SPECTRONIK

PROTIUM-1000

FUEL CELL SYSTEM

USER GUIDE – P-1000-4.2-1.8

VERSION P-1000-4.2-1.8 | 25.08.21

SAFETY, HANDLING & SUPPORT

WARNING: *Read all the safety information below before using PROTIUM-1000. Failure to follow these safety instructions could result in fire, electric shock, or other injuries, or damage to PROTIUM-1000 Fuel Cell System (PROTIUM-1000) or other property.*

Handling Handle PROTIUM-1000 with care. It is made of thin sheet metal, graphite, and plastic and has sensitive electrochemical membrane and components inside. PROTIUM-1000 is not designed for extreme conditions, rough handling, vibration, shock or drop. Keep PROTIUM-1000 away from heat, flame, strong sunlight, water, dust, soil or mud. Do not use a damaged PROTIUM-1000.

Repairing PROTIUM-1000 is assembled under high compression. Do not disassemble or tamper with PROTIUM-1000. Do not troubleshoot, repair or replace any component by yourself.

Hydrogen Use only high purity (99.999%) dry Hydrogen gas with PROTIUM-1000. Hydrogen is a colorless, odorless and highly flammable gas. It is non-toxic but can cause asphyxiation. Follow all local rules and regulations for safe handling, storage and usage of Hydrogen gas. Do not smoke when operating PROTIUM-1000.

Ventilation Operate PROTIUM-1000 in a well-ventilated environment. Fresh air intake for the fuel cell oxidant blower, cooling air entry from the front of the protective mask, and hot air exit from the cooling fans shall not be obstructed or restricted.

Purging PROTIUM-1000 periodically flushes its anode during operation, releasing Hydrogen gas and water from the Hydrogen gas outlet. Do not block the Hydrogen gas outlet. Do not bring flame or electric spark close to the Hydrogen gas outlet. It is advisable to attach a longer gas tubing to the Hydrogen gas outlet connector and safely guide the purge exhaust far away from the fuel cell.

CAUTION: *Always put the Hydrogen gas outlet tubing behind the cooling fan and never in front of the fuel cell stack. Purged Hydrogen mixed with air intake into the fuel cell's cathode channels may cause fire and irreversible damage to the fuel cell.*

Connectors, ports and buttons Never force a connector into a port or apply excessive pressure to a button. If the connector and port do not join with reasonable ease, they probably do not match. Check for obstructions and ensure that the connector matches the correct port.

Disposal and recycling As PROTIUM-1000 contains electronic components, it must be disposed of separately from household waste. When PROTIUM-1000 reaches its end of life, follow local laws and regulations for proper disposal and recycling options.

High-consequence activities PROTIUM-1000 is a customized system with pending safety tests and certifications. It is not intended for use where the failure of the system could lead to death, personal injury or severe environmental damage.

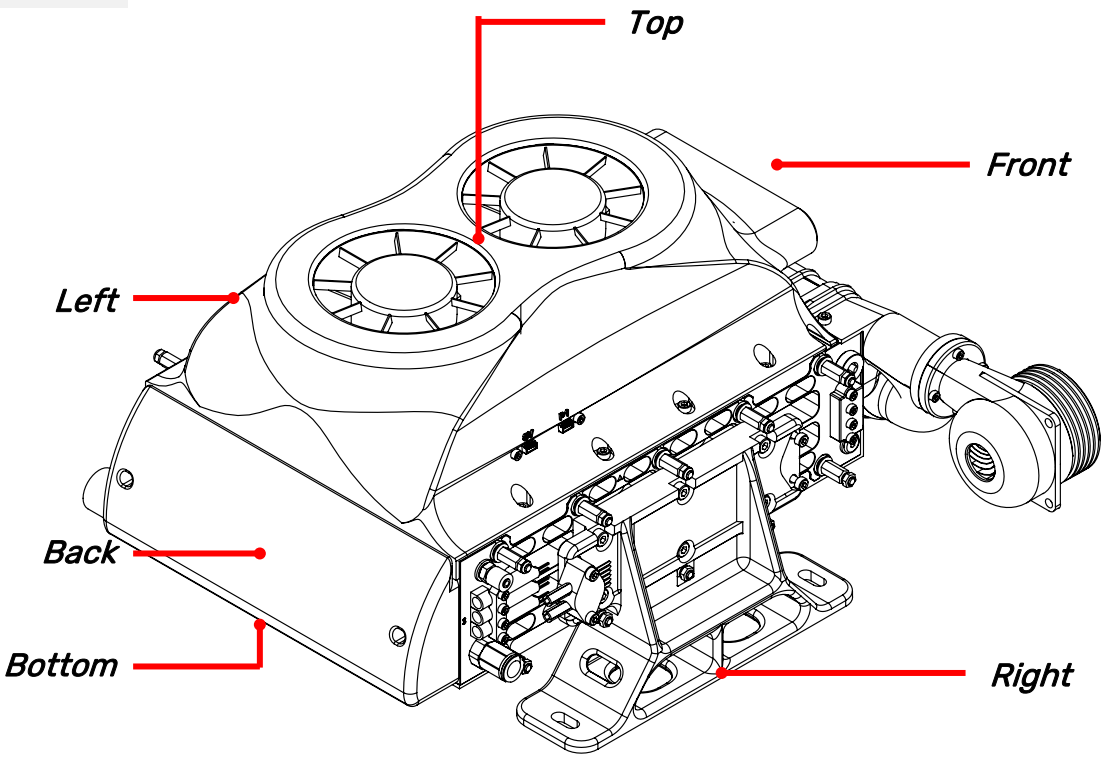
Disclaimer Every effort has been made to ensure that the information in this manual is accurate. This manual serves to adequately recommend safe operating procedures but shall not be treated as comprehensive. Do not use PROTIUM-1000 in any other way than the one recommended in this manual. Spectronik reserves the right to change system specifications, appearance or discontinue the product at any time.

Warranty Spectronik warrants the included hardware product and accessories against defects in materials and workmanship for the first 30 days after delivery. Spectronik does not warrant against normal wear and tear, nor damage caused by accident or abuse.

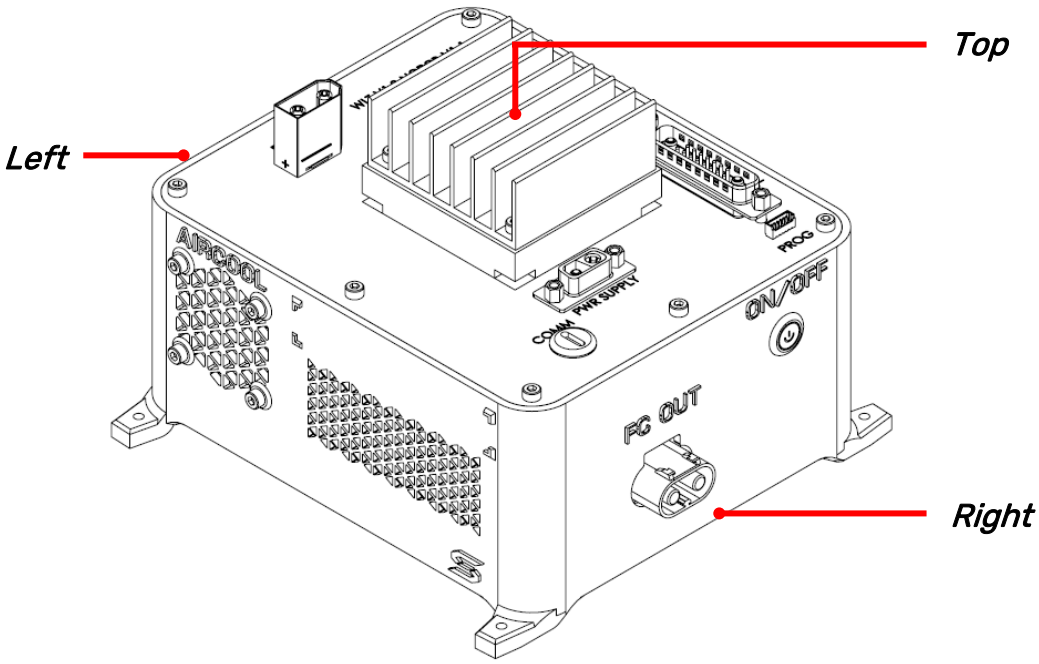
To obtain service, contact: ***hello@spectronik.com***

1 OVERVIEW

Fuel Cell (FC)

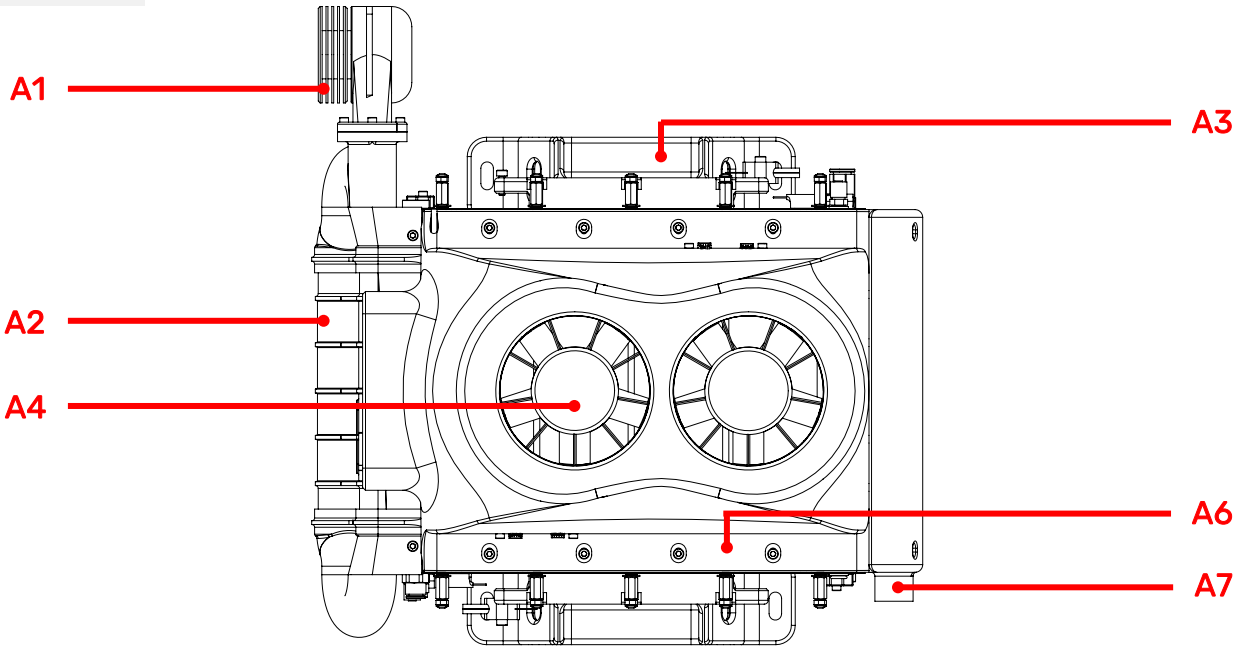


Electronic Controller (EC)

