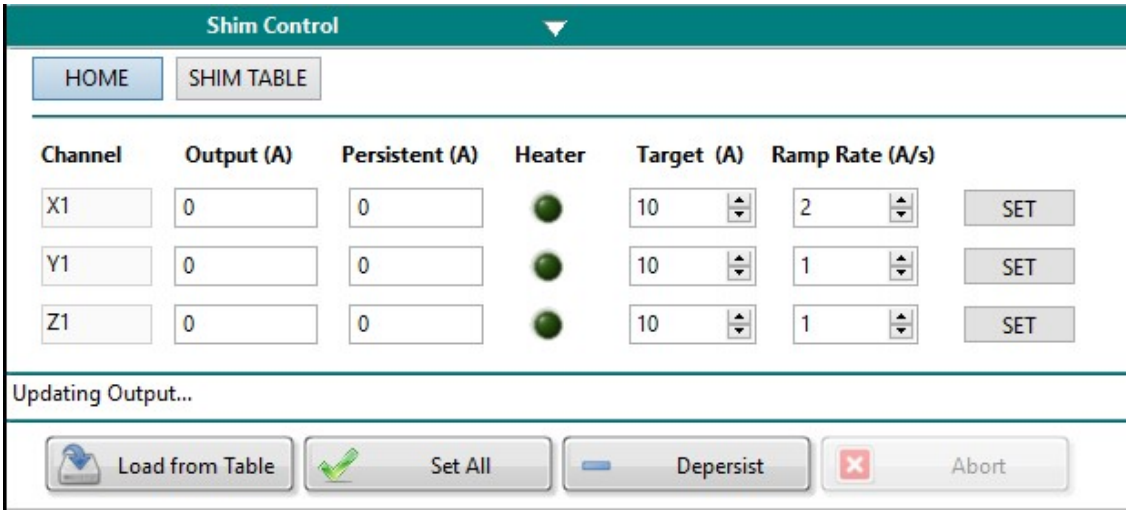

FIGURE 12 - SHIM CONTROL UI

The Shim Control module allows energisation of the shim windings that are used for trimming the homogeneity of a main magnet. Shim windings normally have a persistent mode switch each. The software drives an SMS Cryogenic Ltd power supply which has been fitted with a set of auxiliary heaters to energise the shim coils sequentially.

SHIM CONTROL UI

HOME

This is the main section of the Shim Control user interface, from where targets are set and outputs monitored.

The **Channel** columns lists all shims by name, followed by the current in the leads - **Output (A)** - and the actual current in each winding – **Persistent (A)**. The **Heater** LEDs turn bright green to indicate that a switch is open, i.e. during a ramp, and only one heater at a time can be on during a ramp. The only instance in which all switches can simultaneously be on is when the shims are all at 0 current. This state can be obtained by clicking the **Depersist** button.

To energise a shim winding, a setpoint and ramp rate must be entered in **Target (A)** and **Ramp Rate (A/s)**, respectively. Alternatively, if a *shim table* has been configured, selecting **Load From Table** automatically populates the target column with the optimal shimming values for the current field in the main magnet. To start a ramp in a shim coil **Set** must be pressed. The software switches the corresponding heater on, waits for a preconfigured amount of time then starts the ramp. If the shim is already energised and not at 0 current, the leads are first ramped to the current in the coil then the heater is switched on. During the ramp phase all indicators in the *Output (A)* column show the same value and the *Set* buttons are disabled, as no other ramp is allowed. Once the power supply has reached its target, the heater is switched off and

the leads are ramped back down to 0. This process has to be repeated for all the shim coils that need to be energised. Alternatively, selecting **Set All** automatically ramps each shim to the target shown in *Target (A)* by iterating the procedure above. During a ramp the **Abort** button is enabled and can be used to stop the ramp. If *Set All* had previously been selected, pressing *Abort* stops the current ramp and no new ramps on other shims are launched.

SHIM TABLE

This page is used to display the Shim Table currently in use. The table defines a discrete set of optimal shim currents (in Amps) as a function of the main magnet field (in Tesla). When the Shim Control module is launched the table defaults to the table saved in the configuration file. A table can also be created or edited with any text editor and uploaded by selecting **Load From File.** The software expects a text file where the first line lists the names of the coils. Subsequent lines are floating point numbers. The first column is reserved for the independent coil (or main), while the remaining columns correspond to the shim windings, in the same order as they are presented on the Shim Control UI. The software interpolates the discrete set of values to calculate the optimal shimming currents at any field.

LIST OF SHIM CONTROL STATUS MESSAGES

Connection Lost

Communication with power supply has been lost

Heater Switched On/Heater Switched Off

Indicates that the heater of the shim that is being ramped has been switched on or off

All Heaters Switched Off

All heaters have been switched off

Initialization Complete

Initialization complete and successful

Initialization Failed

Power supply failed to initialize

Initializing

Power supply is being initialised

New Targets Loaded from Table

This message is displayed when either '*Load From Table*' or '*Load From File*' are selected. It indicates that shim coil targets have been extrapolated from the shim table in use and loaded to the *Target (A)* controls on the UI

Quench

The power supply has detected a quench

Ramp Aborted

The user has selected to Abort the ramp

Ramping X1 Leads

The power supply is ramping the leads

Ramping X1 to Target

The power supply is ramping the magnet to the target displayed on the UI

Ramp Leads to Magnet Current

Indicates that the power supply is preparing to ramp the leads to the current in the magnet, in preparation for switching the heater on and setting a new field in the magnet

Ramp Leads to Zero

The power supply is preparing to ramp the leads to 0, having already ramped the magnet and switched the heater off

Shims Depersisted

Indicates that all shims have been ramped to 0 current and all heaters have been switched on

Starting Ramp

Indicates the software has initiated the procedure to ramp a shim

Target Reached

The power supply has reached its final target

Updating Output…

The power supply is acquiring the current output and is ready to ramp

Waiting for X1 Switch to Close/Open

Indicates that the heater on shim X1 has been switched Off/On and the software is waiting for the switch transition to be complete

PSU CONTROLLER

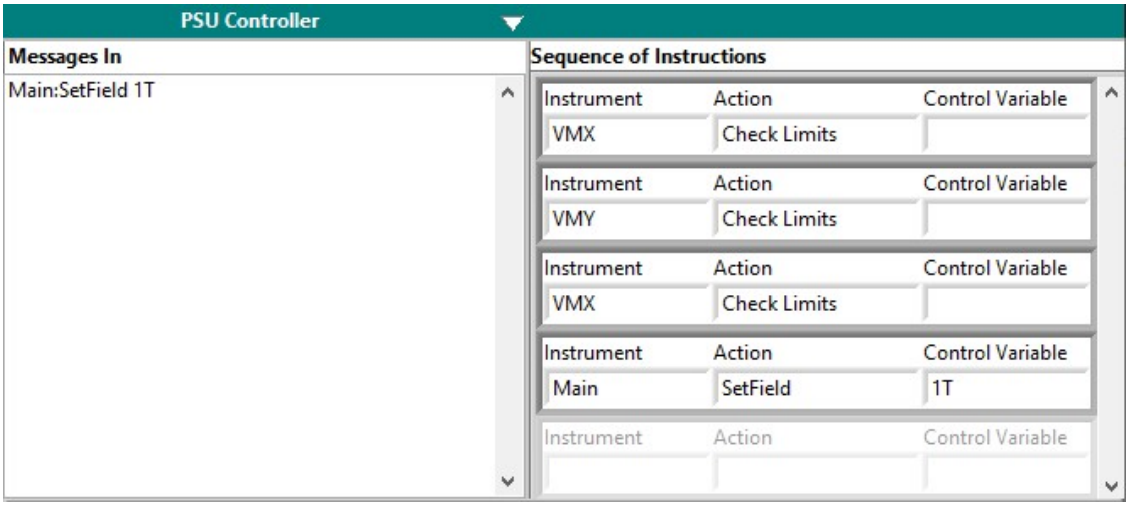

FIGURE 13 - PSU CONTROLLER UI

The PSU Controller coordinates the operation of different power supplies in systems with multiple magnets. This module can be configured to verify that specific constraints are met or that an action is performed on one or more power supplies before a certain magnet is ramped.

When the controller is enabled and configured, every *Sweep* action on any other power supply or shim is automatically forwarded, before being executed, to the PSU Controller, where it is decoded and split into a series of pre-ramp and/or post-ramp actions. Once these have been performed and all other required constraints have been verified, the original command is rerouted to the appropriate instrument by the PSU Controller itself.

As an example, the PSU Controller UI in Figure 13 shows the list of actions that the software performs before setting a 1T field on *Main*. More details on how to configure the controller are given below.

PSU CONTROLLER CONFIGURATION

The **PSU Controller Configuration** is accessed through the *Configuration Editor* module, which can be loaded from the *Options Tree* in the software Main UI.

The configuration consists of two section, the ***Power Supply Operation Constraints*** and the ***Limit Settings***.

The *Power Supply Operation Constraints* lists both the pre and post-ramp actions or operational checks that need to be performed on other power supplies before and after a specific Power Supply can be ramped (seeFigure 14). The possible actions are ***Depersist***, ***Check Limits***, ***Wait Until Ready***, ***Check If Ramping, Switch Heater Off***. For each action an exception can also be defined.

The example in Figure 14 illustrates that before a ramp of the power supply named *Main* can be executed, the software has to *Check Limits* on the instrumnt named *VMX*. The *Limits* are setpoint-dependent lists of constraints and are configured in the *Limit Settings* section of the PSU Controller configuration (see Figure 15).

To configure the limits for a specific power supply, choose its name from the *Instrument* drop down menu (*Main* in the example in Fig.14), then specify the name of a variable of this instrument - *Reference Parameter* - that should be used for the subsequent evaluation. The *Linked Parameters Constraints* set out the limits according to the following logic: for *Reference Parameter* up to *Ref Parameter Value* the product of *Reference Parameter* and *Parameter* from *Linked Instrument* must be less than or equal to *Max Value*. In the example in Figure 15 this would correspond to:

$$(\text{Main\_SetpointTesla}) \times (\text{VMX\_Tesla}) \leq 0.0008$$

The units of *Max Value* depend on the parameters used in the comparison. In the example in Figure 15 Max Value=0.0008T.

