Nexa™ (310-0027) Power Module User's Manual

5,000,001 Series PBS

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i. Revision History

Revision Record				
Rev	**CO**	**Description**	**Revised by**	**Date**
0E	CO07704	Change of 02 warning level from 19.5 to 19.2 %	Chris Gibson	2005/02/28
0D	CO08184	Added note to minimum acceptable fuel pressure specification.	FZ	2004/10/22
0C	CO07613	Updated ISTA procedure from 1 to 1A & 1B	NK	2004/03/30
0B	CO06417	Preventative Maintenance Schedule Added	NK	2004/02/10
0A	CO	Nexa Installation and Integration Guides merged into one document	MT	2003/06/16

ii. Confidentiality

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iii. Certification

The Nexa™ power module is UL and CSA approved.

iv. Disclaimer

This manual incorporates safety guidelines and recommendations. However, it is not intended to cover all situations. It is the responsibility of the customer to meet all local safety requirements and to ensure safety during operation, maintenance and storage of the Nexa™ power module.

Although all efforts have been made to ensure the accuracy and completeness of the information contained in this document, Ballard reserves the right to change the information at any time and assumes no liability for its accuracy.

v. Glossary

AC	Alternating Current
BAR g	Bar gauge pressure
Cold Start	A start up attempt when Nexa™ has reached a steady state at ambient temperature
CVC	Cell Voltage Checking system
DBA	Decibel
DC	Direct Current
Fuel cell stack	Individual fuel cells combined
Indoors	Inside a building or shelter where natural airflow is limited or enhanced by forced ventilation systems
kW	Kilowatt
kPa(g)	Kilo-Pascals gauge pressure
LPH	Litres per hour
MTBF	Mean Time Between Failure
OEM	Original Equipment Manufacturer
Outdoors	Location where natural airflow is not restricted and where Nexa™ is sufficiently protected by an outer enclosure against bad weather. Never operate Nexa™ in wet, freezing or marine conditions. Nexa™ must always be protected from wind, blowing sand and dust.
PSIG	Pounds per square inch – gauge pressure
SCFM	Standard cubic feet per minute
SLPM	Standard litre per minute, measured at 1 atm, 0°C
UPS	Uninterrupted power supply
V	Volt
VDC	Voltage, Direct Current
BOL	Beginning of Life
EOL	End of Life

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1 Introduction

The Nexa™ power module is a small, low maintenance and fully automated fuel cell system designed to be integrated into products for portable and back-up power markets. It is ready to integrate into a variety of products for household and commercial use. The Nexa™ power module is not designed for medical applications or mission critical use.

The Nexa™ system provides up to 1200 watts of unregulated DC power at a nominal output voltage of 26 VDC. With the use of an external fuel supply, operation is continuous, limited only by the amount of fuel storage. Using hydrogen fuel, the Nexa™ module is extremely quiet and produces zero harmful emissions, permitting indoor operations.

This manual describes the Nexa™ system design and operation. It provides technical product specifications, performance characteristics and interface requirements for installation and operation. Important safety information is also included. Please review the contents of this manual before operating your Nexa™ module and contact Ballard Customer Service if you have any questions.

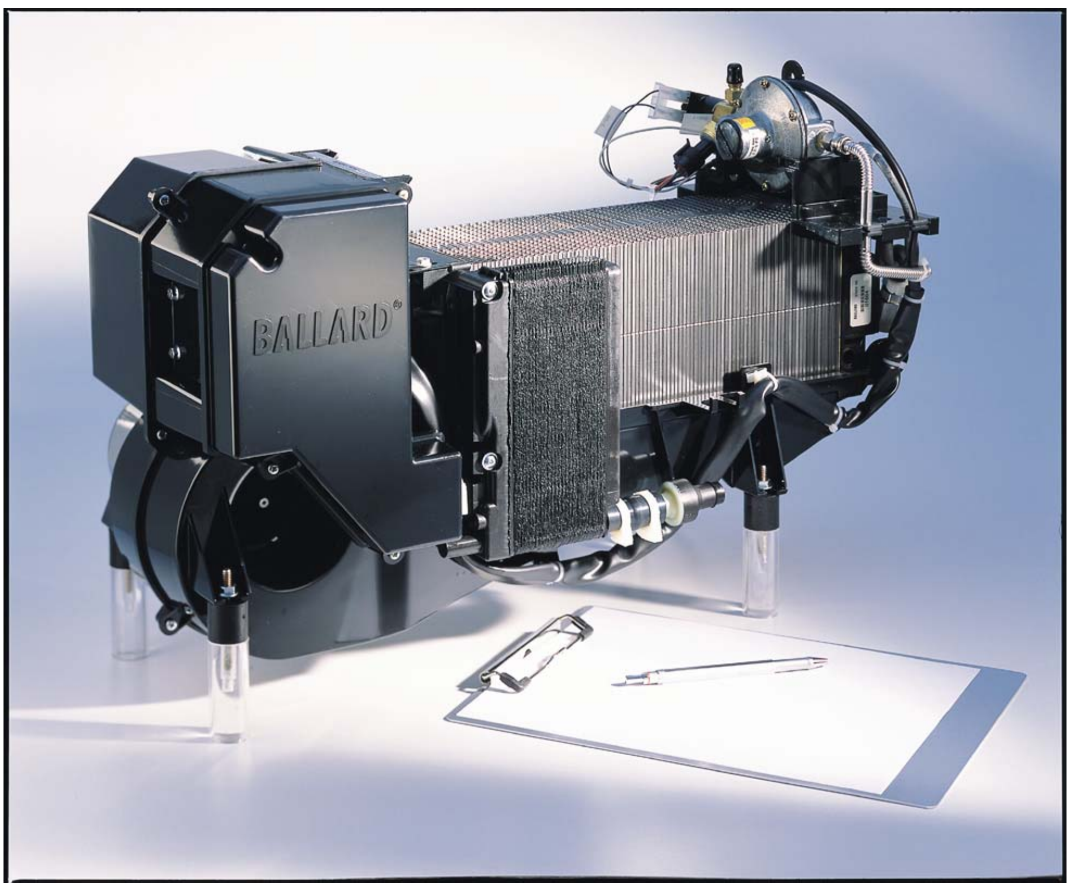


Figure 1: The Nexa™ Power Module

1.1 General Description

The Nexa™ power module is a fully integrated system that produces unregulated DC power from a supply of hydrogen and air. It contains a BALLARD® fuel cell stack, as well as all the ancillary equipment necessary for fuel cell operation. Ancillary subsystems include hydrogen delivery, oxidant air supply and cooling air supply. Onboard sensors monitor system performance and the control board and microprocessor fully automate operation. The Nexa™ system also incorporates operational safety systems for indoor operation.

Figure 2 illustrates the Nexa™ system schematic. The diagram also shows the Nexa™ system boundary and important interface connections to the DC module. Hydrogen, oxidant air, and cooling air must be supplied to the unit, as shown in Figure 2. Exhaust air, product water and coolant exhaust is emitted. The Nexa™ power module produces unregulated DC power for interfacing with external power conditioning equipment. Battery power must be supplied for start up and shut down requirements. Finally, a communications interface must be provided to the Nexa™ unit for providing start/stop signals and for receiving serial port communications.

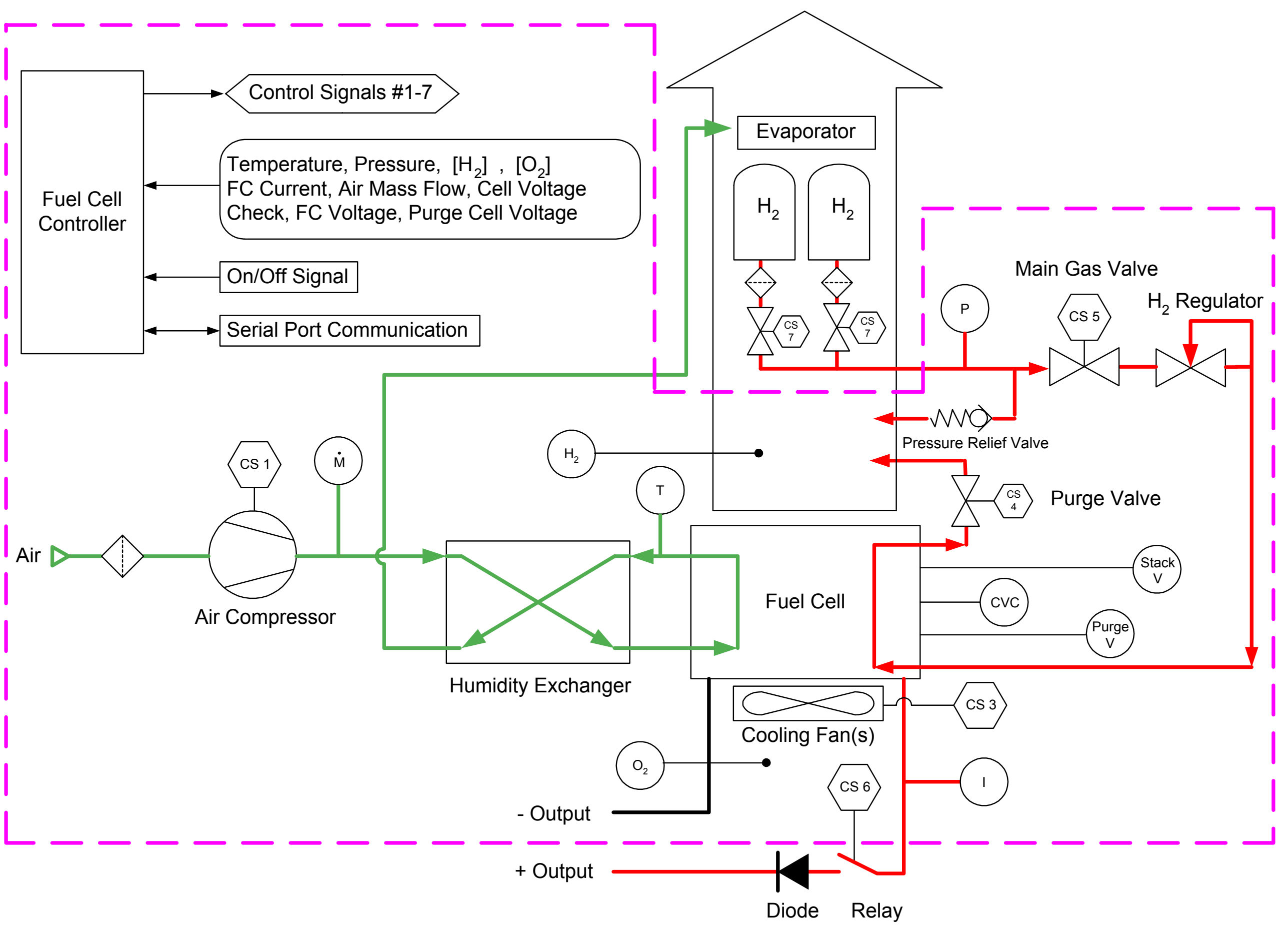


Figure 2: Nexa™ System Schematic

1.2 Fuel Cell Principles

The fundamental component of the Ballard® fuel cell consists of two electrodes, the anode and the cathode, separated by a polymer membrane electrolyte. Each of the electrodes is coated on one side with a thin platinum catalyst layer. The electrodes, catalyst and membrane together form the membrane electrode assembly. A single fuel cell consists of a membrane electrode assembly and two flow field plates, as shown in Figure 3.

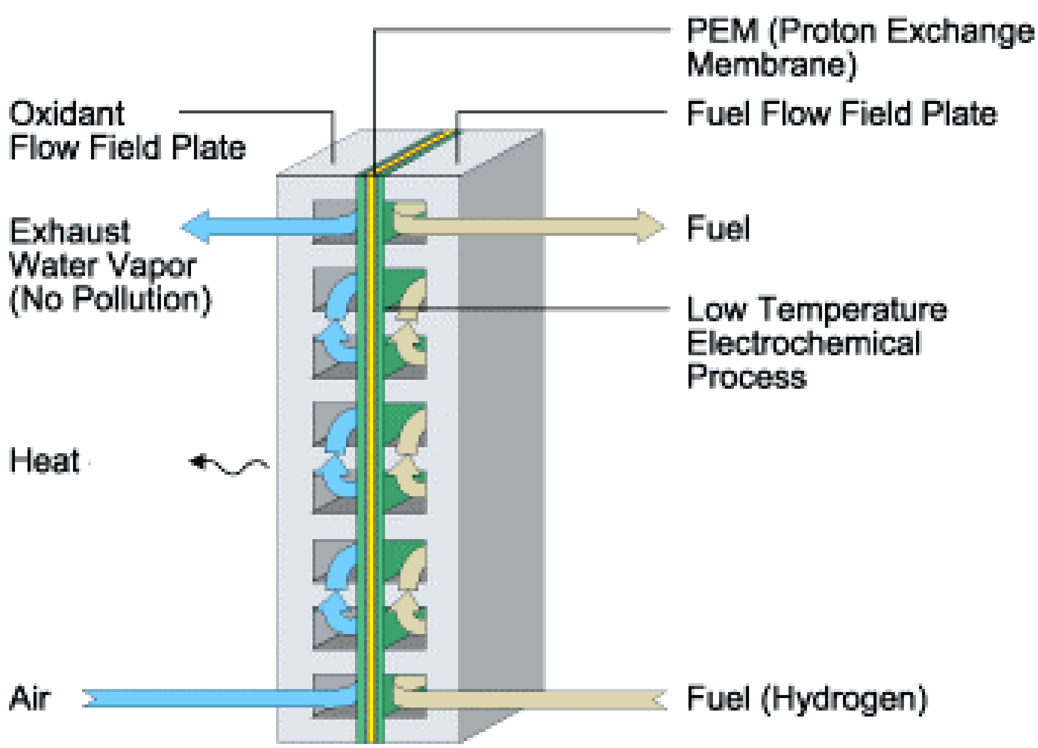


Figure 3: PEM Fuel Cell Principals

Gases (hydrogen and air) are supplied to the electrodes on either side of the membrane through channels formed in the flow field plates. Hydrogen flows through the channels to the anode where the platinum catalyst promotes its separation into protons and electrons. The free electrons are conducted in the form of usable electric current through an external circuit, while the protons migrate through the membrane electrolyte to the cathode. At the cathode, oxygen from the air, electrons from the external circuit and protons combine to form pure water and heat.

Individual fuel cells are combined into a fuel cell stack to provide the required electrical power. A single fuel cell produces about 1 volt at open circuit and about 0.6 volts at full load. Cells are stacked together in series to provide the required output voltage. In turn, the output current of a fuel cell is proportional to its active area. Consequently, the fuel cell stack geometry can be tailored to provide the desired output voltage, current and power characteristics.

1.3 Fuel Cell Stack

PEM fuel cell stacks produce unregulated DC power from hydrogen and air. Water and heat are the only by-products of the reaction. The PEM fuel cell stack incorporated into the Nexa™ system has been developed with a number of important attributes for the portable power market. First, the Nexa™ fuel cell stack operates at low pressure, minimising parasitic losses, reducing noise, and enhancing system reliability. Second, the Nexa™ fuel cell stack architecture does not require external fuel humidification. Furthermore, this fuel cell stack is air-cooled, which further simplifies the overall system design.

The Nexa™ fuel cell stack has been sized to provide 1.2 kW of net output power. The output voltage varies with power, ranging from about 43 V at system idle to about 26 V at full load. During Nexa™ system operation, the fuel cell stack voltage is monitored for diagnostic, control and safety purposes, as shown in Figure 2. In addition, a cell voltage checker (CVC) system monitors the performance of individual cell pairs and detects the presence of a poor cell. The Nexa™ unit will shut down if a cell failure or a potentially unsafe condition is detected in the fuel cell stack.

1.4 Hydrogen System

The Nexa™ power module operates on pure, dry hydrogen from any suitable source. The fuel-supply system, as shown in Figure 2, monitors and regulates the supply of hydrogen to the fuel cell stack. The fuel supply subsystem is comprised of the following components:

- A pressure transducer monitors fuel delivery conditions to ensure an adequate fuel supply is present for Nexa™ system operation.
- A pressure relief valve protects downstream components from over-pressure conditions.
- A solenoid valve provides isolation from the fuel supply during shut down.
- A pressure regulator maintains appropriate hydrogen supply pressure to the fuel cells.
- A hydrogen leak detector monitors for hydrogen levels near the fuel delivery subassembly. Warning and shut down alarms are implemented for product safety.

The fuel cell stack is pressurised with hydrogen during operation. The regulator assembly continually replenishes hydrogen, which is consumed in the fuel cell reaction. Nitrogen and product water in the air stream slowly migrates across the fuel cell membranes and gradually accumulates in the hydrogen stream. The accumulation of nitrogen and water in the anode results in the steady decrease in performance of certain key fuel cells, which are termed "purge cells". In response to the purge cell voltage, a hydrogen purge valve at the stack outlet is periodically opened to flush out inert constituents in the anode and restore performance.

Only a small amount of hydrogen purges from the system, less than one percent of the overall fuel consumption rate. Purged hydrogen is discharged into the cooling air stream before it leaves the Nexa™ system, as shown in Figure 2. Hydrogen quickly diffuses into the cooling air stream and is diluted to levels many times less than the lower flammability limit. The hydrogen leak detector, situated in the cooling air exhaust, ensures that flammable limits are not reached. This feature permits safe, indoor operation of the Nexa™ power module.

1.5 Oxidant Air System

A small compressor provides excess oxidant air to the fuel cell stack in order to sustain the fuel cell reaction. An intake filter protects the compressor and downstream components from particulate in the surrounding air. The compressor speed is adjusted to suit the current demand of the fuel cell stack. Larger currents require more airflow. A downstream sensor measures air mass flow rate and controls fine-tune the compressor speed to suit the required current demand.

Oxidant air is humidified before reaching the fuel cells to maintain membrane saturation and prolong fuel cell lifetime. A humidity exchanger transfers both fuel cell product water and heat from the wet cathode outlet to the dry incoming air.

Excess product water is discharged from the system, as both liquid and vapour, in the oxidant air exhaust. Product water must be managed through end-use integration design. Excess water may be evaporated passively into the surrounding environment, as shown in Figure 2. Alternatively, product water can be drained and collected.

1.6 Cooling System

The Nexa™ fuel cell stack is air-cooled. A cooling fan located at the base of the unit blows air through vertical cooling channels in the fuel cell stack. The fuel cell operating temperature is maintained at 65°C by varying the speed of the cooling fan. The fuel cell stack temperature is measured at the cathode air exhaust, as shown in Figure 2.

Hot air from the cooling system may be used for thermal integration purposes. Heat rejected in the air can be used for integration with metal hydrides, for evolving hydrogen. Hot air may also be used for space heating in some cases.

The cooling system is also used to dilute hydrogen that is purposely purged from the Nexa™ module during normal operation. Hydrogen is released into the cooling air stream by way of the purge solenoid valve, as shown in Figure 2. The hydrogen quickly diffuses into the cooling air and is diluted to levels far below the Lower Flammability Limit (LFL) of hydrogen.[1] For safety, a hydrogen sensor is located within the cooling air outlet stream and provides feedback to the control system. The control system generates warning and alarm signals if the hydrogen concentration approaches 25% of the LFL.

[1] The Lower Flammability Limit (LFL) of hydrogen is the smallest amount of hydrogen that will support a self-propagating flame when mixed with air and ignited. At concentrations less than the LFL, there is insufficient fuel present to support combustion. The LFL of hydrogen is 4% by volume.

1.7 Electronic Control System

Nexa™ system operation is automated by an electronic control system. The control board receives various input signals from onboard sensors. Input signals to the control board include: fuel cell stack temperature, hydrogen pressure, hydrogen leak concentrations, fuel cell stack current, air mass flow, fuel cell stack voltage and purge cell voltage. The status of the Cell Voltage Checker (CVC) system is also an input to the control board, presenting either a Pass or Fail result for the operational status of the stack. Finally, the ambient oxygen concentration is measured by an onboard sensor and sent to the controller, to ensure a safe operating environment for the user.

Analogue and digital output control signals are issued from the control board to regulate system operation. Control commands are issued for opening and closing the hydrogen solenoid valve and purge valve of the Nexa™ module. The speed of the air compressor is varied based on current demand. The speed of the cooling fan is also controlled to regulate the fuel cell stack temperature. An external load relay is opened or closed by the Nexa™ control system for engaging or disengaging the fuel cell stack to external loads. The control system also issues a signal for opening and closing external solenoid valves, to isolate hydrogen storage tanks when the Nexa™ module is not in operation.

Communications to and from the end product are made via the Nexa™ control board. An on/off signal is issued to the fuel cell control board for starting or stopping the Nexa™ module. The controller communicates with external equipment using the RS-485 serial link. Data transmitted from the control board includes status and performance information. The control board will also accept operational commands for self-test and diagnostic purposes.

Unusual or unsafe operating conditions result in either a warning or alarm and automatic shutdown, depending on severity. During a warning, the Nexa™ power module continues to operate and the controller attempts to remedy the condition. During an alarm, the controller initiates a controlled shutdown sequence. Removing the external on/off signal will reset most alarms. Once reset, the Nexa™ power module can then be restarted. For safety reasons, certain alarms can only be reset by Ballard Customer Service. These non-restartable faults include hydrogen leaks, self-test faults and software faults.

When energised, the controller continually transmits data approximately once every 200 ms. Transmitted data includes system status codes, warning codes and alarm codes, as indicated in Table 1. In addition, fuel cell system operating parameters are transmitted for monitoring and display purposes. The data is displayed in engineering units for selected transducers, as indicated in Table 2.

Status Codes	Warning Codes*	Alarm (Failure) Codes
Standby Starting Running Warning Normal Shut-down Failure Shut-down Non-Restartable	No Warnings High Fuel Cell Stack Temperature Warning Low Fuel Cell Stack Voltage Warning High Fuel Cell Stack Current Warning Low Fuel Pressure Warning Fuel Leak Warning Low Oxygen Concentration Warning Low Purge Cell Voltage Warning *Multiple warnings are indicated concurrently	Normal Operation High Fuel Cell Stack Temperature Low Fuel Cell Stack Voltage High Fuel Cell Stack Current Low Cell Voltage Low Fuel Pressure Fuel Leak Detected Low Oxygen Concentration Low Ambient Temperature Low Purge Cell Voltage Low Battery Voltage Startup Time Expired Self Test Fault Software Fault

Table 1: Transmitted Status, Warning and Alarm Codes

Signal	Engineering Unit
Fuel Cell Stack Temperature	ºC
Fuel Cell Stack Voltage	Volts
Fuel Cell Stack Current	Amps
Hydrogen Pressure	Barg
Hydrogen Concentration	Ppm
Cumulative Hydrogen Consumption	Slpm
Oxygen Concentration	%
Ambient Temperature	ºC
Purge Cell Voltage	mV

Table 2: Transmitted Transducer Signals

1.8 Safety Systems

The Nexa™ power module has automatic provisions to ensure operator safety and prevent equipment damage. A warning or alarm occurs when an unusual or unsafe operating condition occurs, depending on severity. During a warning, the power module continues to operate and the controller attempts to remedy the condition. During an alarm, the controller initiates a controlled shutdown sequence. The Nexa™ power module employs the following monitoring and shut down mechanisms to ensure safe fuel cell operation is maintained at all times:

- Fuel cell operating parameters are continuously monitored to ensure they stay within desired limits. These include fuel cell stack operating temperature, fuel cell stack current, output voltage and fuel supply pressure. Warnings and shut down alarms are implemented on each of these parameters

- A Cell Voltage Checker (CVC) system continuously monitors the operation and performance of individual cell pairs. The presence of a failing cell will cause the Nexa™ system to shut down.

- A hydrogen leak detector is implemented within the fuel delivery subassembly. Imbedded properly into the cooling air stream, this sensor can also detect excessive hydrogen purge amounts or the presence of an external fuel leak in the fuel cell stack. The Nexa™ system will shut down automatically if a hydrogen leak is detected.

- The Nexa™ power module comes equipped with an oxygen sensor for measuring ambient oxygen concentrations. This feature prevents users from operating the Nexa™ power module in non-ventilated areas, where oxygen depletion may become a safety concern. The power module shuts down automatically when low ambient oxygen concentration levels are measured.

In addition to warnings and alarms, other safety features are included to the design of the Nexa™ power module:

- A fuel shutoff solenoid valve closes whenever the power module is shut down. This isolates the fuel supply and prevents hydrogen from entering the fuel cell stack in the event of an alarm shutdown.

- Under normal operation, hydrogen released by way of the purge solenoid valve mixes with the cooling air stream, where it quickly diffuses and dilutes to levels far below the LFL of hydrogen. This eliminates the potential formation of a flammable gas mixture in the cooling air flow and permits indoor operation.

- A pressure relief valve discharges hydrogen into the cooling air stream during overpressure conditions to protect the fuel cell stack from damage. When the relief valve opens, the hydrogen concentrations measured in the cooling air stream exceed the hydrogen sensor alarm setting, and the power module shuts down.

1.9 Operation

The Nexa™ power module provides fully automated operation and load response. In order to operate the unit, one must provide a 24V battery connection to support start-up and shut down loads, provide an adequate hydrogen fuel supply and apply a 5V start signal to the control board. Once these steps are taken, the Nexa™ module will export unconditioned DC electric power on demand.

Before battery power is applied, the Nexa™ module remains in the OFF state. In this state, the onboard sensors, actuators and microprocessor are de-energised and therefore unavailable for operation.

Once the 24V battery connection is applied to the control board, the Nexa™ power module transitions to STANDBY state. In this state, sensors and actuators are energised and the onboard microprocessor continually transmits system data and status messages.

When in STANDBY, application of a 5V start signal to the Nexa™ control board will begin the STARTING sequence. The hydrogen solenoid valve opens and the purge valve periodically cycles to fill the fuel cell stack with hydrogen. The air pump turns on to provide air to the fuel cells. Finally, the cooling fan turns on to provide thermal regulation as well as dilution of purged hydrogen. During this sequence, the fuel cell stack voltage quickly increases from zero to normal idling levels. Once a series of internal system checks are passed, the Nexa™ module transitions from STARTING to RUNNING state. This start-up process typically lasts 10-30 seconds.

Once RUNNING state is achieved, the Nexa™ module control board internally transfers parasitic loads from the external battery to the fuel cell stack. In addition, an external load relay control signal is sent to connect the fuel cell stack to load. At this point, power can be drawn from the Nexa™ module. WARNING messages are transmitted, should normal operating parameters be exceeded. Multiple simultaneous WARNING messages are possible during normal operation. Should alarm limits be exceeded, the Nexa™ module will instantly shut down and broadcast the FAILURE SHUT DOWN status message.

When the 5V start signal is removed from the Nexa™ power module, it transitions to the NORMAL SHUT DOWN state. Upon shut down, the external load relay is opened to isolate the fuel cell stack from the load and the control board internally transfers parasitic loads from the fuel cell stack back to the external battery. If the Nexa™ module has been sufficiently operated (longer than 60 seconds), it will also engage a shut down sequence that removes product water from the anode and cathode flow channels using the air pump and hydrogen purge valve. The NORMAL SHUT DOWN sequence lasts 45 seconds.

1.10 Periodic Exercising

The Nexa™ power module requires periodic exercising to maintain peak performance and to offset performance losses encountered during periods or prolonged storage or non-operation. Fuel cell performance loss is characterised by reduced output voltage or reduced power output capacity. Performance gradually declines with increasing storage duration, with an expected floor of approximately 10% degradation in one year. Elevated storage temperatures accelerate the rate of performance loss. In extreme cases, the Nexa™ power module may not be able to start because start up permissive values cannot be achieved.

Storage loss affects are fully reversible through operation. Running the Nexa™ power module continually will recover any loss in performance due to storage. Furthermore, Nexa™ modules, which are exercised frequently or for long periods, will not encounter this performance loss.

Ballard has developed an automated, onboard recovery procedure for the Nexa™ power module, which has been implemented in firmware revision 00.03.01. An extended shut down sequence has been added for specific maintenance intervals, which incorporates an automated rejuvenation process to offset the performance losses due to prolonged storage. In addition, start-up permissive limits, shut down limits and warning levels have been modified to increase availability and extend system performance.

Customers are encouraged to upgrade their Nexa™ units with the latest firmware revision (00.03.01). In order to assure peak performance of the Nexa™ power module, exercise the system every 2-3 months. To initiate the automated rejuvenation process, operate the Nexa™ module at approximately half load for between 10 and 30 minutes. If the required operating conditions are met[2], the Nexa™ module will automatically execute the recovery process as part of an extended shut down sequence. The extended shut down sequence used for this periodic exercising or maintenance interval lasts approximately 4 minutes. Contact Ballard Customer Service for details.

[2] The internal conditions for executing the automated rejuvenation process are: (1) the SYSTEM RUN TIME measured by the onboard controller must be between 10 and 30 minutes and (2) the average stack power, measured over the last 10 minutes of operation, must exceed 200W.

2 Specifications

Specifications for the Nexa^{TM} power module are provided in this manual for reference only. The specifications presented in this document do not supersede and in no way replace or substitute for the specifications that are attached to or referenced by a Sales Agreement with Ballard Power Systems. Refer to your Sales Agreement for Product Specifications and Shipping and Storage Specifications for your Nexa^{TM} modules. Contact Ballard Customer Service if you have questions.

2.1 Product Specification

Output specifications for the Nexa^{TM} power module include power, emissions, physical characteristics and lifetime. These specifications are attributes of the uninstalled Nexa^{TM} power module and do not necessarily reflect the installed performance. Required system inputs are also defined, including: fuel delivery, battery input specifications and operating environment requirements. Nexa^{TM} specifications are subject to change. Refer to the Ballard document Nexa^{TM} Product Specification, attached to your Sales Contract, for the specifications of your Nexa^{TM} modules.

The Nexa^{TM} Product Specification is shown in Table 4, with definitions provided in Table 3. Performance and lifetime specifications are given, along with required system inputs for operation. Please note that the Product Specification does not address the following considerations.

- The Warranty period is defined by the Sales Agreement.
- Outdoor applications for the Nexa^{TM} module were not evaluated under UL component recognition.

Beginning of Life (BOL)	Within the first 40 hours of module operation, within 90 days of receipt from Ballard.
End of Life (EOL)	Characterised by performance below 22V or a non-repairable fuel cell stack failure.
Cold Start	The temperature of the entire Nexa^{TM} power module is at equilibrium with the ambient air temperature.
Indoors or Outdoors	Any location where the Nexa^{TM} power module is protected by the end product outer enclosure against wet, marine, freezing or other inclement conditions and against sand, dust or other particulates.
Uninstalled	Not installed into an enclosure nor integrated with an external thermal management system, fuel supply system or power conditioning system.
Standard Conditions	Evaluated at sea level at an ambient (cooling air and oxidant air) temperature of 30°C.
Voltage at Rated Power	Measured as the minimum 60 second running average within the first 30 minutes of continuous use. At time of module shipment, Rated Power and Voltage will be within +/- 5% of listed specifications.