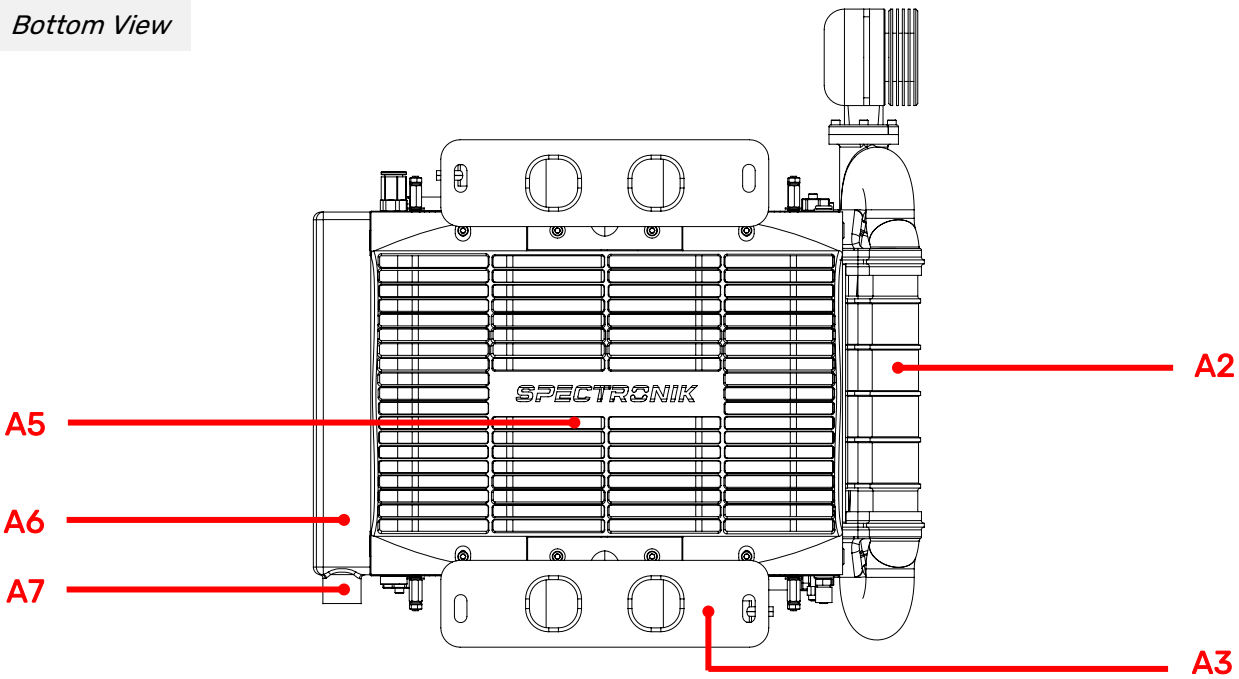


1.1 PROTIUM-1000 FUEL CELL

Top View



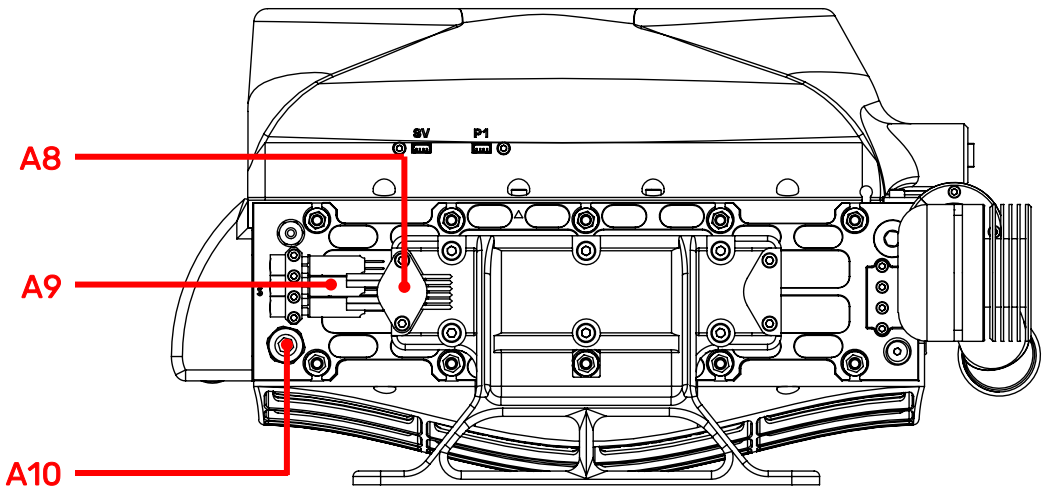
Bottom View



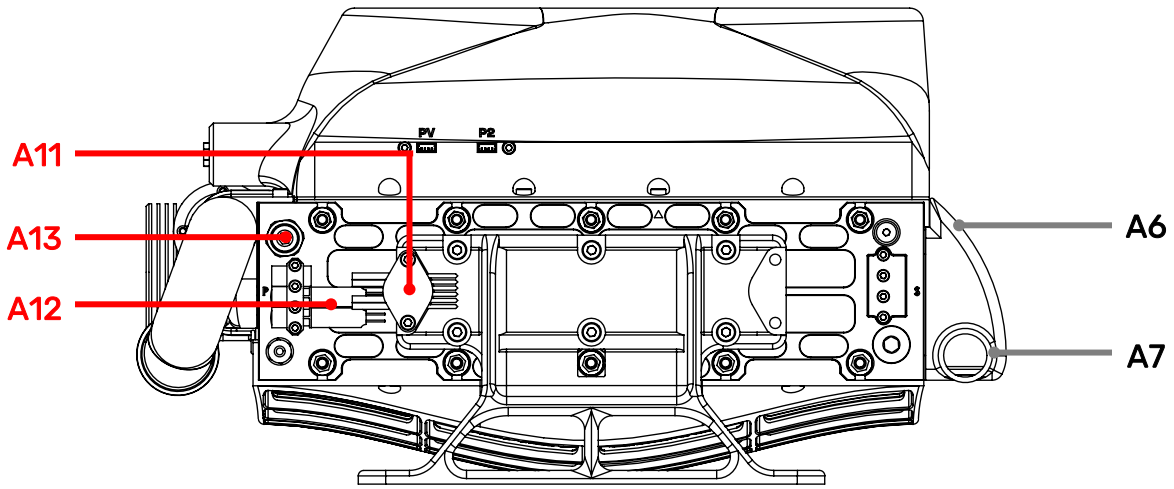
ITEM	DESCRIPTION	ITEM	DESCRIPTION
A1	Oxidant blower	**A2**	Oxidant flow manifold
A3	Mounting plate	**A4**	Cooling fan (x2)
A5	Protective mask	**A6**	Cathode outlet duct
A7	Cathode outlet port (OD Ø20mm)		

1.1 PROTIUM-1000 FUEL CELL

Right View



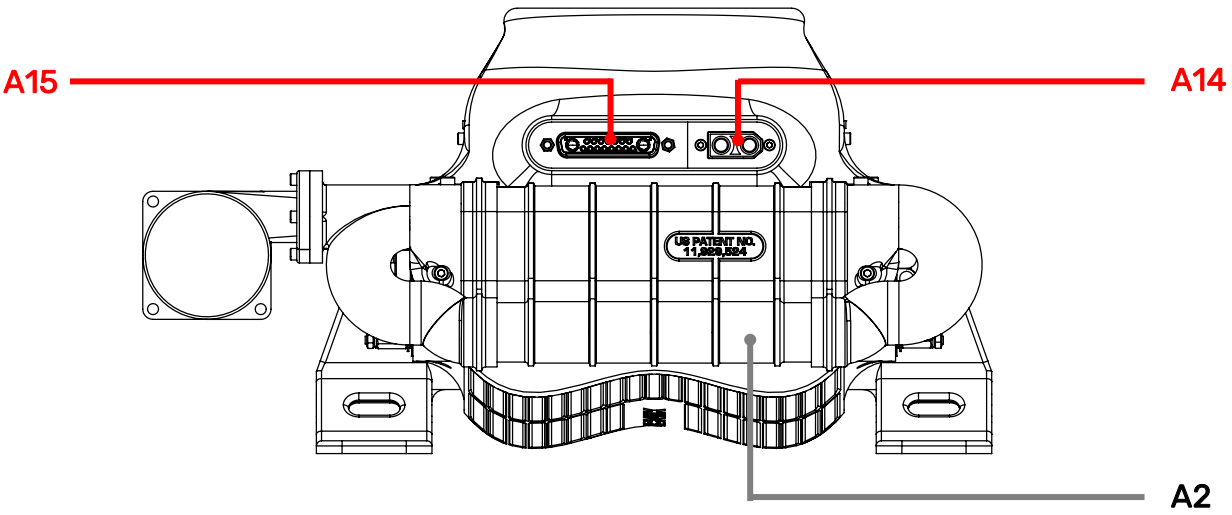
Left View



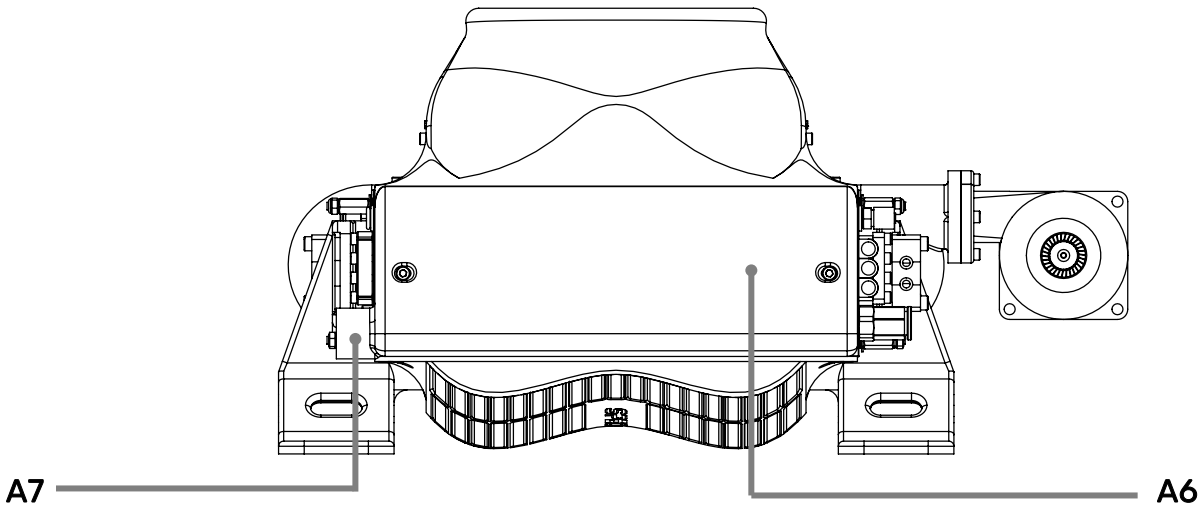
ITEM	DESCRIPTION	ITEM	DESCRIPTION
A8	Gas pressure sensor 1	**A9**	H2 supply valves
A10	H2 gas inlet port *Push-in, tube OD8 ID5.5*	**A11**	Gas pressure sensor 2
A12	H2 purge valves	**A13**	H2 gas outlet port *Push-in, tube OD6 ID4*

1.1 PROTIUM-1000 FUEL CELL

Front View



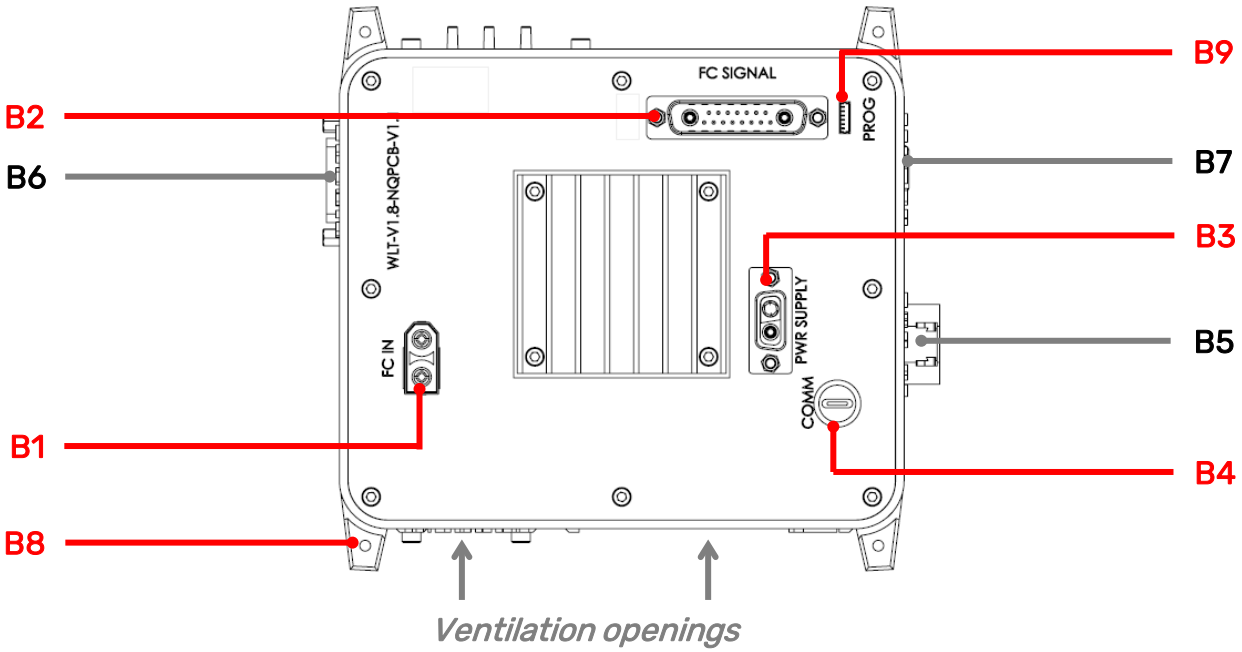
Back View



ITEM	DESCRIPTION	ITEM	DESCRIPTION
A14	FC IN (power input from FC) *XT-90 female*	A15	FC SIGNAL (BOP/Signals with FC) *D-SUB 17W2 receptacle*