Action describes how the software responds when the constraints are not met. In the example below, the ramp is aborted.

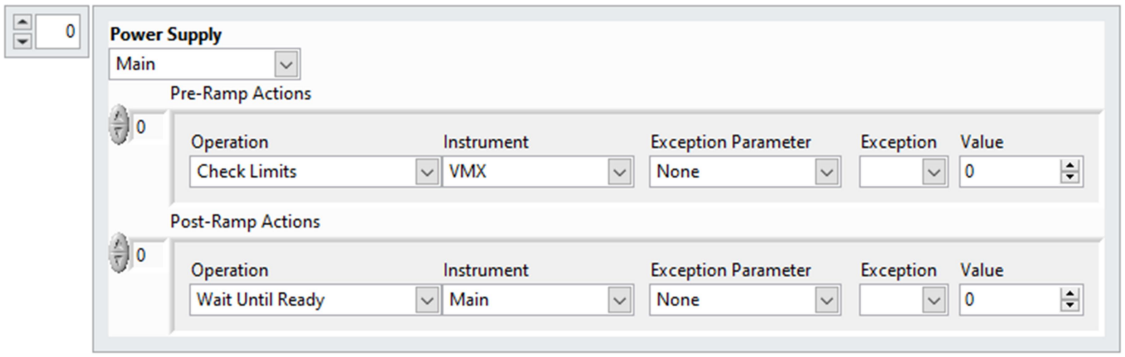

FIGURE 14 – EXAMPLES OF POWER SUPPLY OPERATION CONSTRAINTS

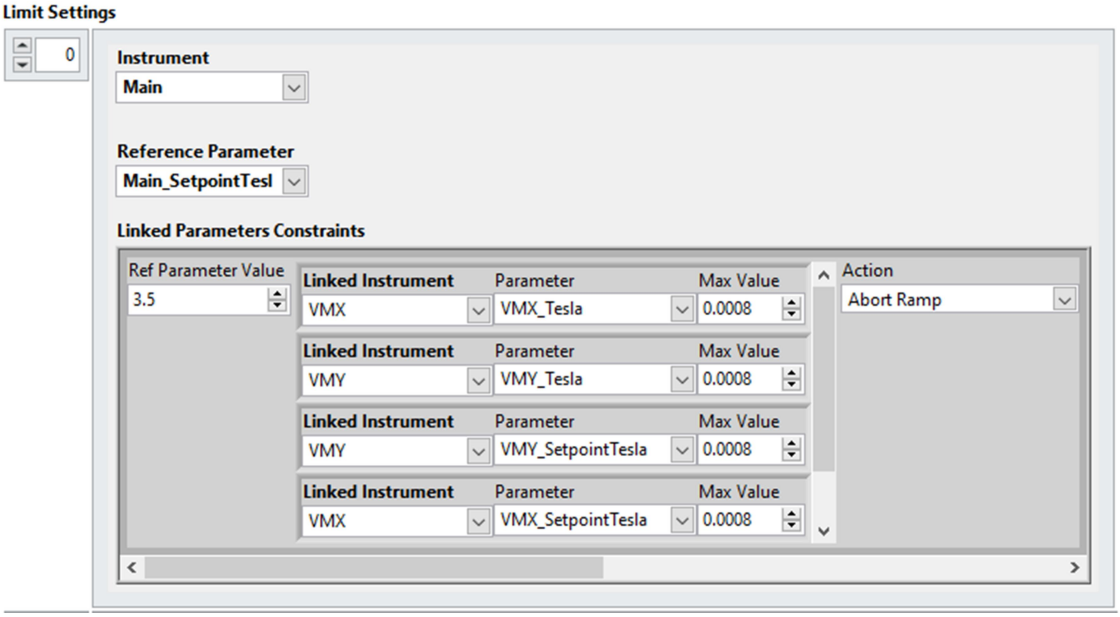

FIGURE 15 - LIMIT SETTINGS

TEMPERATURE MONITOR

This module displays the temperature values measured by sensors located at various positions on the magnet and the cryostat. In cryogen free magnets thermometers are most commonly attached to the first stage, the second stage, the switch, the shield and the magnet, but their number and location can vary.

Temperatures are generally acquired with 2700 Keithley Multimeters or Lakeshore model 218 or 224 monitors.

If a Keithley Multimeter is used, the software acquires the sensor resistance values (in Ohms) and converts these resistances into temperatures, following calibration tables which are specific for each sensor. If using a Lakeshore temperature monitor, temperatures can be acquired directly from the instrument, after the sensor calibration curves have been uploaded to the instrument.

TEMPERATURE MONITOR UI

Sensors are listed in the same order in which they are acquired from the instrument, with the temperatures shown in the **Kelvin** column. **Drift [K/ (time)]** shows the drift rate of the temperature of each sensor and it can be viewed in **K/hour**, **K/min** or **K/sec**.

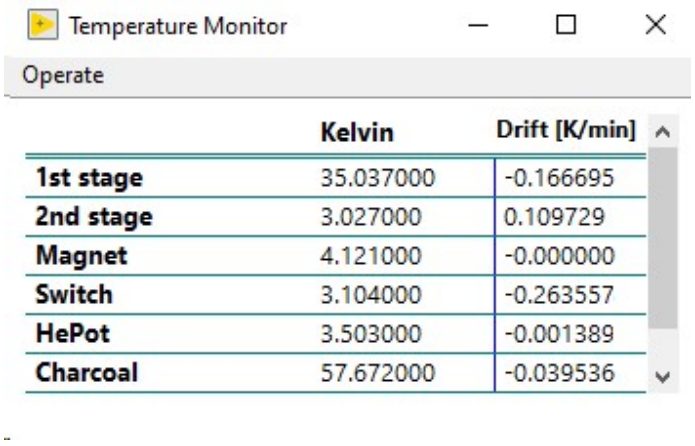

FIGURE 16 - TEMPERATURE MONITOR UI

TEMPERATURE MONITOR CONFIGURATION

The *Temperature Monitory Configuration* is accessed through the *Configuration Editor* module, which can be loaded from the *Options Tree* in the software Main UI.

GENERAL SETTINGS

This section covers some of the most basic settings of the temperature monitor module.

Enabled sets whether the module is included in the main software or ignored.

Name is a label that identifies the specific instrument as a *Temperature Monitor* in the Options Tree. Although this field can be left empty, adding a name is necessary to distinguish different units in systems where more than one monitor is present.

Model lists temperature monitor makes and models. Supported options are Lakeshore 218, 224 and Keithley 2700. The choice of model determines the *Inputs* section discussed below.

COMMUNICATION

This section contains the instrument communication settings.

Interface supports **USB** (also for RS232) or **Ethernet**. If *USB*, all serial parameters (**USB COM Address, Baud Rate**, **Data Bits**, **Parity**, **Flow Control** and **Stop Bits**) need to be set. If the right COM port is not listed, click **Refresh** to update the list. If the interface is *Ethernet*, both **IP Address** and **Remote Port** need to be configured.

Termination Character is the decimal representation of the termination character used in Read operations.

INPUTS - LAKESHORE 2XX

The settings in this section refer to a Lakeshore temperature monitor and define the characteristics of the sensors in input, including units, temperature limits and names (see

Figure 17).

The drop down list under INPUTS allows navigating through the instrument's channels, in the order in which they are scanned by the monitor. A physical **Input** is assigned to each channel. *Inputs* range from 1 to 8 for a Lakeshore 218 and 1 to 12 for a Lakeshore 224.

Label is the name of the sensor. A label can be assigned to each input by typing in a new name. Labels can have a maximum of 15 characters and commas or semi-colons are not allowed.

T Limit is the highest temperature for the sensor.

The list of available sensors (**Type**) varies depending on the model, with possible options being Platinum, Diode or Cernox.

Autorange can be set to 0 if OFF or 1 if ON. If Autorange is OFF, a fixed range for the specific type of sensor can be set in **Range.**

Compensation specifies input thermal correction where 0=OFF and 1=ON.

Units defines the preferred units for the acquisition and display, with options being K, C, Ohm, V.

Excitation is the sensor excitation current, which should be set to keep the power dissipated in the sensor at a minimum, but enough to provide accurate measurements.

The *Filter* applies exponential smoothing to the sensor input readings. **Filter N. Points** defines the filter bandwidth, by defining how many data points the filtering function uses. One filter point corresponds to one new reading on that input. **Filter Window(%)** is a limit for restarting the filter and is set in percent of full scale range.