Table 3: Nexa^{TM} Product Specification Definitions

OUTPUTS	Requirement	Definition	Quantity
Power[1]	Rated Power	Capacity at Standard Conditions, BOL	1200 W
	Voltage	Operating voltage range	22 V to 50 V
		Voltage at Rated Power	26 V
	Start-up Time	Minimum time to achieve Rated Power from a Cold Start condition	2 minutes
Emissions	Noise	Maximum noise emission at 1m	72 dBA
	Water	Maximum quantity of liquid water produced at Rated Power	870 mL/hr
Physical	Dimensions	L x W x H	56 x 25 x 33cm
	Mass	Total system mass	13 kg
Lifetime	Operating Life	Minimum number of operating hours before EOL	1500 hours
	Cyclic Life	Minimum number of start-up & shut-down cycles before EOL	500
	Shelf Life	Minimum storage (non-operation) before EOL	2 years
INPUTS	Requirement	Definition	Quantity
Fuel	Purity	Lowest acceptable concentration of hydrogen	99.99% H_2 (vol)
	Pressure	Allowable range of inlet supply pressure[2]	70 – 1720 kPa(g)
	Acceptable Impurities	Maximum total inert fluids (including helium, argon, nitrogen and water vapour)	0.01% (vol)
		Maximum CO and CO_2 combined	2 ppm (vol)
		Maximum total hydrocarbon	1 ppm (vol)
		Maximum oxygen	500 ppm (vol)
	Consumption	Maximum fuel consumption at Rated Power	<18.5 SLPM
Power Conditioning	Current Ripple	Maximum acceptable current ripple at 120 Hz, with respect to average DC net output current	24.7% RMS 35% peak-peak
DC Power Supply	Voltage	Allowable range of input voltage	18 V to 30 V
	Power	Maximum power draw during start-up	60 W
Operating Environment	Location	Acceptable locations for use	Indoors & Outdoors
	Temperature Range	Range of acceptable ambient, cooling air and oxidant air temperatures	3°C - 40°C
	Relative Humidity	Range of acceptable ambient relative humidity	0% - 95% (non-condensing)
	EMI Tolerance	Tolerant to and operates safely in the EMI environment specified by	UL 991

NOTE: 1. Exercise the Nexa™ power module every 2-3 months to maintain peak performance. Operate at half power for 10-30 minutes to initiate the automated rejuvenation cycle on shut down.

NOTE 2: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 25 for warning and shut-down values).

Table 4: Nexa™ Product Specification

2.2 Shipping & Storage Specification

This section addresses required methods and criteria for packaging, shipping and storing the Nexa™ power module, as well as end products developed using the Nexa™ module. Adhere to these specifications to ensure that damage or performance loss does not occur.

The identified Original Packaging Assembly is to be used for all shipments of the Nexa™ power module. Warranty returns of Nexa™ modules to Ballard must be packaged in the designated shipping crate assembles. Nexa™ packaging must be in good condition. Physical damage to the crate, due to misuse or outside storage, will void the warranty claim.

Nexa™ specifications are subject to change. Refer to the Ballard document Nexa™ Shipping and Storage Specification, attached to your Sales Contract, for the specifications of your Nexa™ power modules.

	Requirements	Definition / Description	Quantity
Nexa™ Module Packaging[1]	Crate Assembly, Nexa™ Single-Pack	Nexa™ Single-Pack Shipping Crate (Part #) Packaging Foam, Lower Pad (Part #) Packaging Foam, Top Pad (Part #)	5000233 5000234 5000226
	Crate Assembly, Nexa™ Four-Pack	Nexa™ Four-Pack Shipping Crate (Part #) Packaging Foam Pad (Part #)	5000197 5000198
End Product Packaging	Packaging Foam	The following packaging foam is recommended for packaging end products using the Nexa™ module: Stratocell® Polyethylene Foam, a product of Sealed Air Corporation, Park 80 East, Saddle Brook, NJ, 07663. Consult Ballard before using other foams, styrofoams or materials.	
Transport	Mode(s) of Transport	The Nexa™ power module is capable of being shipped by water, road or air.	
	Mode of Operation During Transport	The Nexa™ power module will not be operated when being transported.	
	Ambient Temperature	Allowable range of ambient temperature.	-29 C to 70 C
	Shock Loads During Transport	The Nexa™ module and original packaging has been developed and tested according to the requirements of ISTA packaging standards test procedures 1A or 1B. The OEM packaging must also be developed and tested in accordance with ISTA test procedure 1 (or an equivalent industry packaging standard.)	
	Drop and Topple	The Nexa™ power module can withstand drop and topple abusive loads, as described in the test methods of IEC publication 68-2-31, Drop and Topple Basic Environmental Testing Procedures.	
	Drop Test	The Nexa™ power module can withstand a free fall from a height of 1.2m onto a hard surface (concrete or steel). Any failures directly or indirectly emanating from such a load condition shall not present a safety hazard.	

	Requirements	Definition / Description	Quantity
Storage	Ambient Temperature	Allowable range of ambient temperatures.	-29°C to 70°C
	Freezing Storage	Allowable number of freeze/thaw cycles.	50 Cycles
	Relative Humidity	Range of allowable ambient relative humidity	5% to 95%

NOTES: 1. The identified Original Packaging Assembly is to be used for all shipments of the Nexa™ power module. Warranty returns of Nexa™ power modules to Ballard must be packaged in the designated shipping crate assembles. Nexa™ packaging must be in good condition. Physical damage to the crate, due to misuse or outside storage, will void the warranty claim.

Table 5: Nexa™ Shipping and Storage Specification

2.3 Interface Specifications

Interface specifications are provided for the Nexa™ power module, to enable gas, electrical and communication connections for lab installation. The Nexa™ module interfaces are illustrated in Figure 4. Specifications for interface connections follow the figure. Italicised component labels are for reference only.

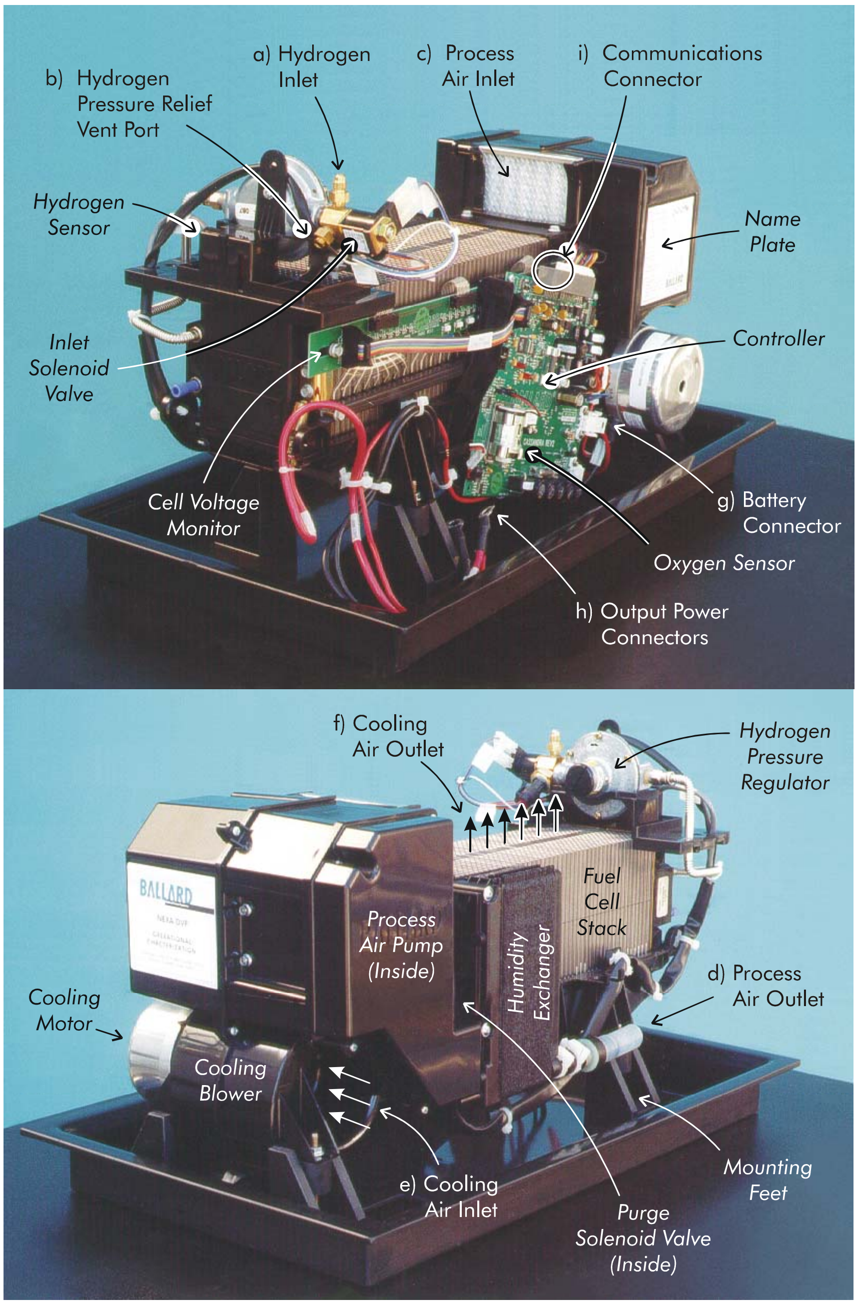


Figure 4: NexaTM Component Layout and Interfaces

2.3.1 Hydrogen Inlet

The hydrogen inlet draws hydrogen from the fuel storage containers for use in the fuel cell power reaction. Specifications for the hydrogen inlet connection are provided in NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 25 for warning and shut-down values).

Table 6. The Nexa™ fuel cell system is designed for operation on *pure* gaseous hydrogen. No fuel humidification is required. Hydrogen can be supplied at pressures ranging from 70 to 1720 kPa(g) (10 to 250 psig). A pressure relief valve is located on the fuel assembly immediately upstream of the fuel regulator. The relief valve vents at 2400 kPa(g) (350 psig) to ensure overpressure conditions are not applied to the downstream pressure regulator assembly. The relief valve discharges into the vicinity of the onboard hydrogen leak detector, thereby shutting down the system in the event of excessive inlet supply pressure. NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 25 for warning and shut-down values).

Table 6 also indicates the required hydrogen purity and allowable contaminant levels for the fuel supply. Adhere to the fuel composition specification to ensure proper Nexa™ system performance.

Description	Specification
Composition	99.99% hydrogen < 0.01% Maximum total inert fluids (He, N_2, Ar, and water vapour) < 2 ppm carbon dioxide + carbon monoxide < 500 ppm oxygen < 1 ppm sulphur compounds < 1 ppm hydrocarbons
Pressure[1]	70 to 1720 kPa(g)
Temperature	5 to 80 ºC
Flow	≤ 18.5 slpm at maximum power
Pressure Relief Valve Setting	2400 kPa(g)
Connection	45º flared tube fitting (male) for 1/4" OD tubing

NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 25 for warning and shut-down values).

Table 6: Hydrogen Inlet Connection

2.3.2 Process Air Inlet

The process air inlet draws air from the ambient surroundings for use in the fuel cell power reaction. Specifications for the process air inlet connection are provided in Table 7.

Description	Specification
Composition	Ambient air
Pressure	Atmospheric
Flow	≤ 90 slpm
Connection	None – External ducting is recommended to separate the process air inlet stream from the cooling air outlet.

Table 7: Process Air Inlet Connection

2.3.3 Process Air Outlet

The process air outlet expels oxygen-depleted air after its use in the fuel cell power reaction. Excess product water from the fuel cell power reaction is entrained in the process outlet air stream in both liquid and vapour form. Specifications for the process air outlet connection are provided in Table 8.

Description	Specification
Composition	Oxygen-depleted air
Maximum allowable flow restriction on outlet connection, measured as pressure drop to ambient	3.44 kPa (0.5 psi) at 100 SLPM, 55ºC
Temperature	< 55 ºC; depends on the fuel cell stack operating temperature
Flow	See process air inlet
Entrained Product Water	870 mL/hour maximum at rated power
Connection	16 mm OD tube

Table 8: Process Air Outlet Connection

2.3.4 Cooling Air Inlet

The cooling air inlet draws air from the ambient surroundings in order to cool the fuel cell stack and regulate operating temperature. Specifications for the cooling air inlet connection are provided in Table 9.

Description	Specification
Composition	Ambient air
Pressure	Atmospheric
Flow	3600 slpm maximum
Connection	None

Table 9: Cooling Air Inlet Connection

2.3.5 Cooling Air Outlet

The cooling air outlet expels warmed air to the ambient surroundings after absorbing heat from the fuel cells. Hydrogen and water, purged from the fuel stream, is released into the cooling air stream. Hydrogen released from the pressure relief vent port during an over-pressure condition also mixes with the cooling air outlet stream. Cooling air outlet specifications are detailed in Table 10.

Description	Specification
Composition	See cooling air inlet
Maximum Allowable Pressure Drop or Back-pressure	0.35 kPa (1.4 inches of water)
Temperature	≅ 17ºC above inlet stream
Flow	See cooling air inlet
Connection	None - External ducting is recommended to separate the cooling air outlet stream from the process air inlet.

Table 10: Cooling Air Outlet Connection

2.3.6 Output Power Connections

The output power connections deliver the unregulated DC output power generated by the fuel cell stack. Specifications for the output power connection are provided in Table 11.

Description	Specification
Power (net)	0 W minimum at idle 1200 W maximum continuous at BOL
Voltage (unregulated)	22-50 VDC at beginning of life, standard operating conditions (sea level, 30°C)
Maximum Imposed Current Ripple	24.7% rms at 120 Hz maximum throughout the operating range; equivalent to 35% peak-to-peak

Connection	AMP 2-321598-3 ring terminal (1/4" ID) for use with STUD: ¼"–20 UNC
Pin-out	P1-2: Power – (Black) P1-1: Power + (Red)

Table 11: Output Power Connection

2.3.7 Battery Connector

The battery connector draws external battery power to start and shut down the Nexa™ power module. During start-up, the battery remains connected for providing auxiliary loads until the Nexa™ module completes its start-up process and is running normally. Once running, the fuel cell system provides its own auxiliary power. The battery remains disconnected from the Nexa™ control board until the stack voltage falls below 18V or the Nexa™ module is shut down. During shut down, the battery is reconnected for providing auxiliary power. Specifications for the battery input connection are provided in Table 12.

Description	Specification
Voltage	18 to 30 VDC
Energy Draw	60 W for 60 seconds maximum (shut down) Note: Additional battery capacity is drawn during the automated rejuvenation process, for firmware revisions 00.03.01 and greater.
Connector	2-way AMP 643226-1 female header Mates with AMP 350777-1 plug and AMP 350922-3 male terminals
Pin-out	J2-1: Battery – J2-2: Battery +

Table 12: Battery Input Connection

2.3.8 Communications Connector

The communications connector provides input, output and communication signals between the Nexa™ power module controller and host equipment. Communications connection specifications are provided in Table 13.

Description	Specification
Communications	
Standard	RS-485 serial
Baud	9600
Start Bits	1

Data Bits	8
Parity	none
Stop Bits	1
Configuration	Full duplex (asynchronous data transmission)
Data Protocol	Serial Line Internet Protocol (SLIP); Internet RFC 1055
Transmit	
Message Period	200 ms, continuous
Message Length	43 bytes to 143 bytes
Receive	
Message Length	5 bytes
Solenoid Valve Output Signal	
Logic	High (13.5 VDC) = open; Low (0 VDC) = closed
Type	Open drain to ground
Voltage	13.5 VDC
Current	0.5 A
Load Contactor Output Signal	
Logic	High (13.5 VDC) = on/closed circuit; Low (0 VDC) = off/open circuit
Type	Open drain to ground
Voltage	13.5 VDC
Current	0.2 A
On/Off Input Signal	
Logic	Current flow = on; No current flow = off
Type	Optically coupled
Voltage Drop Across Input	1.4 VDC maximum
Current	3 – 5 mA; 10 mA maximum
Input Impedance	1 kΩ
Connector	42-way AMP 638184-6 male header Mates with 16-way AMP 174514-1 plug and 040 AMP 345160-1 female receptacles
Pinout	J4-B1: Reserved J4-B2: Reserved J4-B3: External output; tank solenoid valve – J4-B4: External output; tank solenoid valve + J4-B5: External input; on/off signal – J4-B6: External input; on/off signal + J4-B7: External output; load contactor – J4-B8: External output; load contactor + J4-B9: Reserved J4-B10: Reserved J4-B11: Ground J4-B12: Communications common J4-B13: Communications receive – J4-B14: Communications receive + J4-B15: Communications transmit – J4-B16: Communications transmit +

Table 13: Communications Connector

3 Safety

NOTE

The safety guidelines included here may not cover every situation. Use common sense.

3.1 General Information

For this unit to generate electrical power, a supply of hydrogen fuel is necessary. It is important for any operator to be aware of, understand, and follow all local safety requirements related to the handling of hydrogen and compressed gases. Ensure that your facility conforms to all local regulatory requirements, including building codes and recommendations.

The fuel cell system has built-in safeguards and is designed to shut down automatically if any out-of-range operating condition occurs. Possible situations include low cell voltage, high current, high temperature, low fuel pressure, or hydrogen leak detection.

- Do not operate the Nexa™ power module on a grade of more than 45 degrees.
- Do not connect or disconnect power cables when the fuel cell module is energised.
- Do not dismantle the Nexa™ system. Contact Ballard if you have any concerns about operation.

3.2 Using Hydrogen

WARNING! FIRE OR EXPLOSION

Keep all sources of ignition away from hydrogen.

This unit uses hydrogen fuel. Hydrogen is a colourless, odourless and flammable substance. It is highly combustible in the presence of oxygen and burns with a colourless flame.

Leaking gas may be hot and pose a burn danger. Stop the flow of gas – if you are not in danger – and use water to cool the area. If fire occurs, do not attempt to extinguish flames, allow the fire to burn out.

Prevent overexposure to hydrogen. Hydrogen is non-toxic but can act as a simple asphyxiant by displacing the oxygen in the air. There are no warnings before unconsciousness results. When operating the Nexa™ power module in an enclosure:

- Ensure ventilation slots are clear and unobstructed at all times during operation
- Operate within the temperatures limits stated on the Nexa™ system nameplate
- Never operate if an alarm condition exists

3.2.1 Handling Compressed Gas Cylinders

WARNING!

Do not handle compressed hydrogen gas cylinders without training or experience.

- Use a pressure regulator to control the fuel inlet pressure to the Nexa™ system.
- Do not alter the fitting on a regulator. Ask experienced personnel for help.
- Do not attempt to force gas cylinder threads.
- Never transport a gas cylinder with regulators attached. Ensure cylinder caps are in place. Always use a cylinder cart with a safety strap or chain.
- Secure a high-pressure cylinder to a bench, post, or fixed object to avoid accidental contact.
- Avoid unnecessary contact with On/Off valves. They can easily move to "On" by accident.

3.2.2 Hydrogen Leakage

Hydrogen is colourless, odourless and tasteless. Hydrogen is non-toxic but can act as a simple asphyxiant by displacing the oxygen in the air. There are no warning symptoms before unconsciousness results.

WARNING!

Inhaling hydrogen can lead to unconsciousness and asphyxiation.

Hydrogen molecules are smaller than any other gas, making hydrogen more difficult to contain. It can diffuse through many materials considered airtight. Fuel lines, non-welded connections, and non-metal seals such as gaskets, O-rings, pipe thread compounds and packings present potential leakage or permeation sites. Furthermore, hydrogen's small molecule size results in high buoyancy and diffusivity, so leaked hydrogen will rise and become diluted quickly.

Constant exposure to hydrogen causes hydrogen embrittlement in many materials. The mechanisms that cause hydrogen embrittlement effects are not well defined. Factors known to influence the rate and severity of hydrogen embrittlement include hydrogen concentration, hydrogen pressure, temperature, hydrogen purity, type of impurity, stress level, stress rate, metal composition, metal tensile strength, grain size, microstructure and heat treatment history. Moisture content in the hydrogen gas may lead to metal embrittlement through the acceleration of the formation of fatigue cracks. Hydrogen embrittlement can lead to leakage or catastrophic failures in metal and non-metallic components.

Hydrogen leaks emanating from the fuel cell stack are readily detected by way of the hydrogen sensor mounted in the cooling air outlet stream. This sensor triggers warnings and alarms well before the hydrogen/air mixture reaches a flammable concentration.

As a preventative measure, the Nexa™ power module must be operated in a well-ventilated area in order to inhibit potential hydrogen accumulation.

WARNING!

Always operate the Nexa™ power module in a well-ventilated area and ensure that ventilation slots are unobstructed.

3.2.3 Flammability and Volatility

Hydrogen is flammable over concentrations of 4 – 75% by volume in air, and is explosive over concentrations of 15 – 59%. As a result, even small leaks of hydrogen have the potential to burn or explode. Leaked hydrogen can concentrate in an enclosed environment, thereby increasing the risk of combustion and explosion.

Hydrogen flames are pale blue and are almost invisible in daylight due to the absence of soot. Due to its high buoyancy and diffusivity, burning hydrogen rises unlike gasoline, which spreads laterally.

A flammable or explosive hydrogen mixture is easily ignited by a spark or even a hot surface. The auto-ignition temperature of hydrogen is 500 °C (932 °F). The energy of a hydrogen gas explosion is 2.4 times that of gasoline or methane for an equal volume. Hydrogen gas explosions are therefore more destructive and carry further.

WARNING!

A mixture of hydrogen and air is potentially flammable and explosive and can be ignited by a spark or a hot surface.

As in the presence of any fuel, all sources of ignition, including smoking, are not permitted in the vicinity of the power module.

WARNING!

Keep all sources of ignition away. Smoking is not permitted in the vicinity of the Nexa™ power module.

3.3 Oxygen Depletion

Oxygen is a colourless, odourless, non-toxic and tasteless gas. Oxygen is essential for life in appropriate concentrations.

Ambient air contains up to 21% oxygen. Oxygen levels below 19.5% are biologically inactive and may act as simple asphyxiants. Effects of oxygen deficiency may include: rapid breathing, diminished mental alertness, impaired muscular coordination, faulty judgement, depression of all sensations, emotional instability, and fatigue. As asphyxiation progresses, nausea, vomiting, prostration, and loss of consciousness may result, eventually leading to convulsions, coma, and death. At concentrations below 12%, immediate unconsciousness may occur with no prior warning symptoms.

WARNING!

Lack of oxygen can lead to unconsciousness and asphyxiation.

Oxygen is consumed from the ambient air during power module operation. To guard against oxygen depletion, an oxygen sensor mounted on the controller monitors the ambient oxygen concentration. This sensor triggers warnings and alarms before the oxygen concentration drops to a dangerous level.

As a preventative measure, the Nexa™ power module must be operated in a well-ventilated area in order to compensate for the oxygen used within the fuel cells.

WARNING!

Always operate the Nexa™ power module in a well-ventilated area.

3.4 Electrical Safety

WARNING!

Avoid contact with an exposed fuel cell stack. Electrical shock can cause personal injury or death.

- Do not touch fuel cell plates or any electrical components at any time. A running fuel cell stack is a potential electrical hazard that can cause burns or electrical shock.
- Do not wear metallic jewellery – rings, bracelets, watchbands, or necklaces – when you are close to an exposed fuel cell stack.
- Minimise static discharge. If possible, ground all equipment.

- Minimise conductivity. Avoid contact with surfaces that are in contact with water or gases. Do not operate or store in wet or damp conditions
- Use a three-wire grounding plug when connecting electrical devices
- Never use damaged extension cords

The Nexa™ power module generates up to 50 VDC (open circuit voltage). This voltage decreases as current is drawn from the module. The Nexa™ power module produces 26V at maximum power. This voltage is exposed at the output power connections. These low voltages may constitute a shock hazard and can damage electronic components if shorted. Therefore, do not touch individual fuel cells, cell voltage monitoring equipment or electrical components.

WARNING!

Do not touch fuel cells, cell voltage monitoring equipment or electrical components.

Electronic components can also be damaged as the result of static discharge. To minimise this, ground all equipment in contact with the power module. Use a three-wire grounding plug when connecting external loads. Never use damaged extension cords. Minimise conductivity by avoiding surfaces in contact with water; hands and clothes must be dry. Do not operate or store the power module in wet or damp conditions.

WARNING!

Minimise static discharge. Ground all equipment.

Residual reactants within the Nexa™ power module can develop a charge in a matter of minutes when turned off. A reading of zero volts across the entire power module does not guarantee that all fuel cells are uncharged.

WARNING!

Always assume that the fuel cell stack is charged.

Jewellery (such as rings, necklaces, bracelets and watches) may concentrate an electric current when it comes into contact with charged components, or when a shock passes through the human body. Accordingly, no jewellery should be worn near the power module.

WARNING!

Do not wear jewellery near the Nexa™ power module.

3.5 High Temperature

The fuel cell stack is designed to operate at 65ºC. At this operating temperature, the air exhaust stream temperature can reach 55ºC and the cooling air stream can reach 17ºC above ambient conditions. These temperatures are sufficient to cause burns or severe discomfort. Accordingly, avoid contact with the fuel cell stack, or components that convey process or cooling air.

WARNING!

Avoid contact with the fuel cell stack or components that convey process or cooling air.

3.6 High Pressure

Process air and hydrogen gas streams within the Nexa™ power module are regulated to low pressure. These circuits do not pose a high-pressure hazard, and they automatically vent and/or depressurise when the module is shut down.

Hydrogen pressure feeding the power module may reach 17 barg (2400 kPa g) and will typically remain pressurised even when the module is shut down. This high pressure is potentially dangerous. Use caution and ensure that the circuit is de-pressurised prior to access.

WARNING!

Ensure gas circuits are depressurised prior to access. Do not loosen fittings while under pressure. Doing so may result in uncontrolled gas release.

3.7 Rotating Equipment

The Nexa™ power module contains a process air pump and a cooling air fan that contains rotating parts. During normal operation, the air pump is enclosed within the module ductwork whereas the fan is partially exposed. Take care to avoid contact with rotating equipment, especially if protective enclosures have been removed to facilitate maintenance. Loose clothing may become entrained in rotating equipment and should not be worn.

WARNING!

Do not wear loose clothing while operating the NexaTM power module. Do not remove protective enclosures.

4 Installation

Figure 5 illustrates the basic installation of a Nexa™ power module in the lab and the mechanical, electrical and software interfaces necessary for operation. Before getting started, ensure that the following test lab criteria and installation procedures are satisfied:

- Ensure that the Nexa™ system is installed in a well-ventilated lab area equipped with hydrogen alarm sensors. Alternatively, install the Nexa™ unit underneath a fume-hood.
- Ensure the air quality of the test lab is sufficient for fuel cell operation. For example, do not operate the Nexa™ system adjacent to gasoline generators or in a non-ventilated room.

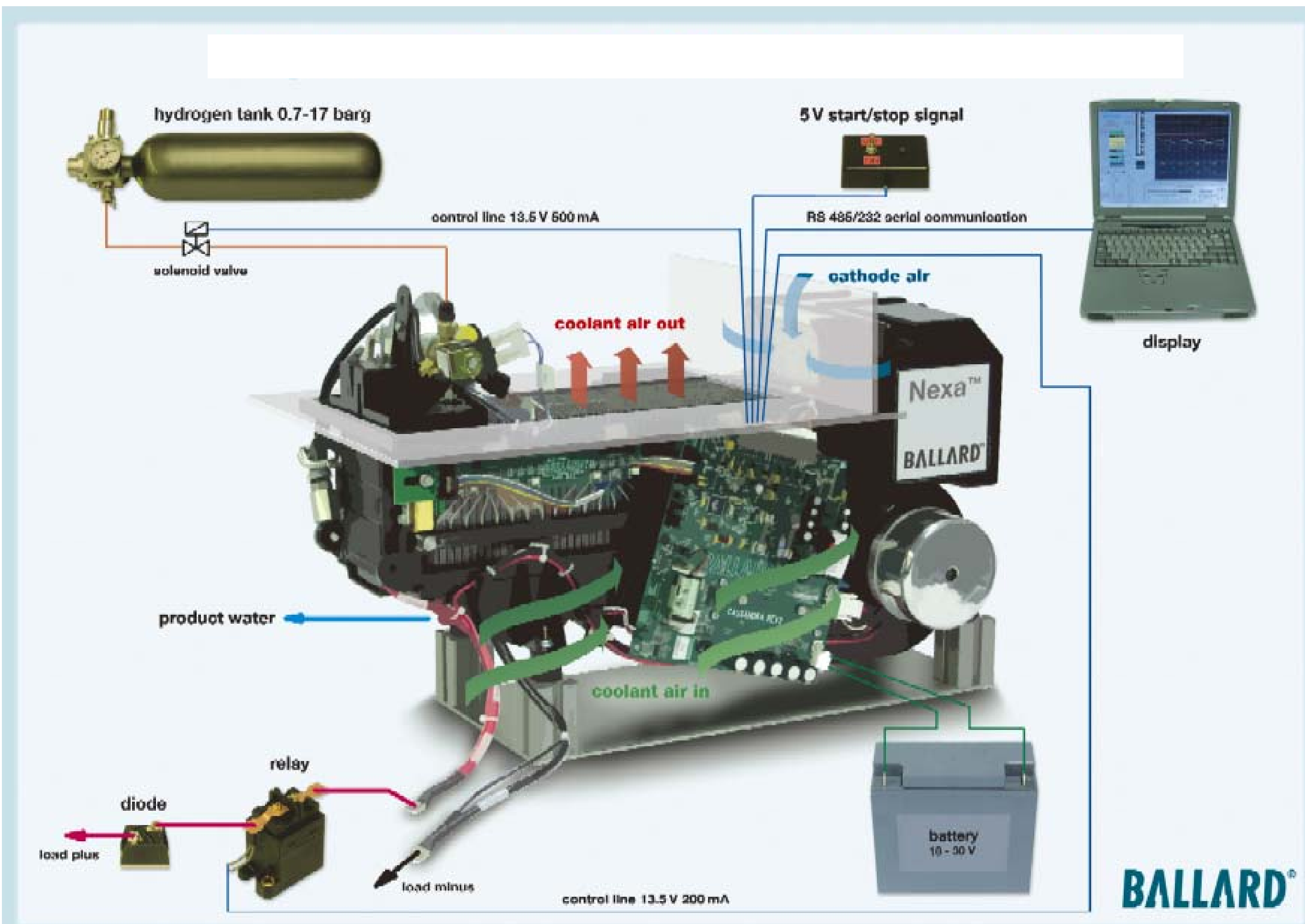


Figure 5: Installation of the Nexa™ power module

Follow the provided instructions to establish a laboratory test station for the Nexa™ power module.

