



Nuvation Energy G4 High-Voltage BMS

Product Manual

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The content in this document must be followed in order to ensure safe operation of Nuvation Energy BMS.



Do **NOT** energize the system until all connections to the G4 Stack Switchgear unit and G4 Cell Interface modules have been made.



The wiring of the battery cell voltage and temperature sensing should be verified **before** connecting to the G4 Cell Interface modules. The temperature sensing must be isolated from the cell voltage sensing and Earth. Although the G4 Cell Interface includes protective circuitry to make it more resilient to brief wiring errors, the same circuitry can result in the battery cells being slowly discharged. Over time, these wiring errors can cause damage to the G4 Cell Interface and/or the cells.



Properly insulate or remove any unused wires. Unused wires can couple excessive system noise into Nuvation Energy BMS which can disrupt communication and lead to undesirable behaviors.



Nuvation Energy BMS relies on your system charger to charge the battery cells; do not leave your charger off while Nuvation Energy BMS is powered from the stack for prolonged periods of time. Nuvation Energy BMS should be shut down when the system is in storage to minimize the drain on the cells.



Insulated handling is required of any connector carrying potentials over 60 V DC relative to chassis.



Please be aware of high voltages present in your system and follow all necessary safety precautions.



The provided module enclosures are not fire enclosures.

1. Introduction

Thank you for choosing Nuvation Energy.

Nuvation Energy's G4 Stack Switchgear provides an integrated battery stack management solution that includes all the hardware and software required to integrate a battery stack into your Energy Storage System. Each G4 Stack Switchgear unit contains Nuvation Energy G4 High-Voltage BMS modules and is designed to be used with other products in the Nuvation Energy BMS family.

1.1. About this Manual

This *Nuvation Energy G4 High-Voltage BMS: Product Manual* is a comprehensive manual, providing:

- Details about all the features offered by your Nuvation Energy G4 High-Voltage BMS
- Mounting and wiring instructions to install this product safely
- Guidance on integrating the device into your Energy Storage System
- Guidance on operating the Nuvation Energy BMS Operator Interface



This document applies to Nuvation Energy BMS Descartes Update 1 software release (Firmware version 4.109.1, Operator Interface version 1.0.1). Content may be inaccurate or incomplete for other versions.



We thrive on your feedback and what we build is driven by your input. Please submit support tickets to support@nuvationenergy.com.

2. Battery Topology Terminology

Energy storage systems are hierarchical in nature. Nuvation Energy has adopted the following definitions for battery pack topology:

Cell

A Cell is the smallest unit of energy storage distinguishable by the Battery Management System. One Cell, as defined from the perspective of the BMS, may actually consist of one or more electrochemical cells connected in parallel. This subtlety is reflected in the nomenclature for completeness. For example, a "1p" Cell refers to a single electrochemical cell, while a "2p" Cell refers to two electrochemical cells connected together in parallel. From the perspective of the BMS, these topologies appear identical except for the capacity of the Cells.

Group

A Group is a set of Cells connected in series and managed together. For example, 12 "1p" Cells in series are referred to as a "12s1p" Group, while 16 "2p" Cells in series are referred to as a "16s2p" Group. Grouping of Cells is highly application-specific and is defined in how BMS hardware interfaces are physically wired up to Cells.

Stack

A Stack is one or more Groups connected in series. For example, five "14s2p" Groups connected in series could be described as a "5g14s2p" Stack. However, it is far more common to describe it as a "70s2p" Stack.

Bank

A Bank is one or more stacks connected in parallel. For example, three "70s2p" Stacks connected in parallel are referred to as a "3x70s2p" Bank.

Pack

A Pack is one or more Banks connected in series.

3. System Overview

The Nuvation Energy G4 High-Voltage BMS provides cell-level and stack-level control for battery stacks up to 1250 VDC. The UL 1973 Recognized BMS modules in each stack ensure safe battery operation and significantly reduce the effort of certifying the energy storage solution to meet UL 1973 and UL 9540. For more information, please contact support@nuvationenergy.com



Figure 1. G4 High-Voltage BMS

A single Nuvation Energy G4 Stack Switchgear unit manages each stack and connects it to the DC bus of the energy storage system. The Nuvation Energy G4 Stack Switchgear, is a pre-configured assembly that incorporates the major functions of Nuvation Energy G4 High-Voltage BMS into a rack-mountable unit which includes stack monitoring, electrical disconnects, pre-charging, current sensing, fuses, and a safety relay for E-Stop. It also includes supporting components like power supplies, indicator LEDs, and external-facing connectors.