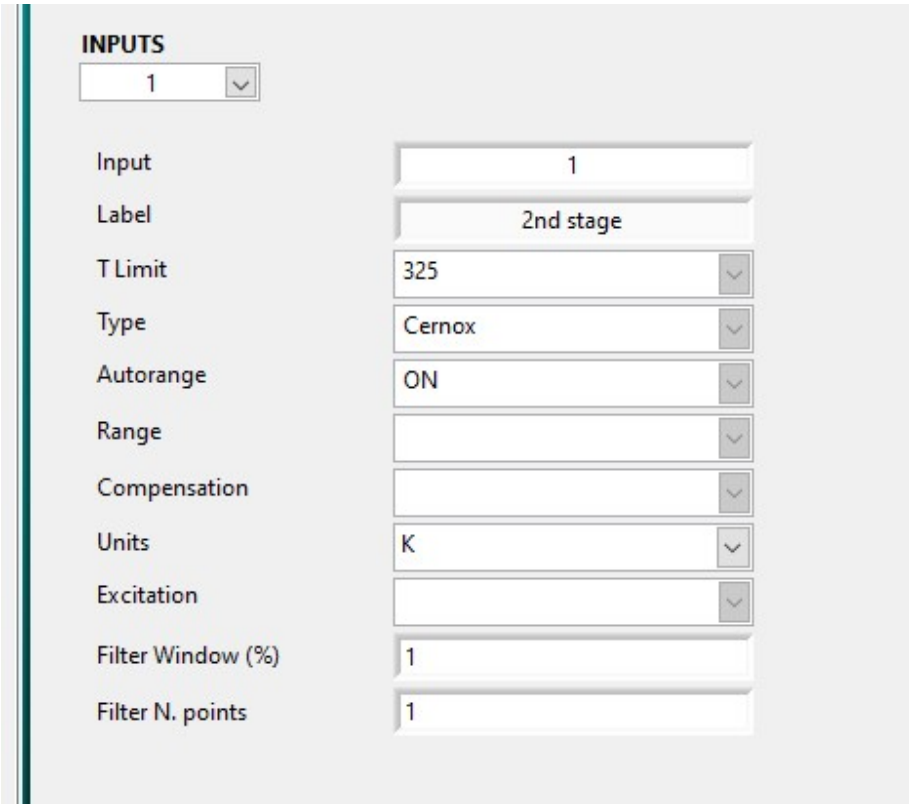

FIGURE 17 - LSXXX TEMPERATURE MONITOR INPUTS

4. TOOLS

TEMPERATURE DIAGNOSTICS

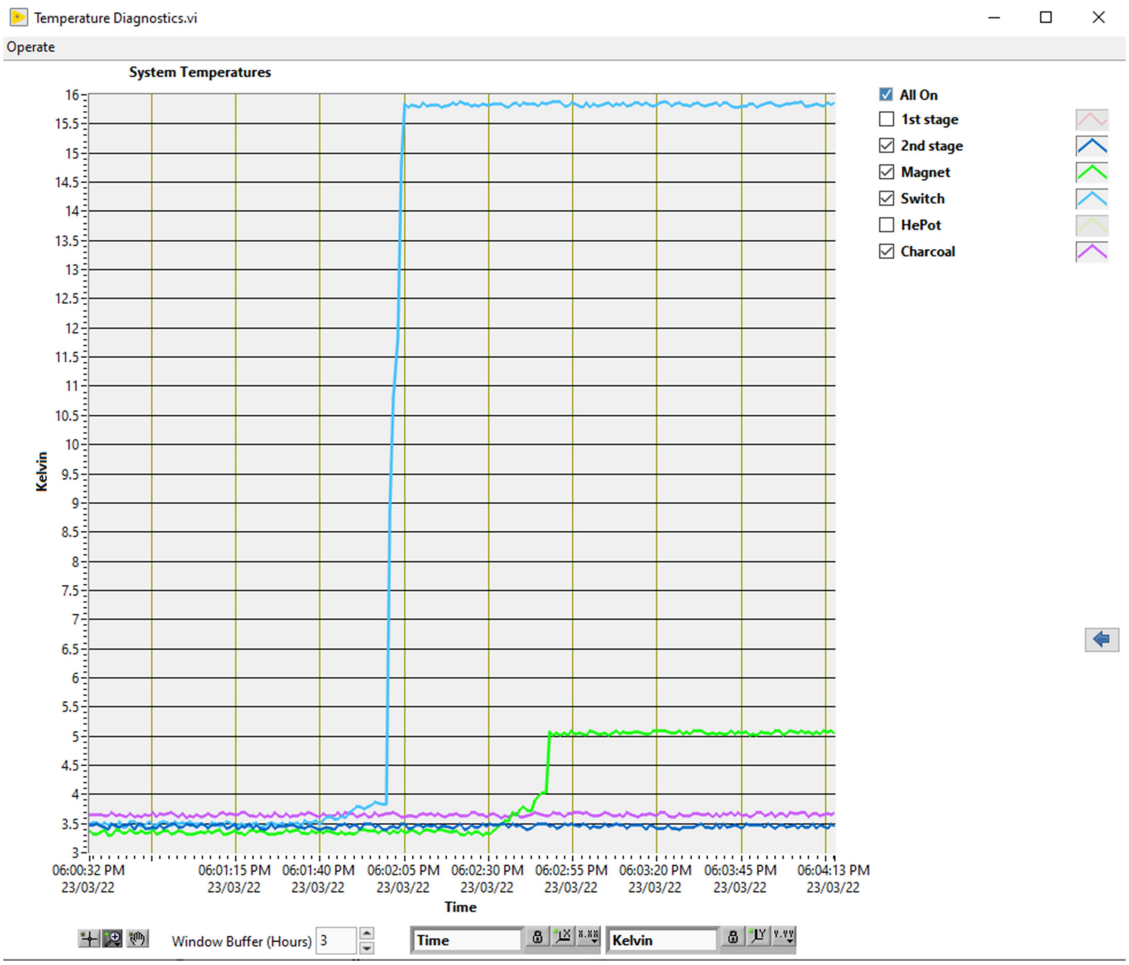

FIGURE 18 - TEMPERATURE DIAGNOSTICS UI

The *Temperature Diagnostics* utility plots the magnet temperatures on graph. The main function of this module is to monitor a magnet cooldown. The plot legend on the right hand side can be used to select what sensors to display and to customise the appearance of each plot. Use **All On/All Off** to show or hide all plots simultaneously. The blue arrow on the right is used to show or hide the plot legend.

Window Buffer (Hours) defines the overall time interval displayed. The bigger the window, the larger the amount of data stored in memory. To limit CPU usage, this value should not be too large, especially when the graph is working in *Autoscaling* mode (padlock symbols locked).

CONFIGURATION EDITOR

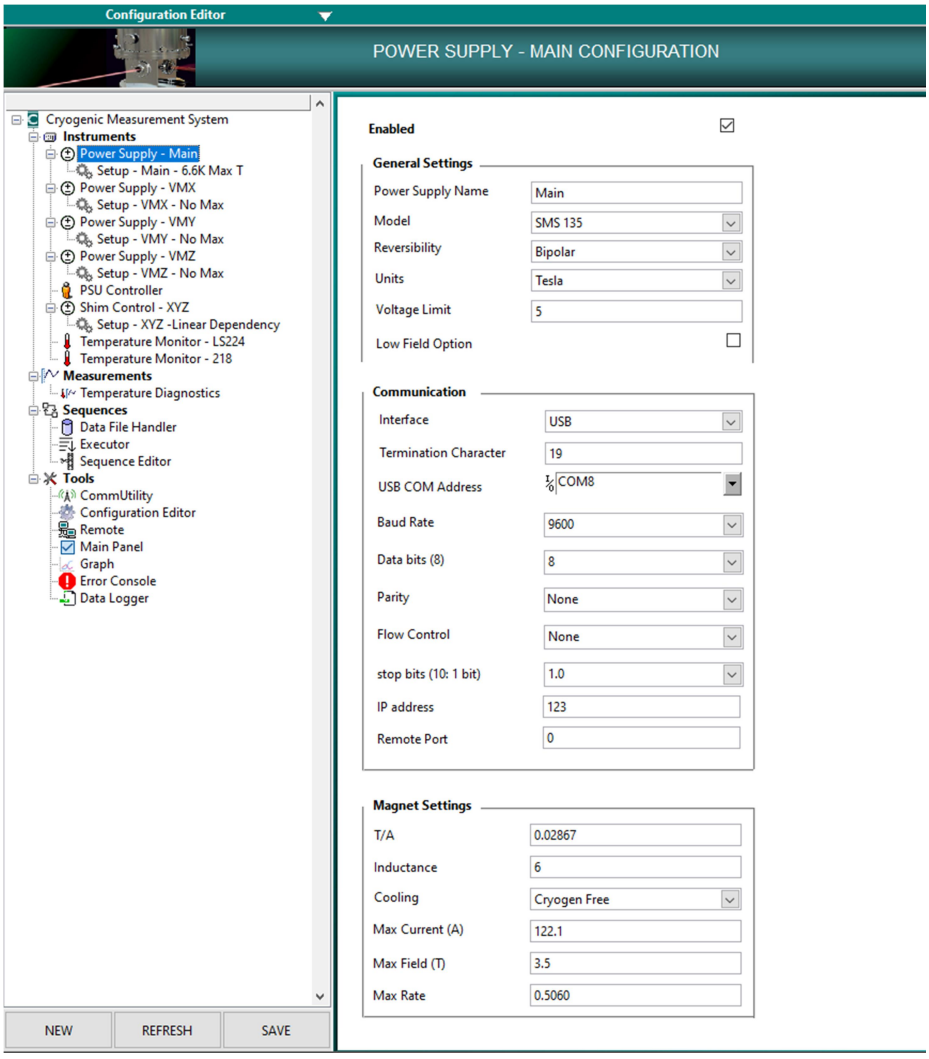

FIGURE 19 - CONFIGURATION EDITOR

The Configuration Editor is a graphical tool to edit or view the configuration of every option in the system. It can be used to create or edit setup files and also to customise the entire application by removing or adding modules.

When launched, the VI scans the software root folder for configuration files (*.ini) and builds the ***Instruments***, ***Measurements***, ***Sequences*** and ***Tools*** nodes of the configuration tree accordingly. These nodes can be opened to display the actual modules that form part of the system. If *setups* have been created for an instrument or measurement, these can be accessed by expanding the node of the corresponding option.

A module's configuration is accessed by clicking its name in the tree. Refer to each module's section in this manual for a detailed description of the available settings and their meaning. Some parameters are common to all options such as ***Name***, which guarantees an instrument can be recognised and properly addressed, and the option to ***Enable/Disable*** the module itself, a feature can be used to temporarily exclude a measurement or instrument from a specific instance of the application, without altering the rest of its configuration.

Right-clicking a node opens a menu with options to ***Add***, ***Remove*** or ***Duplicate*** either a node or a *setup*, depending on the node selected and its features.

Changes made to a configuration are not applied unless ***Save*** is pressed. A balloon message is displayed each time a configuration is modified, to warn the user that changes made might require the module to be re-intialised.