- Install the Nexa™ power module onto a stand using the mounting feet, as shown in Figure 5.
- Provide a suitable supply of hydrogen. Connect the fuel supply to the hydrogen connection, as shown in Figure 5. Refer to the Interface Specifications for detailed fuel purity and connector specifications.
- Connect a 24 VDC battery to the Nexa™ control board, as shown in Figure 5. Alternatively, you may use a 24 VDC power-supply. Ensure the power supply is capable of at least 6 amps to support current surges on system start-up. Refer to the Interface Specifications for detailed installation and connector specifications.
- Install a load relay on the positive output terminal of the fuel cell stack to prevent premature power draw from the Nexa™ module. Connect the load relay control signal to the Nexa™ serial communication port, as shown in Figure 5. Make sure to test the load relay is working properly before operating the system. Refer to the Interface Specifications for connection details.
- Connect a blocking diode on the positive output terminal of the fuel cell stack, as shown in Figure 5, to prevent applying reverse potential to the fuel cell stack by a battery or some other DC power module integration.
- Connect the positive and negative output terminals of the Nexa™ module to a DC load bank for providing a load during system testing.
- Provide a 5 V start signal to the Nexa™ serial communication port, as shown in Figure 5. Refer to the Interface Specifications for connection details.
- Provide suitable water drainage for the oxidant air exhaust line.
- Connect the Nexa™ serial communication port to a computer through a RS485 to RS232 converter. Refer to the Interface Specifications for the serial interface connection details.
- Develop interface software to read and log Nexa™ operational data transmitted through the serial message. Refer to the Software Interface of the User's Manual for the messaging format and communication protocol specifications.

For new customers who may be unfamiliar with Nexa™ power module installation, an Installation Kit can be provided as part of the purchase. The kit provides interface hardware to enable quick and easy installation in the test lab. Labview software is also provided as part of the installation Kit, which provides basic monitoring and logging and features.

4.1 Installation Kit

The Installation Kit is illustrated in Figure 6. It contains the following equipment to enable quick and easy installation of the Nexa™ module into a test lab:

Figure 6: Nexa™ Installation Kit

- Communications Wiring Harness – The communications wiring harness provides several functions. It is used to connect the Nexa™ control board to a 24 V power supply for providing standby and start-up power to sensors and other onboard components. It is also used to send serial information from the Nexa™ module to a laboratory computer for monitoring and diagnostic purposes. The cable connects to the RS485 communications port of the Nexa™ control board and provides an RS485 to RS232 converter for interfacing with a computer's serial port. In addition, the harness includes a start switch, which applies a 5 V start signal to the control board to start the module. Finally, the harness includes a load relay control cable, which connects the control board to an external load relay for engaging and disengaging loads from the Nexa™ module.
- 25 Pin (male) to 9 Pin (female) Serial Cable – The serial cable is used to connect the RS485 to RS232 converter to the serial port of a laboratory computer.
- Load Relay – The load relay is connected to the positive output terminal of the Nexa™ module to prevent premature power draw. The Nexa™ control board, using the Communications Wiring Harness, controls the load relay.
- Nexa System Tray – The system tray provides mounting posts for the module.
- Hose – A hose is provided to supply hydrogen to the Nexa™ module from a cylinder. One end of the hose incorporates a 45° flared tube fitting, which mates with the hydrogen connection of the Nexa™ unit (see Interface Specifications). The other end uses a ¼" male NPT connection. Always use Teflon tape when connecting adapters to NPT fittings.

- Nexamon OEM Software on CD-ROM – Labview software has been developed for providing basic monitoring and diagnostic functions. An installation CD is provided.

Figure 7 illustrates the installation of a Nexa™ module in a laboratory setting. In addition to the Installation Kit, the following additional item are required to operate the Nexa™ module:

- Hydrogen Bottle - Refer to Interface Specifications for hydrogen purity and consumption requirements.
- Pressure Regulator – A pressure regulator must be installed on the hydrogen storage bottle, to reduce the fuel delivery pressure to the Nexa™ module. Refer to the Interface Specifications for the range of allowable hydrogen delivery pressures.
- 24V Power Supply (or battery) - Refer to Interface Specifications for power requirements during system start-up.
- DC load bank – Maximum continuous power demand of 1200W.
- 16mm OD Tube (approximately 6') – The process air exhaust tube interfaces to the base of the humidity exchanger for collecting product water from the fuel cell reaction.
- Bucket for Collection of Product Water – The Nexa™ module produces roughly 790ml/hour of product water at full power.
- Laptop Computer – Refer to the computer hardware requirements for the Ballard monitoring and diagnostic software, presented in the following section.

Figure 7: Nexa™ Laboratory Test Set-up

4.1.1 Installing the NexaTM System Tray

Figure 8 illustrates how the NexaTM module is installed in the system tray. Ensure that the NexaTM system's feet are properly installed in the tray's mounting pads to prevent damage to the control board.

Figure 8: Installing the NexaTM System Tray

4.1.2 Connecting the 24V Power Supply

Figure 9 illustrates the power supply connection to the NexaTM control board, using the Communications Wiring Harness.

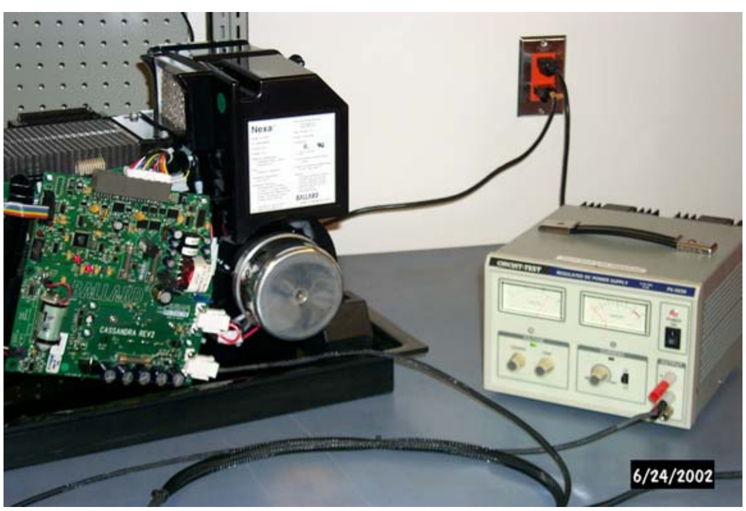


Figure 9: Connecting the 24V Power Supply

4.1.3 Connecting the Communications Port

The Nexa™ communications port provides the interface for all external equipment. Serial messages are transmitted using RS485 protocol to provide fuel cell performance parameters, system states, warnings and alarms to a computer or external controller. A 5 V start signal is applied to the Nexa™ module through the communications port. Control signals are also transmitted here for the actuation of a load relay and external fuel isolation valves. Figure 10 illustrates how the Communications Wiring Harness is connected to the control board.

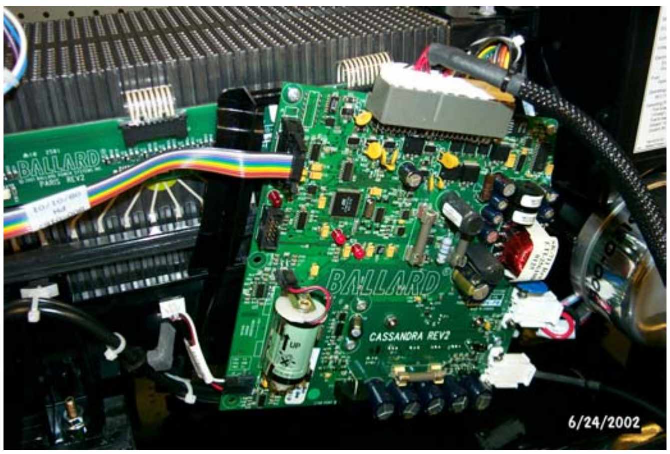


Figure 10: Connecting the Communications Port

4.1.4 Connecting the Serial Cable and Computer

Figure 11 illustrates how the serial cable is used to connect the computer's serial port to the RS485/232 converter box of the Communications Wiring Harness.

Figure 11: Connecting the Serial Cable and Computer

4.1.5 Installing the Load Relay

Figure 12 illustrates how the load relay is connected to the positive output power lead of the Nexa™ module. The signal wire, which controls the relay, is connected to the Communications Wiring Harness, as shown in the figure. Ensure that the load relay is functioning properly before applying load to the module. Confirm that the relay is open when the Nexa™ module is Off or in Standby, and that it closes only when the unit is Running.

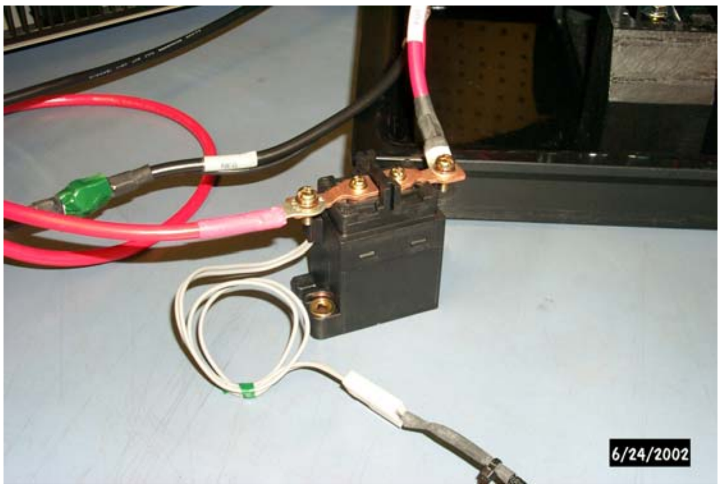


Figure 12: Installing the Load Relay

4.1.6 Connecting the Hydrogen Supply

Figure 13 illustrates the hydrogen supply connection to the Nexa™ module.

Figure 13: Connecting the Hydrogen Supply

4.2 NexaMon OEM Software

The Installation Kit comes equipped with a LABVIEW software program, which provides a graphical user interface to the Nexa™ module's operational status and performance. The software program is not needed to operate the Nexa™ module. However, it provides basic data monitoring, logging and diagnostic features that can be very helpful when conducting a fuel cell testing program in the lab. The features and capabilities are described in this manual.

4.2.1 Hardware Requirements

The following computer and hardware requirements must be followed to run the NexaMon OEM software program.

- Pentium computer with Windows 95 or later, a minimum of 166 MHz clock speed, 64 Mb of RAM and a screen resolution of 1024 x 768 pixels. The computer must come equipped with at least one serial port (9-pin male) for serial communications.
- Communications Wiring Harness, complete with an RS232 to RS485 serial protocol converter, as provided in the Installation Kit.
- Serial cable (9-pin female to 25-pin male), as provided in the Installation Kit.

4.2.2 Program Installation

To install the NexaMon OEM program, insert the provided CD, run the setup.exe file and respond to the self-install queries. The software will be automatically installed onto the hard-drive of your computer in the directory C:\Program Files\NexaMon OEM

To start the NexaMon OEM program, double-click on the NexamonOEM.exe file within Windows Explorer, or select Start/Programs/NexaMon OEM/NexaMon OEM from the Windows Start menu. Alternatively, create a shortcut of the executable file and move it to your desktop. Double-click on the icon to start the NexaMon OEM software.

To close the NexaMon OEM program, click on the X in the top right hand corner of the main screen.

In order to establish effective communications with the Nexa™ module and computer, the NexaMon OEM software must have control of the serial port. Other devices (such as PDA's) may have software installed that also takes control of the serial port when in use, and these devices can interfere with the NexaMon OEM communications. Be aware of other software programs on your computer that utilise and configure the serial port and avoid conflicts with the NexaMon OEM software.

4.2.3 Main Screen

The main screen of the NexaMon OEM software is illustrated in Figure 14. The main screen is the user interface through which all Nexa™ data monitoring, logging, diagnostics and system control functions are accessed. A description of the software interface and basic functions is provided in this manual.

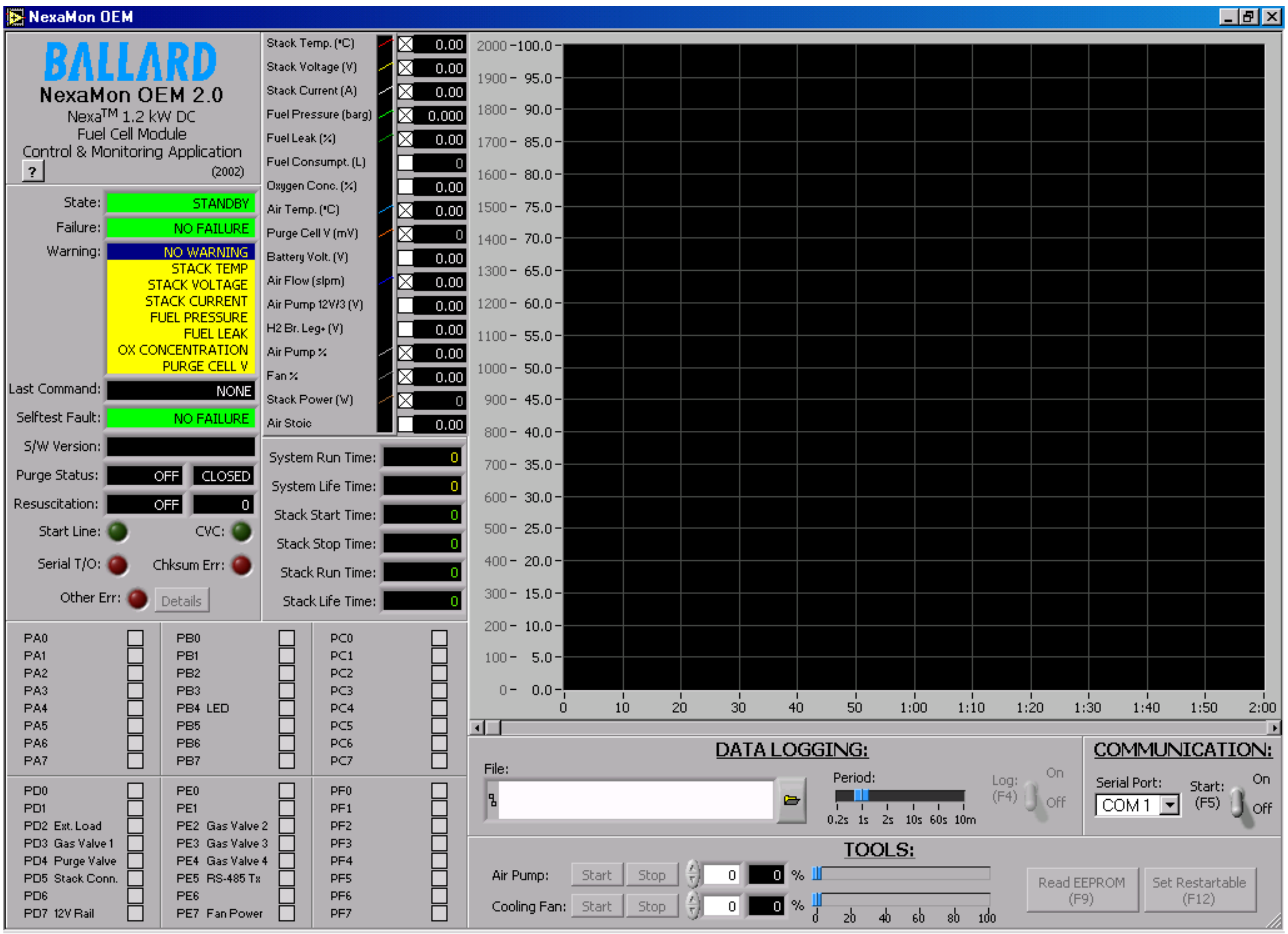


Figure 14: NexaMon OEM™ Main Screen

Opening the NexaMon OEM software does not engage the Nexa™ module in any way, nor does it initiate serial communications with the unit. To initiate serial communications and receive real-time data updates from the Nexa™ module, one must toggle the Communication Start Switch (F5). The monitoring, logging and diagnostic features of the NexaMon OEM software are only available when the Communication Start Switch has been toggled to the ON position.

4.2.4 Status Fields

The Nexa™ Status Fields, located in the upper left-hand corner of the Main Screen, indicate the operating state of the power module, warning and failure codes, as well as control system settings during operation. A description of each field is provided.

Nexa™ State Field - Indicates the current operating state of the power module, which may include any one of the following system states:

- Standby - The Nexa™ system is in Standby when power is being supplied to the control board from an external power supply or battery, but a start signal has not been applied.
- Starting - When a start signal is applied, the Nexa™ system enters the Starting State. The cooling fan and the air pump are started and the solenoid valve isolating fuel supply is opened to create stack voltage. During the start-up sequence, stack performance, sensor readings and operating conditions are monitored and evaluated against permissive criteria to determine if the system is capable of running. If any of the start-up criteria are not met during the Starting sequence, the system fails (Start Time Expired) and flags the Nexa™ State Field accordingly.
- Running - After the start-up criteria are met, the Nexa™ power module enters the Running State and power may be drawn from the unit. At this point, the Nexa™ controller closes the external relay that connects the fuel cell module to load.
- Warning - A Warning State is issued if any of the fuel cell system operating parameters fall outside of a desired range. The Nexa™ module will still operate and produce power during a warning. Refer to the Warning Status Field description for details.
- Stopping – If the start signal is removed, the Nexa™ module goes through its normal shutdown procedure. Hydrogen is vented from the fuel cell stack to remove water from the anode flow channels. The air pump blows product water from the cathode side of the fuel cells for storage. After, the cathode air and cooling air supply are stopped, and the hydrogen solenoid and purge valves are closed to isolate the stack.
- Failure - A Failure State is issued if any of the fuel cell system operating parameters fall outside of a permitted range. If this occurs, the Nexa™ module shuts down immediately. The system remains in the Failure State until it is returned to Standby by removing the start signal. Refer to the Failure Status Field description for details.
- Non-Restartable – In most cases, failures are resettable by removing the start signal, returning the Nexa™ module to Standby mode and starting again. However, for safety reasons, certain types of failures (hydrogen leaks, software faults & self-test faults) are defined as Non-Restartable. If any of these faults occur, the system is put into a Non-Restartable State and cannot be restarted by simply toggling the start signal. The Non-Restartable State persists until it is cleared using the diagnostic software features provided by NexaMon OEM, with the assistance of Ballard Customer Service.

Failure Status Field - Indicates the kind of failure that has occurred after the Nexa™ module has been put into the Failure State. Types of failures include: High Stack Temperature, Low Stack Voltage, High Stack Current, Low Cell Voltage, Low Fuel Pressure, Fuel Leak, Low Oxygen Concentration, Low Air Temperature, Low Purge Cell, Low Battery Voltage, Start

Time Expired, Self-Test Fault and Software Fault. Refer to Table 14 for the failure alarm limits of the Nexa™ power module. The latest firmware revision (00.03.01) incorporates modified alarm limits to increase availability and extend system operation.

Warning Status Field - Indicates the kind of warning that is occurring when the Nexa™ module is in the Warning State. Types of warnings include: Stack Temperature, Stack Voltage, Stack Current, Fuel Pressure, Fuel Leak, Oxygen Concentration and Purge Cell Voltage Warning. Multiple warnings can be displayed concurrently. Refer to Table 14 for the warning alarm limits of the Nexa™ power module. The latest firmware revision (00.03.01) incorporates modified warning limits to improve product robustness.

Parameter	Warning Level	Failure Level	Restartable
Fuel Cell Stack Temperature	> 71 °C	> 73 °C	Yes
Fuel Cell Stack Voltage	< 23 Volts	< 18 Volts	Yes
Fuel Cell Stack Current	> 60 Amps	> 70 Amps	Yes
Firmware Revision 00.03.01	> 65 Amps	> 75 Amps	Yes
Cell Voltage Checker	N/A	0.85 V/cell pair	Yes
Hydrogen Pressure	< 1.0 barg	< 0.5 barg	Yes
Hydrogen Concentration	80%	100% (10,000 ppm)	No
Oxygen Concentration	< 19.2%	< 18.7%	Yes
Ambient Temperature	N/A	< 3 °C (start-up)	Yes
Battery Voltage	N/A	< 18 Volts (start-up)	Yes
Purge Cell Voltage	< 1.0 Volts	< 0.8 Volts	Yes
Firmware Revision 00.03.01	< 0.8 Volts	< 0.7 Volts	Yes
System Time-out during Start-up	N/A	Digital	Yes
Self Test Fault	N/A	Digital	No
Software Fault	N/A	Digital	No

Table 14: Warning and Failure Alarm Limits

Last Command - Indicates the last serial (RS-485) command received by the Nexa™ power module.

Self-Test Fault - If a Self-Test Fault has occurred, this field will indicate the kind of Self-Test Fault that has happened.

S/W Version - Indicates the software version installed on the Nexa™ power module controller.

Purge Status - Displays the status of the fuel purge control system (Off, On or Disabled) and (Open or Closed).

Resuscitation - Shows the fuel cell resuscitation status (Off or On) and the total number of resuscitations. Resuscitations are automatically initiated by the Nexa™ control system in response to low cell voltages and restore fuel cell performance.

4.2.5 Status Lights

The following status lights are displayed on the NexaMon OEM Main Screen.

- The green Start Line light comes on when the start line has been activated. The start line indicates that the Nexa™ power module has been signalled to start.
- The green Cell Voltage Check light comes on when the voltages of the individual fuel cells are high enough for proper operation.
- The red Serial Timeout light comes on when there is a problem with the serial inputs or outputs, such as when the communications connector is unplugged or the data transfer is too slow.
- The red Checksum Error light comes on when there is a checksum error in serial communication from the Nexa™ power module, indicating poor communications.
- The Other Error light is for all other errors. An error message will be displayed once but the error light will remain on as long as the problem persists. Click "Details" to view more information about the error.

4.2.6 Process Variables

The NexaMon OEM software monitors 17 key process parameters of the Nexa™ power module, when the Communication Start Switch in the Main Screen has been toggled to the ON position. During system operation, the real-time process values are indicated in the parameter field, and the chart plots the progress of those variables that are checked. The monitored process variables are:

- Stack Temperature
- Stack Voltage
- Stack Gross Current (including parasitic loads internal to the power module)
- Fuel Pressure (entering the power module upstream of the inlet pressure regulator)
- Percentage of Fuel Leak Alarm (where 100% indicates 10,000 ppm or 25% LFL of hydrogen in air)
- Fuel Consumption (relative to start of run)
- Oxygen Concentration in the ambient air (as measured in the vicinity of the controller)
- Ambient Air Temperature (as measured in the vicinity of the controller)
- Purge Cell Voltage
- Battery Voltage (used to start the power module)
- Process Air-Flow (as measured by the mass flow meter)
- Air Pump Operating Voltage
- Hydrogen Concentration Bridge Voltage
- Process Air Pump Duty Cycle
- Cooling Air Fan Duty Cycle
- Stack Gross Power (calculated from current and voltage measurements)
- Air-Flow Stoichiometry (calculated from the air mass flow and the current draw)

4.2.7 Chart

The chart plots the progress of the checked process variables. The chart line colour for each process variable is shown beside the process variable name. Turn the process variable chart lines on or off by clicking on the check box beside the variable's name. The check box state does not affect the information that is logged to disk.

The X-axis represents time in seconds and has a default range of two minutes. Alter the range by selecting the rightmost or leftmost value and entering a new value. Use the mouse to zoom in to an X-axis location.

The Y-axis represents the values of all the process variables. The grey Y-axis scale corresponds to the grey process variable fields, and the black scale corresponds to the black process variable fields. You can alter either scale by selecting either the top-most or bottom-most value, and entering a new value.

4.2.8 Time Field

The following time fields are displayed in the Main Screen of NexaMon OEM.

- System Runtime is the time since battery power was applied to the Nexa™ power module.
- System Lifetime is the total time that battery power has been applied to the Nexa™ power module.
- Stack Start Time is the time taken for the most recent startup of the Nexa™ power module.
- Stack Stop Time is the time taken for the most recent shutdown of the Nexa™ power module.
- Stack Runtime is the time since the Nexa™ power module was last successfully started, or the total time the system was most recently run for.
- Stack Lifetime is the total time the Nexa™ power module has been in the running or warning states.

The format of all time fields is hh:mm:ss.

4.2.9 Data Logging

The data logging facility provides real-time sensor and status data, as measured by the Nexa™ power module controller. All process variable values are logged, when the logging feature is turned on, whether they appear on the chart or not. This data can be viewed in graphical form on the host computer.

Figure 15 illustrates how configure a data log file using NexaMon OEM.

- The Data Logging File field shows the name of the file that the data is being saved to.
- The Period slider allows you to choose a data download interval of between 0.2 seconds and 10 minutes. The one-second interval is the default logging interval the first time NexaMon OEM is run. The logging period is stored when NexaMon OEM is closed.
- The Logging switch allows you to turn the data logging function on and off.

Click the Browse button to select a file name. A dialogue box will appear, which will allow you to enter the desired name and path for the stored data file. The file is automatically saved in the comma separated variable (CSV) format and can be easily imported into a spreadsheet program, such as Microsoft Excel. To change the data logging filename or directory, click the mouse cursor on the button right of the data logging name field. You can then enter a new filename and/or choose a different file path.

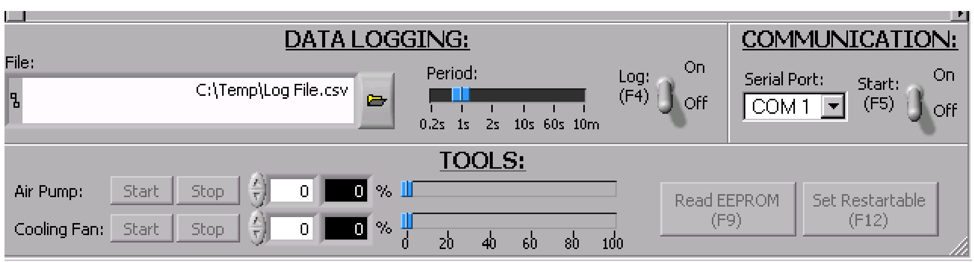


Figure 15: Configuring a Data Log File

☞ **NOTE: The power module sensors are used for system control and safety and may not provide accurate performance data. When possible, use calibrated external sensors to measure system data.**

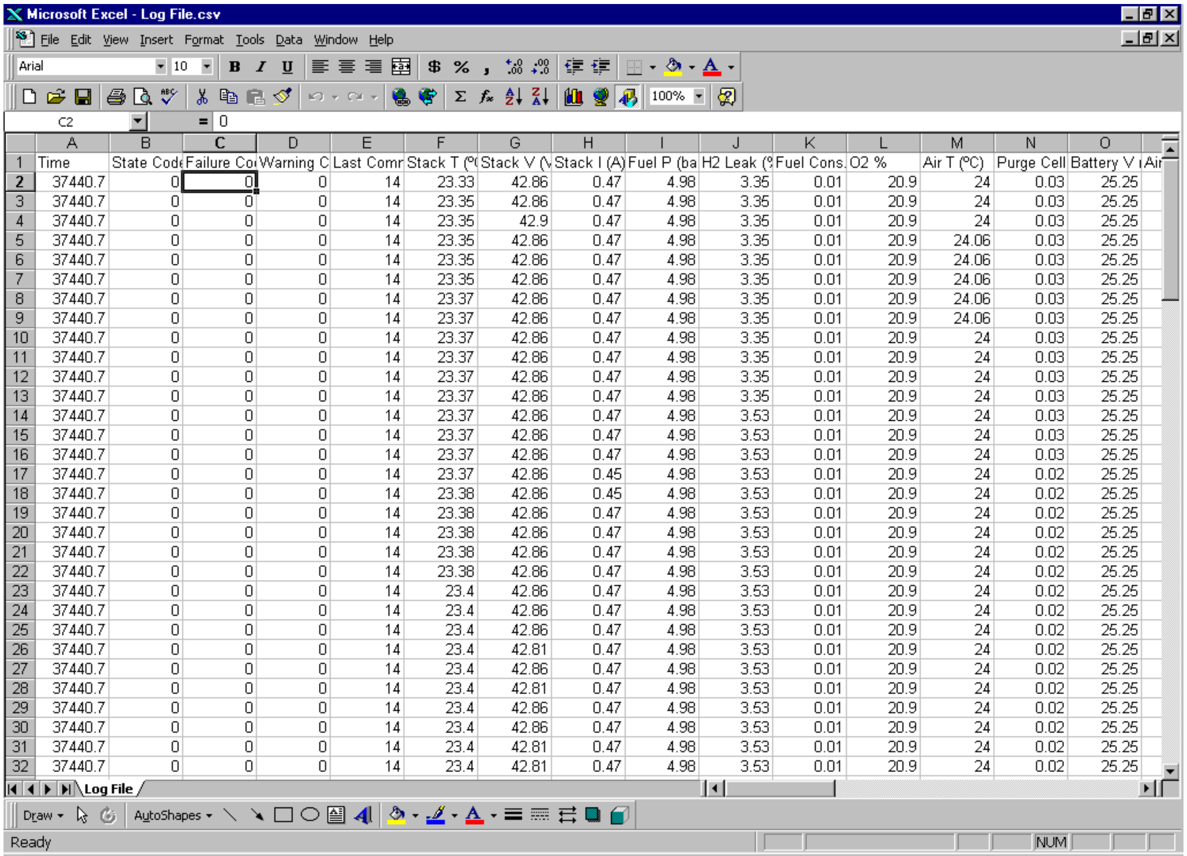
The data logging files contain all of the information displayed on the Main Screen of NexaMon OEM, as illustrated in Figure 14. The data logging files also contain additional internal signal data for Ballard Power Systems use only. Each parameter and its associated unit of measure is detailed in Table 15.