1.2 ELECTRONIC CONTROLLER

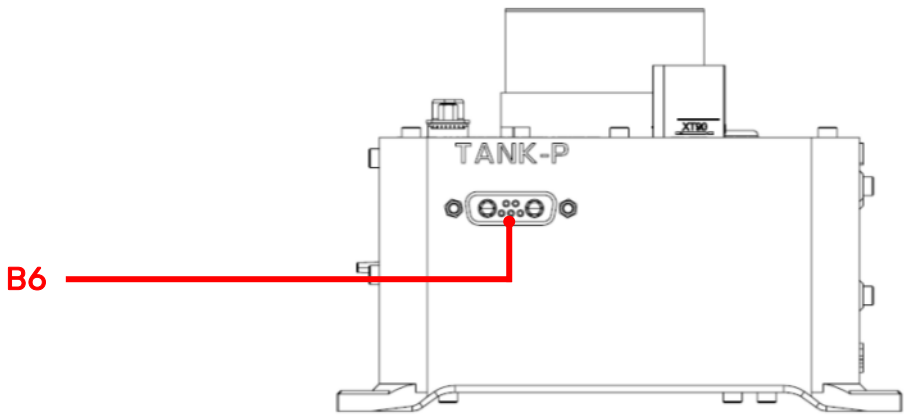
Top View



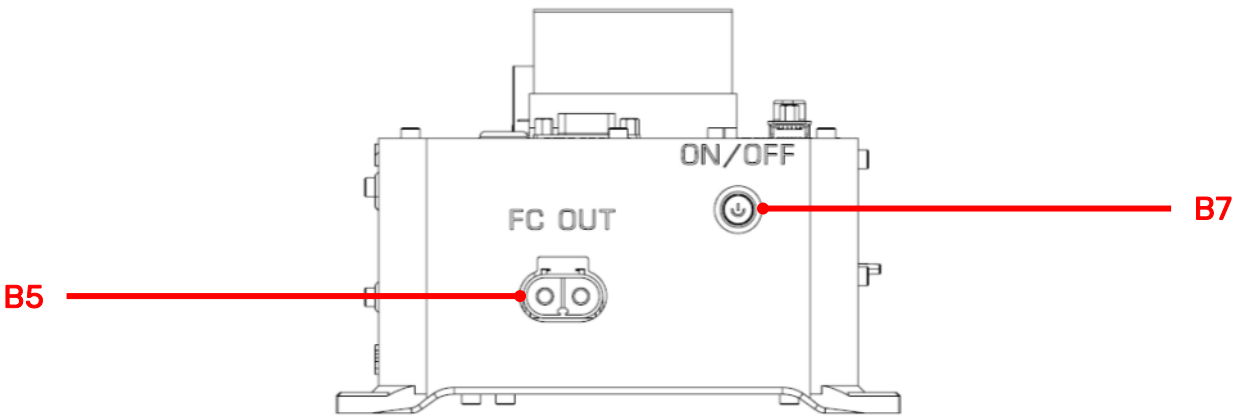
ITEM	DESCRIPTION	ITEM	DESCRIPTION
B1	FC IN (power input from FC) *XT-90 male*	**B2**	FC SIGNAL (BOP/Signals with FC) *D-SUB 17W2 plug*
B3	PWR SUPPLY (auxiliary power input) *D-SUB 2W2 receptacle*	**B4**	COMM (PC Communication) *USB-C female connector*
B5	FC OUT (power output to load) *LCB-50 male*	**B6**	TANK-P (Gas tank pressure monitoring)* *D-SUB 7W2 receptacle*
B7	ON/OFF (FC system on/off) *push-button with LED*	**B8**	Mounting holes *4X Ø3mm*
B9	PROG (firmware programming) *MX1.25 connector*		*only with Spectronik's Miniature Gas Pressure Regulator

1.2 ELECTRONIC CONTROLLER

Left View

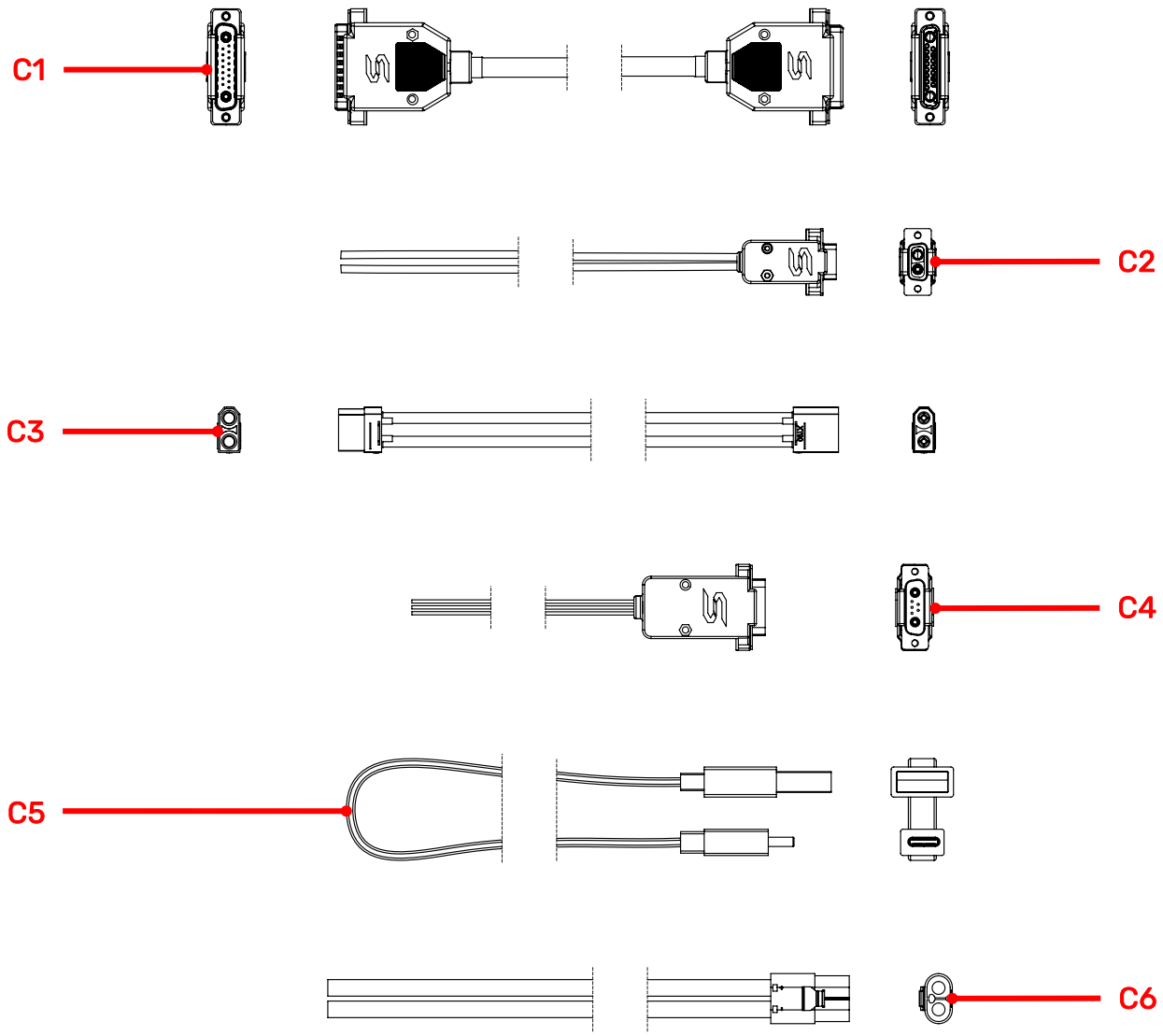


Right View



ITEM	DESCRIPTION	ITEM	DESCRIPTION
B5	FC OUT (power output to load) *LCB-50 male*	B6	TANK-P (Gas tank pressure monitoring)* *D-SUB 7W2 receptacle* *only with Spectronik's Miniature Gas Pressure Regulator
B7	ON/OFF (FC system on/off) *push-button with status LED*		