Refresh can be used to update the tree.

REMOTE

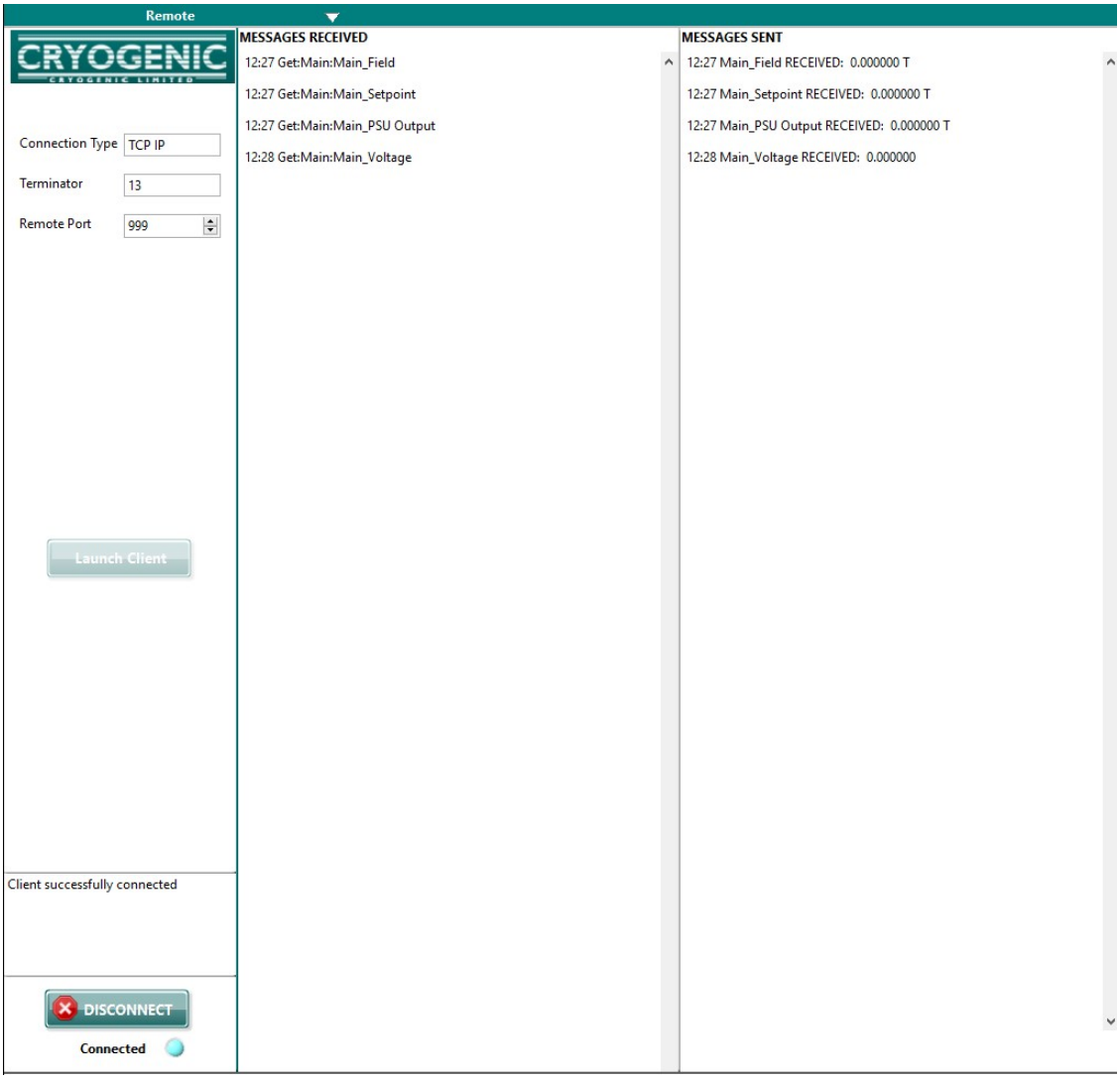

FIGURE 20 - REMOTE MODULE UI

The **Remote** module allows monitoring and control of the system's parameters from an external application (see Figure 20 - Remote Module UII). This module creates a communication link between a remote client and the *Cryogenic Software Suite*. It is designed to receive commands and requests and to either issue a response or to reroute the command to a specific *instrument* or *measurement* in the application. Commands and responses are issued in the form of ASCII strings following the syntax of a specific instruction set.

The communication protocols for the data exchange currently supported are *TCP IP*, *UDP* and *RS232*. The communication parameters are normally set in the Remote module's *Configuration* and loaded at start-up. They can also be edited directly from the module's user interface.

If set to run at application start up, the module will automatically either open a connection or create a listener at the port specified in ***Remote Port***, depending on whether it is configured for RS232 or UDP/TCP IP protocol.

If the module is manually launched from the Main UI, communication can be established by clicking ***Connect***.

Once a network connection is accepted, the '*Client successfully connected*' message is displayed, the blue LED *Connected* switches on and the software is ready to receive incoming messages. Clicking on ***Launch Client*** opens a test VI that can be used to verify the module functionality locally on the same *localhost*.

REMOTE CONFIGURATION

The *Remote Configuration* is accessed through the *Configuration Editor* module, which can be loaded from the *Options Tree* in the software Main UI (see Figure 20).

Enabled is used to include the module in the main application. If left unchecked, the *Remote* option will not be loaded the next time the software is launched and will not appear in the list of available options in the Main UI.

Run at Application Startup sets whether the module is launched automatically or on demand. If selected, the module will run when the main application starts and will immediately open the connection configured in the *General Settings*.

From **General Settings** the **Connection Type** can be selected as *TCP IP*, *RS232* or *UDP*. **Emulation** should be set to *Standard*, the *Instrument* option referring to a special use of the module to emulate an external temperature controller or power supply.

Termination is the decimal representation of the termination character used by the communication protocol.

Remote Port is the port with which to establish a connection.

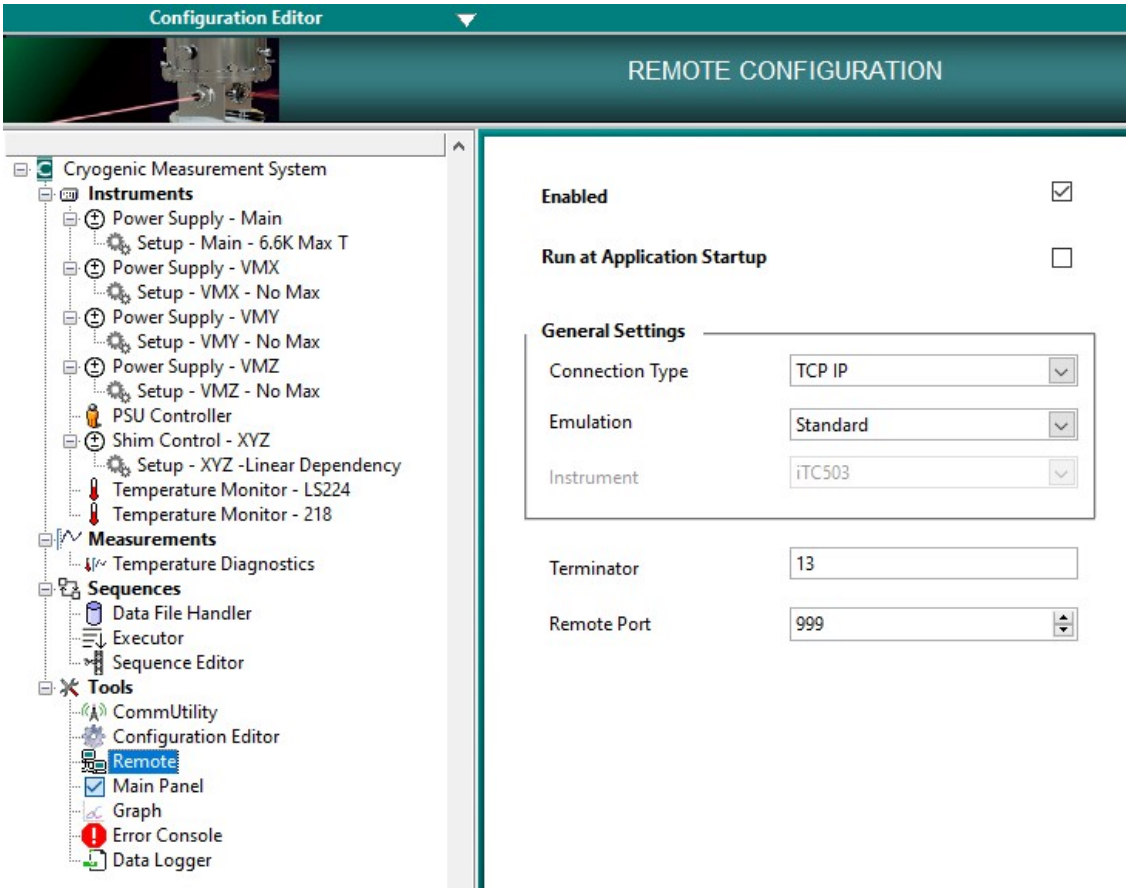

FIGURE 21 REMOTE CONFIGURATION UI

REMOTE MESSAGES SYNTAX

The set of instructions for the Remote module includes two forms of messages: *Get* and *Set*. The root of each message is made up of 3 parts: the query ID (Set or Get), the recipient (*Instrument* or *Measurement*) and the actual instruction. These 3 parts are separated by colons (':').

Set instructions can have one or more arguments, which are appended at the end of the full message and separated by commas (','). A space is always included between the instruction and the first argument. The response to a *Set* instruction is the echo of the whole message followed by 'RECEIVED'.

Get instructions can return one or more parameter, separated by commas ','. If a command returns a two dimensional array (table), its elements are returned in rows and separated by commas, while the end of a row is marked by a semicolon ';'. The full reply to a *Get* instruction is made of the echo of the command, without the *Get* query ID, followed by *RECEIVED:*, followed by the actual response.