Parameter	Units
Time	*MS Excel Time Format – The number of days since Jan 1, 1900.*
State Code (a.k.a. "Nexa™ status")	0 = Standby 1 = Starting 2 = Running 3 = Warning 4 = Stopping 5 = Failing 6 = Non-Restartable
Failure Code (a.k.a. "Failure status")	*0 = Normal Operation* *1 = High Fuel Cell Stack Temperature* *2 = Low Fuel Cell Stack Voltage* *3 = High Fuel Cell Stack Current* *4 = Low Cell Voltage* *5 = Low Fuel Pressure* *6 = Fuel Leak Detected* *7 = Low Oxygen Concentration* *8 = Low Ambient Temperature* *9 = Low Purge Cell Voltage* *10 = Low Battery Voltage* *11 = Startup Time Expired* *12 = Self Test Fault* *13 = Software Fault*
Warning Code (a.k.a. "Warning status")	1 byte, additive: *0 = No Warnings* *1 = High Fuel Cell Stack Temp. Warning* *2 = Low Fuel Cell Stack Voltage Warning* *4 = High Fuel Cell Stack Current Warning* *8 = Low Fuel Pressure Warning* *16 = Fuel Leak Warning* *32 = Low Oxygen Concentration Warning* *64 = Low Purge Cell Voltage Warning*
Last Command	(Ballard use only)
Stack (Air Exhaust) Temperature	ºC
Stack Voltage	*V*
Stack Current	*A (gross)*
Fuel Pressure	*barg*
Fuel Leak (Hydrogen Concentration)	% Alarm (100% = 1% H_2)
Fuel Consumption	*L*
Oxygen Concentration	*%*
Air (Ambient) Temperature	ºC
Purge Cell Voltage	V
Battery Voltage	VDC
(Process) Air Flow	SLPM
Air Pump 12/3 Operating Voltage	VDC

(Hydrogen Sensor) Bridge Voltage	VDC
(Process) Air Pump Duty Cycle	%
(Cooling Air) Fan Duty Cycle	%
Port A to Port F	(Ballard use only)
Stack Voltage ADC (analog-to-digital conversion)	(Ballard use only)
Stack Current ADC	(Ballard use only)
Fuel Pressure ADC	(Ballard use only)
Purge Cell ADC	(Ballard use only)
Stack Temperature ADC	(Ballard use only)
Oxygen Percentage ADC	(Ballard use only)
Air Flow ADC	(Ballard use only)
Ambient Temperature ADC	(Ballard use only)
Battery Voltage ADC	(Ballard use only)
Fuel (H2) Leak ADC	(Ballard use only)
Bridge Voltage ADC	(Ballard use only)
12/3 Voltage ADC	(Ballard use only)
DAC A Loop ADC	(Ballard use only)
DAC B Loop ADC	(Ballard use only)
Spare ADC	(Ballard use only)
Ground ADC	(Ballard use only)
Pump DAC (digital-to-analog conversion)	(Ballard use only)
Fan DAC	(Ballard use only)
System Run Time	Seconds
System Life Time	Seconds
Stack Start Time	Seconds
Stack Stop Time	Seconds
Stack Run Time	Seconds
Stack Life Time	Seconds
Self Test (Fault)	(Ballard use only)
Purge (Status)	*0 = CLOSED* *1 = OPEN* *2 = DISABLED*
Resuscitation Status	0 = OFF 1 = ON 2 = DISABLED
Resuscitation Number (over the lifetime of the power module)	# (ASCII Text)
Start Line (status light)	0 = OFF 1 = ON
Cell Voltage Check (status light)	*0 = OFF* *1 = ON*

Table 15: NexaMon OEM Data Logging Format

A portion of a sample data-logging file is illustrated below. Each row corresponds to a single time stamp. Each column of the data table corresponds to the parameters listed in Table 15.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Time	State Code	Failure Co	Warning C	Last Comm	Stack T (º	Stack V (V	Stack I (A)	Fuel P (ba	H2 Leak (%	Fuel Cons.	O2 %	Air T (ºC)	Purge Cell	Battery V (
2	37440.7	0	0	0	14	23.33	42.86	0.47	4.98	3.35	0.01	20.9	24	0.03	25.25
3	37440.7	0	0	0	14	23.35	42.86	0.47	4.98	3.35	0.01	20.9	24	0.03	25.25
4	37440.7	0	0	0	14	23.35	42.9	0.47	4.98	3.35	0.01	20.9	24	0.03	25.25
5	37440.7	0	0	0	14	23.35	42.86	0.47	4.98	3.35	0.01	20.9	24.06	0.03	25.25
6	37440.7	0	0	0	14	23.35	42.86	0.47	4.98	3.35	0.01	20.9	24.06	0.03	25.25
7	37440.7	0	0	0	14	23.35	42.86	0.47	4.98	3.35	0.01	20.9	24.06	0.03	25.25
8	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.35	0.01	20.9	24.06	0.03	25.25
9	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.35	0.01	20.9	24.06	0.03	25.25
10	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.35	0.01	20.9	24	0.03	25.25
11	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.35	0.01	20.9	24	0.03	25.25
12	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.35	0.01	20.9	24	0.03	25.25
13	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.35	0.01	20.9	24	0.03	25.25
14	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.53	0.01	20.9	24	0.03	25.25
15	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.53	0.01	20.9	24	0.03	25.25
16	37440.7	0	0	0	14	23.37	42.86	0.47	4.98	3.53	0.01	20.9	24	0.03	25.25
17	37440.7	0	0	0	14	23.37	42.86	0.45	4.98	3.53	0.01	20.9	24	0.02	25.25
18	37440.7	0	0	0	14	23.38	42.86	0.45	4.98	3.53	0.01	20.9	24	0.02	25.25
19	37440.7	0	0	0	14	23.38	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
20	37440.7	0	0	0	14	23.38	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
21	37440.7	0	0	0	14	23.38	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
22	37440.7	0	0	0	14	23.38	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
23	37440.7	0	0	0	14	23.4	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
24	37440.7	0	0	0	14	23.4	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
25	37440.7	0	0	0	14	23.4	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
26	37440.7	0	0	0	14	23.4	42.81	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
27	37440.7	0	0	0	14	23.4	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
28	37440.7	0	0	0	14	23.4	42.81	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
29	37440.7	0	0	0	14	23.4	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
30	37440.7	0	0	0	14	23.4	42.86	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
31	37440.7	0	0	0	14	23.4	42.81	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25
32	37440.7	0	0	0	14	23.4	42.81	0.47	4.98	3.53	0.01	20.9	24	0.02	25.25

Figure 16: Sample of Data Logging File

4.2.10 Read EEPROM

The diagnostic data download facility reads the contents of the Nexa™ power module controller's non-volatile "electronically erasable programmable read-only memory" (or "EEPROM"). This data can be viewed on the host computer's monitor and stored in a file for further assessment.

The power module's EEPROM stores the following information:

- EEPROM Header Data — this contains factory information pertaining to the controller hardware and software
- Fault Statistics — this contains a record of the total number of each type of alarm
- Configuration Data — this contains oxygen and current sensor calibration data
- Cumulative System Data Cell — this contains overall lifetime and other cumulative information
- Last Fault Status Data — this contains detailed information pertaining to the last fault that occurred. Data includes operating state settings, system (process variable) data, port configuration, analogue-to-digital conversion values, and time information.
- Historical Fault Data — this contains information pertaining to the last 20 faults that have occurred. This data is less detailed than the last fault status data. Specific data includes operating state settings, time information, and system (process variable) data. The historical fault data is accessed by clicking on a fault in the fault list (see below.)

To retrieve the diagnostic data:

1. Connect the computer to the Nexa[TM] module, using the communication wiring harness, as illustrated in the previous section.

2. Start the NexaMon OEM software program.

3. Provide 24VDC to the Nexa control board using a power supply or battery, as illustrated in the previous section. Establish communications between the Nexa[TM] module and computer by toggling the Communication Start Switch to the ONB position on the main screen. The Nexa[TM] system should be in Standby State.

4. Press on the Read **EEPROM** button (F9) on the main screen. The last fault data screen appears, as shown in Figure 17.

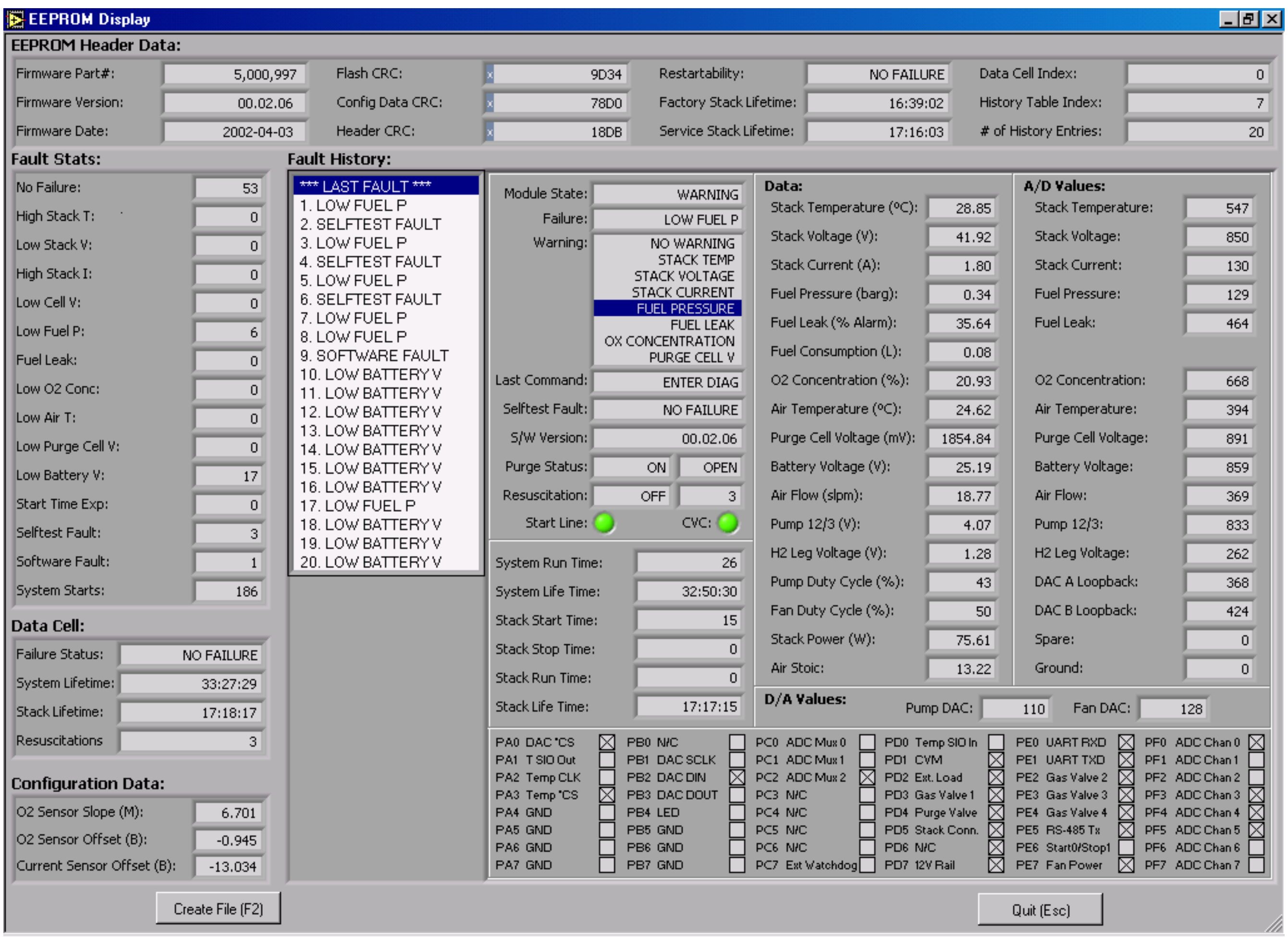


Figure 17: Sample of Last Fault Data Screen

5. To view one of the 20 previous faults, click on the desired fault on the fault list. The header and sidebar items remain the same, and the fault history shows the historical fault data, as shown in Figure 18. This screen is similar to the last fault screen but only contains information pertaining to the selected fault.

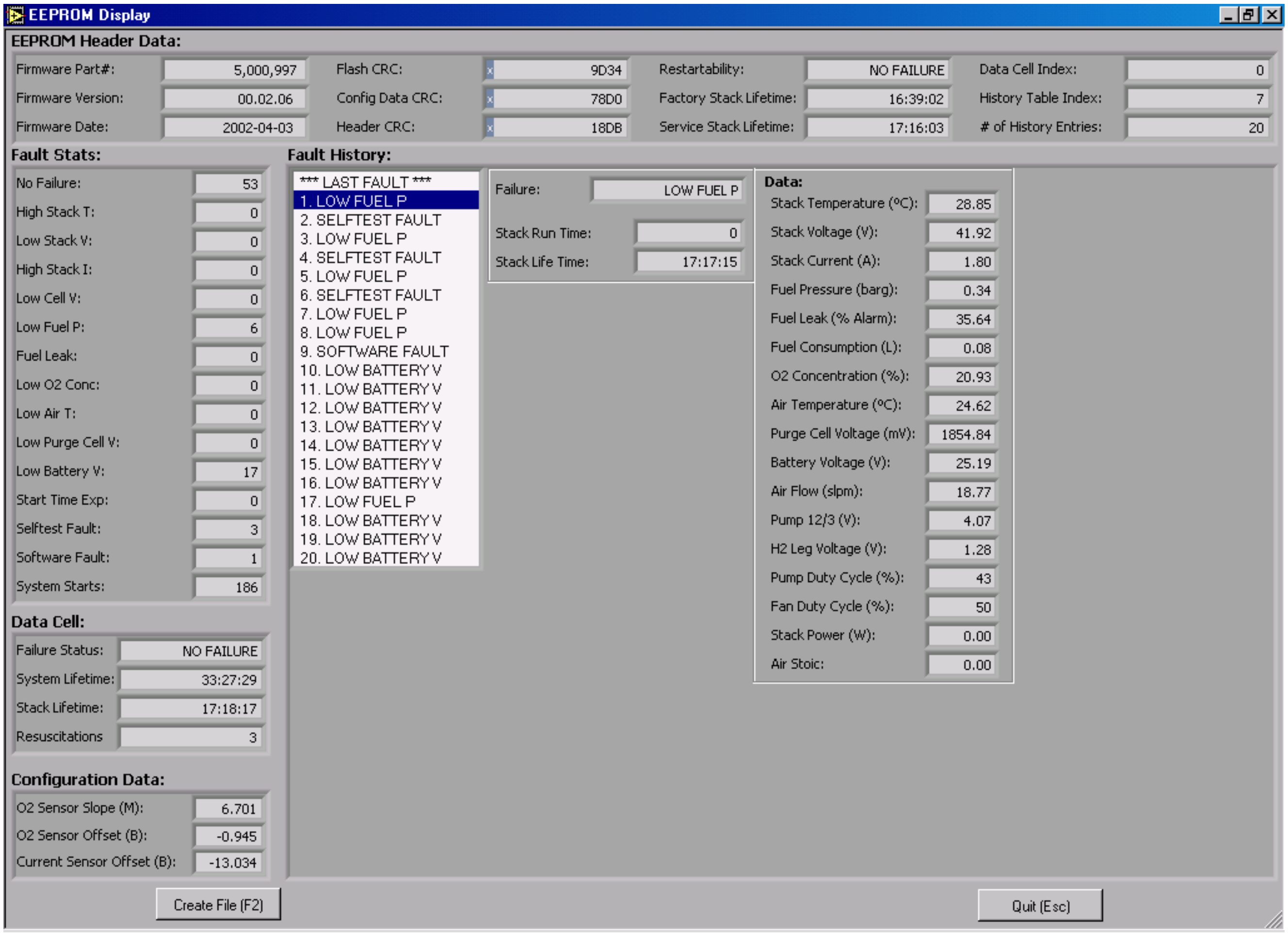


Figure 18: Sample of Historical Fault Data Screen

6. Press the **CREATE FILE** button, or F2, to store the information to a diagnostic data report. The program prompts you to select or enter a file name and directory. A sample of the diagnostic data report is shown in Figure 19.

7. Press the **CLOSE** button to return to the main screen.

EPROM HEADER DATA

Software Part Number	*5,000,997*
Software Revision ID	*00.02.06*
Software Build Date	*2002-04-03*
Software Flash CRC-16	*0x9D34*
Configuration Data CRC-16	*0x78D0*
EEPROM Header CRC-16	*0x18DB*
System Restartability Status	*NO FAILURE*
Factory Stack Lifetime Stamp	*0016:39:02*
Service Stack Lifetime Stamp	*0017:16:03*
Cumulative Time Cell Index	*0*
History Table Entry Index	*7*
Number of History Entries	*20*

CONFIGURATION DATA

O2 Sensor Slope (M)	*6.70*
O2 Sensor Offset (B)	*-0.94*
Current Sensor Offset (B)	*-13.03*

FAULT STATISTICS

Normal Shutdowns	*53*
HIgh Stack Temperature	*0*
Low Stack Voltage	*0*
High Stack Current	*0*
Low Cell Voltage	*0*
Low Fuel Pressure	*6*
Fuel Leak Detected	*0*
Low Oxygen Concentration	*0*
Low Ambient Temperature	*0*
Low Purge Cell Voltage	*0*
Low Battery Voltage	*17*
Startup Time Expired	*0*
Selftest Fault	*3*
Software Fault	*1*
Startups/Resets	*186*

CUMULATIVE SYSTEM DATA CELL

Last Shutdown/Failure Type	*NO FAILURE*

Total System Lifetime	*0033:27:29*
Total Stack Lifetime	*0017:18:17*
Cumulative Resuscitations	*3*
LAST FUEL CELL FAULT STATUS DATA	
System State at Time of Fault	*WARNING*
System Fault Type	*LOW FUEL P*
System Warning Bit Mask	*0x04*
Last Command Acknowledged	*ENTER DIAG*
System Selftest Status	*NO FAILURE*
Purge Status	*ON*
Purge Valve	*OPEN*
Resuscitation Status	*OFF*
Total Resuscitations	*3*
System Start Line Status	*ON*
Cell Voltage Checking	*ON*
Stack Temperature (ºC):	*28.85*
Stack Voltage (V):	*41.92*
Stack Current (A):	*1.80*
Fuel Pressure (barg):	*0.34*
Fuel Leak (% Alarm):	*35.64*
Fuel Consumption (L):	*0.08*
O2 Concentration (%):	*20.93*
Air Temperature (ºC):	*24.62*
Purge Cell Voltage (mV):	*1854.84*
Battery Voltage (V):	*25.19*
Air Flow (slpm):	*18.77*
Pump 12/3 (V):	*4.07*
H2 Leg Voltage (V):	*1.28*
Pump Duty Cycle (%):	*43.00*
Fan Duty Cycle (%):	*50.00*
Stack Power (W):	*75.61*
Air Stoic:	*13.22*
PORT A	*0x09 (00001001)*
PORT B	*0x04 (00000100)*
PORT C	*0x04 (00000100)*
PORT D	*0xFE (11111110)*
PORT E	*0xBF (10111111)*
PORT F	*0x39 (00111001)*

ADC0 Stack Voltage	*850*
ADC1 Stack Current	*130*
ADC2 Fuel Pressure	*129*
ADC3 Purge Cell Voltage	*891*
ADC4 Stack Temperature	*547*
ADC5 Oxygen Concentration	*668*
ADC6 Air Flow Rate	*369*
SPI Air Temperature Sensor	*394*
ADC7 MUX0 Battery Voltage	*859*
ADC7 MUX1 H2 Leak Sensor	*464*
ADC7 MUX2 H2 Sensor Leg+	*262*
ADC7 MUX3 12/3 Volt Rail	*833*
ADC7 MUX4 DAC A Loopback	*368*
ADC7 MUX5 DAC B Loopback	*424*
ADC7 MUX6 Spare	*0*
ADC7 MUX7 Ground	*0*
DACA Air Compressor	*110*
DACB Cooling Fan	*128*

Current System Run Time	*0000:00:26*
Total System Lifetime	*0032:50:30*
Current Stack Start Time	*0000:00:15*
Current Stack Stop Time	*0000:00:00*
Current Stack Run Time	*0000:00:00*
Total Stack Lifetime	*0017:17:15*

FAULT HISTORY DATA

(Additional fault list data here for 20 faults total)

Figure 19: Sample of Diagnostic Data Report

4.2.11 Set Restartable

Certain faults are non-restartable and must be reset using diagnostic software before the Nexa™ system can be restarted. In NexaMon OEM, the Set Restartable button is used to reset non-restartable faults in the Nexa™ module. If executed, the user will be prompted to verify that the source of the fault has been addressed before continuing. For instance, if the onboard sensor detects a hydrogen leak, the power module will be automatically shut down and placed in a Non-Restartable State. If the user attempts to clear that fault using the NexaMon OEM software, he will be prompted to check that the source of leak has been removed before continuing, as illustrated in Figure 20.

Figure 20: Resetting Non-Restartable Faults

If you experience a Non-Restartable Fault with your Nexa™ module and are unsure of the cause, contact Ballard Customer Service for further guidance.

4.2.12 Air Pump and Cooling Fan

Diagnostic tools are included to test the air pump and cooling fan separately. The Start button turns on the pump or the fan according to a preset speed. The Stop button turns off the device. Use the slider bars to adjust the speed of the fan or the pump, or alternatively type in the speed setting ranging from 0 to 100%.

Note that running the air pump when the Nexa™ module is not in operation can cause drying of the fuel cell membranes and reduced system lifetime. When conducting an air pump diagnostic test, minimise the amount of time that the air pump is left running.

4.2.13 Changing the Serial Port

The Serial Port menu allows you to choose a serial communications port from COM 1 to COM 8. The default port is COM 1, when NexaMon OEM is first run. The port state is stored on shutdown. The **Start** switch must be turned off to access the Serial Port menu. The serial port applies to all program communications. The selected port must be the one that is hooked up for system communication. To change the serial port:

1. Set the Start switch (on the main screen) to Off. This enables the serial port menu.
2. Select a serial port by dropping the serial port menu (or by pressing F2) and select the desired COM number, as illustrated in
3. Set the start switch to On. If the selected port is not hooked up, the Serial Timeout light will come on.

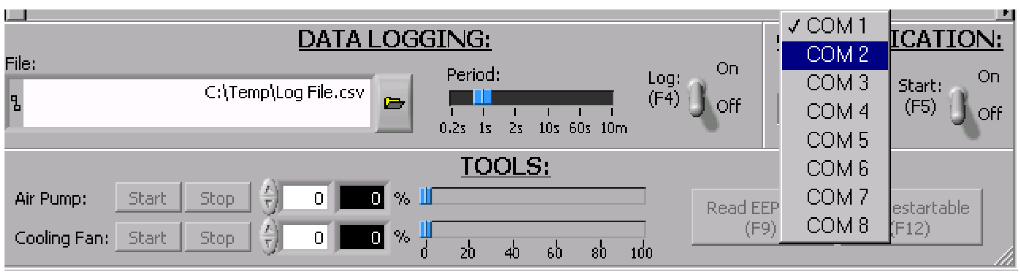


Figure 21: Changing the Serial Port

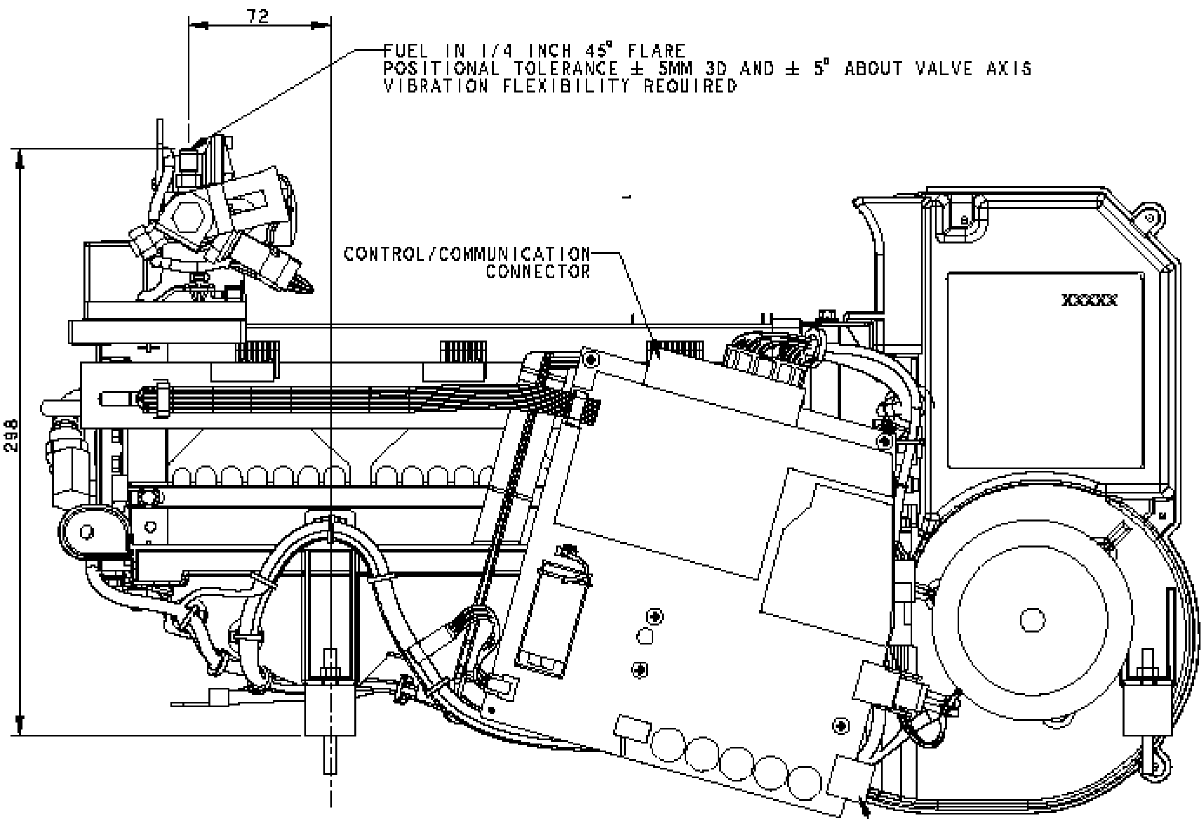
5 Mechanical Interface

This section provides a detailed description of the mechanical interface requirements for the Nexa™ power module. The physical layout and dimensions of the power plant are shown, along with the location of interface connections. Detailed specifications are also provided for the hydrogen supply, cathode air and cooling air interface.

5.1 Physical Layout, Connections & Dimensions

The physical layout and dimensions of the Nexa™ system are shown in the following figures. The location and description of interface connections for process gases, electrical power and communications is also provided.

A solid model of the Nexa™ system layout and interface connections is included as part of this manual to assist OEMs in their installation and packaging design. Speak to a Ballard Customer Support representative for information.