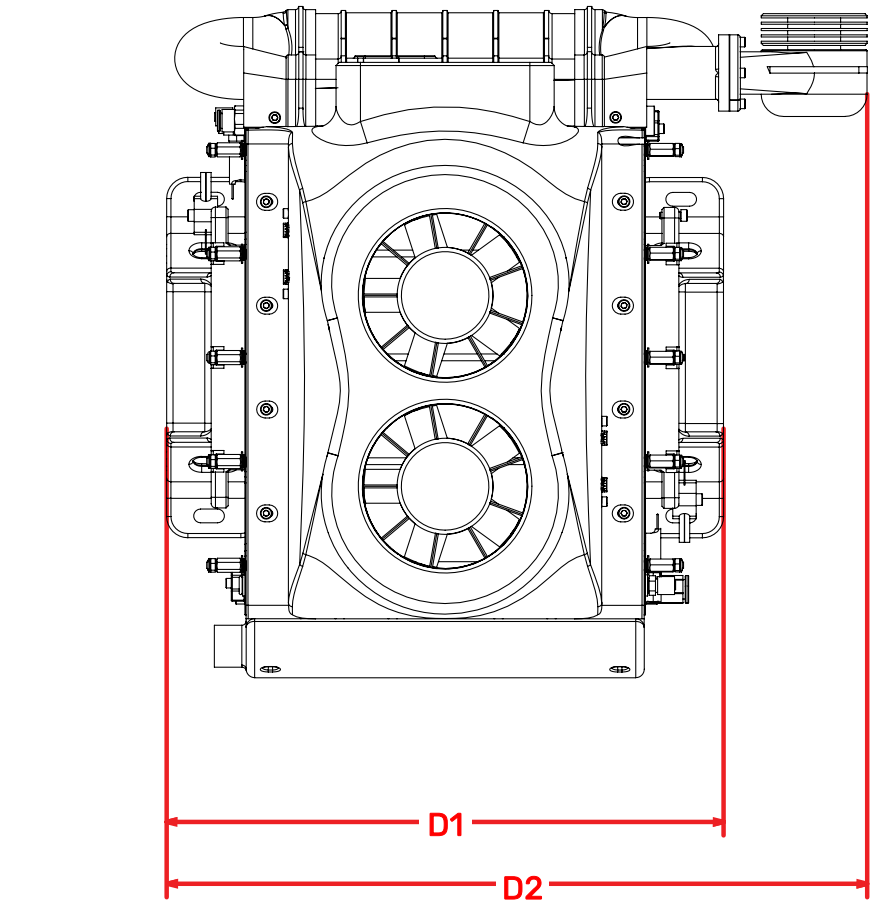
1.3 STANDARD ACCESSORIES

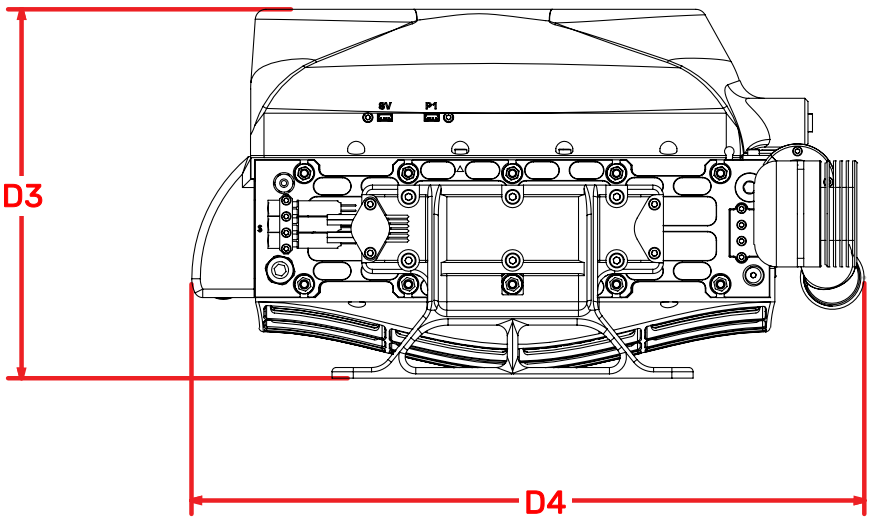


ITEM	DESCRIPTION
C1	FC SIGNAL cable (FC & EC) *Bundled wires with D-SUB 17W2 plug & receptacle*
C2	PWR SUPPLY cable (EC & aux. power) *D-SUB 2W2 plug with free-end wires*
C3	FC POWER cable (FC & EC) *AWG 8 wires with XT-90 male & female*
C4	TANK MONITORING cable* *D-SUB 7W2 plug with free-end wires*
C5	PC COMMUNICATION cable (EC & PC) *Type-c fast data cable*
C6	POWER OUTPUT cable (EC & Load) *LCB-50 female with free-end AWG8 wires*

*only with Spectronik's Miniature Gas Pressure Regulator

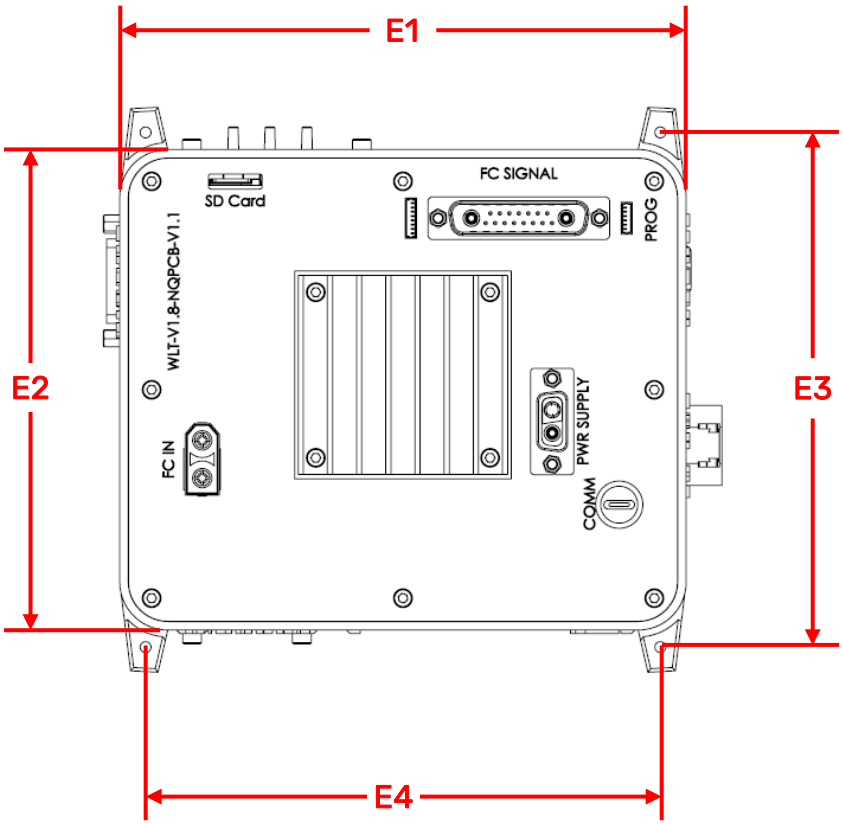
1.4 MECHANICAL DIMENSIONS – PROTIUM-1000

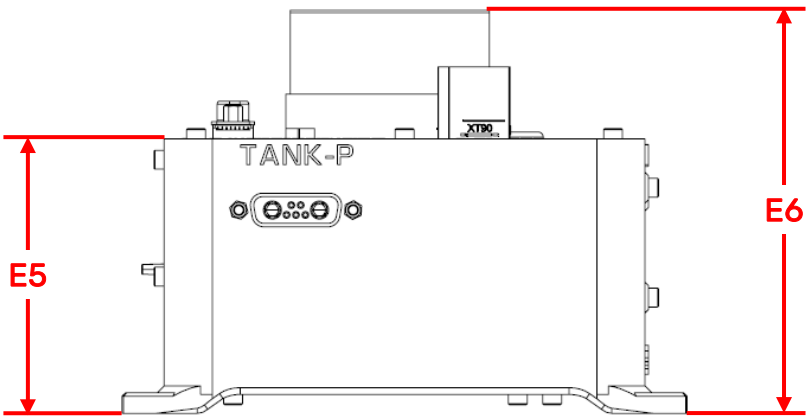




ALL DIMENSIONS IN MM			
D1	263.00	**D2**	331.00
D3	174.00	**D4**	317.00

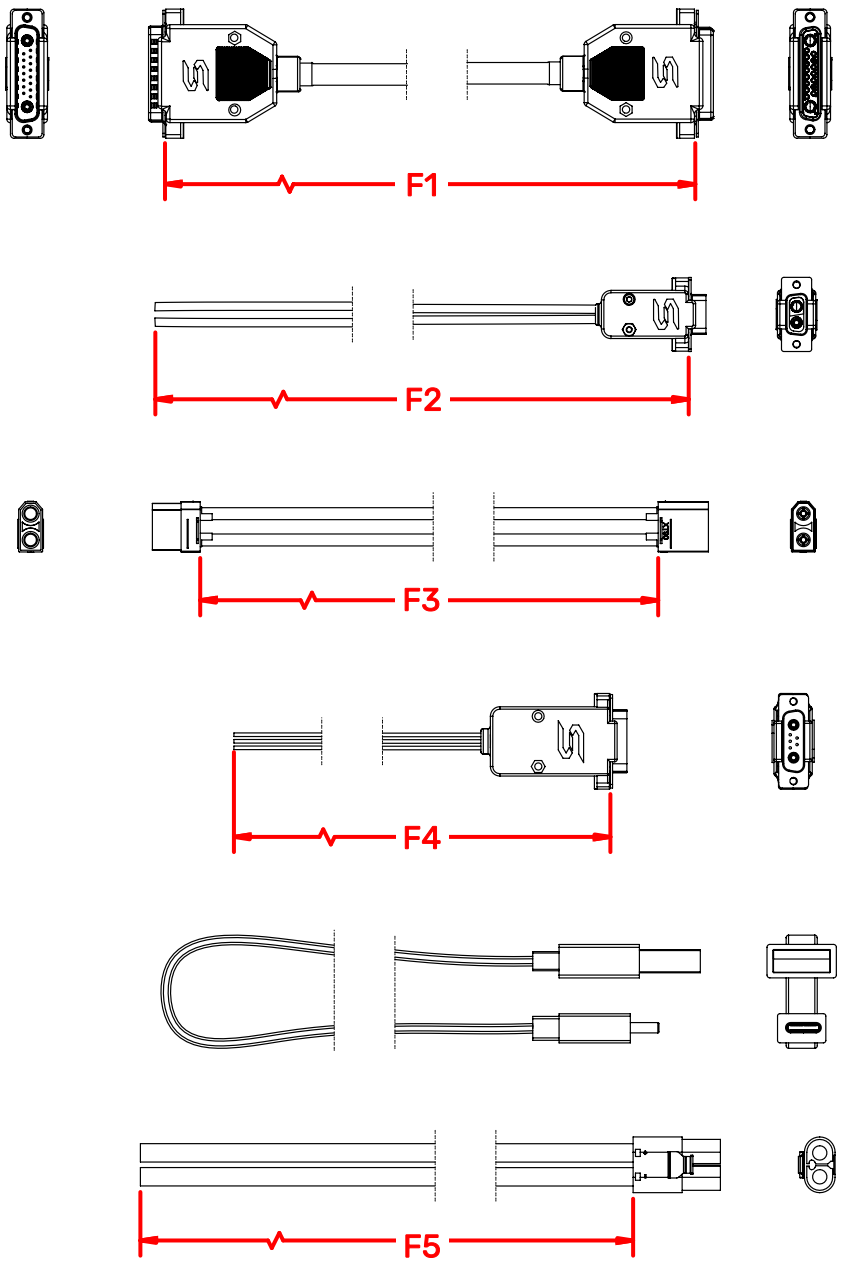
1.5 MECHANICAL DIMENSION – ELECTRONIC CONTROLLER





ALL DIMENSIONS IN MM			
E1	165.10	**E2**	141.10
E3	150.00	**E4**	150.00
E5	80.00	**E6**	117.50

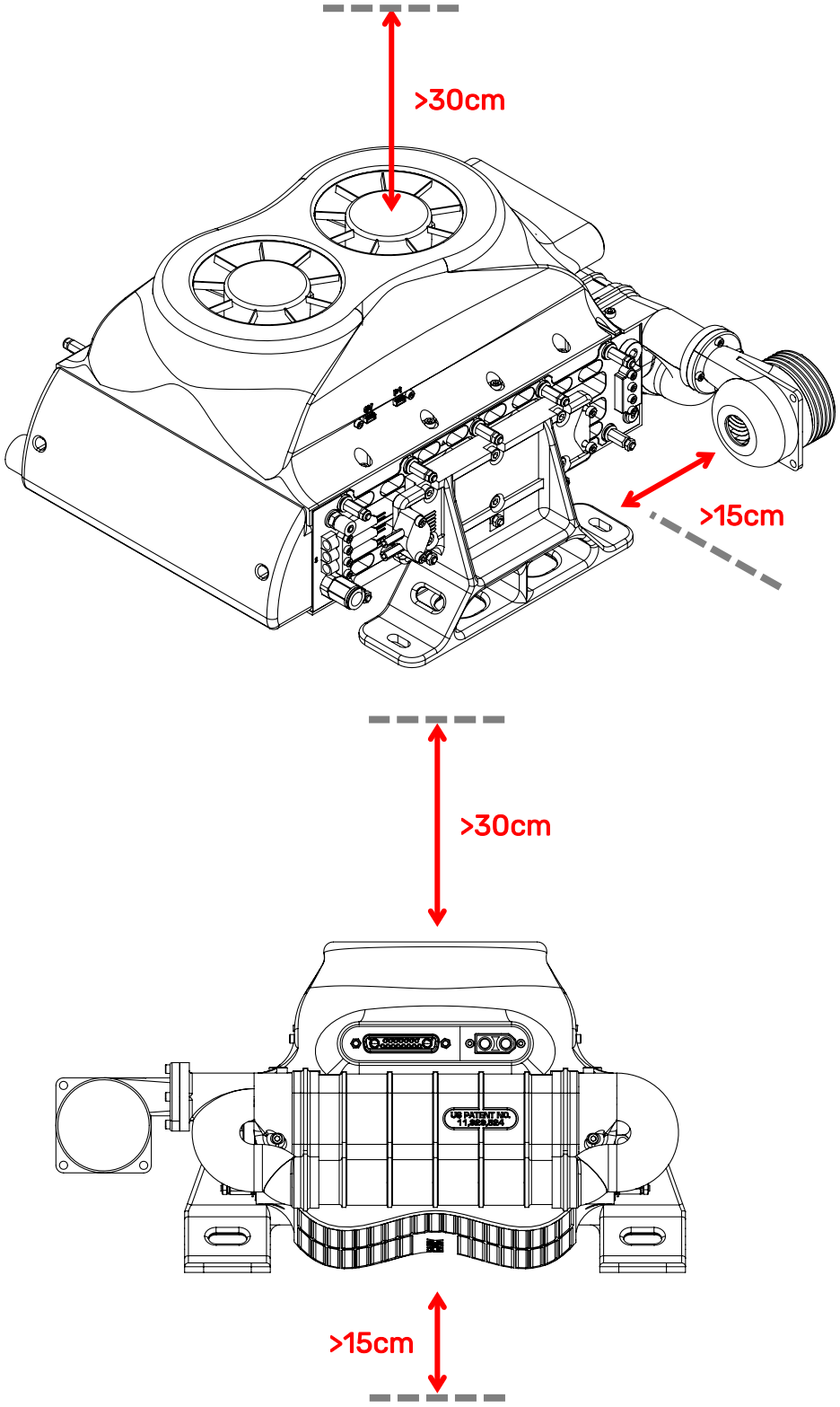
1.6 MECHANICAL DIMENSIONS – STANDARD ACCESSORIES