If a command does not exist or its syntax is incorrect, the message '**ERROR: invalid command'** is returned after the command echo. If an instrument is not running or the Remote module cannot access it, the message **ERROR: instrument not found** is issued.

The list of currently available instructions is presented in the next section.

LIST OF COMMANDS

The following section lists the full set of available commands for remote operation. These are grouped by module, with *Set* commands listed first.

Arguments for *Set* commands are included between '< >' at the end of each message. A brief description of the command function is included, followed by a description of the arguments, if any.

Arguments are defined through format specifiers, with '%' used to indicate the beginning of the format specifier. The code `%s` indicates the argument is a string (for example, `abc`), while `%f` is used to represent a floating-point number with fractional format (for example, `12.345`).

Each *Set* command also includes an example of response issued by the module.

Get commands include a description of the functionality followed by the expected response, which also specifies if and what values are returned. Values are also defined through format specifiers as previously described. Lastly, as for *Set* instructions, an example of response issued by the module is provided.

Power Supply Module

The instructions available for this module and listed below apply to an example instrument named Main, but they can be used for any power supply in the system by replacing the tag *Main* with the actual name of the power supply of interest.

Set:Main:Sweep <target><field units>

```
Sets target and units on Main Coil and starts ramp

target=%f

field units=A|T

A=Amps

T=Tesla

Set:Main:Sweep 1T RECEIVED
```

Set:Main:SetRate <rate>

```
Sets Main Coil ramp rate

rate=%f

Set:Main:SetRate 0.1 RECEIVED
```

Set:Main:ChangeRateUnits <rate units>

Sets Main Coil ramp rate units

rate units=A/s|T/s|T/min|T/h

Set:Main:ChangeRateUnits T/min RECEIVED

Set:Main:Abort

Aborts Main Coil ramp

Set:Main:Abort RECEIVED

Set:Main:ResetQuench

Clears Quench message on Main

Set:Main:ResetQuench RECEIVED

Set:Main:SetPM <status>

Sets Persistent Mode status

status=0|1|2

0= Heater On @ Target

1= Heater Off @ Target & leads to 0

2= Heater Off @ Target & leads at Target

Set:Main:SetPM 1 RECEIVED

Set:Main:SetApproach <approach>

Sets target approach mode

approach=0|1|2|3

0=direct

1=overshoot

2=cycle

3=degaussing

Set:Main:SetApproach 0 RECEIVED

Set:Main:SetOvershoot <overshoot>,<hold time>

Sets target overshoot parameters

overshoot=%f (% of final target)

hold time=%f (seconds)

Set:Main:SetOvershoot 3,20 RECEIVED

Set:Main:SetCycling <start value>,<damping factor>,<accuracy>,<hold time>

Sets target cycling parameters

start value=%f (% of final target)

damping factor=%f (% of next target)

accuracy=%f (absolute field value)

hold time=%f (seconds)

Set:Main:SetCycling 3,10,0.01,20 RECEIVED

Set:Main:SetDegaussing <start value>,<damping factor>,<stop value>,<hold time>

Sets degaussing parameters

start value=%f

damping factor=%f (% of next target)

stop value=%f

hold time=%f (seconds)

Set:Main:SetDegaussing 0.5,10,0.001,20 RECEIVED

Get:Main:Main_Field

Gets Main Coil Field

Main_Field RECEIVED: <field><field units>

field=%f

field units=A|T

A=Amps

T=Tesla

Main_Field RECEIVED: 0.000000T

Get:Main:Main_Setpoint

Gets Main Coil Target

Main_Setpoint RECEIVED: <target><target units>

target=%f

target units=A|T

A=Amps

T=Tesla

Main_Setpoint RECEIVED: 0.000000T

Get:Main:Main_PSU Output

Gets Main Coil Power Supply Output

Main_PSU Output RECEIVED: <PSU Output><field units>

PSU Output=%f

field units=A|T

A=Amps

T=Tesla

Main_PSU Output RECEIVED: 0.000000T

Get:Main:Main_Voltage

Gets Main Coil Voltage

Main_Voltage RECEIVED: <voltage>

voltage=%f

Main_Voltage RECEIVED: 0.000000

Get:Main:Main_Ramp Rate

Gets Main Coil Ramp Rate

Main_Ramp Rate RECEIVED: <ramp rate><rate units>

rate units=A/s|T/s|T/min|T/h

ramp rate=%f

Main_Ramp Rate RECEIVED: 0.024000A/s

Get:Main:Main_Heater

Gets Main Coil Heater status

Main_Heater RECEIVED: <heater>

heater=

HEATER ON

HEATER OFF

HEATER OFF at B

No Switch

Main_Heater RECEIVED: HEATER OFF

Get:Main:Main_Persistent Mode

Gets Main Coil Persistent Mode setting status

Main_Persistent Mode RECEIVED: <PM settings>

PM setting= Heater On @ Target|Heater Off @ Target & leads to 0 |Heater Off @ Target & leads at Target

Main_Persistent Mode RECEIVED: Heater OFF at Target, leads to 0

Get:Main:Main_Approach

Gets Main Coil target approach mode

Main_Approach RECEIVED: <approach>

approach= direct|overshoot|cycle|degaussing

Main_Approach RECEIVED: Direct

Get:Main:Main_Status

Gets Main Coil status, general description of the power supply module current behaviour

Main_Status RECEIVED: <status>

status=%s

Main_Status RECEIVED: Waiting for Switch Transition

Get:Main:Main_Units

Gets Main Coil Units (applies to Setpoint and Output)

Main_Units RECEIVED: <units>

units= A|T

A=Amps

T=Tesla

Main_Units RECEIVED: T

Get:Main:Main_Rate Units

Gets Main Coil ramp rate units

Main_Rate Units RECEIVED: <rate units>

rate units= A/s|T/s|T/min|T/h

Main_Rate Units RECEIVED: T/min

Get:Main:Main_Ready

Returns TRUE if the power supply can be ramped, FALSE otherwise. Reasons for FALSE can be magnet too hot, quench, temperature readings not available

Main_Ready RECEIVED: <ready>

ready=TRUE|FALSE

Main_Ready RECEIVED: TRUE

Get:Main:Main_Error

Returns the latest error thrown by this module

Main_Error RECEIVED: <error>

error=%d

Main_Error RECEIVED: 5300

Shim Control Module

Set:Shim Control:Sweep <shim name>,<current>

Sets current on a shim Coil

Shim name=%s

current=%f

Set:Shim Control:Sweep X1,10 RECEIVED

Set:Shim Control:SweepAll <current1>,<current2>,...,<currentN> or empty

Sets all shims in sequence

currentN=%f

Set:Shim Control:SweepAll 10,20,8 RECEIVED

Set:Shim Control:SweepAllTable

Based on the currently loaded table, sets all shims to the right values for the current field in the reference magnet

Set:Shim Control:SetFieldAllTable RECEIVED

Set:Shim Control:SetRate <rate>

Sets ramp rate (one setting for all coils)

rate=%f

Set:Shim Control:SetRate 0.1 RECEIVED

Set:Shim Ramp:SetRate <rate>

Sets the shim coil ramp rate during a ramp (one setting for all coils)

rate=%f

Set:Shim Ramp:SetRate 0.2 RECEIVED

Set:Shim Control:SweepDepersist

Sets all shims to 0 in sequence and switches all heaters on

Shim Control:SweepDepersist RECEIVED

Set:Shim Control:SweepCycle <cycles>

Sets all shims according to the currently loaded table and the current field in the refernce coil. Iterates 'cycles' number of times

cycle=%d

0=OFF

Set:Shim Control:SweepCycle 2 RECEIVED

Set:Shim Control:SetTable <ref(1),I1(1),I2(1),...;ref(N)I1(N),I2(N),...;>

Sets Shim Coils Table

ref(n)=%f (Tesla)

currentN(n)=%f (Amps)

Set:Shim Control:SetTable 0,0,0,0;1,0,0,1.54;2,0,0,3.09;3,0,0,4.63;3.5,0,0,5.40; RECEIVED

Set:Shim Control:LoadTable <file name> or no argument

Loads targets from a Shim Coils Table. If no file name is given, targets are loaded from current setup. The table file name must not contain spaces and must be saved in the Shim Control Support Files. This command does not require the file full path, only its name and extension.

file name=%s

Set:Shim Control:LoadTable ShimTable.txt RECEIVED

Set:Shim Ramp:Abort

Aborts a ramp on te Shim Control

Shim Control:Abort RECEIVED

Get:Shim Control:ShimN_Field

Gets actual current in the shim coil named "ShimN"

ShimN_Field RECEIVED: <field><units>

ShimN=X1|Y1|Z1…

field=%f

units=A

X1_Field RECEIVED: 11.200A

Get:Shim Control:ShimN_Output

Gets the value of the current in the leads in the shim coil power supply. This is the same for all shim coils, therefore the response will be the same regardless of the shim name in the query.

ShimN _Output RECEIVED: <output><units>

ShimN=X1|Y1|Z1…

output=%f

units=A

X1_Output RECEIVED: 11.200A

Get:Shim Control:ShimN_Setpoint

Gets ShimN Target

ShimN _Setpoint RECEIVED: <target><units>

ShimN=X1|Y1|Z1…

target=%f

units=A

X1_Setpoint RECEIVED: 1.000A

Get:Shim Control:ShimN_Rate

Gets the current ramp rate. This value is the same for all shims

ShimN_Rate RECEIVED: <rate><units>

ShimN=X1|Y1|Z1…

rate=%f

units=A/s

X1_Rate RECEIVED: 10.0000A/s

Get:Shim Control:Shim Control_Status

Gets Shim Control status, general description of the shim coil control module current behaviour

Shim Control_Status RECEIVED: <status>

status=%s

Shim Control_Status RECEIVED: Updating Output...