G4 Cell Interface modules in each stack connect directly to battery cells to measure cell voltages and temperatures and provide cell balancing.

The G4 Stack Switchgear and G4 Cell Interface modules operate together as a complete system called the G4 High-Voltage BMS. Available units/modules are listed below.

Table 1. G4 Stack Switchgear and G4 Cell Interface Modules

Model	Unit/Module Name
NUVSSG-1250	G4 Stack Switchgear, 1250 V
NUV100-CI-12-1	G4 Cell Interface - 12 channel
NUV100-CI-16-1	G4 Cell Interface - 16 channel
NUV100-CI-4M12-1	G4 Cell Interface - 12V 4 channel

Generally, a single battery stack uses one G4 Stack Switchgear and one or more G4 Cell Interface modules. A breakdown of a single battery stack is shown in [Figure 2, "G4 High-Voltage BMS single system diagram"](#)

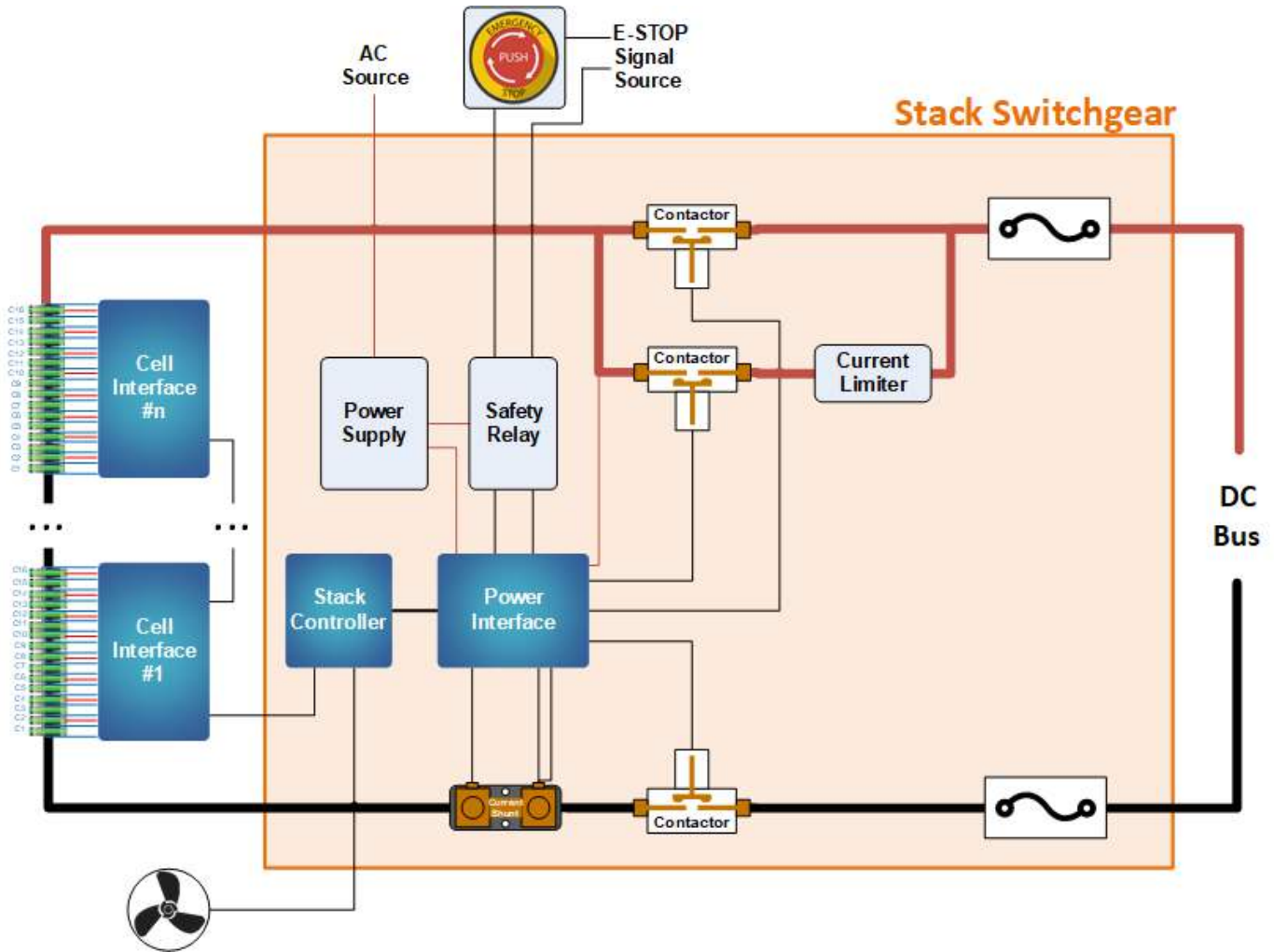


Figure 2. G4 High-Voltage BMS single system diagram

In a multi-stack G4 High-Voltage BMS configuration, as shown in [Figure 3, "G4 High-Voltage BMS multi-stack diagram"](#), each G4 Stack Switchgear unit is responsible for monitoring the state and safety of one battery stack. All G4 Stack Switchgear units connected to a single common DC bus in the system may be managed by a single Nuvation Energy Multi-Stack Controller, where an Operator Interface provides a unified view and central control of the multi-stack system.