ALL DIMENSIONS IN MM			
F1	1000.00	**F2**	1000.00
F3	1000.00	**F4**	500.00
F5	1000.00		

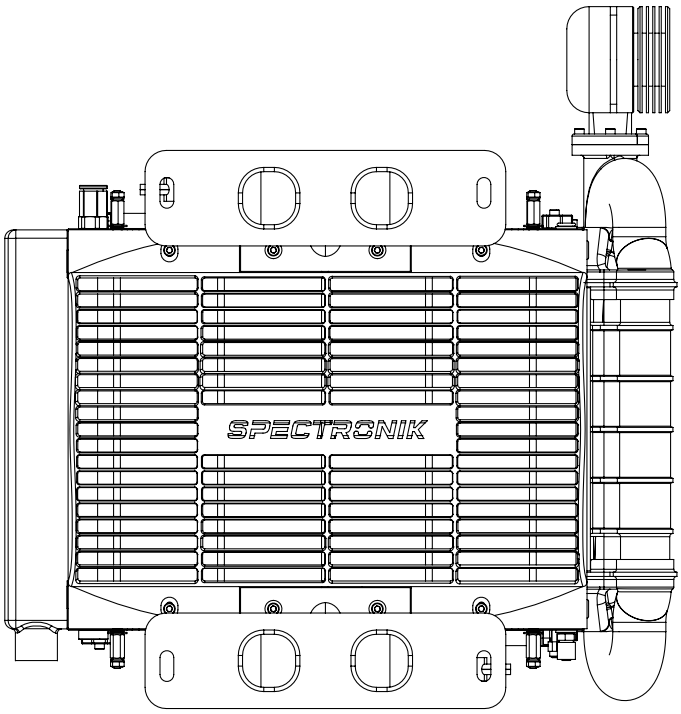
1.7 MOUNTING AND AIR CLEARANCE

Recommended Orientation of PROTIUM-1000



1.7 MOUNTING AND AIR CLEARANCE

Alternative Orientation of PROTIUM-1000

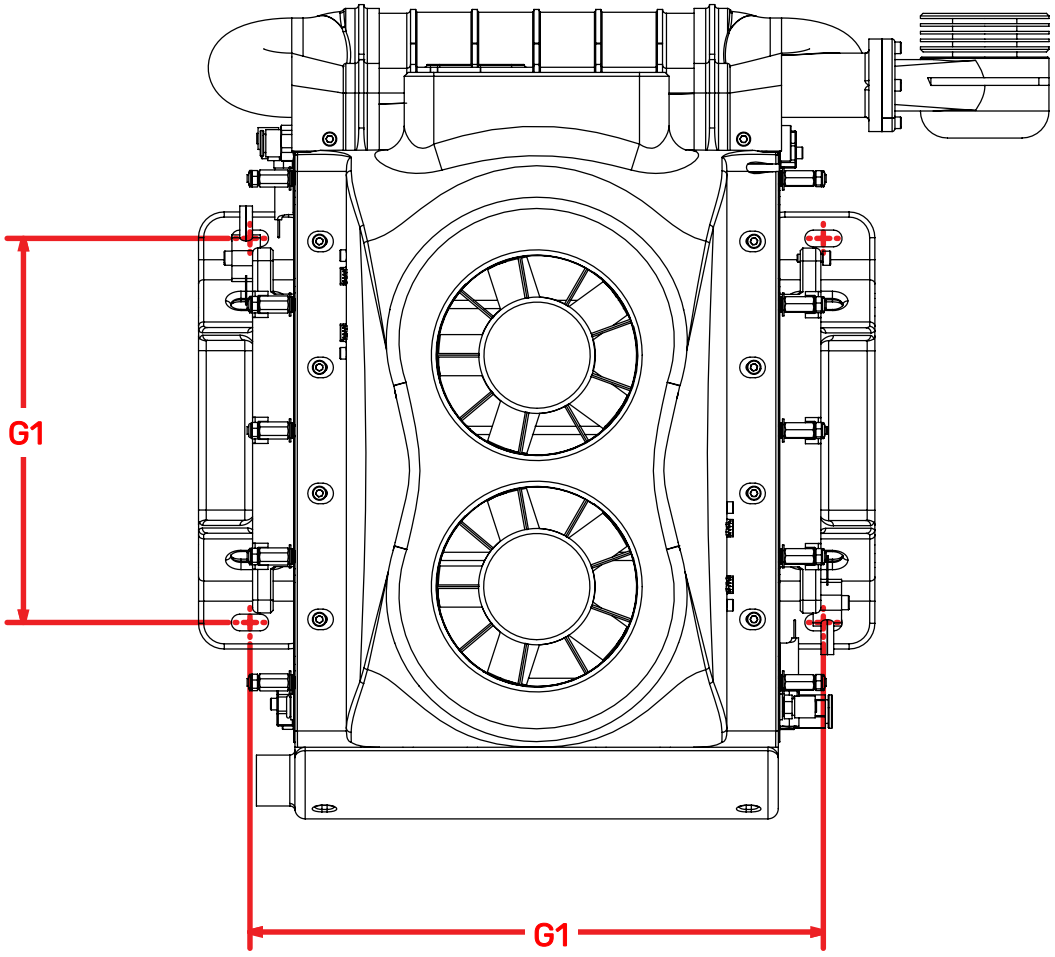


PROTIUM-1000 cannot be mounted in any orientation due to internal routings of the gas streams within the fuel cell stack. The stack should also be level to ensure water does not get trapped in the Cathode channels, obstructing the oxidant flow and causing potential performance drop and cell damage. Mount PROTIUM-1000 horizontally in the recommended orientation.

Alternatively, PROTIUM-1000 can also be mounted vertically with the protective mask facing you.

For optimal oxidant and cooling airflows, it is also recommended that there is at least 15cm unobstructed clearance from the protective mask and oxidant blower inlet, and 30cm unobstructed clearance from the cooling fans' outlet.

1.8 MECHANICAL DIMENSION – MOUNTING AND CLEARANCE



Dimensions of the mounting holes

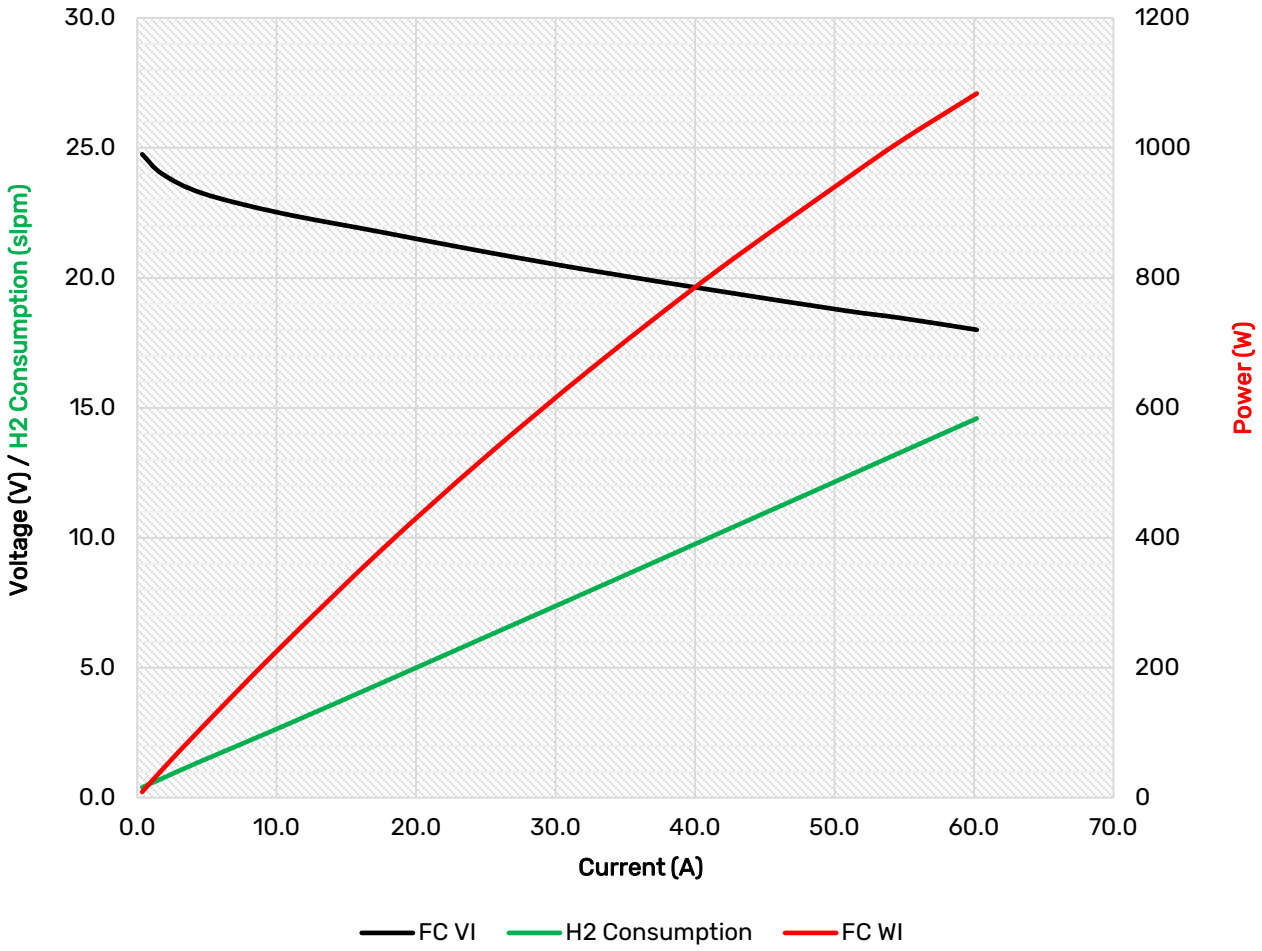
ALL DIMENSIONS IN MM			
G1	149.41 (for M6 bolt)	**G2**	223 ± 8 (slot for adjustment)