Get:Shim Control:Shim Control_Table

Gets shim control table currently in use

Shim Control_Table RECEIVED: <ref(1),I1(1),I2(1),..,IN(1);...;>

ref(n)=%f (Tesla)

IN(n)=%f (Amps)

Shim Control_Table RECEIVED: 0,0,0,0;1,0,0,1.54;2,0,0,3.09;3,0,0,4.63;3.5,0,0,5.40;

Get:Shim Control:Shim Control_Ready

Returns TRUE if the power supply can be ramped, FALSE otherwise. Reasons for FALSE can be magnet too hot, quench, temperature readings not available

Shim Control_Ready RECEIVED: <ready>

ready=TRUE|FALSE

Shim Control_Ready RECEIVED: TRUE

Get:Shim Control:Shim Control_Error

Returns the latest error thrown by this module. Empty if no error

Shim Control_Error RECEIVED: <error code>

<error code>=%d

Shim Control_Error RECEIVED:

Compressor Module

Set:Compressor:Start <compressor name>

Starts specific compressor

compressor name=%s

Set:Compressor:Start A RECEIVED

Set:Compressor:Reset <compressor name>

Resets specific compressor alarm condition

compressor name=A|B

Set:Compressor:Reset A RECEIVED

Set:Compressor:Stop <compressor name>

Stops specific compressor

<compressor name>= A|B

Set:Compressor:Stop A RECEIVED

Get:Compressor:Compressor_Error

returns the latest error thrown by the actual Compressor module (not an error on a specific compressor)

Compressor_Error RECEIVED: <error>

<error>=%d

Compressor_Error RECEIVED: 6200

Get:Compressor:CompressorName_RunTime

returns run time in hours of a specific a compressor

CompressorName_RunTime RECEIVED: <hours>

hours=%f

A_RunTime RECEIVED: 1020.2

Get:Compressor:CompressorName_Ready

returns TRUE if the specific compressor is ready

CompressorName_Ready RECEIVED: <ready>

ready=TRUE|FALSE

A_Ready RECEIVED: FALSE

Remote Module

Get:Remote:Remote_Error

returns the latest error thrown by the Remote module

Remote_Error RECEIVED: <error>

<error>=%d

Remote_Error RECEIVED: 6800

Get:Remote:Remote_Status

Gets status, general description of the Remote module current behaviour

Remote_Status RECEIVED: Receive

Get:Remote:Remote_Ready

returns TRUE if the module is ready, i.e. running and initialised

Remote_Ready RECEIVED: <ready>

ready=TRUE|FALSE

Remote_Ready RECEIVED: TRUE

Temperature Monitor Module

Get:Temperature Monitor:Temperature Monitor_Temperatures

Returns all system temperatures

TemperatureMonitor_Temperatures RECEIVED: <T1K,T2K,T3K,..TnK>

Tn=%f

Temperature Monitor_Temperatures RECEIVED:
52.787K,3.555K,48.072K,3.069K,3.841K,3.801K,3.828K,3.652K,3.712K,72.308K,3.973K
,4.070K,3.942K,4.043K,3.913K,4.197K,63.284 K,3.968 K,4.881K,3.379K

Get:Temperature Monitor:Temperature Monitor_Error

Returns the latest error thrown by this module

Temperature Monitor_Error RECEIVED: <error code>

error code=6100

Temperature Monitor_Error RECEIVED: 6100

Get:Temperature Monitor:Temperature Monitor_Status

Gets status, general description of the Temperature Monitor module current behaviour

Temperature Monitor_Status RECEIVED: Taking Readings...

Get:Temperature Monitor:Temperature Monitor_Ready

returns TRUE if the module is ready, i.e. running and initialised

Remote_Ready RECEIVED: <ready>

ready=TRUE|FALSE

Temperature Monitor_Ready RECEIVED: TRUE

Extra Commands

GetAll

Bulk variable access. Returns all system variables simultaneuosly

GetAll RECEIVED: <list>

<list>=parameter1:value1;parameter2:value2;…parameterN:valueN;

GRAPH

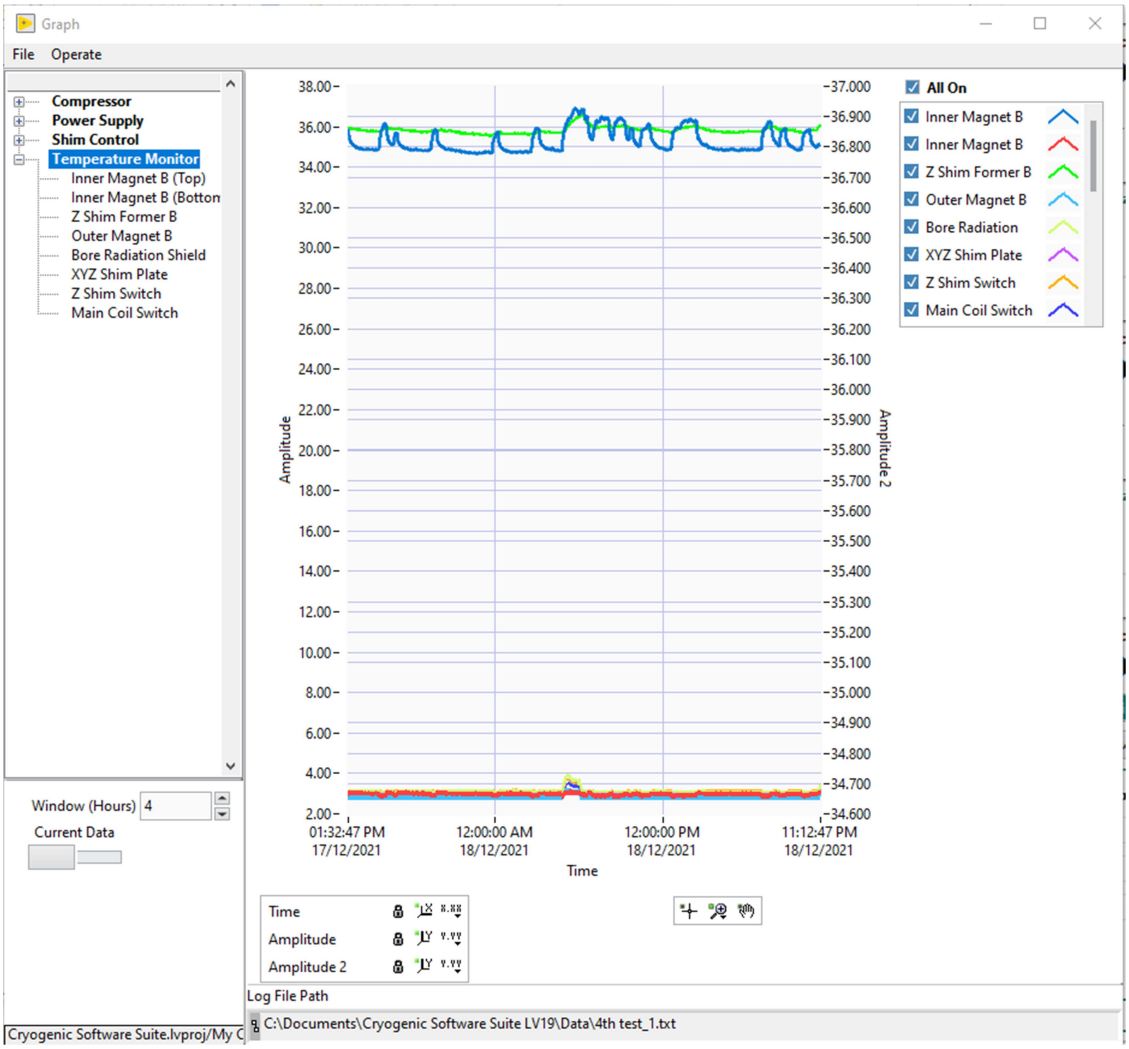

FIGURE 22 - GRAPH UI

The **Graph** module is used to plot the values of a set of parameters in real time and also to plot data from an existing log.

Available parameters are listed in a tree. Select a parameter by clicking on its name and add more by pressing Ctrl + Mouse Left Click. Clicking a module name automatically selects all parameters under that module.

A switch on the UI can be used to toggle between **Current Data** and **Log File.** When the latter is enabled, the **Browse** button can be used to browse for an existing log file and the path to the file currently displayed is shown in **Log File Path**. Clicking **Interval** opens a separate set of controls from where the user can define a **Start Point** and an **End Point** on the graph time axis. This option is particularly useful for large files, as it provides a tool to directly zoom into a specific portion of a log.

Just as with the *Graph* module, the plot legend on the right hand side of the graph can be used to select what sensors to display and to customise the appearance of each plot. Use **All On/All Off** to show or hide all plots simultaneously.

To plot sets of data with different scales, two Y axes are provided on the same graph, **Amplitude** and **Amplitude2**, with *Amplitude* being the default axis. Clicking on a glyph and selecting the *Y Scale* option in the shortcut menu allows a different axis to be assigned to a specific plot. More options are also provided to customize how the plot appears in the graph.

Window (Hours) defines the overall time interval displayed. The bigger the window, the larger the amount of data stored in memory. To limit CPU usage, this value should not be too large, especially when the graph is working in *Autoscaling* mode (padlock symbols locked).