Unless otherwise specified, dimensions are in millimeters

Figure 22: Left Side View of the Nexa™ Power Module

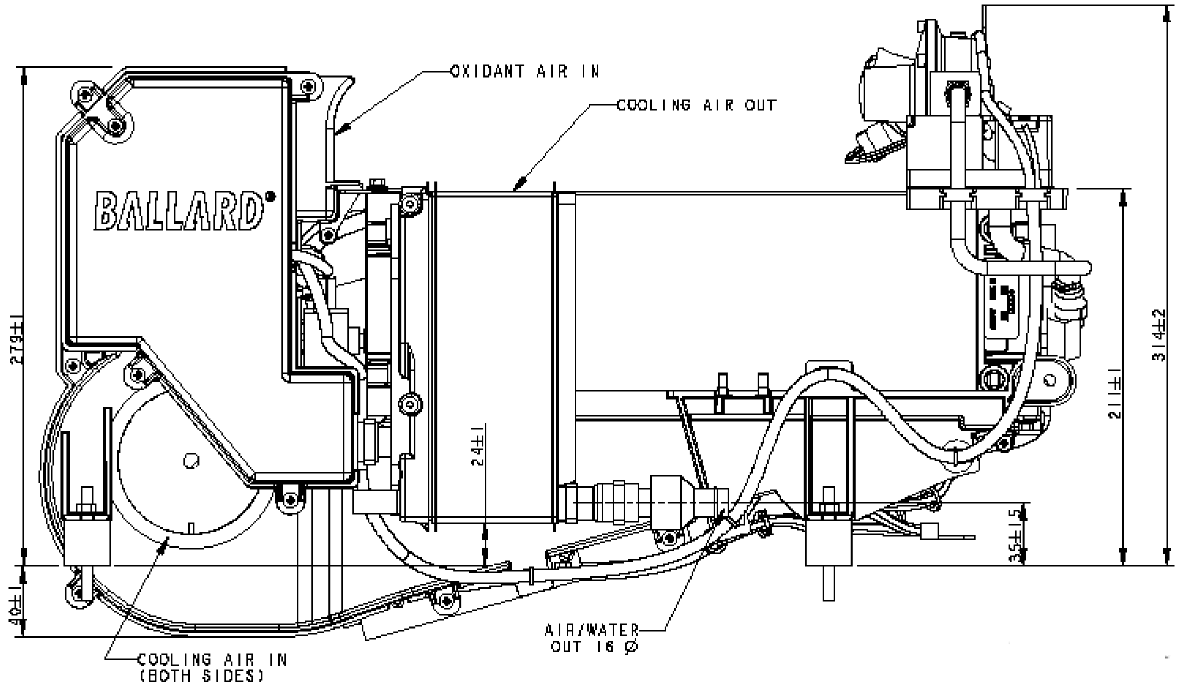


Figure 23: Right Side View of the Nexa™ Power Module

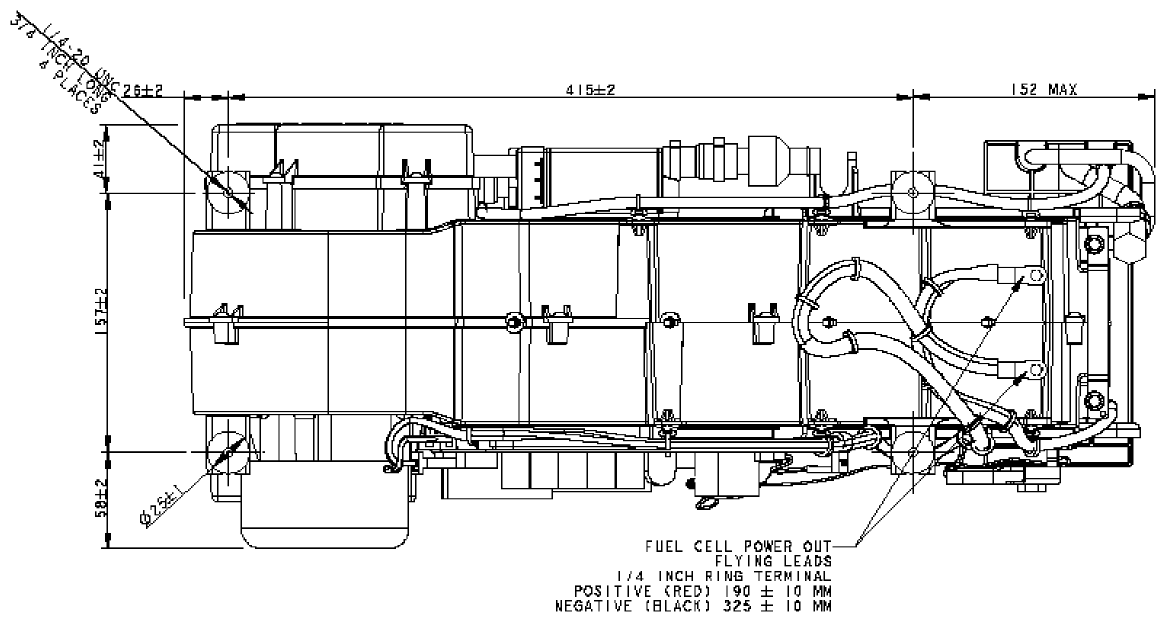


Figure 24: Base View of the Nexa™ Power Module

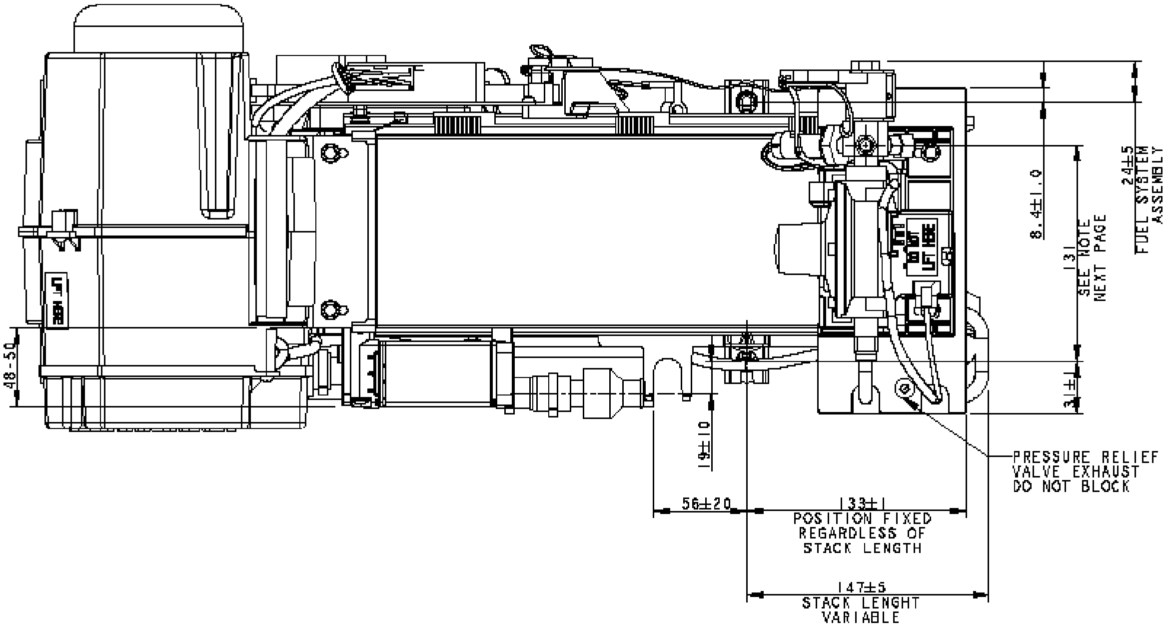


Figure 25: Top view of the Nexa™ Power Module

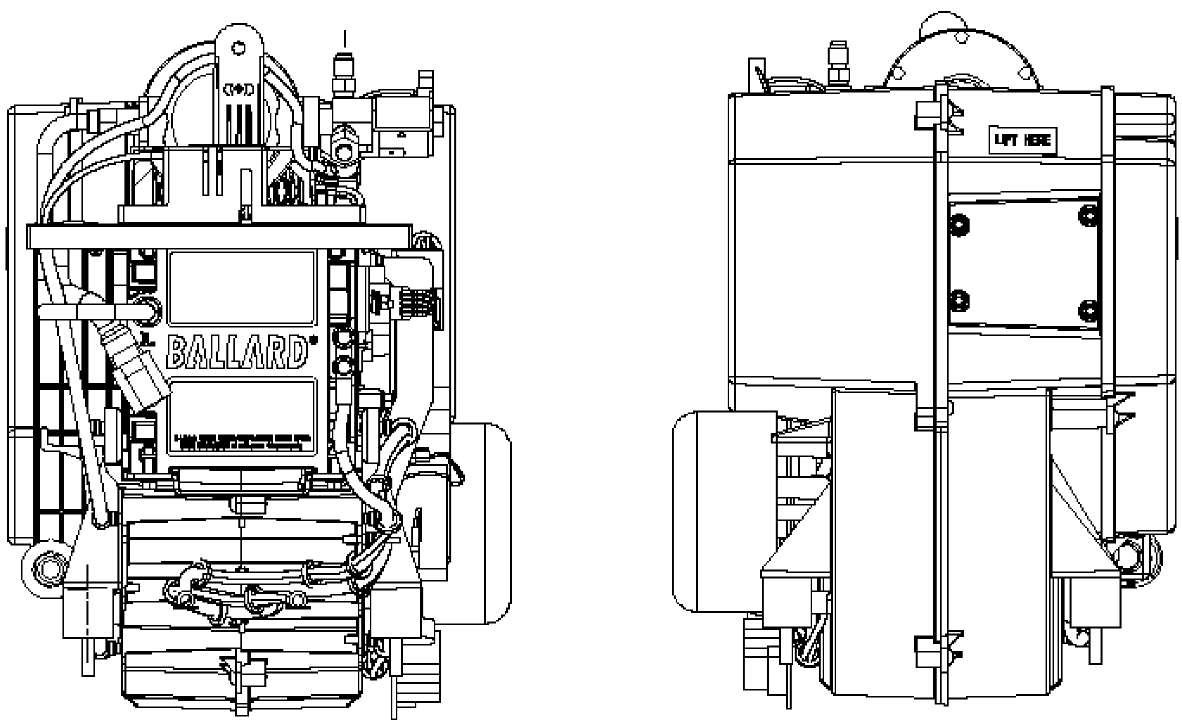


Figure 26: Front and Back Views of the Nexa™ Power Module

5.2 Hydrogen Supply Interface

Hydrogen supply interface specifications for the Nexa™ power module are shown in NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 14 for warning and shut-down values).

Table 16. The Nexa™ fuel cell system is designed for operation on *pure* gaseous hydrogen. No fuel humidification is required. Hydrogen can be supplied at pressures ranging from 70 kPa(g) to 1720 kPa(g). A pressure relief valve is set for 2400 kPa(g) to ensure overpressure conditions are not applied to the downstream pressure regulator assembly. The relief valve discharges into the vicinity of the onboard hydrogen leak detector, thereby shutting down the system in the event of excessive inlet supply pressure. NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 14 for warning and shut-down values).

Table 16 also indicates the required hydrogen purity and allowable contaminant levels for the fuel supply. Adhere to the fuel composition specification to ensure proper Nexa™ system performance.

Requirement	Description	Quantity
Fuel type	Gaseous hydrogen	
Fuel composition	99.99% H2, Dry	99.99% H_2
Fuel humidification	Dry gas	None required
Fuel inlet supply pressure	Allowable range of fuel inlet supply pressure[1]	70 – 1720 kPa(g) (10 – 250 psig)
Fuel inlet supply temperature	Allowable range of fuel inlet supply temperatures: 5°C - 80°C	5°C - 80°C
Pressure relief valve	Hydrogen pressure relief valve setting	2400 kPa(g) (350 psig)
Acceptable impurities	Inert gases (He, Ar, N2, water vapour)	< 0.01%
	Hydrocarbons	< 1 ppm
	Oxygen	< 500 ppm
	CO and CO2 combined	< 2 ppm
	Sulphur compounds	< 1 ppm
	Ammonia	< 0.01 ppm
H_2 fuel connection	45° flared tube fitting (male) for 1/4" OD tubing	1/4" OD
H_2 fuel consumption	H_2 fuel consumption at maximum power (BOL) ≤ 18.5 slpm	≤ 18.5 slpm
Maximum H_2 fuel flow rate	Maximum H_2 fuel flow rate at maximum power during anode purging	≤ 20.0 slpm

Requirement	Description	Quantity
Nominal purge gas flow rate	Average purge gas flow rate measured over a period of continuous operation	δ ≅ 60 cc/min
Maximum purge gas flow rate	Maximum instantaneous purge gas flow rate	δ ≅ 500 cc/min
Stack leak rate (BOL)	Fuel leak to external at 350 mbarg	10 cc/min
Stack leak rate (EOL)	Fuel leak to external at 350 mbarg	50 cc/min
Stack pressure relief valve (PRV)	Stack PRV setting	96 kPa(g) (14 psig)
	Stack PRV reseal pressure	75 kPa(g) (11 psig)

NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 14 for warning and shut-down values).

Table 16: Hydrogen Interface Specifications

The fuel connection to the Nexa™ system utilises a 45° flared tube fitting (male) for ¼ inch OD tubing. Refer to Figure 22 for the connection location and tolerances. Ensure that the hydrogen supply lines to the power module are provided with vibration isolation.

NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 14 for warning and shut-down values).

Table 16 indicates the hydrogen fuel consumption rate at maximum power is less than or equal to 18.5 slpm. A detailed fuel consumption curve is provided in the Performance Characteristics section of this guide.

NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 14 for warning and shut-down values).

Table 16 also indicates the maximum hydrogen fuel flow rate at maximum power during anode purging is 20.0 slpm. Greater hydrogen flow rates are required during an anode purge because of (1) reduced fuel cell stack operating pressure and (2) excess hydrogen required to purge water out of the flow channels. The maximum instantaneous hydrogen purge rate is approximately 500 cc/min, while the average hydrogen purge rate measured over a period of continuous operation is about 60 cc/min. Excess hydrogen is purged into the cooling air stream and diluted before it exits the Nexa™ system boundary. Water entrained in the hydrogen purge stream is evaporated into the cooling air and dismissed into the surrounding environment. Always ensure that the cooling air is ducted over the Nexa™ hydrogen leak detector to ensure safe dilution levels are maintained in the exhausted air stream. The Nexa™ system will shut down automatically if the leak detector reading reaches 10,000 ppm, which is ¼ of the lower flammability limit (LFL) of hydrogen.

Under normal operation, the Nexa™ fuel cell stack will leak a small amount of hydrogen externally to its surrounding environment. NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 14 for warning and shut-down values).

Table 16 indicates the anticipated stack external leak rate at beginning of life (BOL) and end of life (EOL). Damage to the fuel cell stack, such as a fractured plate, can lead to external leak rates many times greater than normal. During the integration design phase, it is important to ensure that the fuel cell compartment is properly ventilated and monitored to ensure that explosive gas mixtures are not formed. ¼ LFL (10,000 ppm) should be used as the maximum tolerable hydrogen gas concentration within the fuel cell compartment. It is advised that the Nexa™ cooling fan intake be used to ventilate the surrounding fuel cell enclosure. In this way, the Nexa™ hydrogen leak detector, situated in the cooling air exhaust, can also be used to monitor for unsafe gas compositions within the enclosure. Alternatively, the OEM integrator may incorporate a separate compartment ventilation fan and hydrogen leak detector within his packaging design. The OEM is responsible for ensuring adequate ventilation and hydrogen leak detection is incorporated into their packaging design.

The NexaTM fuel cell stack is equipped with a pressure relief valve. NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 14 for warning and shut-down values).

Table 16 provides specifications for the valve. In the event of a stack over-pressure condition, the relief valve discharges into the vicinity of the hydrogen leak detector (refer to Figure 23) and the unit is shut down.

The Nexa™ power module incorporates a solenoid valve for isolating hydrogen supply to the fuel cell stack. The valve fails closed so that the fuel supply is immediately removed in the event of a system failure. An external solenoid valve is also recommended for isolating hydrogen supply at the source. The Nexa™ system provides a control signal for the proposed secondary fuel solenoid so that both fuel isolation valves may be controlled in tandem. Refer to the Electrical Interface Specifications for control signal details.

5.3 Oxidant Air Interface

Oxidant air inlet and outlet interface specifications are provided in Table 17. The Nexa™ system consumes oxygen from the ambient air for producing electrical power. The maximum air consumption rate is approximately 90 slpm at rated power. For protection against oxygen depletion, always operate the Nexa™ power module in a well-ventilated area. For additional safety, the system is equipped with an oxygen sensor. Refer to the Software and Communication Interface for alarm and shut down details.

Figure 23 illustrates the oxidant air inlet to the Nexa™ system. A removable air filter is located at the inlet to the air pump assembly. The filter is installed to catch particles down to the 10 micron level in the air before they get into the process air pump. Additional air filtration is not required. Periodic replacement of the air filter may be needed, depending on the ambient air quality. The filter should not be cleaned, since the used cleansing agent could be a source of contamination for the fuel cell. For periodic maintenance, ensure that the air filter is accessible when designing the final product packaging. Also, ducting should be incorporated in the product packaging to ensure cool, fresh air is supplied to the oxidant inlet. Separation of the air pump inlet and cooling air exhaust is recommended.

The Nexa™ power module produces water as a by-product of the fuel cell reaction. Excess product water is discharged in the oxidant air exhaust as both liquid and vapour. At full power, approximately 870 ml/hour are generated. Detailed water production curves are provided in the Performance Characteristics section of this guide. System integration requires design strategies for handling excess product water. Product water may be evaporated passively into the ambient environment or condensed and collected. Ensure that downstream processes do not add excessive flow restriction to the air pump, to maintain adequate airflow to the fuel cells. Refer to Table 17 for details.

Figure 23 illustrates the oxidant air outlet connection to the Nexa™ system. A check valve on the outlet of the humidity exchanger isolates the oxidant exhaust when the system is shut down, keeping the fuel cell stack humidified during periods of storage. A 16 mm OD tube stub is provided for external connection to the cathode air exhaust.

Requirement	Description	Quantity
Oxidant Type	Ambient Air	
Air Inlet Supply Pressure	Atmospheric	~ 1 atmosphere
Air Flow Rate	Oxidant air flow rate at maximum power (beginning of life) ≤ 90 slpm	≤ 90 slpm
Air Inlet Filtration	The Nexa™ DC Power Module incorporates an oxidant air inlet filter. Additional filtration is not required.	None required
Air Inlet Connection	Ducting is recommended to separate the oxidant air inlet from cooling air exhaust.	Ducting recommended
Air Outlet Connection	Check valve preserves stack hydrogen during storage. Outer diameter of oxidant air outlet tube is 16 mm.	16 mm OD
Air Outlet Temperature	Oxidant air outlet temperature is determined by fuel cell stack operating temperature.	< 55°C
Flow Rate of Product Water	Maximum flow rate of product water (at rated power) as both liquid and vapour.	< 870 ml/hour
Air Outlet Restriction	Maximum flow restriction on outlet duct of oxidant air stream at 100 slpm air flow rate, 55°C, as measured by pressure drop to ambient.	3.4 kPa(g) (0.5 psi)

Table 17: Oxidant Air Inlet and Outlet Interface Specifications

5.4 Cooling Air Interface

A cooling fan maintains the desired fuel cell stack operating temperature at 65°C. Cooling air is drawn into the sides of the squirrel cage fan, as shown in Figure 23. Air is ducted to the base of the stack and flows vertically upward through cooling channels between fuel cells. Cooling air exhaust exits at the top of the fuel cell stack.

To maximise the capacity of the Nexa™ cooling system, ensure that the fan intake draws in fresh ambient air. External cooling air ducting must be added to the fuel cell stack in order to ensure that coolant exhaust does not mix with the fan intake. If the operating environment is dusty, it is recommended that the cooling air be filtered to remove particulates. Use temperature resistant and non-conductive materials for the housing and ducting channels. Furthermore, when integrating power-conditioning equipment with the Nexa™ system, ensure that the waste heat from the inverter or battery charger is separately ducted out of the unit enclosure. Avoid dumping waste heat from power electronics into the cooling fan intake, as this will compromise the Nexa™ cooling system capacity.

The cooling air exhaust should be ducted over the hydrogen leak detector of the hydrogen delivery assembly. In this way, the leak detector continuously monitors hydrogen levels purged into the cooling air stream. The detector also checks for external leaks from the fuel cell stack that may be caused by physical damage or seal failure. The integration of the cooling system, hydrogen leak detection warnings and alarms are an important element of the Nexa™ safety system design. For this reason, when performing packaging design, it is recommended that the cooling fan intake draws some of its air from around the fuel cell stack, thereby providing ventilation and leak detection to the fuel cell enclosure.

The Nexa™ power module cooling air exhaust specifications are shown in the table below. The maximum cooling airflow rate required for maintaining desired stack operating temperature at full power is 3600 slpm. In order to assure that the cooling fan can deliver the needed airflow, the OEM must limit the flow restriction to the fan intake and exhaust. At maximum cooling airflow rate, a pressure loss of 1.4 inches of water is available to the OEM for performing ducting and grill geometry design.

Requirement	Description	Quantity
Coolant Type	Ambient air	
Pressure	Atmospheric	~ 1 atm
Temperature	Cooling air outlet temperature at rated load and operating temperature	~ 17°C above ambient
Flow Rate	Maximum required cooling air flow rate	3600 slpm (140 scfm)
Coolant Outlet Restriction	Maximum allowable pressure loss in OEM system design (ducting, grill geometry, etc) at maximum cooling air flow rate.	1.4 inches of water

Table 18: Cooling Air Exhaust Specifications

5.5 Product Water

At full power, the Nexa™ power module produces 870ml/hr of water. In theory, water produced by the cathode of a fuel cell is pure and free of contaminants. However. certain chemical species, which exist in air, quickly dissolve in the water as it travels through the cathode flow fields in contact with air. As a result, the conductivity of the product water is generally greater than the conductivity of pure water. Although the conductivity varies according to the operating and environmental conditions, the conductivity of water has been measured to be in the range of 5 to 10 µS.

In approximately the first 100 hrs of operation, the OEM may notice tiny black particulate in the product water. These particulate are generally silicones or silicates arising the high volume manufacturing processes employed to manufacture the electrodes and flow field plates.

5.6 Contaminants

PEM fuel cells are susceptible to contaminants in the fuel and air. Contamination typically manifests as a drop in fuel cell output voltage. In most cases, the effect is reversible through operation, once the source of contamination has been removed. However, in some cases the damage is permanent.

Carbon monoxide, sulphur compounds and hydrocarbons are the principal fuel contaminants in PEM fuel cell systems. The Hydrogen Supply Interface section of this guide provides detailed purity specifications for the fuel supply and allowable contaminant levels to ensure proper Nexa™ system performance and lifetime. Refer to NOTE 1: Refers to pressure supplied to the Nexa inlet during operation. Depending on the users fuel supply design, pressure will droop below the user's regulator set-point due to losses from fuel flow. Also note that there will be a low fuel pressure warning at a higher pressure than the minimum supply pressure (see Table 14 for warning and shut-down values).

Table 16.

The air quality surrounding the Nexa™ module must also be considered when packaging, transporting, storing or operating the unit. Table 19 provides a list of known contaminants that could reduce output performance or system lifetime if ingested by the fuel cell through its air intake. Common sources for these contaminants are provided, along with the degree of concern and concentration limits, when known.

Operating the Nexa™ module in the presence of combustion exhaust is one mechanism for fuel cell contamination. Nitric oxide and/or sulphur dioxide in the air can block catalytic sites and reduce fuel cell output performance. However, in most cases, the performance loss due to combustion exhaust gases is fully recoverable through operation in fresh air. General-purpose cleaners, paint strippers, dyes, paints and other chemicals can also lead to fuel cell contamination. In some cases, these chemicals irreversibly absorb on the catalyst and cause permanent damage. In others, the affect is reversible through operation. Refer to Table 19.

A list of industrial and household products containing substances that may cause contamination to the fuel cell stack can never be exhaustive. Given that the Nexa™ unit does not require an external water supply and is to use only fuel meeting Ballard Power Systems' specifications, the sole path for the ingestion of contaminants is its requirement to draw air from the surrounding local atmosphere. Many of the contaminants in the following list are contained in various products used in industry and around the home. However, if an airborne form does not exist, there will be no method of delivery and the fuel cell will not become contaminated. When the unit is not operating, a closed environment should be maintained, to prevent airborne contamination.

Harmful Compounds / Substances	Common Products or Devices in which compounds / substances can be found	Degree of Concern
Fossil Fuel Combustion By-Products		
Nitric Oxide, Sulphur Dioxide	Operation of indoor gas heaters, fireplaces, wood burning heaters and internal combustion engines. Tobacco smoke and incense also produce these compounds.	Concern – High 1 ppm Nitric Oxide 10 ppm Sulphur Dioxide.
Halogenated Organic Compounds		
Dichloromethane, Carbontetrachoride	Commonly used general-purpose cleaners, dry cleaning and paint strippers.	Concern – High Can irreversibly absorb on catalyst.
Methyl Bromide	Commonly used in fumigation of industrial dry foodstuffs and produce, and residentially on rugs, furniture and clothing in sealed vacated homes	Concern – High Can irreversibly absorb on catalyst.
Aromatic Compounds		
Toluene, Xylene	Dyes, paints, gasoline, coatings, insecticides, adhesives, varathanes and corrosion inhibitors.	Concern – Low Effects catalyst, but may be removed through oxidation during normal operation.
Aliphatic hydrocarbons		
Methane, Propane, Octane and Kerosene	Fossil fuels, i.e. gasoline, diesel, natural gas, propane gas, paraffin. Commercial products include turpentine, furniture polish, household cleaners and propellants.	Concern – Low unless combustion occurs A source of nitric oxide and sulphur dioxide upon combustion.
Esters	Perfumes, general purpose cleaners, pesticides, cosmetics, food flavours	Concern – Low Effects cathode, but may be removed through oxidation during normal operation.

Methanol (Wood Alcohol)	Paint strippers, windshield wiper solution, duplicator fluid, Remote control hobby airplane and car fuel, antifreeze, dry gas, aerosol products	Concern – Low Effects cathode, but may be removed through oxidation during normal operation.
Sulphur Compounds		
Mercaptans	Cosmetics, shampoo, latex paints, pesticides.	Concern – Low Can irreversibly absorb on catalyst.
Halides		
Chlorine, Bromine or Iodine as gaseous decomposition products.	Household bleaches, swimming pool disinfectants	Concern – Low Can irreversibly absorb on catalyst.

Table 19: List of Contaminants and Common Sources

5.7 Material Compatibility

The design of a PEM fuel cell system requires attention to material compatibility issues that may differ from conventional engine design. Trying to determine which *specific* materials are suitable for fuel cell use can be difficult, as few materials are in a "pure" state. Plastics can contain plasticizers. Metallic components are usually alloyed and can be brazed or soldered together. The best approach for determining fuel cell material compatibility, to avoid the possibility of MEA contamination, considers the following:

- What materials are present
- Whether a transport mechanism exists (i.e. water or gas flow)

There are three general types of contaminants that are known to have a negative effect on fuel cell performance:

1. Organic contaminants
2. Inorganic contaminants (metals & non-metals)
3. Gaseous contaminants

The key factor as to whether the contaminant has any effect is not *if* a contaminant is present, but *how much*.

5.7.1 Organic Contaminants

Organic contaminants are carbon-containing compounds, of which there are thousands. Almost all organics will adsorb on the catalyst if they can get to it. This results in a loss in fuel cell performance due to a loss in platinum surface area.

The most difficult issue in determining whether materials are compatible is locating possible sources of organic contaminants. In a fuel cell system, the majority of organic contaminants come from plasticizers in polymers, compressor oils, lubricants on fittings, and degradation of adhesives and seals.

It is difficult to determine if some organics are worse than others, but smaller molecules (i.e. plasticizers like phthalates) would likely have a larger negative impact on fuel cell performance, as they are more mobile than larger polymers.

Organic materials do not need water to move (unlike anionic and cationic contaminants) and can be transported by the gas itself, depending on the volatility of the organic species. Smaller molecules are generally more volatile than large molecules, but volatility depends on the nature of the organic material.

Therefore, when choosing plastics for use in a fuel cell system, find materials that have either no plasticizers or very little. Also, consider that some plastics and adhesives degrade over time, depending on their local conditions (potential, water, heat, chemical attack, stress, etc.), and may release organic contaminants to the fuel cell.

The following materials have been identified as incompatible with PEM fuel cell systems, either because they degrade under normal fuel cell conditions or they have a tendency to off-gas harmful VOCs/semi-VOCs. Table 20 does not present an exhaustive list of incompatible materials, but rather provides an example of materials and their issues with fuel cell system integration.

Material	Used in	Issue
Nylon™ 66	Water circuits	Degrades in water circuits
Polyester	Gasketing over membrane, MEA.	Degrades in oxidising environment
Urethanes, Poly-urethanes	Acoustic foam, packing foam	Gives off aromatic VOCs, resulting in degradation.
Ultem™ (poly-ether-imide)	Gasketing over membrane, MEA.	Degrades in oxidising environment

Table 20: Known Incompatible Materials

5.7.2 Inorganic Contaminants

5.7.2.1 Metals

In general all metallic (cationic) contaminants pose a contamination risk. However, transport of the contaminants to the fuel cell usually requires water. This is assuming that the components have been cleaned and there is no metallic dust present. Without water present, cationic contamination can be avoided. If no transport mechanisms are present, all metals should be acceptable. However, stainless steel SS 316L has shown the best passivity in water. Metals that develop passive layers, or are naturally immune at the pHs and potentials present in a fuel cell are be the best metals to consider for use in fuel cell systems.

5.7.2.2 Non-metals

Non-metals include materials containing boron (B), silicon (Si), sulfur (S), chlorine (Cl), arsenic (As), selenium (Se), phosphorous (P), bromine (Br), tellurium (Te) and iodine (I).

Many of these materials (B, P, As, Se, Te, Br, I) are not likely to be found in materials used in fuel cell systems. Some elements like arsenic and selenium are known to be catayst poisons, and should be avoided.

The other elements (Si, S, Cl) occur quite frequently in various materials used in fuel cells and fuel cell systems. Silicon is the main component in silicone seals, greases and oils. Ballard has used various silicone and fluorosilicone seals with some success. Silicone oils and greases have seen shown to negatively impact fuel cell performance. Chlorine containing compounds should also be avoided, as chlorine can adhere to the catalyst.

Silica (glass, SiO_2) itself is not believed to cause any deleterious effects of fuel cells as the silica is fully oxidised.

Sulphur and sulphur containing compounds (thiols, mercaptans[3]) are used extensively as plasticizing agents in many rubbers. Sulphur and sulphur containing compounds cannot be tolerated to any extent in a fuel cell system. Even small amounts can severely affect fuel cell performance.

5.7.3 Gaseous Contaminants

These items include compounds like nitrous oxides (NO and NO_2), ammonia (NH_4), sulfurous oxides (SO_2 and SO_3), carbon monoxide, and dioxide (CO and CO_2), hydrocarbons, reduced sulphur compounds[4], PM10[5], total suspended particulate, and suspended metals. Many of these compounds are air-borne pollutants.

These materials are typical environmental pollutants and may not be present in fuel cell materials, but were included for completeness. Unless the fuel cell system materials degrade and out-gas these compounds, they need not be considered. Note, however, that some of the

[3] Mercaptans are used to "scent" natural gas and other potentially dangerous fuels.

[4] Naturally occurring compounds that come from bogs, swamps, etc.

[5] Atmospheric particulates 10 µm or less in diameter.

gaseous compounds (NH_4, SO_2, SO_3, CO, CO_2, hydrocarbons) are known to poison the fuel cell. There is evidence that nitrous oxides may also contaminate fuel cells.

6 Electrical Interface

Figure 27 illustrates the electrical interface and required electrical connections for the Nexa™ power module. External battery power must be supplied to the DC module for providing ancillary power during startup and shut down. The battery is connected to the Nexa™ control board through a switch, as shown in Figure 27 to prevent the battery from being drained during non-operational periods. The fuel cell terminals must be connected to load through a load relay to ensure power is not drawn from the fuel cell stack until the system is running. The Nexa™ control board actuates the load relay when the stack is ready to supply power. An external 5 V start signal must be applied, as shown in Figure 27, to turn on the unit. A serial communication interface must also be provided to read performance and diagnostic data sent from the Nexa™ control board. Finally, an external hydrogen tank valve control line is supplied to energize a fuel isolation valve at the OEM storage tank. The communication and battery interface connections to the Nexa™ control board are shown in Figure 22.

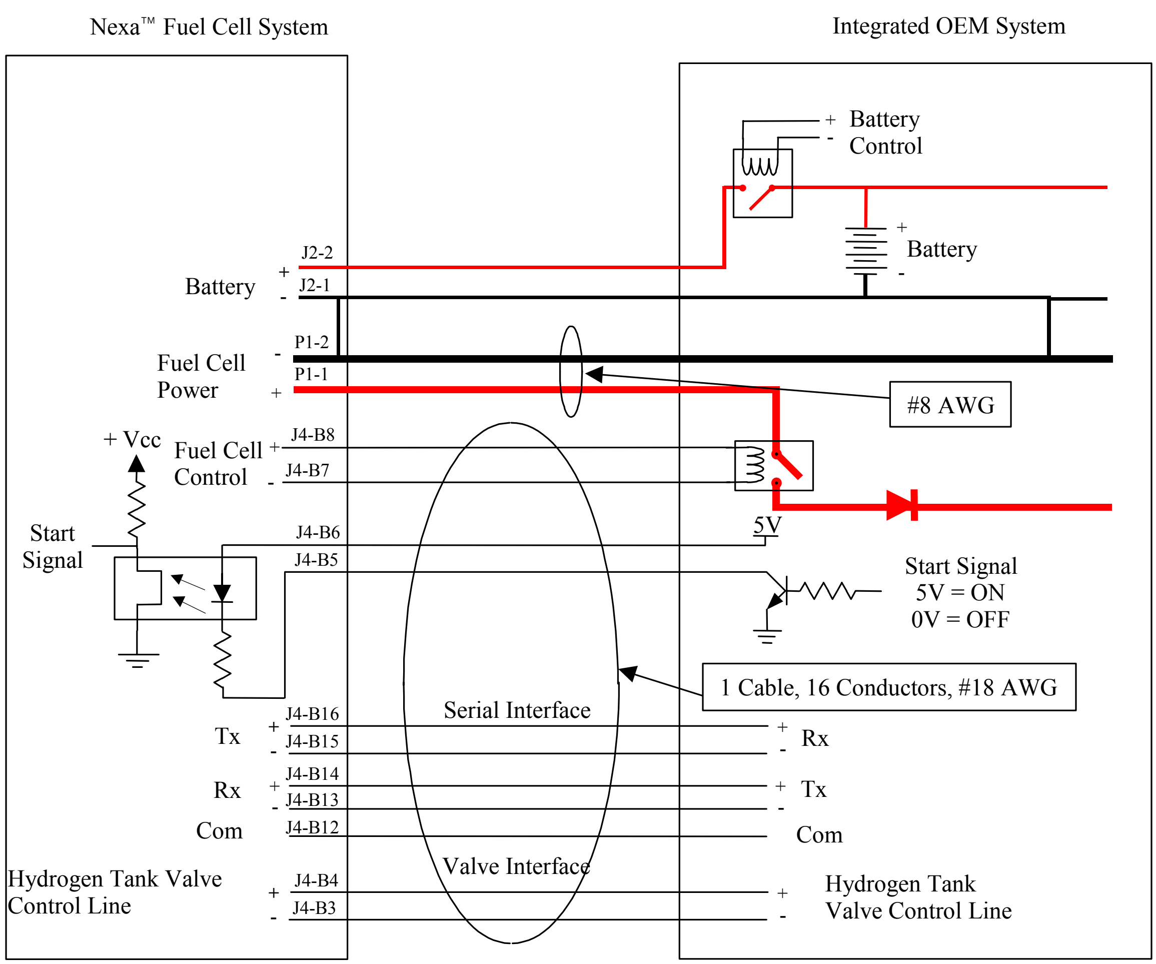


Figure 27: Electrical Interface Diagram

6.1 Power Connection

The fuel cell power wires are #8 AWG wire and are terminated with Amp Ring Terminal Part #2-321598-3, suitable for connection to 1/4" posts. The fuel cell power leads are illustrated in Figure 24.