2 SPECIFICATIONS

2.1 PROTIUM-1000 TECHNICAL DATA SHEET

Fuel Cell	PROTIUM-1000
Type	PEM
No. of cells	30
Architecture	Closed cathode
Coolant	Air cooled
Rated/gross power	1000/1200W
Rated/gross current	55.5/66.6A
Voltage output	18-27VDC
Start-up time	30s
Operating ambient temp.	[-10,45]°C
Operating altitude without power derating	1500m AGL
System weight	5.1kg
Max dimension	331 x 174 x 317mm
Fuel Supply	
Hydrogen gas	Dry, 99.999% purity
Delivery pressure	0.7bar (10 psig)
Fuel consumption @ rated power	12.5L/min
Gas tubing	PU, 8 x 5.5 (Supply); 6 x 4 (Purge)
Supply & purge control	Solenoid valves with integrated pressure sensor
Stack leakage checks	Automated via integrated pressure sensors
Electronic Controller	
Processor board	WELTER V1.8
External/Auxiliary power supply requirement	15-18V, 150W max
Weight (including casing)	950g
Output connector	LCB-50 male (DC unregulated voltage)
Warning & protections	Low voltage, high/low temperature, high/low pressure, low external/auxiliary power supply, stack leakage
Communication	UART (USB type-c fast data cable for PC connectivity provided)
Data acquisition (DAQ) software GUI	PC app
Remote control	Fan speed, blower speed, manual purge, remote on-off

2.2 VI CURVE

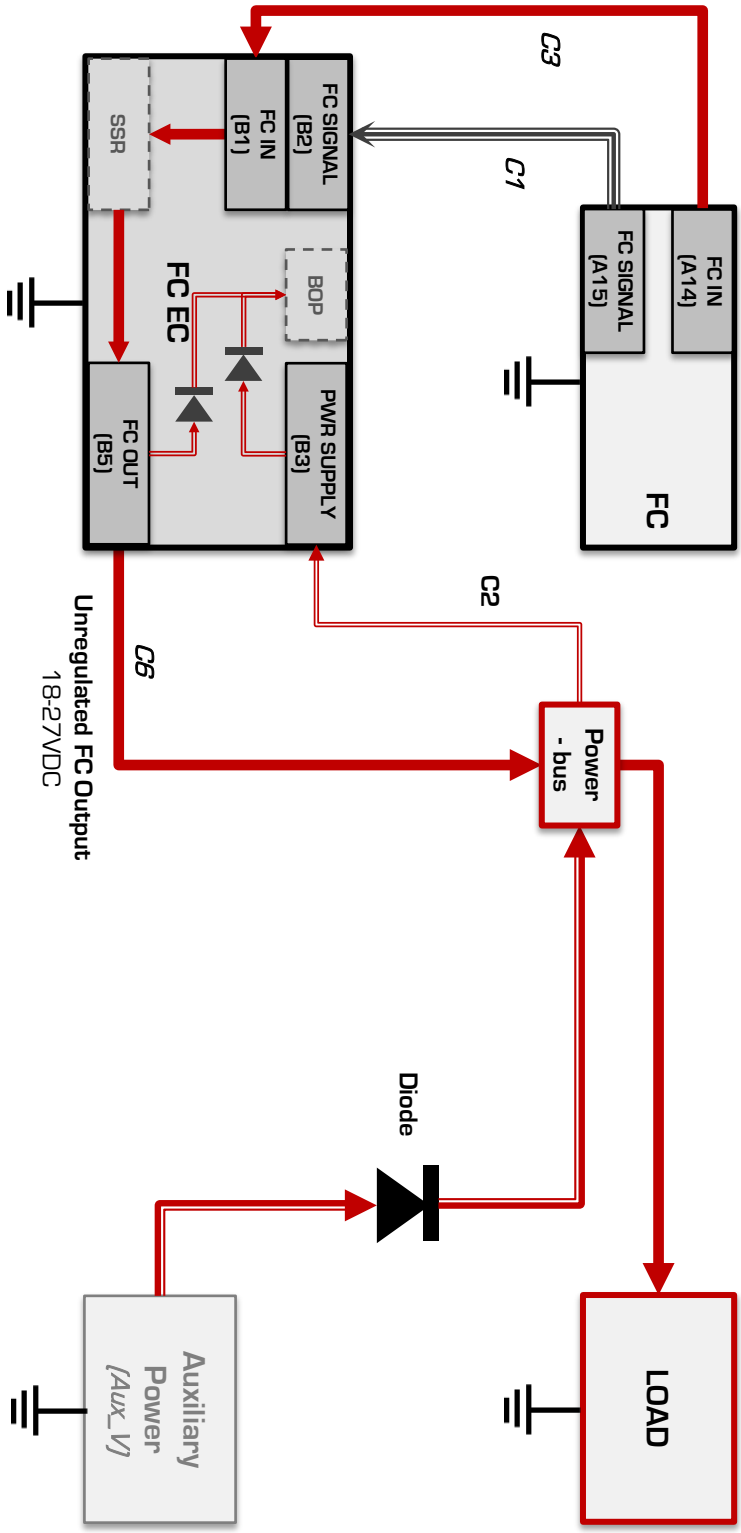


Nominal polarization curve for a fully conditioned PROTIUM-1000 at its Beginning-of-Life (BOL).

TEST CONDITIONS

- Ambient temperature: 24°C
- Relative humidity: 60%
- H_2 supply pressure: 10psig
- Dead-ended operation
- Balance-of-plant (BOP) powered by fuel cell
- T_{cell} at 1000W: 66°C

2.3.1 SYSTEM BLOCK DIAGRAM 1: FC UNREGULATED OUTPUT + PARALLEL AUXILIARY POWER



NOTES

1. When PROTIUM-1000 is at an OFF state, there is no power output at B5. An Auxiliary Power supply (15-18VDC, 150W) is required to initially turn on PROTIUM-1000. This is to power the EC and PROTIUM-1000's Balance-of-Plant (BOP) such as oxidant blower and cooling fans during the **Starting Phase**, when PROTIUM-1000 will do a series of internal diagnostic checks.

2. If everything is normal, PROTIUM-1000 will enter its **Running Phase**. There will now be power output at B5. FC output is unregulated and will range from 27VDC (Open Circuit) down to 18VDC (at its rated power output of 1000W).

3. In Running Phase, the fuel cell will be able to power its own BOP and LOAD, **if FC OUT (B5) voltage is higher than the Auxiliary Power voltage (Aux_V)**.

Tip: use 18VDC Auxiliary Power supply (Aux_V) to ensure that it is always lower than the FC OUT, maximizing PROTIUM-1000's power output.

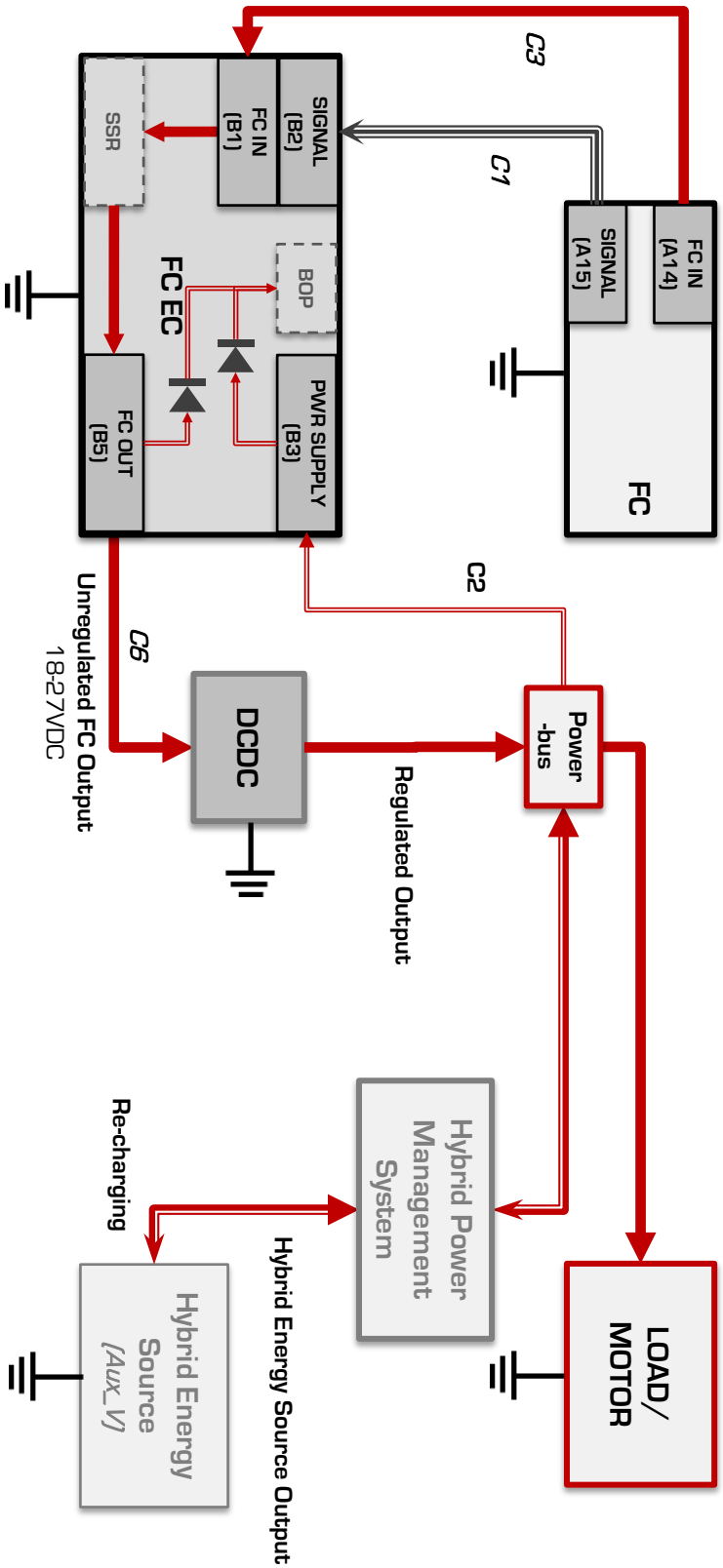
4. The Power-bus is a common point for power distributing and sharing. The source with the higher voltage will contribute first to its maximum power capacity. Demanding more power than this source could provide will cause its voltage to fall and reach the voltage of the other source. Both power sources will then share the LOAD.

Warning: Pulling more power than the respective sources' capacities may cause a short-circuit.

5. A diode can be placed at the Auxiliary Power output. Therefore, a higher voltage at the Power-bus would not cause current reverse flow into the Auxiliary Power supply.

Warning: Ensure that the diode is correctly sized (voltage & current) for its role.

2.3.2 SYSTEM BLOCK DIAGRAM 2: REGULATED DC OUTPUT + PARALLEL BATTERY WITH HYBRID POWER MANAGEMENT SYSTEM



NOTES

1. For a stable and regulated DC voltage output, a DC-DC converter can be added at FC OUT.

Basic requirements for the DC-DC converter:

- Accepts an input voltage range greater than PROTIUM-1000 FC OUT voltage of 18-27VDC;
- Outputs a stable voltage that is required by the application/LOAD;
- Allows the maximum power at both its input and output points at various voltages;
- Withstands higher voltage at the Power-bus than its own output setting;
- Protects against short-circuit and over-voltage;


Tip: Spectronik's Cerebral-55 Smart DC-DC Converter may be considered.

2. A Hybrid Power Management System is a bi-directional device that allows other energy source (e.g. a battery) to be connected in parallel to PROTIUM-1000.