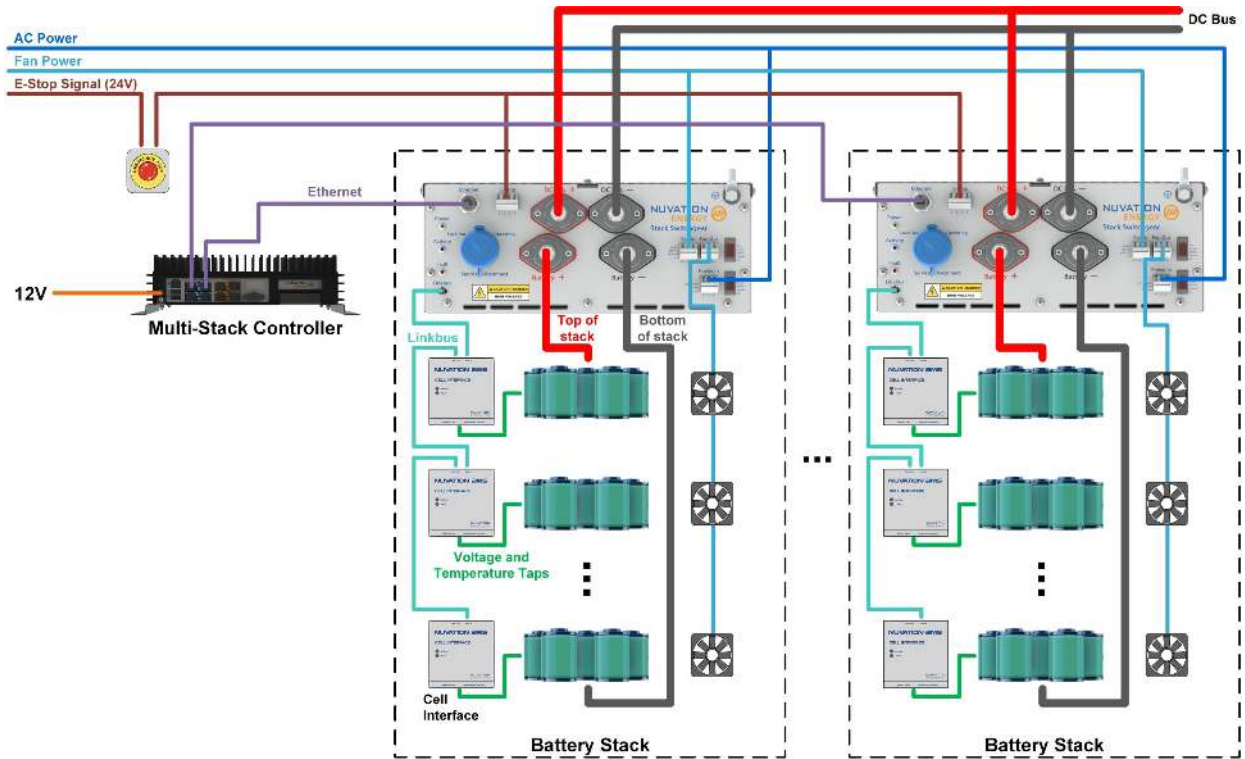


Figure 3. G4 High-Voltage BMS multi-stack diagram

3.1. G4 Stack Switchgear

The high-level system design of G4 Stack Switchgear is shown in [Figure 2, "G4 High-Voltage BMS single system diagram"](#). Within a battery stack, the G4 Stack Switchgear connects to the daisy-chained Nuvation Energy G4 Cell Interface modules. The G4 Cell Interface modules convert cell voltage and temperature measurements to digital values to be relayed to the G4 Stack Switchgear, and enable or disable cell balancing as required. Daisy-chaining the G4 Cell Interface modules facilitates the design of flexible and scalable Battery Energy Storage Systems.

The G4 Stack Switchgear has high-voltage, high-current connectors that are accessible on the front of the unit. These connect the battery stack to the rest of the system, which is typically a common DC bus. Safety precautions are required to handle and connect cables into this unit.

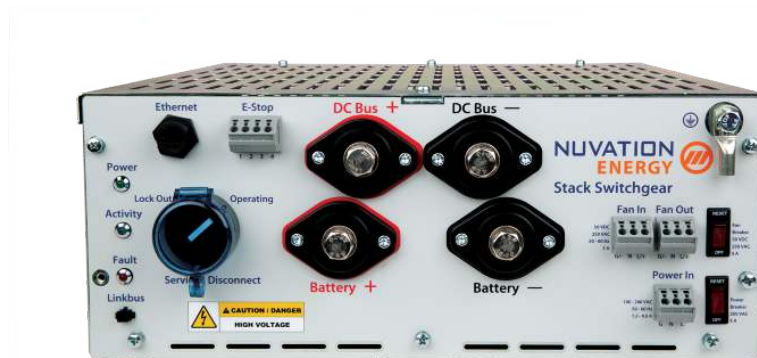


Figure 4. Nuvation Energy G4 Stack Switchgear Unit

The external interfaces to this unit are:

- Battery Stack and DC Bus connectors
- Service Disconnect Switch
- 10/100 Base-T Ethernet RJ45 jack (Modbus-TCP)
- Link Bus connector
- E-stop connector
- Fan control connectors with breaker switch
- Power In connector with breaker switch
- Status LEDs (Power, Activity, and Fault)
- Earth bonding connection (grounding stud)