A relay and diode are required, as shown in Figure 27, to prevent power draw from the fuel cell when it is not running and to prevent a backwards flow of current from integrated system sources such as a battery, grid connection or capacitors into the fuel cell. These two components must be installed on the OEM distribution board to ensure that all spark-emitting components are in a separate chamber from the fuel cell. Wires from the fuel cell control board will control the power relay, as shown in Table 21.

Actuator	Description	Operating Range	Control Signal	Signal Type
Power Switch	Relay	50 A continuous 50 VDC maximum	13.5 VDC 200 mA (max)	Digital low side switch

Table 21: Power Load Relay Specifications

The Nexa™ module provides unregulated DC power. Integration of power conditioning equipment may be required for supporting battery-charging capability or to power AC loads. Nominal Nexa™ output conditions are 26 VDC at 46 A. Refer to the Performance Characteristics section for detailed polarisation curves. When integrating power-conditioning equipment with the DC module, it is recommended that all sparking and arcing components are separated from the hydrogen-containing environment of the fuel cell compartment.

The maximum current ripple specification for the Nexa™ unit is 24.7 % RMS (or 35% peak-to-peak) at a switching frequency of 120 Hz. Ensure that the fuel cell current ripple induced by power conditioning equipment does not exceed this specification.

6.1.1 Battery Connection

Connect the battery to the fuel cell system as shown in Figure 27. It is recommended that the battery should be installed such that all spark-emitting components are in a separate chamber from the fuel cell. The Nexa™ control board uses an AMP 643226-1 connector. To interface to the control board, use an AMP 350777-1 plug and male terminal AMP 350922-3.

The fuel cell system will operate with a battery voltage between 18 and 30 volts. The battery should be disconnected when the OEM system is unplugged and non-operational, or is in long-term storage, to prevent battery depletion. As battery power is applied to the control board, the controller begins its initialisation sequence. The battery power should not be removed during this sequence, as it will cause a microprocessor fault on the subsequent start-up. As a rule, the power to the control board should not be cycled more frequently than every 5 seconds.

Battery power is drawn by the fuel cell system during the start up sequence, the shut down sequence, and during standby to run the microprocessor and the hydrogen sensor. A summary of the expected power draw from the battery is provided in Table 22.

Operating Mode	Estimated Max. Power	Estimated Max. Time
Off	0 Watts	N/A
Standby	2.5 Watts	N/A
Start up	35 Watts (average)	10 seconds
Operating	0 Watts	N/A
Normal Shut down[1]	60 Watts	60 seconds
Failure Shut down	60 Watts	1-2 seconds

Note: 1. Additional battery capacity is drawn during the automated rejuvenation process, for firmware revisions 00.03.01 and greater.

Table 22: Expected Power Draw Requirements from the Battery

When the Nexa™ system reaches its normal operating voltage (> 22V), the fuel cell will take over the power supply for all ancillaries. The battery remains disconnected until the stack voltage falls below 18V. During normal operation, a battery charger should be implemented into the final product design to re-charge the battery from fuel cell power. Battery charger integration is part of the OEM responsibility.

Depending on the end-use duty cycle, a larger battery may also be incorporated into the product to provide load-sharing capability with the fuel cell. In this configuration, the battery should be primarily responsible for current surges in the system. However, the fuel cell system is able to handle current surges for short duration when it is warm. Figure 28 illustrates the current surging capability of the Nexa™ system and is intended as a design guide for implementing battery load-sharing with the fuel cell. The fuel cell system will shut down if the stack current is detected to exceed the rated maximum of 70 amps for more than 50 milliseconds. Figure 28 shows the recommended maximum fuel cell current, as a function of duration, to avoid shut downs due to other effects (low cell voltages, temperature, etc). Note that the latest firmware revision (00.03.01) increases the maximum stack current limit to 75A. Refer to Section 7.2 for details regarding Nexa™ module warning and failure levels.

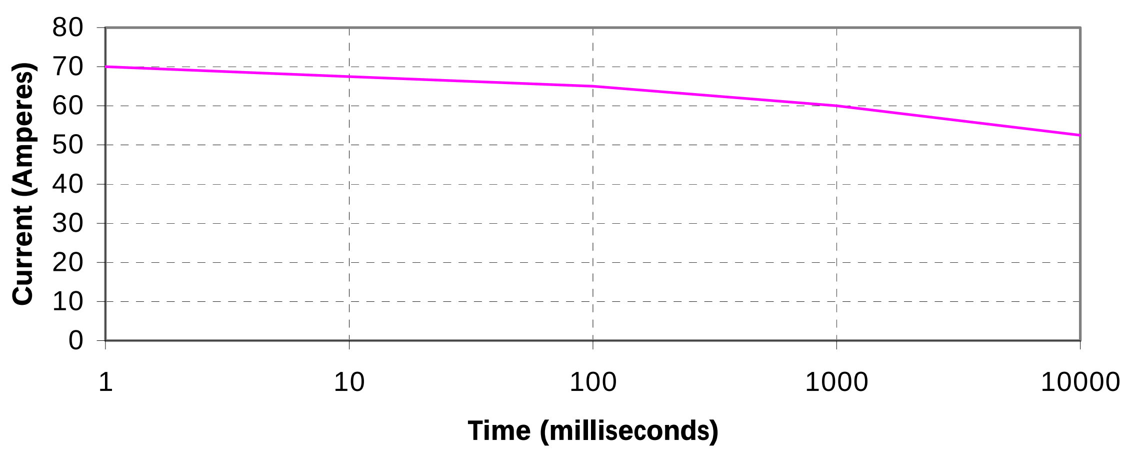


Figure 28: Maximum Fuel Cell Current as a function of Duration

6.2 On / Off Signal

A hardwired signal is used to start and stop the fuel cell system as shown in the interface diagram. A 5 V signal will start the fuel cell system and a 0 V signal will stop the fuel cell system. The 5 V start signal must be held active to keep the fuel cell system turned on.

6.3 Serial Interface

A serial port is used to communicate information about fuel cell operation to the OEM and to communicate diagnostic and instructional information from the OEM to the fuel cell system. The serial port interface uses full duplex communication, a pair of wires for transmission, a pair of wires for reception and a single ground wire. The differential voltage levels used by the serial port are defined by the RS-485 standard. In order to connect the Nexa™ serial port to a computer, use a RS-485 to RS-232 converter.

The serial port header used in the Nexa™ control board is designated AMP 638184-6. In order to connect to the control board, use the plug designated AMP 174514-1 and receptacles AMP 173716-1.

6.4 Hydrogen Tank Valve Control

An external solenoid valve is also recommended for isolating hydrogen supply at the storage tank. The Nexa™ system provides a control signal for the proposed secondary fuel solenoid so that it may be controlled in tandem wit the internal fuel solenoid. Figure 27 illustrates the electrical connection for the hydrogen storage tank valve. Table 23 shows the electrical interface specification for the valve control signal.

Actuator	Description	Operating Range	Control Signal	Signal Type
Hydrogen Tank Valve	DC Solenoid Valve	Normally Closed	13.5 VDC 500 mA (max)	Digital

Table 23: Hydrogen Storage Tank Valve Interface Specifications

6.5 Interface Connectors

The following table lists the part numbers for each side of the connection:

Connector Name	Nexa™ Connector	OEM Connector
Signal Interface	Header: AMP 638184-6 Ballard Designation: J4-B	Plug: AMP 174514-1 Receptacle: AMP 173716-1
Battery Connection	Header: AMP 643226-1 Ballard Designation: J2	Plug: AMP 350777-1 Male Terminal: AMP 350922-3
Power Connection	Ring Terminal: AMP 2-321598-3 Ballard Designation: P1	Stud: 1/4"-20 thread

Table 24: Electrical Interface Connectors

6.6 Grounding

Figure 29 illustrates a recommended grounding methodology for Nexa™ end-product integration. In this example, the end-product is providing AC power through an inverter to a wall outlet. The Nexa™ module positive and negative terminals provide power to the inverter, which in turn provides *hot* and *neutral* connections to the wall outlet. The enclosure chassis is connected to earth ground of the wall outlet, and the fuel cell stack and inverter are allowed to float with respect to earth ground. In Figure 29, the fuel cell negative output terminal is connected to chassis ground through a 10 kΩ resistor, to create a resistively grounded system and to prevent large voltage potential differences from ground.

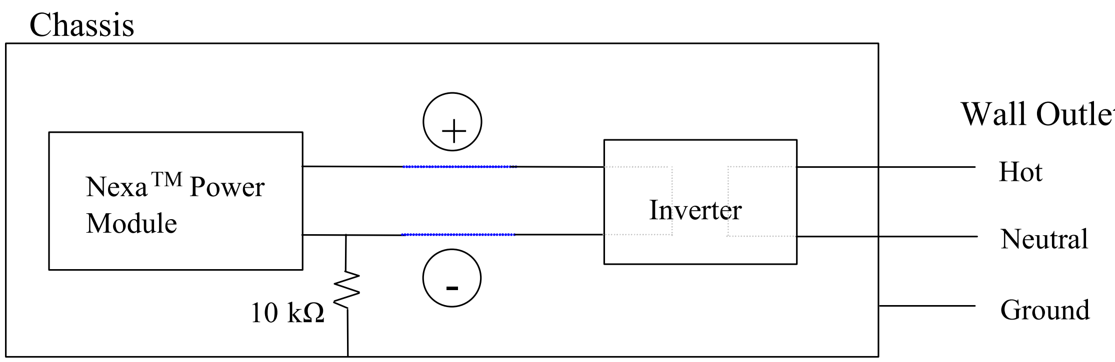


Figure 29: Grounding of Power Leads

Figure 30 illustrates the grounding scheme of the Nexa™ communications signals. The Nexa™ control board is connected to the stack negative output terminal and therefore shares its potential. Transmit and receive signals to and from the control board to the OEM controller or computer use the RS485 protocol. To interface to a computer serial port, these signal lines are converted to RS232 protocol.

The serial communication scheme of the Nexa™ module was designed for use with an OEM interface that shares the same ground as the Nexa™ control board, as illustrated in Figure 29. When communicating to a computer, particularly a desk-top computer with a grounded power supply as shown in Figure 30, special care must be taken when considering grounding. If the control board potential (fuel cell negative terminal) floats out of range with respect to earth ground (>12V, <-7V), ground currents can develop, which will interfere with proper communications. For this reason, it is recommended that an optically isolated RS232 to RS485 converter be used when establishing communications to a laboratory computer.

The COM signal can be useful when integrating the Nexa™ communications to a computer or other serial device, particularly if the external device is at a floating potential. The COM signal ties the ground of an external device to the ground of the Nexa™ control board, to avoid communications failure due to ground currents. A 100Ω resistor is used to connect the COM channel of the communications port to the ground of the control board, to avoid large ground currents from developing.

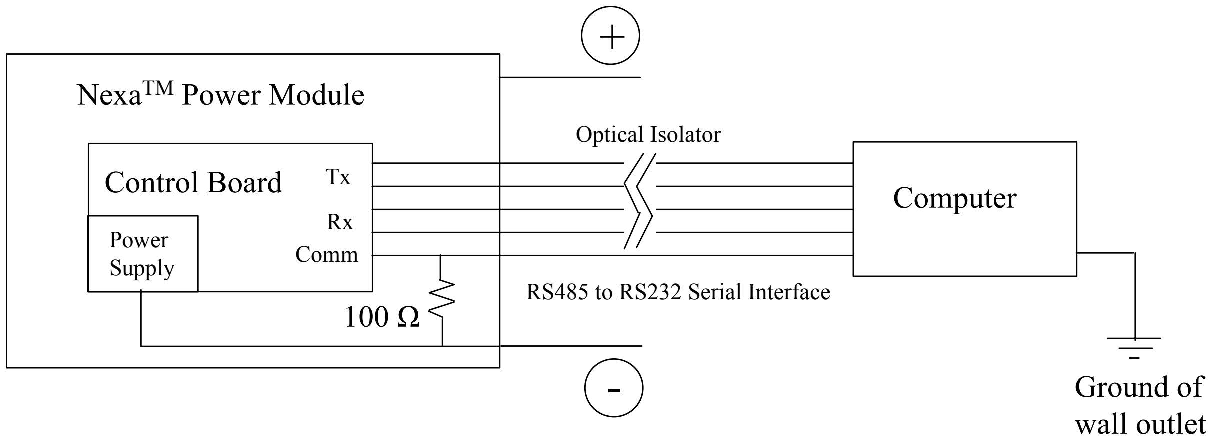


Figure 30: Grounding of Communications Signals

Figure 31 illustrates the energizing of external actuators, such as the hydrogen solenoid valve that isolates the OEMs fuel supply. The solenoid valve is powered by a 13.5V signal from the Nexa™ control board. When the FET transistor is turned on, it completes the circuit by providing a ground path. It is recommended that the valve casing be connected to the OEM chassis ground (earth ground) for safety.

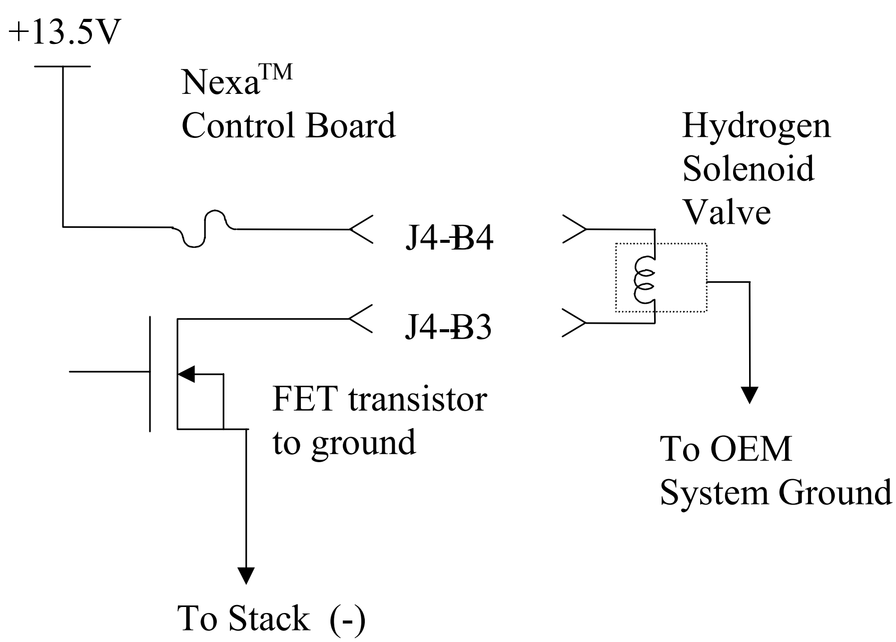


Figure 31: Grounding of External Valves and Actuators

7 Software and Communications

The Nexa™ power module is a fully automated system. An onboard microprocessor regulates fuel cell operation, executes startup and shut down sequences, issues warning alarms and maintains safe operation at all times. A serial port transmits fuel cell operational data to the OEM systems. This section provides software and communication interface details, which enable the OEM to access the serial message, interpret Nexa™ operational data and develop a dedicated monitoring, control and diagnostic interface for the end-use product.

7.1 Operating States

Figure 32 shows the operation of the Nexa™ system software state machine. The states (Off, Standby, Start Up, Normal Operation, Normal Shutdown, and Failure Shutdown) are described below to assist with Nexa™ software integration.

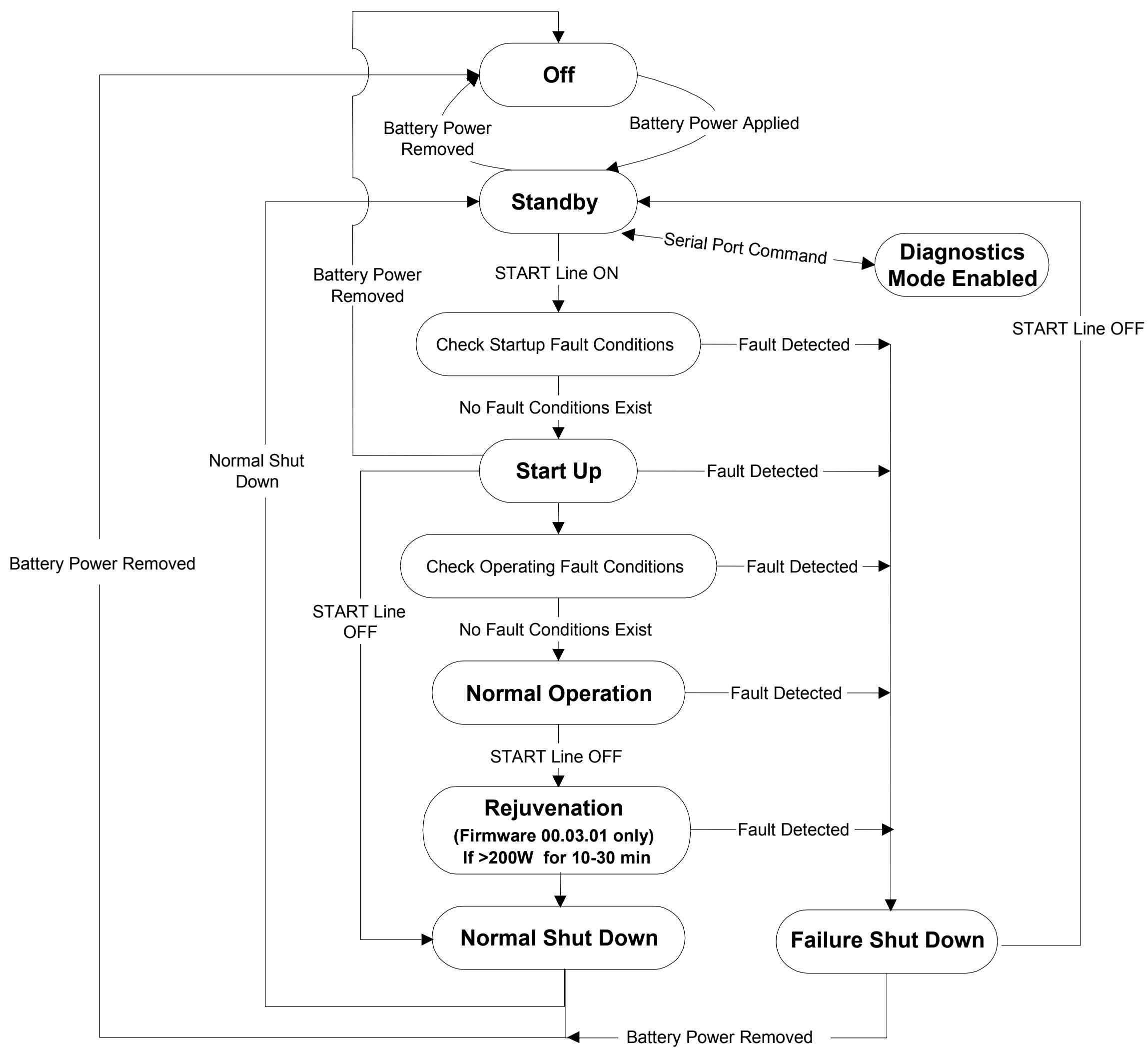


Figure 32: Operating States

7.1.1 Off State

In the Off state, no battery power is applied to the control board. To progress to Standby, battery power is applied to the control board, causing a power-on reset to occur.

7.1.2 Standby

When entering Standby, the control board will wake up, power up the hydrogen sensor, and begin continuously transmitting status messages to the OEM. In Standby mode, diagnostic commands can be sent to the control board to facilitate repairs or understand failures.

For the first 20 seconds after power up, the hydrogen sensor needs to reach its operating temperature. Until it does, its reading is unreliable and falsely indicates a high hydrogen concentration. Starting the fuel cell during this 20-second period is not possible if the hydrogen sensor is reading above 80%.

7.1.3 Pre-Start Checks

To start the fuel cell system from Standby, the hardwired start line must be activated and kept activated. When the start line is turned on, the control program reads the restartability flag from the EEPROM. If the system was last shutdown due to a non-restartable fault (hydrogen leak, self test or software fault) all subsequent start requests are ignored. Otherwise the system verifies that the minimal startup conditions exist:

1. The stack temperature is below 73 degrees Celcius
2. The H2 sensor is functioning properly and the measured H2 leak concentration is below 100% alarm.
3. The O2 sensor is functioning properly and the measured O2 concentration is above 18.7%
4. The ambient air temperature is above 3 degrees Celcius
5. The battery voltage is above 18 volts.

If the above conditions are met, then the system proceeds to the Starting State.

7.1.4 System Start-up (Starting State)

When the start line is applied and the startup conditions are met, the system process with the following start-up procedure:

1. A signal is sent from the control board to open the external solenoid valves
2. The cooling fan is started and set to a duty cycle of 50%
3. The air compressor is started up 1sec after the cooling fan
4. The main H2 solenoid valve is opened
5. The stack purge cycle is initiated. The purge valve opens for 1 sec and closes for 1sec until the start-up sequence is complete.

6. After 6 sec, if the stack voltage is greater than 38V, the purge cell voltage greater than 1.5V and the Cell Voltage Checker issues a PASS, then the system transfers the internal loads from the battery to the stack. Firmware revision 00.03.01 has lowered the Stack Voltage and the Purge Cell Voltage permissive limits to 30V and 0.8V, respectively.
7. If during the next 5 seconds after the internal loads are transferred to the stack, any of the variables mentioned in 6. (above) fail to be met, then the system transfers internals back to the battery

7.1.5 Normal Operation (Running State)

The fuel cell will start in approximately 15 seconds if no operating faults are detected during the startup sequence. Operational faults may include hydrogen leak present, low oxygen concentration, low hydrogen pressure, high fuel cell stack temperature, low fuel cell stack voltage, high fuel cell stack current, low cell voltage and low purge cell voltage. Once the start up sequence is completed, the system enters Normal Operation. At this point, the power relay is closed and power is available from the fuel cell system. Normal Operation is the only state in which power can be drawn from the fuel cell. In this state, all functions necessary for fuel cell operation under dynamic loading conditions are performed by the system components and no current should be drawn from the battery.

7.1.6 Normal Shut Down (Stopping State)

If the start line is turned off, the fuel cell system will go through a Normal Shutdown sequence.

If the stack has been in RUNNING or WARNING state for less than 60 seconds, then the System Shutdown Procedure is called to stop the stack and return it STANDBY state. Refer to section 7.1.7.

If the stack has been operating for more than 60 seconds, the system will initiate the following Shutdown Sequence to ensure proper water management upon storage.

In the first 10 seconds

1. The external load relay is disconnected
2. The cooling fan is set to idle to cool the stack
3. The purge valve is opened to rid the stack of contaminating gases
4. The air pump is set to 70% duty cycle to flush the stack of residual water

During the next 5 seconds

1. Stack power is disconnected
2. H2 solenoid valve are closed
3. Purge valve is closed

The cooling fan is stopped 15 seconds after the Start signal is removed. The air pump continues to operate until 45 seconds has expired and the system returns to the Standby state.

If an emergency or rapid shut down is required by the Nexa™ system, the start line should be turned off and battery power removed, returning the system immediately to the Off state.

7.1.6.1 Rejuvenation (firmware revisions 00.03.01 or greater)

The Rejuvenation sequence is performed prior to the Normal Shutdown, if the Nexa™ module has been running for between 10-30 minutes at an average gross stack power of 200W or greater, measured over the last 10 minutes of operation. The Rejuvenation process restores fuel cell stack performance (that may have been degraded by prolonged storage or certain contaminants) by repeatedly cycling stack voltage under the presence of internal parasitic loads. The automated Rejuvenation process lasts approximately 3 minutes. All safety systems of the power module are available during the Rejuvenation process. Note that a separate software state has not been designated for the Rejuvenation cycle. During Rejuvenation, the Nexa™ module broadcasts the Normal Shutdown (stopping state) message.

7.1.7 System Shutdown Procedure

The System Shutdown Procedure is called in the following cases:

- In RUNNING or WARNING state when the Start line is deasserted after the stack has been running for less than 60 seconds.
- In STOPPING state, after the stack has been running for more than 60 seconds and the 45 second purge is completed
- In FAILURE state, when the Start line is deasserted after a non-leak fault, or when the Start Line is deasserted after a H2 leak fault, and the cooling fan has shutdown
- When a self-test or software fault is detected.

The System Shutdown Procedure stop the operation of the fuel cell system according to the following sequence:

1. The external load is disconnected
2. The H2 fuel valves are all closed
3. The purge valve is closed
4. Internal loads are transferred from the stack to the battery
5. The air pump is turned off
6. The cooling fan is turned off
7. If the shutdown was initiated due to a fault, the failure data is recorded in the EEPROM.
8. If a non-restartable fault occurs, the non-restartable status is written to the EEPROM
9. If no faults have occurred, the system returns to STANDBY state.

When a fault is detected ,the fuel cell will follow a System Shutdown Procedure and enter a Failure Shut Down mode. The fuel cell system cannot be re-started from this state until the start line is turned off or battery power is cycled to the control board.

Note: Do not cycle the battery power to the Nexa™ module faster than once every 5 seconds.

7.2 Warning & Failure Levels

Table 25 shows the warning and failure levels used by the fuel cell system. If a failure level is exceeded during operation, the system executes a failure shut down. If a warning level is exceeded, the system may continue operating but the OEM integrator should take corrective action to remove the alarm condition. Note that the latest firmware revision (00.03.01) incorporates some changes to the warning and alarm limits.

Parameter	Warning Level	Failure Level	Restartable
Fuel Cell Stack Temperature	> 71 °C	> 73 °C	Yes
Fuel Cell Stack Voltage	< 23 Volts	< 18 Volts	Yes
Fuel Cell Stack Current	> 60 Amps	> 70 Amps	Yes
Firmware Revision 00.03.01	> 65 Amps	> 75 Amps	Yes
Cell Voltage Checker	N/A	0.85 V/cell pair	Yes
Hydrogen Pressure	< 1.0 barg	< 0.5 barg	Yes
Hydrogen Concentration	80%	100% (10,000 ppm)	No
Oxygen Concentration	< 19.5%	< 18.7%	Yes
Ambient Temperature	N/A	< 3 °C (start-up)	Yes
Battery Voltage	N/A	< 18 Volts (start-up)	Yes
Purge Cell Voltage	< 1.0 Volts	< 0.8 Volts	Yes
Firmware Revision 00.03.01	< 0.8 Volts	< 0.7 Volts	Yes
System Time-out during Start-up	N/A	Digital	Yes
Self Test Fault	N/A	Digital	No
Software Fault	N/A	Digital	No

Table 25: Warning and Failure Alarm Limits

A few notes about alarm conditions:

- Fuel cell stack current alarms refer to the gross output of the stack, not the net output of Nexa™. Refer to the Performance Characteristics section for output performance details.
- The hydrogen failure alarm is set to 10,000 ppm or 1%, which is ¼ of the lower flammability limit of hydrogen. The hydrogen concentration reading is expressed as a percentage of this shut down limit.
- Low battery voltage and low ambient temperature alarms are effective only during system start-up. Once the Nexa™ system is running, the OEM integrator is responsible for shutting down the power module and balance of plant in the event of an undesirable battery voltage or ambient temperature environment.

After a failure shut down, the Nexa™ system can be returned to Standby mode by removing the start command. In most cases, the system is Restartable after a shut down. However, when a hydrogen leak or a self-test fault leads to a failure shutdown, the Nexa™ unit will enter a Non-Restartable mode for safety reasons. In these cases, the system must be reset by a BALLARD Field Service or Customer Support representative.

7.3 Communications

A serial port is used to communicate information about fuel cell operation to the OEM and to communicate diagnostic and instructional information from the OEM to the Nexa™ system. The serial port interface uses full duplex communication, a pair of wires for transmission, and a pair of wires for reception. The full duplex communication allows asynchronous data transmission without needing to handle bus contention. The differential voltage levels used by the serial port are defined by the RS-485 standard. The following items outline the features of the serial port communications:

1. Communication is asynchronous at 9600 baud, with the Nexa™ system sending a data stream to the OEM approximately once every 200 ms.
2. SLIP (Serial Line Internet Protocol, Internet RFC 1055) is used to encode and decode the messages sent between devices. The SLIP code uses a one-byte tag (0xC0) at the beginning and at the end of each message. Three other special characters called "escape characters," 0xDB, 0xDC, and 0xDD are required to handle cases where 0xC0 must occur in the middle of the message.
3. The message from the Nexa™ power module to the OEM will always include a 40 bytes segment at the beginning of the message that includes all relevant operating data for the OEM. Up to an additional 100 bytes may be added for diagnostic and fault code retrieval purposes to the end of the message. These bytes should be considered unused bytes by the OEM except for the purposes of computing the checksum at the end of the message.
4. In addition to the varying length of the message that accounts for the diagnostic transmission, additional bytes are required to handle the transmission of the "escape characters".
5. A check sum is computed over the entire message and displayed as the last byte at the end of the message. The check sum is computed as a simple summation of the message bytes. Overflow bits are discarded. The Check Sum does not include the Tags or any "escape characters."
6. Each character is sent containing 1 start bit, 8 data bits, no parity bit, and 1 stop bit.
7. The format for the message from the Nexa™ system to the OEM is given below:

Tag	Status	Fail Code	Warning Bitmap	Last Command Acknowledge	Stack Temperature	Stack Voltage	Stack Current	Hydrogen Pressure

Hydrogen Concentration	Cumulative Hydrogen Consumption	Oxygen Concentration	Ambient Temperature	Purge Cell Voltage

Additional diagnostic and fault code bytes (0 to 100 extra bytes)	Check Sum	Tag

8. Information in the message header and footer (the 2 Tags, the Status, the Fail Code, the Warning Bitmap, the Last Command Acknowledge, and the Check Sum) are sent as single bytes.
9. The Nexa™ system has the following Status Codes:

   0x00 = Standby
   0x01 = Start up
   0x02 = Normal Operation
   0x03 = Warning
   0x04 = Normal Shut Down
   0x05 = Failure Shut Down
   0x06 = Non Restartable

10. The Nexa™ system has the following Fail Codes:

    0x00 = Normal Operation
    0x01 = High Fuel Cell Stack Temperature
    0x02 = Low Fuel Cell Stack Voltage
    0x03 = High Fuel Cell Stack Current
    0x04 = Low Cell Voltage
    0x05 = Low Fuel Pressure
    0x06 = Fuel Leak Detected
    0x07 = Low Oxygen Concentration
    0x08 = Low Ambient Temperature
    0x09 = Low Purge Cell Voltage
    0x0A = Low Battery Voltage
    0x0B = Startup Time Expired
    0x0C = Self Test Fault
    0x0D = General Software Fault
    0x0E = Spurious Interrupt Fault

11. The Nexa™ system has the following Warning Bitmap Codes:

    0x00 = No Warnings
    0x01 = High Fuel Cell Stack Temperature Warning
    0x02 = Low Fuel Cell Stack Voltage Warning
    0x04 = High Fuel Cell Stack Current Warning
    0x08 = Low Fuel Pressure Warning
    0x10 = Fuel Leak Warning
    0x20 = Low Oxygen Concentration Warning
    0x40 = Low Purge Cell Voltage Warning

    These warning codes are designed so that more than one warning can be issued at one time. The bitmap is a combination of the warnings present. The warning codes are combined with "OR" logic to form a single byte. For example, to send Low Fuel Cell Stack Voltage and Low Fuel Pressure Warnings simultaneously, the code 0x0A would be sent.