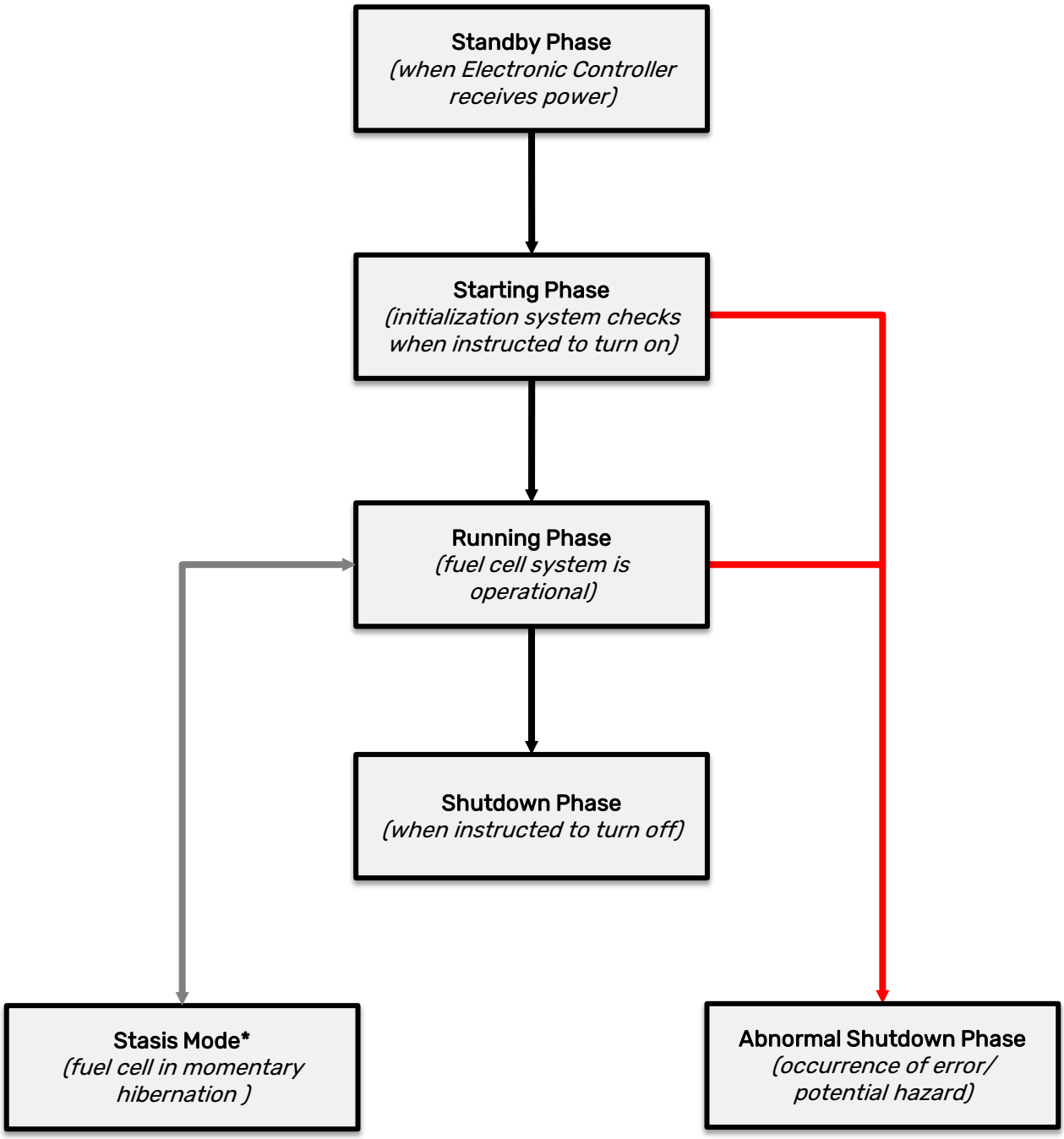
Basic functions of the Hybrid Power Management System:

- Discharges power from the energy source (e.g. battery) to the LOAD, therefore contributing additional "Hybrid power" to supplement PROTIUM-1000;
- Recharges the energy source (e.g. battery) in a controlled manner (set Voltage and Current limits) whenever PROTIUM-1000 has excess power (i.e. LOAD < 1000W).


Tip: Spectronik's Hybrid Power Management System may be considered.


Warning: Ensure correct power/current sizing for both the charging/discharging paths and that all cables/wires are of adequate gauge sizes. Incorrect voltage setting or unlimited current in the charging direction may damage the Hybrid energy source and pose danger to the end-user.

2.4 SYSTEM OPERATION FLOW



*only with purchase of Spectronik Cerebral-55 Smart DC-DC Converter. Also see Section 3.4.

3 OPERATING PROCEDURES

3.1 SETTING UP PROTIUM-1000

1. Mount PROTIUM-1000 securely in the recommended orientation. Ensure that there is nothing blocking the cooling air inlet below the protective mask (**A5**), and sufficient unobstructed clearance from the oxidant blower (**A1**) inlet and cooling fan (**A4**) outlets.

2. There is one Hydrogen gas purge tubing on the left of the fuel cell stack. Ensure that it is securely connected to the H2 gas outlet port (**A13**).

⚠ **Caution:** during operation, there might be unreacted Hydrogen gas coming out of the purge tubing. channel the purge tubing far away from the oxidant blower (**A1**) inlets. Keep away from fire and electric spark. Ensure sufficient ventilation.

3. Connect PROTIUM-1000 to the Electronic Controller using the FC SIGNAL (**C1**) and FC POWER (**C3**) cables.

4. Connect the POWER OUTPUT cable (**C6**) to your load.

Tip: check that the polarity is correct. It is also advisable to put an ON/OFF switch at your LOAD and ensure that it is turned OFF at this time.

5. Connect an Auxiliary Power supply (15-18VDC, 150W) to the PWR SUPPLY receptacle (**B3**) using the supplied PWR SUPPLY plug (**C2**). Make sure that the Auxiliary Power supply is OFF at this stage.

6. PROTIUM-1000 has one H2 gas inlet port (**A10**). Connect your Hydrogen gas here. Make sure that your Hydrogen gas supply is OFF at this stage.

⚠ **Caution:** ensure that the gas pressure is regulated to 0.5-0.7bar gauge. Insufficient delivery pressure may cause cell flooding and drop in performance, while excessive pressure may rupture the fuel cell membrane, causing dangerous gas leakage and irreversible cell damage.

Tip: A good practice is to prepare a gas pressure regulator that can supply 2x PROTIUM-1000's maximum Hydrogen consumption, i.e. around 25L/min at ≥0.5barg.

Spectronik recommend the Miniature Gas Pressure Regulator which is designed to be compatible with PROTIUM-1000.

7. Check that all gas tubing and electrical wire connections are firm and secure.

The setup is now completed and PROTIUM-1000 is ready to be turned on.

3.2 TURNING ON PROTIUM-1000

1. Download the Spectronik Data Acquisition Graphic User Interface (DAQ GUI) PC app from PROTIUM-1000 product webpage and install it on your PC. Follow the instructions in its user manual. If you do not wish to use the DAQ GUI, you can turn on/off PROTIUM-1000 by using the physical ON/OFF push button (**B7**). However, you will not be able to monitor the performance nor access some functions.

2. Connect the PC COMMUNICATION cable (**C5**) to the COMM port (**B4**) and your PC. Launch the DAQ GUI software. Choose the Com Port, set the Baud Rate (57600) and click the S button.

3. Turn on your Auxiliary Power supply and wait for 5s. A welcome message should appear in the GUI. Status LED on the ON/OFF push button (**B7**) will blink at 10%. Once the Electronic Controller receives power, it will enter **Standby Phase**, awaiting instruction to initiate.

4. Click START. Alternatively, press and hold the ON/OFF push button (**B7**) for more than 2s. PROTIUM-1000 will enter its **Starting Phase** and the message "Low H2 supply" should appear.

5. Turn on your H2 gas supply.

6. PROTIUM-1000 will do a series of gas purging and internal diagnostic checks. The cooling fans and oxidant blower will turn on. If everything is normal, the system will enter its **Running Phase** – indicated by the message in the GUI and a solid white Status LED. All system parameter values can now be seen in the GUI. If there is something wrong, the Status LED will flash and error message will appear in the GUI. Follow the basic troubleshooting guide in section 4.

7. During operation, it is normal to see water coming out of the Cathode outlet duct (**A6**) and purge tubing. Ensure that water does not drip to any electrical components.

Tip: Connect a tubing to the Cathode outlet port (**A7**) to channel the water to a drainage or collection point.

PROTIUM-1000 is now ready to power your application.

3.3 POWERING YOUR LOAD WITH PROTIUM-1000

1. Turn ON your load and draw power as per normal. ***Caution:*** *never pull the fuel cell voltage below 18V or draw power beyond 1000W.*

   If Hybrid Energy Source (e.g. Lithium battery) is connected at the Power-bus, PROTIUM-1000 will provide up to its maximum rated output and the rest is augmented by the battery. The total power available depends on the capacity of the battery. If no battery is connected at the Power-bus, the following guideline is recommended:

Electronic Load Modes	Range	Ramp-rate
Constant Voltage Load	Open circuit voltage to 18VDC min or 1000W max	-1VDC/second
Constant Current Load	0A to 55A or 1000W max	+5A/second
Constant Power Load	0W to 1000W max	+100W/second

2. During **Running Phase**, the following live status of the fuel cell can be monitored from the GUI.

Parameters	Description
FC_V	FC voltage (V)
FC_A	FC current (A)
FC_W	FC power (W)
ENERGY	Energy delivered by the fuel cell during this operation (Wh)
FCT1	FC temperature at location 1 (˚C)
FCT2	FC temperature at location 2 (˚C)
FAN	Cooling fan duty cycle (%)
BLW	Oxidant blower duty cycle (%)
EXIT-IP*	Initiation Point for fuel cell to exit stasis mode (V)
ENTRY-TP*	Termination Point for fuel cell to enter stasis mode (V)
H2P1	H_2 supply pressure (Barg)
H2P2	H_2 pressure in FC (Barg)
Tank-P**	Gas tank pressure (Barg)
AuxV	External power supply voltage (V)

* only with purchase of Spectronik Cerebral-55 Smart DC-DC Converter. Also see Section 3.4.
** only with purchase of Spectronik Miniature Gas Pressure Regulator.

3. During **Running Phase**, you may manually control PROTIUM-1000 by clicking commands in the GUI such as Purge, increasing/decreasing oxidant blower speed and cooling fan speed.

⚠ **Caution:** manual control is recommended for advanced users only. For optimal performance, remember to reset to AUTO controls.

3.4 RUNNING PROTIUM-1000 IN STASIS MODE WITH CEREBRAL-55

The **Stasis Mode** function allows autonomous transition for PROTIUM-1000 to enter a temporary hibernation. The primary function is to save Hydrogen fuel. The Trigger Points to enter/exit Stasis Mode is purely dependent on the Aux_V Voltage.

Stasis Mode is recommended only for advanced users with strong knowledge of Lithium battery and fuel cell hybridization setup including sizing the battery capacity to receive fuel cell charging power.

To ensure user's safety, **Stasis Mode** is currently only available with the purchase of Spectronik Cerebral-55 Smart DC-DC Converter and its accompanying DAQ GUI (PRO) version.

Stasis Mode function can be set active/inactive via the DAQ GUI only during **Standby Phase**. Toggle the STASIS MODE button on/off as desired.