DATA LOGGER

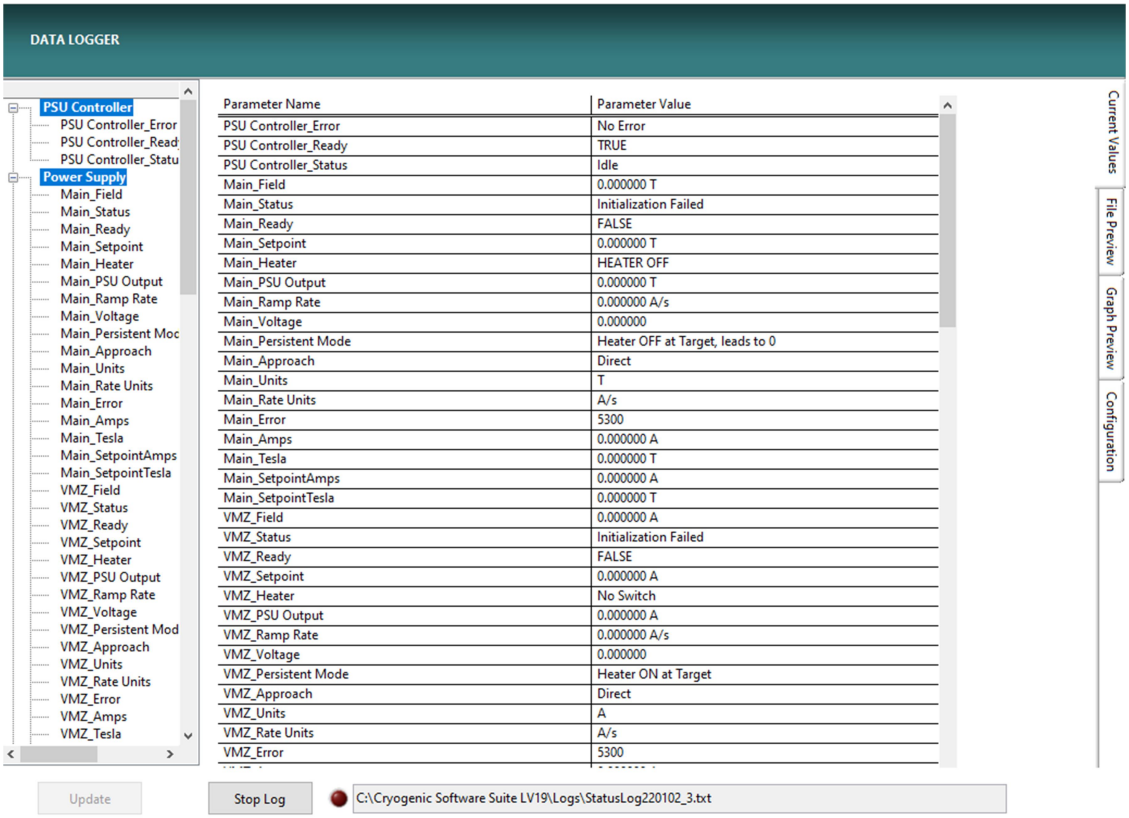

FIGURE 23 - DATA LOGGER UI

The **Data Logger** module allows logging of the various parameters and variables in the system.

Parameters that are available to log are listed in a tree view. Nodes in bold show the various modules in the application while the actual variables are listed under the module they belong to. To select a parameter simply click on the parameter's name. Multiple parameters can be selected by pressing Ctrl + Mouse Left Click. Selecting a module name automatically selects all parameters under that module.

A new log is started by clicking **Start Log**., while logging can be stopped with **Stop Log**.

The first three tabs on the right hand side offer different previews of the parameters being logged: as list of current values, as they are saved to file or as a graph. The graph option should only be used if all of the parameters selected are numeric.

The **Configuration** tab is used to change the **Log Interval** and the log **Max File Size** in MB. Two different ways to update a variable are provided, but **Log at a fixed interval** should normally be enabled.

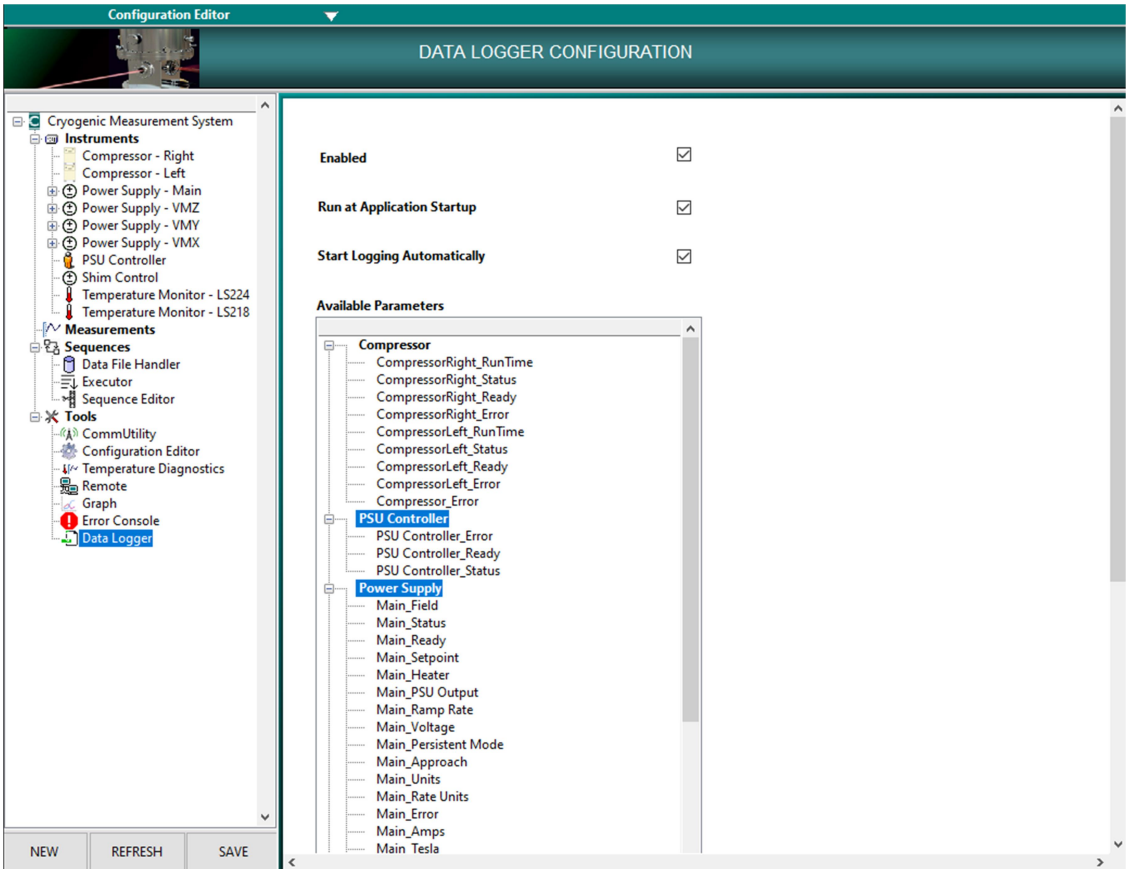

FIGURE 24 - DATA LOGGER CONFIGURATION

The Data Logger module can be configured to **Start Logging Automatically** a specific set of parameters at application startup. The **Data Logger Configuration** can be accessed from the *Configuration Editor* option from the Main UI. Available parameters are listed as tree view, exactly as in the main *Data Logger* module and can be selected with the same criteria. After **SAVE** is selected, changes are applied when the module is re-initialised.

ERROR CONSOLE

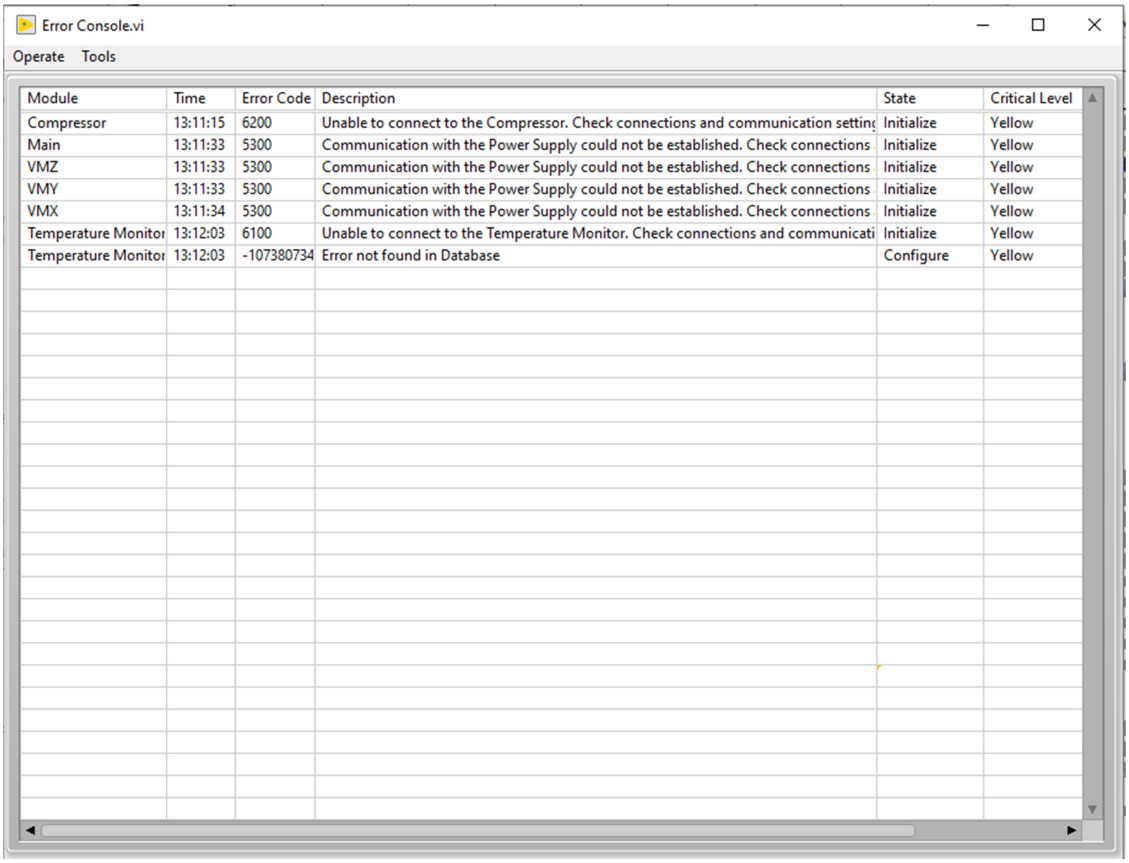

FIGURE 25 - ERROR CONSOLE UI

The **Error Console** module displays and logs all errors reported by the various components of the application. Errors are arranged in a table in chronological order as shown in Figure 25.