12. The Last Command Acknowledge is a repetition of the last command received from the OEM. See below for the structure of commands sent to the Nexa™ system.

13. The data (Fuel Cell Stack Temperature, Voltage, Current, Hydrogen Pressure, Hydrogen Concentration, and Cumulative Hydrogen Consumption, Oxygen Concentration) are sent as floating point numbers using the following 4 byte format as follows:

Sign (1 bit)	Exponent (8 bits)	Mantissa (23 bits)

The 4 bytes are arranged in the following fashion:

Sign (1 bit) + Exponent (7 MSB's)	Exponent (LSB) + Mantissa (7 MSB's)	Mantissa (8 bits)	Mantissa (8 LSB's)
Fourth Byte Sent	Third Byte	Second Byte	First Byte

The mantissa and the exponent are arranged so that the Most Significant Bit (MSB) is on the left and the Least Significant Bit (LSB) is on the right. To convert this format into a decimal number, the following formula is used:

$$X = (-1)^{Sign} \cdot (2^{(Exponent-127)}) \cdot (1.Mantissa)$$

Where: Sign is either 1 or 0
Exponent is 8 bits (0 to 255)
Mantissa is 23 bits

Example: The number +46.28 would be sent as 0xB8, 0x1E, 0x39, 0x42, in that order.

14. The engineering units for the data are as follows:

Data Name	**Engineering Unit**
Fuel Cell Stack Temperature	° C
Fuel Cell Stack Voltage	volts
Fuel Cell Stack Current	amps
Hydrogen Pressure	bar (gauge)
Hydrogen Concentration	ppm
Cumulative Hydrogen Consumption	standard litres
Oxygen Concentration	percent (%)
Ambient Temperature	° C
Purge Cell Voltage	volts

15. Messages from the OEM to the Nexa™ control board are always 5 bytes long. The format for the message is given below:

Tag	Command	Failure Acknowledge	Check Sum	Tag

16. All of the information in the OEM command will be single bytes with the check sum computed in the same fashion as above.

17. The commands needed by the Nexa™ system are developed for customer-specific diagnostic and field service functions.
18. The Failure Acknowledge will be a repetition of the last Fail Code received from the control board.

7.3.1 Notes on Slip Decoding

In Normal Mode, the Nexa™ system transmits a 40-character status message followed by a 1-byte checksum. If the status data contains the SLIP End Character 0xC0 or the SLIP Escape Character 0xDB then each occurrence of these characters is encoded as a two-byte escape sequence consisting of the Escape Character 0xDB followed by the Escape-Esc Character 0xDC or the Escape-End Character 0xDD, as appropriate. Hence an encoded SLIP message is transmitted by the Nexa™ unit as a character stream that is a minimum of 43 bytes (0xC0, 40 status bytes, 1 byte checksum, 0xC0) and a maximum of 84 bytes. In reality, the 84-byte max will never be observed since the values 0xC0 and 0xDB will never appear in the status message status code, failure code, warning bit map, and acknowledgement fields.

As an aside, the Nexa™ system has a Diagnostic Mode in which an extended status message is transmitted. A receiver that knows only the structure of the basic Normal Mode message can still correctly process a Diagnostic Mode message without knowing its complete structure since the first 40 bytes of the diagnostic Mode message are the same as the Normal Mode message and the last byte is always the checksum over the entire message. Thus, the receiver should compute the checksum over any valid message it gets, regardless of length, and compare it to the last byte in the message to determine the message's validity. Then the receiver can decide whether to make use of the first 40 bytes or the extended message, as appropriate.

In summary, the invocation of the SLIP decode routine by the receiver should not depend on or be triggered by the receipt of any specific of characters. Instead, the SLIP decode routine should be called whenever a 0xC0 character is received. The receive algorithm can be implemented in one of two ways. Note that Receive Algorithm B is a simplification of Algorithm A.

<u>Receive Algorithm A</u>

1. When any character arrives on the serial interface, put the character into the serial receive buffer.

2. If the received character is 0xC0, call the SLIP decode routine, passing it all the data currently in the receive buffer.

3. If the SLIP decode routine returns 0, then the decode operation failed. This will happen if the receive buffer contained only the 0xC0 character or if there was noise on the serial line and a byte-stuffed SLIP character was dropped from the message.

4. If the SLIP decode routine returns a non-zero value, N, then the first N-1 characters constitute the Nexa status message and the Nth character is the 8-bit checksum over the preceding N-1 characters. Compute the checksum over the first N-1 characters and

compare it to the Nth octet. If they match, then the (N-1)-char status messages has been received intact. If not, discard the message.

Receive Algorithm B

1. When any character arrives on the serial interface, examine it to see if it is the SLIP End Character, 0xC0. If not, put the character in the receive buffer. If so and the receive buffer is empty, continue. Otherwise, invoke the SLIP decode routine on the contents of the receive buffer.

2. If the SLIP decode routine returns 0, then the decode operation failed. This will only happen if there was noise on the serial line and a byte-stuffed SLIP character was dropped from the message.

3. If the SLIP decode routine returns a non-zero value, N, then the first N-1 characters constitute the Nexa status message and the Nth character is the 8-bit checksum over the preceding N-1 characters. Compute the checksum over the first N-1 characters and compare it to the Nth octet. If they match, then the (N-1)-char status messages has been received intact. If not, discard the message.

Strictly speaking, a packet that conforms to the SLIP protocol need only have the trailing 0xC0. It is standard practice, however, to prefix a SLIP-encoded message with a leading 0xC0. The purpose of this is to 'flush' a partially-received message from the receiver's buffer, i.e. a message whose tail (including its trailing 0xC0) was corrupted or truncated due to noise on the serial line. The leading 0xC0 of the next message will cause the partially-received data of the previous message to be flushed out of the receive buffer and be passed to the SLIP decode routine. The SLIP decode operation may or may not succeed.

Regardless, integrity of a Nexa message is protected by its checksum. If the checksum byte has been damaged or dropped then the checksum calculation that follows the SLIP decode will detect the damaged message.

Note that it is crucial that a character beginning and ending with 0xC0 not be passed to the SLIP decode routine. If a 0xC0 appears in the receive data passed to this routine it must only be at the end of the buffer. The serial receive algorithm outlined above guarantees that this is the case. Under normal circumstances where there is no noise on the serial line, the receive interface will get both the leading 0xC0 and the trailing 0xC0.

In Receive Algorithm A above, the leading 0xC0 will be passed to the SLIP decode routine by itself. Since it is preceded by no data, the SLIP decode routine will return 0, indicating that a valid SLIP message has not been received. When the trailing 0xC0 is received, the SLIP-encoded message and the trailing 0xC0 will be passed to the SLIP decode routine and the message will be properly decoded. Therefore, it is typical that the SLIP decode routine will be called twice for each status message transmitted by the Nexa™ system, the first time for the leading 0xC0 and the second time for the status message and the trailing 0xC0.

In Receive Algorithm B, a simplification of Receive Algorithm A, the SLIP decode routine is invoked only once per Nexa™ status message since the 0xC0 character is not added to the receive buffer and the decode routine is called only if the receive buffer is not empty.

8 Product Integration

8.1 Packaging & Enclosure Design

The Nexa™ power module has been developed for both indoor and outdoor application. Allowable outdoor applications are restricted to cases where the DC module is sufficiently protected by the OEM end product outer enclosure against inclement weather. The fuel cell system should never be operated in wet, freezing or marine conditions. The system should also be adequately protected from wind blown sand and dust.

The Nexa™ system is rated for ambient temperatures ranging from 3°C to 30°C. The power module has not been designed for freezing start conditions and the system will not start up if the ambient temperature is measured to be less than 3°C. The Nexa™ control board measures ambient temperature, adjacent to the fuel cell stack. Once the system is operating, waste heat from the fuel cell reaction warms its immediate surroundings and increases the corresponding ambient temperature reading. Subzero operation may be possible after the system is running, depending on the packaging design implemented by the OEM. However, the OEM must ensure that the system is turned off if at any time the ambient temperature is measured to be below 3°C by the Nexa™ control board.

8.2 Electro-Magnetic Interference

The Nexa™ power module has been thoroughly tested and passes for electromagnetic radiated emission limits tests as specified in the Federal Communications Commission Standard FCC15B without any external housing.

It is the responsibility of the integrator to ensure the final product which contains a Nexa™ power module passes appropriate FCC emission limit tests. It is possible to couple electronic noise from Nexa™ components, which are then radiated through OEM supplied components, such as wires or metallic parts. Design and routing of interface cables, such as the main power connections, battery power connections, and control interface connections can also effect emission levels. Cables should not be routed near the power supply sections of the control board. It is possible for both the Nexa™ power module and the integrator supplied equipment to independently pass radiated emission limit tests, but fail when packaged together.

The Nexa™ power module is also electromagnetically tolerant as will operate safely within the EMI environment as presented in the standards specified by UL991.

8.3 Shock & Vibration

The Nexa™ power module has been designed and tested to withstand vibration loads described in the UL991 standard, which applies to safety-related controls employing solid-state devices. UL991 requires shaking the device from 10Hz to 60Hz at a constant displacement of 0.35mm and then a constant acceleration of 5g from 60Hz to 150Hz. A total of ten cycles are performed followed by shaking at any noted resonance frequencies for 10 minutes. The Nexa™ system passed all such tests with no damage.

The Nexa™ power module has also been designed and tested to withstand shock loads described in the IEC 68-2-31 (Basic Environmental Testing Procedures: Drop and Topple). The standard essentially states that the DC module shall be subjected to a free fall drop test from a height of 1.2 m onto a hard surface (concrete or steel). Any failures directly or indirectly emanating from such a load condition shall not present a safety hazard. The Nexa™ system has been tested to such standards, with an aluminum frame providing support in lieu of an OEM enclosure.

8.4 Design for Maintenance

The Nexa™ power module was design with ease of maintenance in mind. Components such as the humidity exchanger, hydrogen sensor, fuel regulator can be removed and replaced within minutes. More complex components such as the fuel cell stack and cooling fan assembly require longer repair times due to their complexity and location in the system.

The OEM integrating the Nexa™ into a commercial product should consider designing a product with maintainability in mind. The OEM should consider providing access to replace items which are more likely to wear and require replacement such as the humidity exchanger or air pump. Replacement of the fuel cell stack, cooling fan, purge valve and control board will likely require that the Nexa ™ be removed from the OEM's product.

On an ongoing operating basis, the air filter is the only component requiring routine maintenance.

8.5 Certification Requirements

8.5.1 CSA Certification

The Nexa™ Power Module is a CSA approved under CSA Class 2725 Sections 01 and 81 Fuel Cell Power Generators. Any physical or software change made to this product will void this certification as well as the UL recognition.

An OEM integrating the Nexa™ power module in a commercial product must consider the following conditions of acceptability in order to retain the CSA approval:

- The Fuel Gas Valve train (valves, controls, piping and tubing through which hydrogen is supplied to the Fuel Cell Stack and by which hydrogen gas is controlled) shall be evaluated in the end product
- The end product manufacturer shall be informed of the low voltage limit setting as a design parameter due to the variations of the minimum voltage
- This Fuel Cell Module shall be used with a non-field adjustable certified pressure regulator (with a 5psi outlet pressure)
- The suitability for use in a hazardous location area of the oxygen sensor, hydrogen sensor and PCB-Controller, shall be evaluated in the end product.
- The module grounding shall be evaluated in the end product
- The end product for which this fuel cell module is intended must be evaluated to approved requirements.
- The reliability and suitability of the software to provide safety control of the fuel cell module must be evaluated in the end product to ensure compliance with standards IEC730 or UL1998
- The stainless steel isolating plate of the purge valve was not evaluated for compatibility of materials with the working fluids.

For further information on CSA certification please refer to the CSA Master Contract 201446 and Report 1135246, or contact your Ballard Power Systems Customer Support Representative.

8.5.2 UL Certification

The Nexa™ Power module is also recognised by Underwriters Laboratories (UL). OEM looking to have their products also recognised by UL, also must ensure the following Conditions of Acceptability are met:

- The Product shall be used within the ratings noted.
- Grounding of dead-metal parts shall be accomplished in the end application

- It shall be determined in the end application if air purging prior to module start-up, ambient air ventilation, and equipment shutdown in the event of air ventilation failure is adequate
- Means shall be provided to seal the fuel manifold pressure regulator adjustment prior to shipping the end product.
- Testing of the end product incorporating the component (Nexa™) will be necessary to determine of the shutdown system controls will operate as designed in the complete product. Review of the test cell conditions in which shutdowns occurred due to oxygen depletion, or hydrogen leakage (an abnormal situation) need to be conducted. It will not be necessary to repeat all the test cell conditions, but review of the end product attributes will allow consideration of worst case scenarios. Consideration should be made to include one or two oxygen depletion scenarios while instrumenting the room for oxygen content, two or more hydrogen leak scenarios to address a leak within the end product enclosure, and a leak that may propagate from the end product and into the test cell (room).
- The fuel connection made to the Nexa™ power module will be investigated per the applicable end product standard. Requirements for total system shutdown as a result of various abnormal conditions suggest two safety valves or other configuration.
- The Nexa™ power module shall be implemented in the end product as per the manufacturer's User's Manual. Special consideration should be paid to the parameters for operation, transportation and storage.

9 Performance Characteristics

Performance characteristics of the Nexa™ power module are presented. All performance data is given for baseline operating conditions, defined at sea-level and room ambient temperature.

9.1 Polarization Characteristics

Figure 33 illustrates the beginning of life (BOL) polarization characteristics of the Nexa™ system. Performance variability (plus/minus 2 sigma) among systems is also indicated by the minimum and maximum expected performance. Net output power ranges from zero at system idle to 1200 watts at rated power. Net output current ranges from zero to 46 amps across the operating range of the power plant. Output voltage varies with operating load according to the polarization characteristics of the fuel cell stack. Normal idle voltages of the Nexa™ system are approximately 43 VDC. At rated power, the Nexa™ system output voltage ranges from 26 VDC to 29 VDC at beginning-of-life.

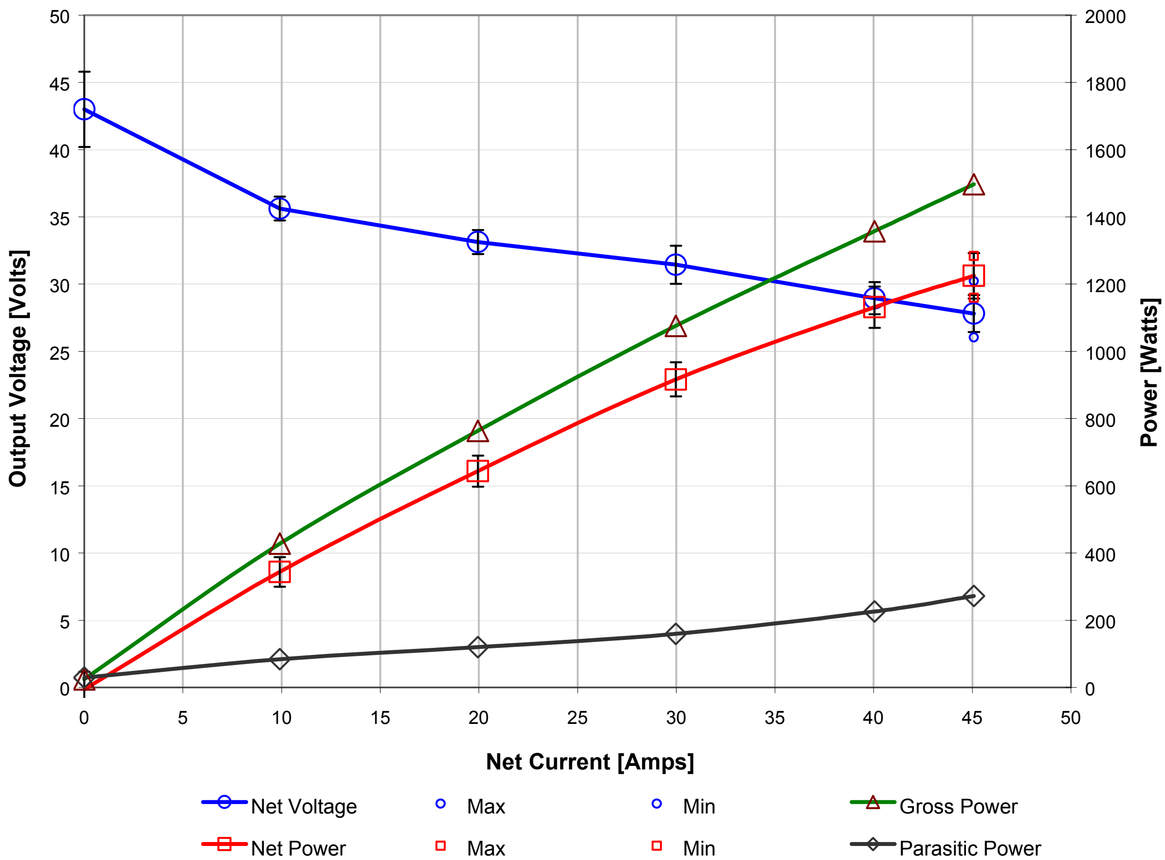


Figure 33: Polarization and Power Curves

Figure 33 also illustrates the system parasitic load as a function of net current and net output power. To support Nexa™ system operation, the fuel cell stack provides power to the air pump, cooling fan, as well as onboard sensors, actuators and controllers. The auxiliary power requirement at system idle is approximately 35 watts. Auxiliary loads increase with increasing current, primarily to support higher air pump and cooling fan duty. At rated system power approximately 250 watts of auxiliary load is required.

9.2 Hydrogen Consumption

Figure 34 illustrates the beginning of life (BOL) Nexa™ system hydrogen consumption as a function of net output current and average net output power. The maximum hydrogen consumption rate of the Nexa™ power module at rated power is less than 18.5 slpm. As illustrated in Figure 34, the hydrogen consumption rate is proportional to the gross fuel cell current demand and nearly proportional to the net output current delivered.

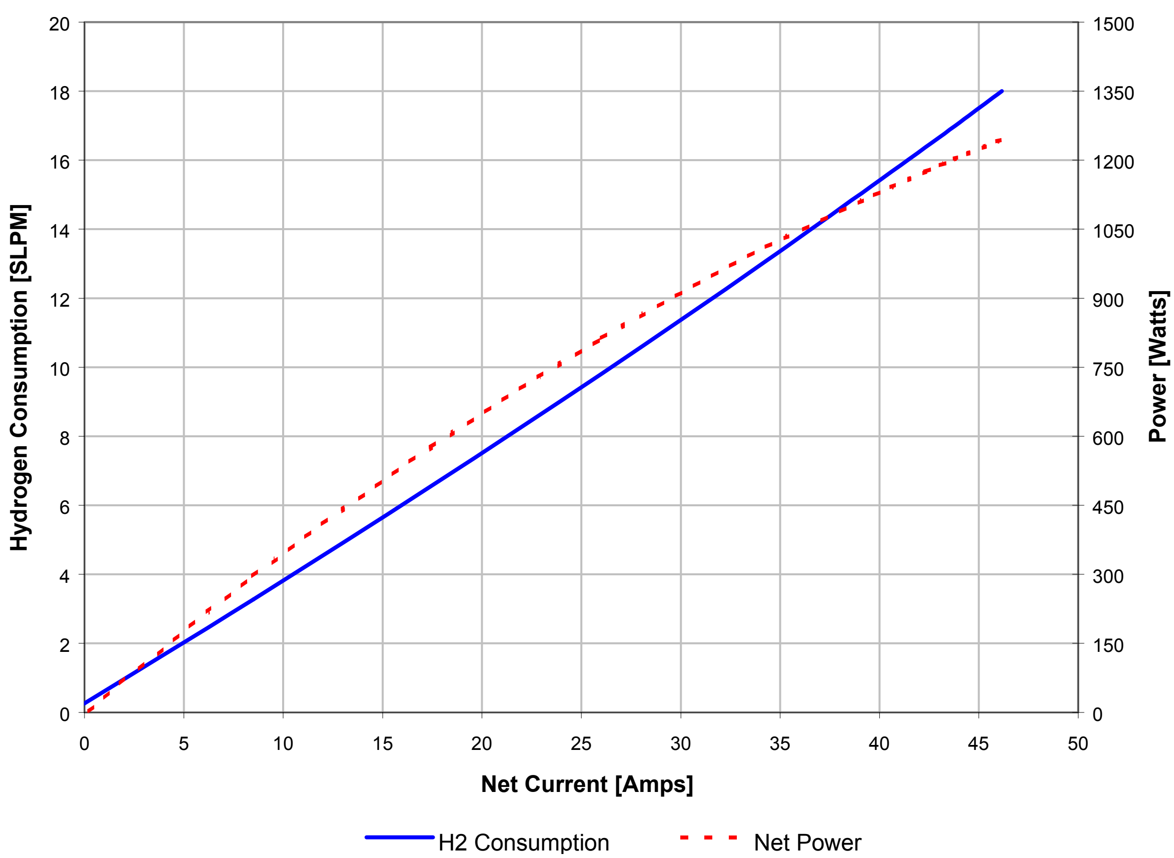


Figure 34: Hydrogen Consumption Rates

9.3 Efficiency

Figure 35 illustrates the beginning of life (BOL) net system efficiency of the Nexa™ power module as a function of net output current and net output power. The system efficiency presented in Figure 35 is defined by the ration of net output power to the lower heating value of hydrogen consumed in the fuel cell reaction.

The Nexa™ system efficiency at full power is approximately 38%. Maximum system efficiency is about 50% and occurs at part load, approximately 300W(net). The system efficiency quickly declines for part loads less than 300W, as the auxiliary loads begin to dominate the requirement for hydrogen consumption.

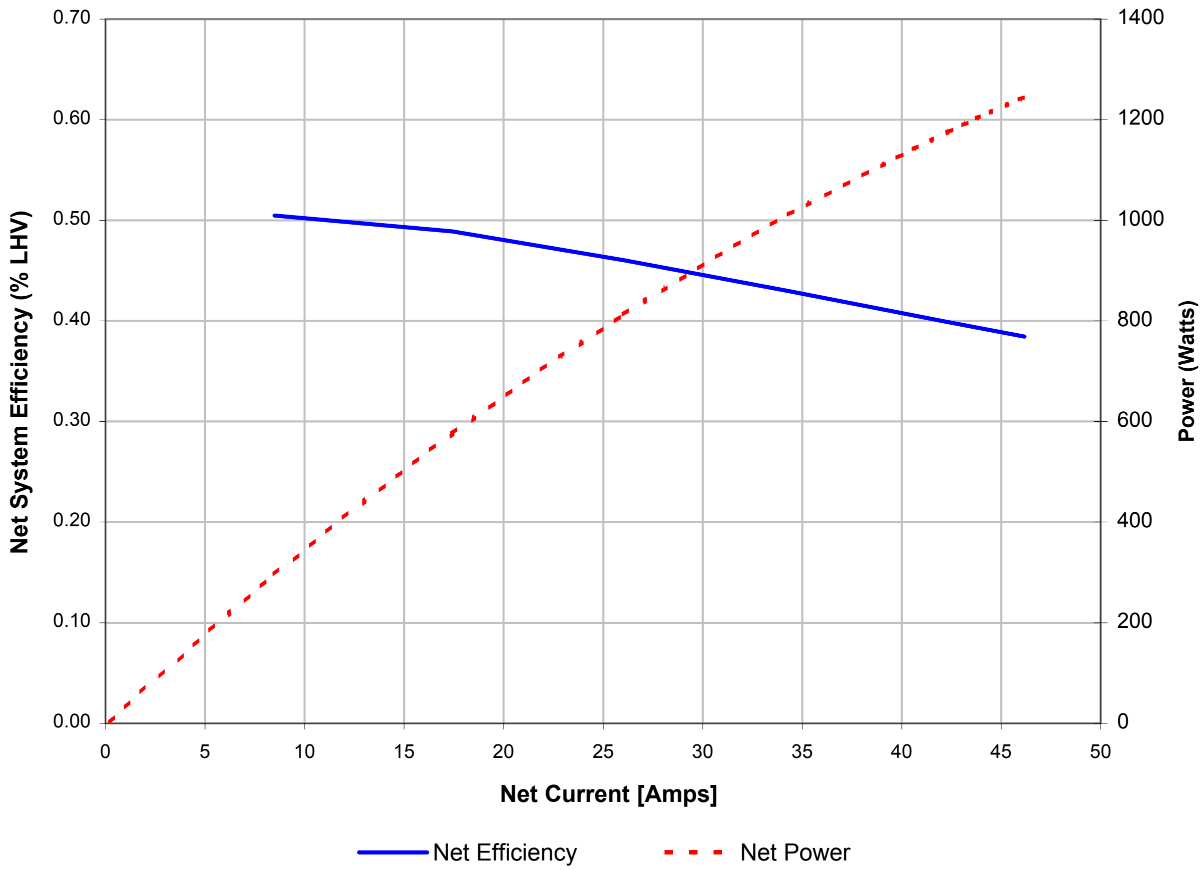


Figure 35: Net System Efficiency Curve

9.4 Heat Production

Figure 36 illustrates the beginning of life (BOL) total Nexa™ system heat production as a function of net output current and average net output power. The waste heat production of the Nexa™ power module increases with increasing load, as the voltage and efficiency of the unit is reduced and the parasitic loads increase. At rated power, approximately 1650 watts of waste heat are generated by the fuel cell system. Most of this heat is available in the cooling air stream for thermal integration purposes.

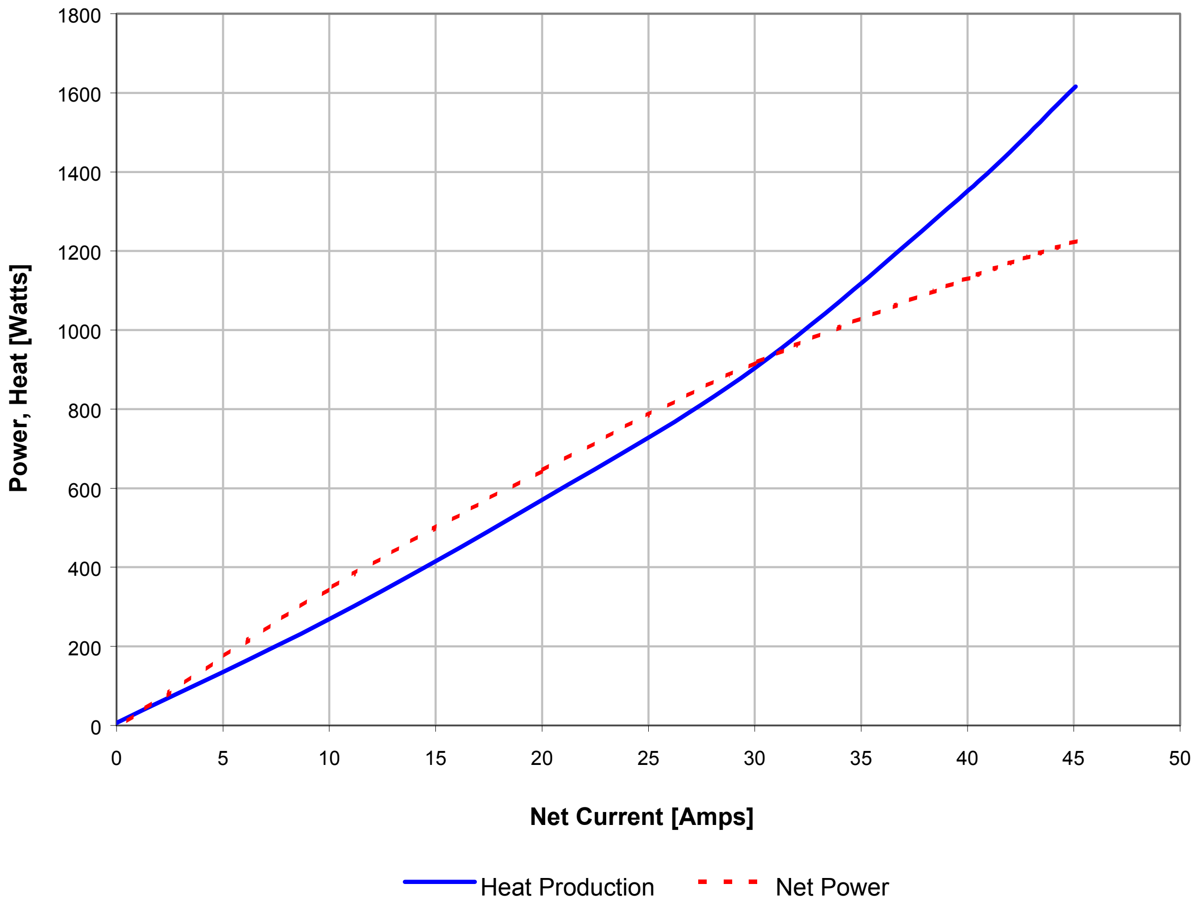


Figure 36: Heat Production Rates

9.5 Water Production

Figure 37 illustrates the beginning of life (BOL) Nexa™ system water production as a function of net output current and average net output power. Approximately 870 ml/hour of water is produced by the fuel cells at rated power, either as vapour or liquid. As shown in Figure 37, water production is nearly proportional to net output current.