The G4 Stack Switchgear (NUVSSG-1250) supports 1250 VDC. There are multiple options for current rating (from 100 A to 350 A) and fuse rating (from 200 A to 500 A). The G4 Stack Switchgear fuse rating is determined by the application power profile which is based on continuous power, cycle duration, and cycle frequency.

For ordering details, please refer to [G4 Stack Switchgear Ordering Information](#).

3.1.1. Features

The Nuvation Energy G4 Stack Switchgear internally includes the following major hardware components:

- Nuvation Energy High-Voltage Stack Controller
- Nuvation Energy High-Voltage Power Interface
- Current measuring shunt
- Three high-voltage DC contactors
- Pre-charge circuit
- Two fuses (short-circuit protection)
- Safety relay (for E-Stop)

The following subsections describe the components in more detail.

3.1.1.1. Stack Controller and Power Interface

The G4 Stack Switchgear contains a single Nuvation Energy High-Voltage Stack Controller and Nuvation Energy High-Voltage Power Interface.

The Stack Controller has a central MCU which handles processes and decision-making required by the Battery Management System. The Power Interface contains a redundant MCU to handle processes and decision-making required to control the high-current contactors.

The Stack Controller and Power Interface are UL-recognized components, for use in UL 1973 stationary Battery Energy Storage Systems. For more information on the capabilities of the Stack Controller and Power Interface please refer to the datasheets available online at <https://www.nuvationenergy.com/technical-resources>.