Module indicates the option that generated the error.

Time is the absolute time when the error was reported.

Error Code is the unique code that identifies both the module and the error.

Description gives information on the possible cause of the error.

State indicates where in the module the error occurred. *State* and **Critical Level** are only used for debugging purposes.

The data displayed on the console is also automatically logged. Error files are saved to the *Logs* folder in the application root directory. The current date is appended to the file base name as "*ErrorLogDDMMYY.txt*". Errors that occur on the same day are written to the same file, while new files

are created if errors occur on different dates. A maximum file size of 1MB is allowed, after which a new file is also created with the same naming convention as above.

A notification is always displayed on screen for each error or warning in the form of a green pop up balloon message, even when the Error Console is not visible (see Figure 26). Notifications can be either manually dismissed by clicking on each message, or let to automatically disappear after 60 seconds.

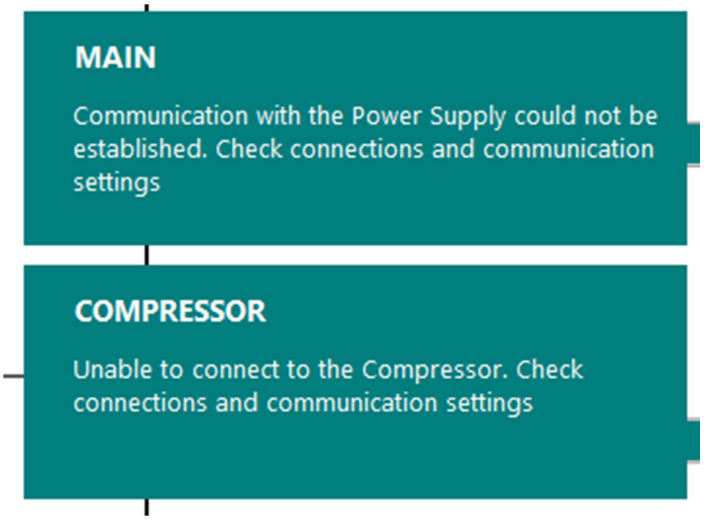

FIGURE 26 - EXAMPLE OF ERROR BALLOON NOTIFICATION

ERROR CODES

Error Code	Module	Description	Next State	Critical Level
5000	Launcher	No description available	Error	Red
5001	Launcher	Main User Interface cannot be started	Error	Red
5100	Controller	No description available	Error	Red
5101	Controller	Unable to launch one or more Modules	Error	Red
5102	Controller	Unable to scan for options	Error	Red
5200	UI	No description available	Exit	Red
5201	UI	Unable to communicate with system Controller	Exit	Red
5202	UI	Cannot display VI because it is already displayed in another window	Idle	Yellow
5300	Power Supply	Communication with the Power Supply could not be established. Check connections and communication settings	Initialization Failed	Yellow
5301	Power Supply	MAX value cannot be set	Idle	Yellow
5302	Power Supply	Coil Constant value cannot be set	Idle	Yellow
5303	Power Supply	Unable to configure Voltage Limit	Idle	Yellow
5304	Power Supply	Unable to set MID value to current output	Idle	Yellow
5305	Power Supply	Unable to connect to SMS power supply. Check cables and connection settings	Idle	Red

5306	Power Supply	SetField command invalid syntax	Idle	Red
5307	Power Supply	Unable to acquire temperatures. Magnet ramping is disabled	Wait For TM	Yellow
5308	Power Supply	Magnet temperature readings not valid. Temperature safety checks have been disabled		Yellow
5309	Power Supply	Switch temperature readings not valid. Ramping has been paused	Idle	Red
5310	Power Supply	Switch temperature readings not valid. Ramping is disabled	Idle	Red
5311	Power Supply	Setpoint Out Of Range	Idle	Red
5312	Power Supply	incorrect Ramp Rate Units Format	Idle	Yellow
5313	Power Supply	Connection Lost	Idle	Red
5400	Data Logger	Data log cannot be started	Error	Yellow
5800	Error Console	Error log cannot be started	Error	Yellow
5900	Configuration Editor	The configuration on disk has been modified. Some modules might need restarting for changes to take effect		Yellow
6100	Temperature Monitor	Unable to connect to the Temperature Monitor. Check connections and communication settings	Initialization Failed	Yellow
6101	Temperature Monitor	Connection Lost	Idle	Red
6200	Compressor	Unable to connect to the Compressor. Check connections and communication settings	Initialization Failed	Yellow
6201	Compressor	Connection Lost	Idle	Red

6202	Compressor	Alarm	Idle	Yellow
6300	Shim Control	Unable to connect to the Shim Control. Check connections and communication settings	Initialization Failed	Yellow
6301	Shim Control	SetField instruction format incorrect. Ramp Aborted	Idle	Yellow
6302	Shim Control	Connection Lost	Idle	Red
6700	PSU Controller	Unable to execute command. Parameter outside allowed limits	Idle	Yellow
6800	Remote	Queue not found. Could not execute command	Idle	Yellow
6801	Remote	Connection to client has been lost	Initialize	Yellow
7000	Error Console	Error not found in Database	Idle	Yellow

COMMUNICATION UTILITY

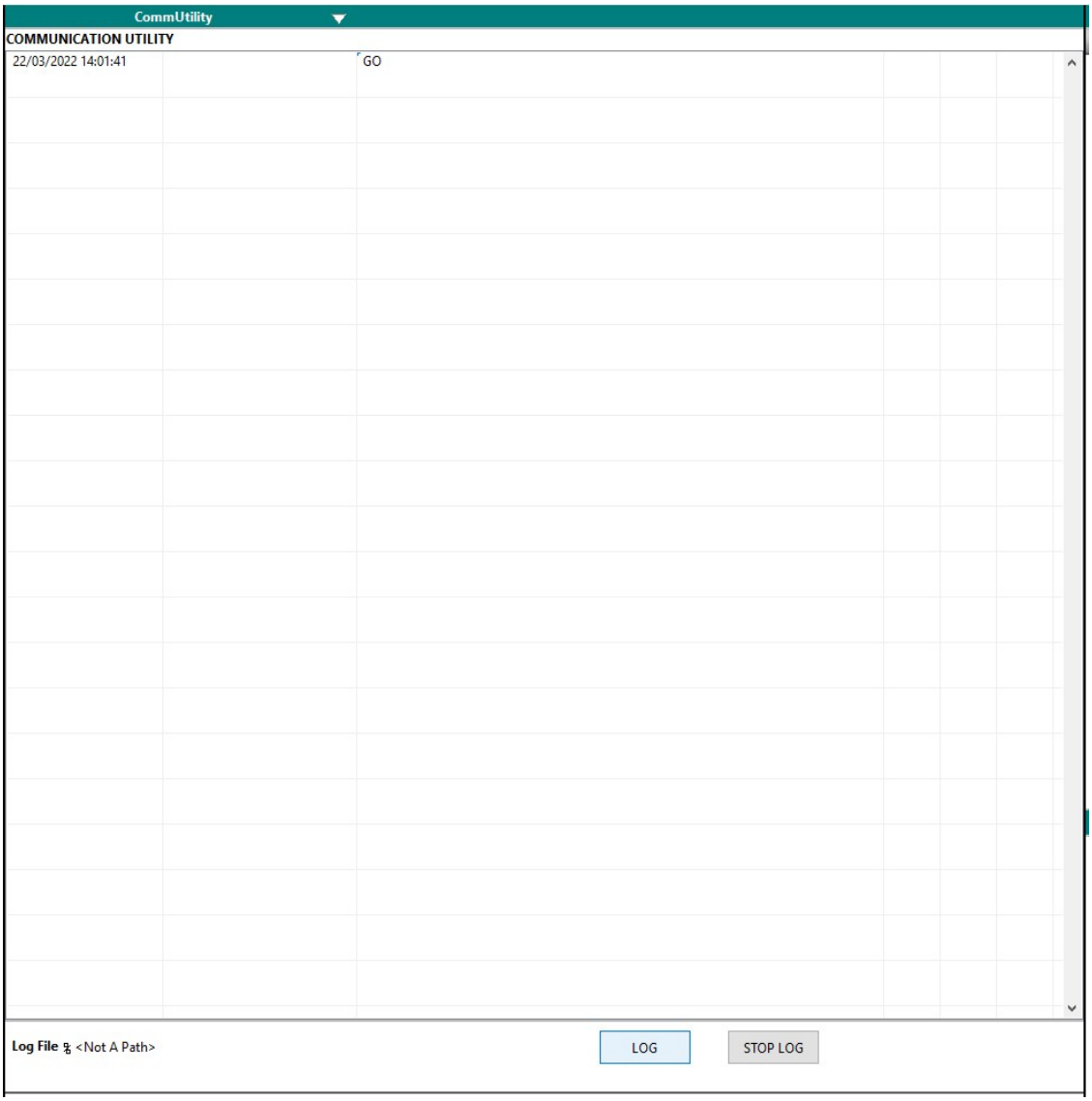

FIGURE 27 - COMMUTILITY UI

The CommUtility is a simple utility to monitor the communication between software and connected instruments. It can be used as a diagnostics tool to help identify and solve communication or hardware problems.

The module UI lists all running instruments by the name they have been assigned in their respective configurations. Outgoing messages and their responses are displayed next to each instrument's name and updated in real time. A timestamp indicates at what time and date the communication exchange between software and hardware happened.

A log file of all communication can be started/stopped by clicking **LOG/STOP LOG**. When the module is logging the **Log File** indicator shows the path to the current file.

5. List of Abbreviations

PSU - Power Supply Unit

TM - Temperature Monitor

UI - User Interface

VI - Virtual Instrument, a program developed in LabVIEW

VM - Vector Magnet