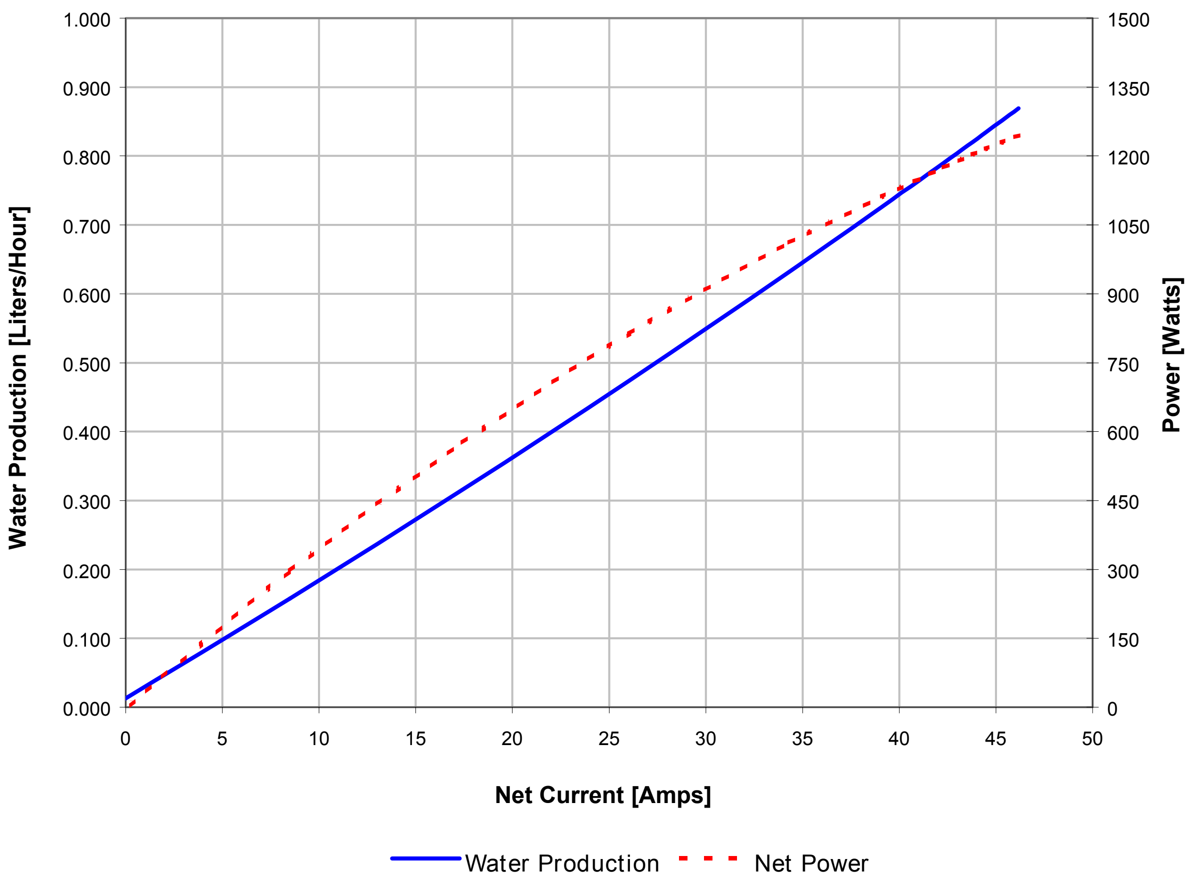


Figure 37: Water Production Rates

9.6 Noise Emissions

Figure 38 illustrates the beginning of life (BOL) Nexa™ system noise emissions as a function of net output power. Two curves are shown for operation at sea-level. One is for operation at room temperature and the other is for operation in 30°C ambient temperature. Higher ambient temperature results in higher fan speed and greater overall noise emission. The Nexa™ system produces approximately 65 dBA at 1 meter at rated output power, operating at 30°C and sea-level. Higher noise emissions are possible at higher altitudes or higher ambient temperatures. The maximum noise emission of the Nexa™ power module is 72 dBA at 1 meter.

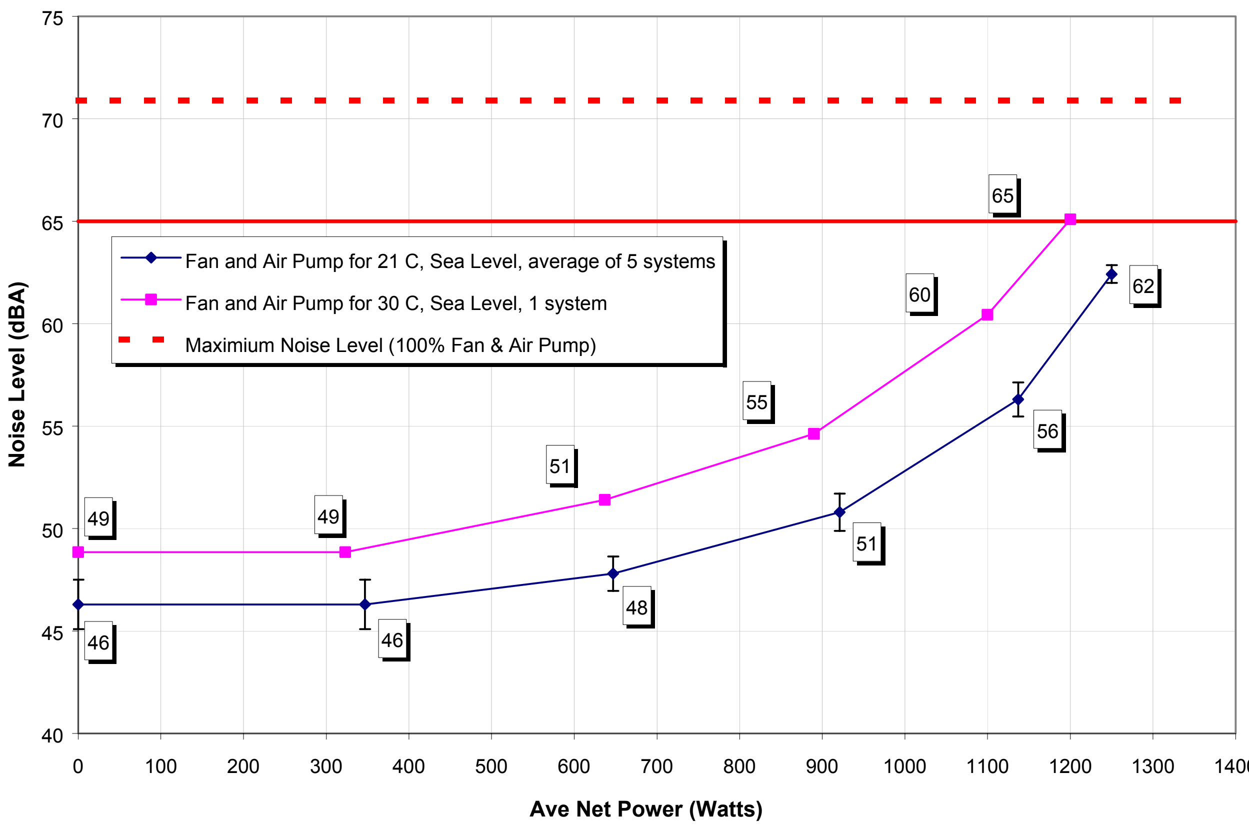


Figure 38: Noise Emissions at 1 Meter

9.7 Transient Response Characteristics

Transient response characteristics of the Nexa™ power module are shown in Figure 39. The graph illustrates the system's response to step changes in load. The fuel cell stack immediately provides current to support a load step change. The required hydrogen flow rate is supplied automatically by the regulator assembly, provided sufficient fuel delivery pressure is maintained. The air pump flow response, however, is vital to maintaining system performance during load changes.

Figure 39 illustrates the changes in output voltage, stack current and airflow that accompany a step change in load. At idle, the oxidant airflow rate closely tracks the requested flow at about 16 slpm. After a load step to full power (54 A_{gross}), the air pump rapidly speeds up to provide an airflow rate of about 85 slpm. There is a brief (~ 0.5 seconds) undershoot (~ 2.5 volts) in stack voltage during this transient, before the output voltage stabilises at 26 V. Stack current also increases slightly during this transient interval, due to increased parasitic power draw from the air compressor.

A similar transient interval occurs after a load step from full power to idle. Airflow is gradually reduced, due to inertia in the air pump. Output voltage gradually recovers and stabilises to 43 volts over a 0.5 seconds interval.

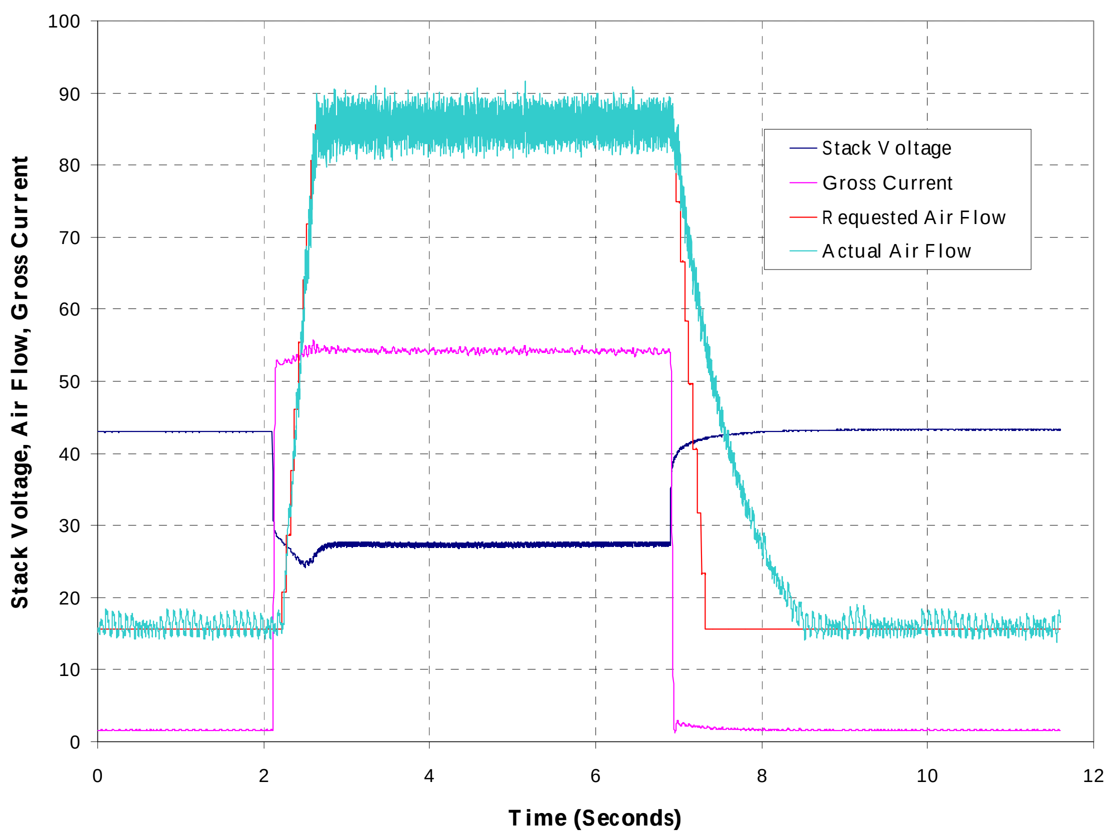


Figure 39: Transient Response Characteristics

9.8 Power De-Rating Curves

The Nexa™ power module is rated for 1200 W(net) at a minimum nominal output voltage of 26 V. The output power rating is for standard baseline operating conditions, which are defined at sea-level in ambient temperatures ranging from 3°C to 30°C. The Nexa™ system is capable of operating at higher altitudes and in higher ambient temperature conditions, but an appropriate power de-rating factor must be applied. Operating in high elevations reduces fuel cell performance (output voltage) by reducing the partial pressure of oxygen in the air. Operation in high ambient temperature conditions also reduces system performance by increasing the parasitic load for stack cooling.

De-rating curves for the Nexa™ power module are illustrated in Figure 40. The output power capacity of the Nexa™ system is de-rated such that the minimal nominal output voltage remains 26 V. As shown, the rated output power is 1200 W(net) for sea-level conditions between 3°C to 30°C. The system power output capacity is de-rated by 15 watts for every 100 meters above sea-level. At 2000 meters elevation, the Nexa™ power module can provide 900 W(net) at 26 V. The output power capacity is also de-rated by 10 watts for every degree Celsius above 30°C, up to a maximum of 40°C. At sea-level and 40°C, the Nexa™ module is able to provide 1100 W(net) at 26 V.

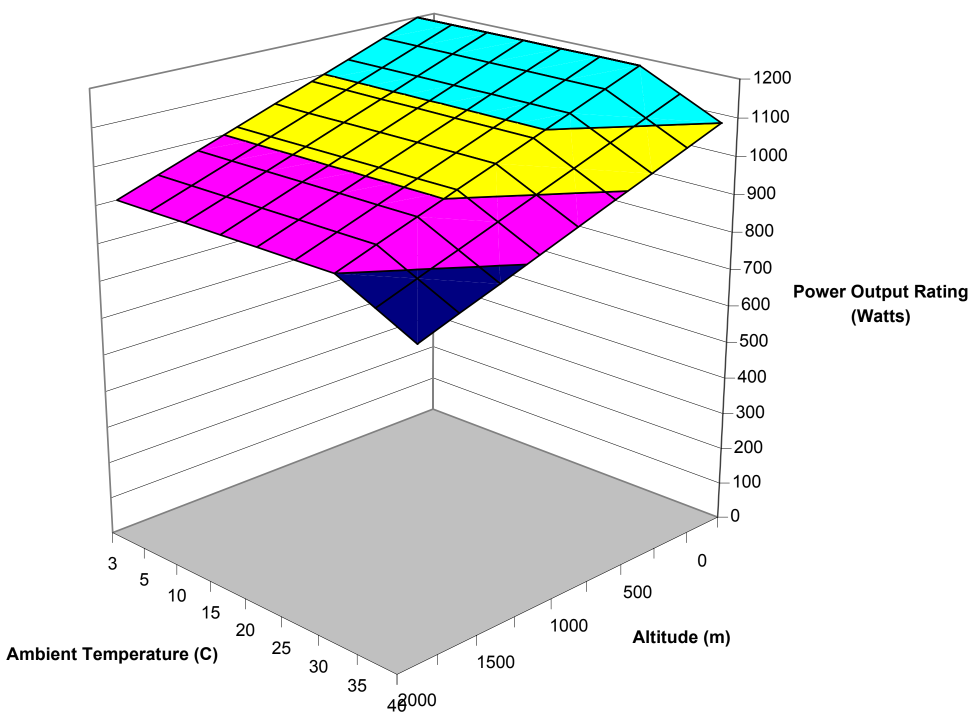


Figure 40: Power De-Rating Curves

The Nexa™ module is capable of higher power levels than those shown in Figure 40, provided the fuel cell output voltage is permitted to fall below 26V.

9.9 Lifetime & Degradation Characteristics

Lifetime specifications for the Nexa™ power module are:

- 1500 hours of continuous operation
- 500 start/stop cycles
- 2 years of storage

Performance specifications for the Nexa™ power module are provided for beginning of life. Over its lifetime, fuel cell performance may degrade, the amount depending on how the system is operated and stored. The lifetime characteristics presented in this section describe how the performance of the Nexa™ module can be expected to vary over its lifetime, and how that variation is affected by operating and storage conditions. This information is considered typical for Nexa™ modules. Individual units may vary.

Table 26 summarises the lifetime and degradation characteristics of the Nexa™ module, evaluated under the following conditions over its specified lifetime.

- Steady-state operation at full load (46A)
- Steady-state operation at idle (<35A)
- Dynamic load profiles that vary from idle (0A) to full load (46A)
- On/Off cycling
- Storage under freezing conditions
- Storage under room temperature conditions
- Freeze/thaw cycling

Operating continuously at full power over its lifetime, the Nexa™ module output performance degrades at a rate of about 0.54 mV/hour. As a result, after 1500 hours of continuous operation at 46A(net), the system output voltage is expected to lose approximately 0.8V. Under fixed current conditions, this translates into a power loss of about 37W. Note that additional power can be drawn from the Nexa™ module to compensate for this loss by further increasing the output current of the system.

Operating continuously under part load conditions (<35A), the Nexa™ module exhibits essentially zero degradation. There has been no observed decay in voltage output over the system lifetime when operating under steady-state part load conditions.

The impact of dynamic loads on system lifetime and performance degradation has also been evaluated over 1500 hours of continuous operation. A variety of load profiles have been tested, including instantaneous load changes between idle and full power. Essentially zero output voltage degradation was witnessed under dynamic load test conditions.

In addition to continuous steady-state and dynamic loads, the Nexa™ module has been evaluated for its on/off cycling ability. The module is capable of executing 500 cycles between the off state and full power operation, as detailed in the product specification. Over the course of on/off cycling, the Nexa™ module output performance degrades at a rate of about 1.1 mV/cycle. Over 500 cycles, the system output voltage is expected to lose approximately 0.56V.

Operation	Conditions	Degradation Rate	Period	Losses
Steady-State	Full Power (46 A_{net})	- 25 mW/hr - 0.54 mV/hr	1500 hours	- 37 W - 0.8 V
	Part Load (< 35 A_{net})	0 mW/hr 0 mV/hr	1500 hours	0 W 0 V
Dynamic Loads	Idle to full power	0 mW/hr 0 mV/hr	1500 hours	0 W 0 V
On/Off	Off – 46 A(net)	- 52 mW/cycle - 1.1 mV/cycle	500 cycles	- 26 W - 0.56 V
Storage Hours	-20°C, 5% RH	- 8 mW/hr - 0.17 mV/hr	1 month	- 5.5 W - 0.12 V
	20°C, 5% RH	- 25 mW/hr - 0.56 mV/hr	1 month	- 18 W - 0.4 V
Freeze/Thaw	-20°C to 40°C	- 1.0 W/cycle - 23 mV/cycle	50 cycles	- 50 W - 1.1 V

Table 26: Lifetime Characteristics

Storage losses for the Nexa™ power module have been evaluated under both freezing and above-freezing conditions, after several months of storage. Table 26 normalises the storage loss on a per-month basis. Freezing storage conditions induce very little performance degradation in the Nexa™ module. Higher storage temperatures accelerate the storage loss of the unit. Under typical room temperature conditions, the Nexa™ module loses about 0.4V per month of storage. The rate of storage loss gradually declines over time, with an anticipated floor of about 10% .

The Nexa™ module (firmware revisions 00.03.01 or greater) incorporates an automated rejuvenation process, which corrects for storage losses and recovers system performance upon shutdown. To maintain peak performance, it is recommended that customers exercise their Nexa™ modules every 2-3 months to initiate this rejuvenation process. Refer to Section 7.1.6.1 for details on the rejuvenation process.

The Nexa™ module can be frozen, so long as it is thawed before its next operation. The onboard controller does not permit start-up if it detects the stack is still frozen. The lifetime and performance impacts of up to 50 freeze/thaw cycles have been evaluated, as shown in Table 26. The system output voltage degrades at a rate of about 23 mV/cycle, or 1.1V after 50 freeze/thaw cycles are executed. The affect of additional freeze/thaw cycles on output performance has not been evaluated at this time.

The information presented in this section is considered typical for Nexa™ power modules and should be used as a guide for developing system integration design concepts. Contact Ballard Customer Service for more detailed information and design guidelines.

10 Planned Maintenance

Component	Action	Frequency
Nexa™ power module	Exercise/Rejuvenate	2 – 3 Months
Air Filter	Replace	500 Hours
Humidity Exchanger	Replace	800 Hours

10.1 Exercise / Rejuvenation

The Nexa™ module (firmware revisions 00.03.01 or greater) incorporates an automated rejuvenation process, which corrects for storage losses and recovers system performance upon shutdown. To maintain peak performance, it is recommended that customers exercise their Nexa™ modules every 2-3 months to initiate this rejuvenation process. Refer to Section 7.1.6.1 for details on the rejuvenation process.

10.2 Air Filter

The Nexa™ air filter requires replacement every 500 hours or as required depending on operating environment.

10.3 Humidity Exchanger

The Nexa™ module incorporates a humidity exchanger that requires replacement after 800 operating hours. This repair should be conducted by an authorized service provider.

11 Trouble-Shooting

This troubleshooting guide provides useful information for interpreting and diagnosing Nexa™ system alarms and shutdowns. Warning and failure limits are given, along with description of non-re-startable faults that may occur during Nexa™ system operation. An easy to follow troubleshooting checklist is also provided to assist with interpreting failure, alarm readings, and determine possible causes.

11.1 Warning & Failure Levels

The Nexa™ power module issues warnings when certain performance parameters fall outside of a pre-defined range. Warnings are not a requirement for shut down. They are intended, however, to provide the system integrator comments and opportunity for modifying operation or interface conditions in order to alleviate the alarm condition. On the other hand, the Nexa™ system is immediately shut down when failure limits are exceeded. The following table shows the warning and failure levels used by the fuel cell system:

Parameter	Warning Level	Failure Level	Restartable

Fuel Cell Stack Temperature	> 71 °C	> 73 °C	Yes
Fuel Cell Stack Voltage	< 23 Volts	< 18 Volts	Yes
Fuel Cell Stack Current	> 60 Amps	> 70 Amps	Yes
Firmware Revision 00.03.01	> 65 Amps	> 75 Amps	Yes
Cell Voltage Checker	N/A	0.85 V/cell pair	Yes
Hydrogen Pressure	< 1.0 barg	< 0.5 barg	Yes
Hydrogen Concentration	80%	100% (10,000 ppm)	No
Oxygen Concentration	< 19.2%	< 18.7%	Yes
Ambient Temperature	N/A	< 3 °C (start-up)	Yes
Battery Voltage	N/A	< 18 Volts (start-up)	Yes
Purge Cell Voltage	< 1.0 Volts	< 0.8 Volts	Yes
Firmware Revision 00.03.01	< 0.8 Volts	< 0.7 Volts	Yes
System Time-out during Start-up	N/A	Digital	Yes
Self Test Fault	N/A	Digital	No
Software Fault	N/A	Digital	No

Table 27: Warning and Failure Alarm Limits

11.2 Non-restartable Faults

Certain Nexa™ system failures are considered non-restartable. After a non-restartable fault has occurred, the system cannot be turned on until a Field Service Support representative has reset it. This precaution is implemented for failure modes that present a potential safety implication to the end user. These include both hydrogen leak failures and self-test (microprocessor or sensor) faults. When either of these occur, field service is required.

11.3 Trouble-Shooting Checklist

DESCRIPTION OF WARNING OR FAILURE	POSSIBLE CAUSE	SUGGESTED ACTION
Fuel Cell Stack Temperature	The Nexa™ system output power level is too high.	Ensure continuous net power production does not exceed 1200W (net).
	Ambient temperature is above the operating limit for the Nexa™ system	Review the product specification for Nexa™.
	Fuel cell stack performance (voltage) is too low.	Repeat Low Fuel Cell Stack Voltage troubleshooting suggestions below.
	Cooling fan intake obstructed.	Ensure cooling fan intake is unobstructed.
	Coolant exhaust obstructed.	Ensure coolant exhaust is

DESCRIPTION OF WARNING OR FAILURE	POSSIBLE CAUSE	SUGGESTED ACTION
		unobstructed.
	Cooling fan/motor is failing or has failed.	Perform audio-visual inspection of fan and motor. Call Ballard Field Service for further support.
	Air exhaust is cross leaking into fan intake.	Check the product enclosure for gaps and cracks.
	Fuel cell failure	Call Ballard Field Service if the problem persists.
Fuel Cell Stack Voltage	Nexa™ system output power level is too high.	Ensure continuous net power production does not exceed 1200W (net). Review power de-rating requirements.
	Fuel cell stack is not receiving sufficient oxidant air.	Listen for air pump operation. Call Ballard Field Service if a problem is found.
		Check humidity exchanger for leaks. Call Ballard Field Service for replacement humidity exchanger.
		Check air filter for blockages.
	Oxidant air inlet is contaminated.	Ensure the Nexa™ system is not running adjacent to automobile or portable generator exhaust. Consult end user on operating environment.
	Inadequate inlet air humidification.	Call Ballard Field Service for replacement humidity exchanger.
	Purge valve is not working.	Call Ballard Field Service to perform a more detailed diagnosis.
	Hydrogen fuel supply is contaminated.	Ensure hydrogen fuel supply satisfies the purity specification for the Nexa™ system.
	Onboard current sensor is un-calibrated.	Check zero reading of onboard current sensor. Call Ballard Field Service for further support.
	Short circuit through an external conductor on/near the stack	Inspect stack and terminals for debris or damage. Contact Ballard Field Service for further support.
	Non-Operating Performance Loss (NOPL) or fuel cell contamination (air or fuel supply)	Execute Rejuvenation procedure on shut down (for firmware revisions 00.03.01 or greater)
	Fuel cell failure	Call Ballard Field Service for further

DESCRIPTION OF WARNING OR FAILURE	POSSIBLE CAUSE	SUGGESTED ACTION
		support.
Fuel Cell Stack Current	Nexa™ system output power level is too high.	Ensure continuous net power production does not exceed 1200W (net).
	Fuel cell stack performance (voltage) is too low.	Repeat Low Fuel Cell Stack Voltage troubleshooting suggestions above.
	Failed current sensor or failed sensor signal to the control board	Check zero reading of onboard current sensor. Contact Ballard Field Service for further support.
	Detected surge current from the fuel cell stack exceeds 70 amps.	Provide current limiting in power conditioning design. Ensure that current surges from the fuel cell stack exceeding 70 amps are shorter than 50 ms in duration.
	Non-Operating Performance Loss (NOPL) or fuel cell contamination (air or fuel supply)	Execute Rejuvenation procedure on shut down (for firmware revisions 00.03.01 or greater)
	Fuel cell failure	Call Ballard Field Service for further support.
Fuel Pressure	System is out of fuel.	Check pressure in hydrogen fuel tanks.
	Fuel delivery pressure is set too low.	Check pressure regulator settings of storage tanks. Ensure delivery pressure is within limits provided in interface specifications.
	Hydrogen solenoid valve is not working.	Measure and confirm 12 V signal is applied to the solenoid. Listen for solenoid clicking. Call Ballard Field Service for detailed diagnostics.
	Fuel delivery assembly is leaking.	Check the Nexa™ system leak detector readings using software interface. Verify using hand-held leak detector. Snoop all connections using soapy water.
Low (CVC) Cell Voltage		Repeat Low Fuel Cell Stack Voltage troubleshooting suggestions above.
	Shorted Cells, Air pump failure, Control board failure	Contact Ballard for further support.
	Localised overheating of cells	Check the top of the fuel cell stack for blockage of the cooling channels
	Blocked oxidant air inlet or outlet	Check air intake filter and the air outlet line for blockage

DESCRIPTION OF WARNING OR FAILURE	POSSIBLE CAUSE	SUGGESTED ACTION
	Hydrogen fuel supply is contaminated.	Ensure hydrogen fuel supply satisfies the purity specification for the Nexa™ system.
	Onboard current sensor is un-calibrated.	Check zero reading of onboard current sensor. Contact Ballard Field Service for further support.
	CVC fingers not in proper contact with fuel cell plates.	Check CVC finger contacts. Contact Ballard Field Service for further support.
	CVC fingers not properly plugged into CVC board.	Check CVC finger connectors. Contact Ballard Field Service for further support.
	Non-Operating Performance Loss (NOPL) or fuel cell contamination (air or fuel supply)	Execute Rejuvenation procedure on shut down (for firmware revisions 00.03.01 or greater)
	Fuel cell failure	Call Ballard Field Service for further support.
Low Purge Cell Voltage		Repeat Low Fuel Cell Stack Voltage troubleshooting suggestions above.
	Purge Valve Stuck Open	Listen for audible clicking of purge valve during system operation. Contact Ballard Field Service for further support.
	Faulty Regulator – incorrect supply pressure	Contact Ballard Field Service for further support
	Blocked purge valve tubing	Contact Ballard Field Service for further support
	Non-Operating Performance Loss (NOPL) or fuel cell contamination (air or fuel supply)	Execute Rejuvenation procedure on shut down (for firmware revisions 00.03.01 or greater)
	Purge Cell failure	Contact Ballard Field Service for further support
	Fuel Cell stack failure	Contact Ballard Field Service for further support
Fuel Leak Detected	Confirm non-restartable fault using software interface.	Contact Ballard Field Service for further support.
	Fuel delivery assembly is leaking.	Inspect the fuel cell stack, fuel storage tanks, solenoid valves, and the connections to the fuel system. Contact Ballard Field Service for further support.

DESCRIPTION OF WARNING OR FAILURE	POSSIBLE CAUSE	SUGGESTED ACTION
	Purge valve failed open.	Listen for audible clicking of the purge valve during system operation. Contact Ballard Field Service for further support.
	Cooling fan/motor is failing or has failed.	Perform audio-visual inspection of fan and motor. Call Ballard Field Service for further support.
	External fuel cell stack leak.	Contact Ballard Field Service for further support.
Time Out on System Start Up	CVC system is not properly assembled and plugged in.	Check CVC fingers are making proper connection with plates. Check cable connections.
	Solenoid valve is not opening.	Measure and confirm 12 V signal is applied to the solenoid. Listen for solenoid clicking. Call Ballard Field Service for detailed diagnostics.
	Purge valve is not opening.	Confirm purge valve clicks and visually inspect for hydrogen venting. Call Ballard Field Service for support.
	Stack voltage is too low.	Refer to Low Stack Voltage troubleshooting suggestions. Contact Ballard Field Service for support.
	Non-Operating Performance Loss (NOPL) or fuel cell contamination (air or fuel supply)	Execute Rejuvenation procedure on shut down (for firmware revisions 00.03.01 or greater)
	Load relay closed and system is starting under load	Verify that the load relay is open on system start up.
Software Faults	Confirm non-restartable fault using diagnostic software.	Contact Ballard Field Service for further support.
	Sensors unplugged or out of range (H2, O2, P, T, I)	Check sensor connections. Contact Ballard Field Service for further information.
	Loose wiring harness connection to the control board.	Check the pins and connector.
	Software/control board failure.	Call Ballard Field Service.

Table 28: Troubleshooting Checklist