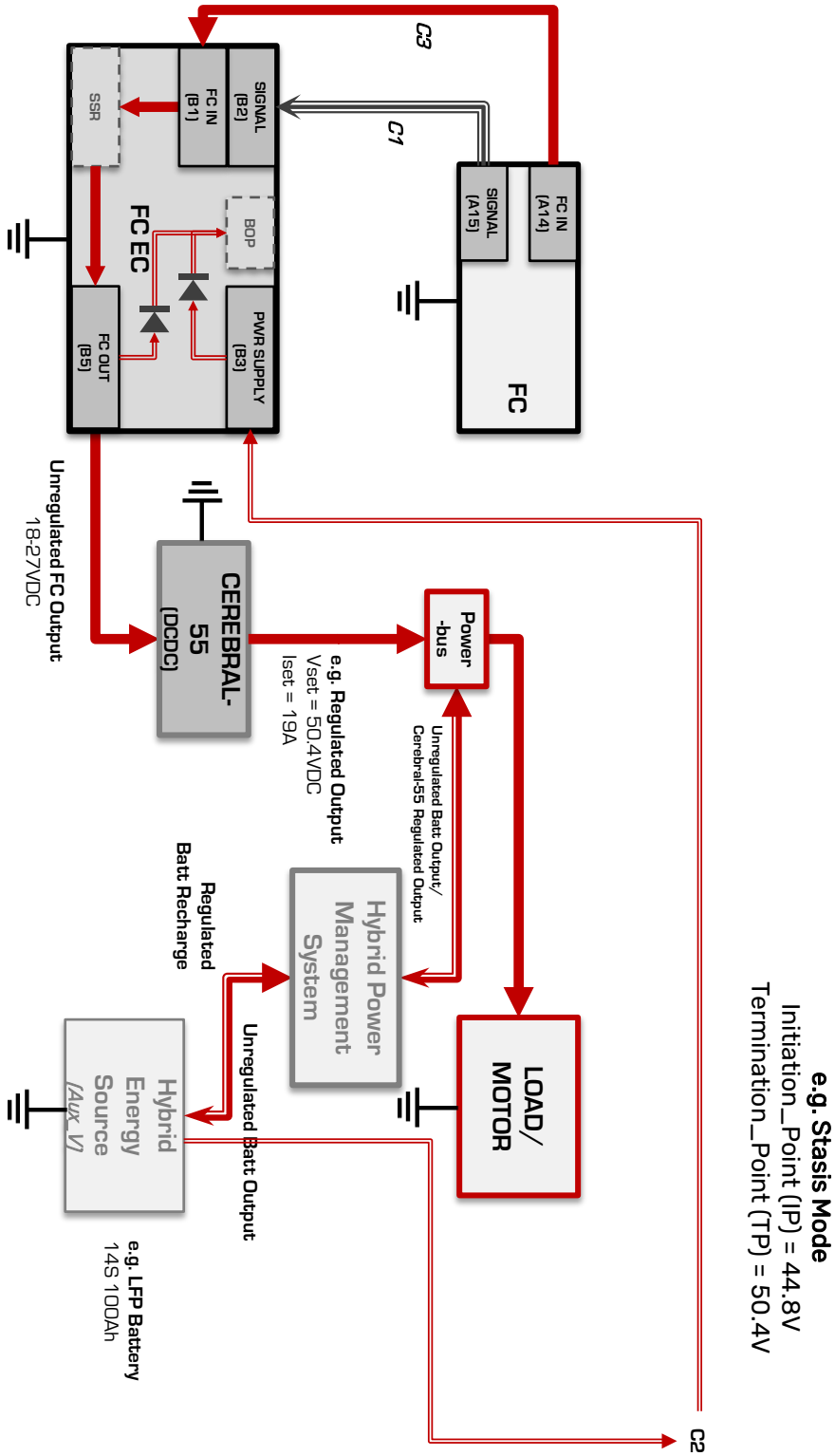
Stasis Mode is restricted by the following conditions (see block diagram on next page):

- Cerebral-55 is connected to FC OUT (**B5**), providing stable Voltage and Current output to the Power-bus (e.g. Vset = 50.4VDC, Iset = 19A, Power = 958W).

⚠ **Caution:** the Voltage and Current output limits of Cerebral-55 must be adhered to, and that the product of the Voltage and Current output cannot exceed the fuel cell's rated power output.

- Hybrid Energy source output (e.g. LFP battery 14S 100Ah) is connected in parallel to Cerebral-55 output at the Power-bus.
- PWR SUPPLY (**B3**) must now be connected directly to the Hybrid Energy source and will serve as its voltage sensing line.
- The fuel cell will autonomously enter hibernation when Aux_V reaches Termination Point (TP) – defined as the voltage where the battery is deemed to be full (e.g. TP = 50.4VDC).
- The fuel cell will autonomously exit hibernation when Aux_V drops to Initiation Point (IP) - defined as the voltage where the battery is deemed to be depleted and requires fuel cell recharging (e.g. IP = 44.8VDC).

Example of **Stasis Mode** configuration:



3.5 SHUTTING DOWN PROTIUM-1000

1. Turn OFF your load. The cooling fans will turn faster to cool down the fuel cell, before returning to their minimum speed.

2. In the GUI, click END. Alternatively, press and hold the ON/OFF push button (**B7**) for more than 2s. The message "Shutdown Initiated" will appear in the GUI and PROTIUM-1000 will enter its **Shutdown Phase** by carrying out a series of shutdown procedures such as turning off the gas supply valves, cooling fans and oxidant blower.

3. The message "System OFF" will appear in the GUI. PROTIUM-1000 is now turned off. Status LED on the ON/OFF push button (**B7**) will blink at 60% on standby awaiting the next start-up command.

4. If you do not intend to restart the system soon, turn OFF your Hydrogen gas supply and remove the Hydrogen gas tubing from the H2 gas inlet port (**A10**).

⚠ **Caution:** some remaining gas in the tubing will be released into the atmosphere.

5. Turn OFF the Auxiliary Power supply. All the cables can now be disconnected.

PROTIUM-1000 is now ready to be kept for storage.

4 SYSTEM MONITORING, PROTECTIONS & MANUAL CONTROL

4.1 MANUALLY CONTROLLING THE PROTIUM-1000

The PROTIUM-1000 comes with in-built firmware control that is optimized to bring out its best performance over the applicable ambient environment range. In normal use-case scenario, there is no need for user to fine-tune the parameters. For advanced user who wishes to control the fuel cell manually, the following commands can be entered via the GUI's keyboard function:

Command	PROTIUM-1000 action
start <enter>	Starts the system
end <enter>	Enters normal shutdown phase
ver <enter>	Displays the firmware version
f <enter>	Return to automatic cooling fan control
b <enter>	Return to automatic oxidant blower control
p <enter>	Open the Hydrogen purge valve for 2s. This is useful to remove excess water if cell flooding is suspected due to decreasing power output.
= (equal)	Increase cooling fan speed by 5% (manual control)
- (hyphen)	Decrease cooling fan speed by 5% (manual control)
0	Increase cooling fan speed by 1% (manual control)
9	Decrease cooling fan speed by 1% (manual control)
]	Increase oxidant blower speed by 3% (manual control)
[	Decrease oxidant blower speed by 3% (manual control)

Tip: you may also long press the ON/OFF push button (**B7**) by >2s to turn ON/OFF the system instead of entering "start" and "end" command via the GUI.

4.2 SYSTEM WARNING & PROTECTIONS

PROTIUM-1000 has several in-built protections. The Status LED on the ON/OFF push button (**B7**) will flash and error message will appear in the GUI. Follow the basic troubleshooting guide below. Most errors should be rectified once the suggested corrective action has been done and the system restarted.

If the error persists, contact hello@spectronik.com.

4.3 SYSTEM WARNING & PROTECTIONS – STARTING PHASE

Warning messages during Starting Phase:

Message	Meaning/ Corrective Action
Gas Tank Not Detected *	Either the gas tank communication cable is not connected or the tank is empty.
Gas Tank Pressure Low *	There is less than 20 Bar remaining in the gas tank.
Gas Tank Insufficient Pressure *◉	There is not enough pressure in the gas tank to start.
Low H2 Supply	Hydrogen supply pressure is low and the system will wait up to 1min for correction. Please check and correct the delivery pressure.
Error: Low H2 Supply ◉	Hydrogen is not correctly supplied within the stipulated time limit. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
Over Pressure	Hydrogen supply pressure is too high and the system will wait for 1min. Reduce the delivery pressure.
Error: Over Pressure ◉	Hydrogen is not properly supplied within the stipulated time limit. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
High Temperature	Stack temperature is too high and the system will wait for 1min.
Error: High Temperature ◉	Disconnect everything and wait for system to cool down and restart after 10min. If the problem persists, internal temperature sensor might have been compromised. Contact Spectronik.
Error: FC Over Cooled ◉	Stack temperature is too low. Wait for ambient temperature to increase and restart the system.
FC Sealing Compromised ◉	Possible stack leakage. Check and ensure all gas tubing and connectors are securely connected.
Error: Low Voltage ◉	Stack open circuit voltage is too low. Check and ensure sufficient hydrogen supply and correct delivery pressure. Restart after 1 min.
Purge Valve Error ◉	The Purge Valves might not be activating. If the environment is cold, try heating it up.
Supply Valve Error ◉	The Supply Valves might not be activating. If the environment is cold, try heating it up.
Gas Tank Outlet is Leaking *◉	There has been an unwarranted pressure drop between Gas Tank and Supply Valves. Please verify gas line connections.

◉ *Emergency Shutdown = **Abnormal Shutdown Phase** would be activated*

* *with purchase of Spectronik Miniature Gas Pressure Regulator*

4.4 SYSTEM WARNING & PROTECTIONS – RUNNING PHASE

Warning messages during Running Phase:

Message	Meaning/ Corrective Action
High Temperature ●	Stack temperature is too high. The fuel cell power output to load will be temporarily disconnected for 5s for system to recover. LED will blink. Reduce your load.
Error: High Temperature ◉	Stack temperature is too high. Disconnect everything and wait for system to cool down and restart after 10min. If the problem persists, internal temperature sensor might have been compromised. Contact Spectronik.
Low Temperature ●	Stack temperature is low. LED will blink.
Error: FC Over Cooled ◉	Stack temperature is too low for operation.
Low Voltage ●	Stack Voltage at minimum threshold of 0.6V/cell.
Error: Low Voltage ◉	Stack Voltage below safety threshold limit.
Low H2 Supply ●	Hydrogen supply pressure is low and the fuel cell power output to load will be temporarily disconnected. LED will blink. Check and ensure sufficient Hydrogen supply and correct delivery pressure.
Error: Low H2 Supply ◉	Hydrogen supply pressure is too low. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
High H2 Supply Pressure ●	Hydrogen supply pressure is too high and the supply valve will be temporarily shut off. Reduce the delivery pressure.
Error: High H2 Supply Pressure ◉	Hydrogen supply pressure is too high. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
Low AuxV ●	The External Power Supply is at below 15V.
Gas Tank Running Low *●	The pressure in the gas tank is below 20 Bar.
Gas Tank Depleting *●	The pressure in the gas tank is below 10 Bar.

◉ *Emergency Shutdown = **Abnormal Shutdown Phase** would be activated*

● *Status LED flashing at 80% to alert warning during **Running Phase***

* *with purchase of Spectronik Miniature Gas Pressure Regulator*

4.5 SYSTEM WARNING & PROTECTIONS – LED STATUS & OTHER MESSAGES

LED Status:

Phase	Blink % (at 1Hz)	Meaning
Power ON/ Standby Phase	10%	5s after start-up power is provided into the Electronic Controller, LED will blink at 10%, indicating that the system is ready to receive its “start” command
Starting Phase	40%	Executing **Starting Phase** procedures
Running Phase	100%	System in normal **Running Phase**
Running Phase	80%	System warning during **Running Phase**
After shutdown	60%	System off due to normal shutdown and on standby for the next “start” command
Abnormal Shutdown Phase	0%	System off due to abnormal shutdown

Other messages:

Message	Meaning
Fan PWM auto	Cooling fans control is in auto mode
Fan PWM manual	User has manually changed the fan setting
Blower auto	Blower control is in auto mode
Blower manual	User has manually changed the blower setting
Mileage	Cumulative Watt-Hour of the system
Shutdown Initiated	Entering normal **Shutdown Phase**
Abnormal Shutdown Initiated	Entering **Abnormal Shutdown Phase** due to an error
System off	System is turned off and ready to restart at the next command
Battery reached set point; system entered stasis mode	AuxV reached Termination Point (TP) voltage and fuel cell enters **Stasis Mode**
Running in Stasis Mode	Fuel cell is in **Stasis Mode**

5 MAINTENANCE AND STORAGE

5.1 MAINTENANCE FOR PROTIUM-1000

When not in use, Spectronik recommends that PROTIUM-1000 is reconditioned at least once a month.

1. Set up PROTIUM-1000 as per instructions in Section 3 (System Block Diagram 1 with Auxiliary Power supply set at 18VDC), using a DC electronic load in lieu of your regular load.

2. After the system enters **Running Phase**, set constant voltage (CV) load of 18VDC and run the system for 1h. The fuel cell should recover to its maximum rated power output.

PROTIUM-1000 is now ready for usual operation or can be stored again for future use.

5.2 STORAGE

Keep PROTIUM-1000 in an open, cool (standard room temperature of 25^{o}C) and dry place.