3.1.1.2. Current Measuring Shunt

A precision current shunt in series with the negative side of the stack is used to measure the stack charging/discharging current. Current measurement is performed by the Power Interface.

3.1.1.3. DC Contactors

High-voltage contactors are used by the BMS to connect the battery stack to the DC bus. There are contactors on both the positive and negative sides of the stack. Nuvation Energy BMS opens the contactors either by request of an external controller or in fault conditions. A third high-voltage contactor is used in the pre-charge circuit (see [Section 3.1.1.4, "Pre-Charge Circuit"](#)).

Contactors with auxiliary switch feedback are used so the BMS can raise a fault when it detects contactor failure during opening or closing. Note that the expected lifespan of a contactor is impacted significantly each time it connects or disconnects under load.

3.1.1.4. Pre-Charge Circuit

The G4 Stack Switchgear has a pre-charge circuit to ensure safe connection of its battery stack to the DC bus. The pre-charge circuit temporarily connects the stack to the DC bus through a power resistor. This resistor allows a smaller current (proportional to the difference in voltage between the stack and the DC bus) to flow between the stack and the DC bus. After a 5-second pre-charge timeout, if the measured current is below a safe threshold, the BMS bypasses the pre-charge circuit by connecting the stack directly to the DC bus.

This ensures the battery stack will not connect to the DC bus when an unsafe voltage mismatch is present. By default, the G4 Stack Switchgear is configured with a 150 Ω, 300 W power resistor, suitable for a DC bus capacitance of 15 mF at 1000 V and 10 mF at 1250 V. As a custom request, the pre-charge resistor can be sized specific to the end application.

3.1.1.5. Fuses

There are multiple options for current rating and fuse rating. The G4 Stack Switchgear fuse rating is determined by the application power profile which is based on continuous power, cycle duration, and cycle frequency.

Inline fuses are used on both the positive and negative connections and are sized according to the G4 Stack Switchgear variant. The fuses interrupt a short circuit event; two of them are used to provide redundancy and to permit use of the G4 Stack Switchgear with an ungrounded battery stack.

The following are the current rating and fuse rating options available for the G4 Stack Switchgear (NUVSSG-1250).

Table 2. G4 Stack Switchgear (NUVSSG-1250) current rating options

Current Rating
100 A
200 A
300 A
350 A

Table 3. G4 Stack Switchgear (NUVSSG-1250) fuse rating options

Fuse Rating	Interrupt Current Rating
200 A	100 kA
250 A	100 kA
315 A	100 kA
350 A	100 kA
400 A	100 kA
450 A	100 kA
500 A	100 kA

3.1.1.6. Safety Relay (for E-Stop)

The G4 Stack Switchgear has an internal safety relay for monitoring an external E-Stop signal. A

safety relay is used to ensure the relay cannot fail shorted.

This relay meets the requirements of the following standards: EN 954-1, EN 60204-1, VDE 0113-1 and IEC 60204-1. It also has approvals from UL, cUL, CCC and TUV. For more information about the E-Stop functionality, see [Section 4.2.6, "Connect E-Stop"](#).

3.2. G4 Cell Interface

The Nuvation Energy G4 Cell Interface is the direct link between the individual battery stack cells and the rest of the Battery Management System. It facilitates battery monitoring and balancing functionalities.

In a stack managed by the G4 Stack Switchgear, one or more G4 Cell Interface modules are used to convert and relay cell voltage and temperature measurements digitally to the G4 Stack Switchgear. When using multiple G4 Cell Interface modules, the same G4 Cell Interface variant must be used—i.e. all NUV100-CI-12-1, or all NUV100-CI-16-1, or all NUV100-CI-4M12-1. The firmware does not support a mixed chain of different Cell Interface variants.

The following are variants of the Nuvation Energy G4 Cell Interface:

- The NUV100-CI-12-1, G4 Cell Interface - 12 channel can monitor up to 12 series-connected cells
- The NUV100-CI-16-1, G4 Cell Interface - 16 channel can monitor up to 16 series-connected cells
- The NUV100-CI-4M12-1, G4 Cell Interface - 12V 4 channel can monitor up to 4 series-connected 12V lead-acid cells. Note that cell balancing is not supported in G4 Cell Interface - 12V 4 channel.

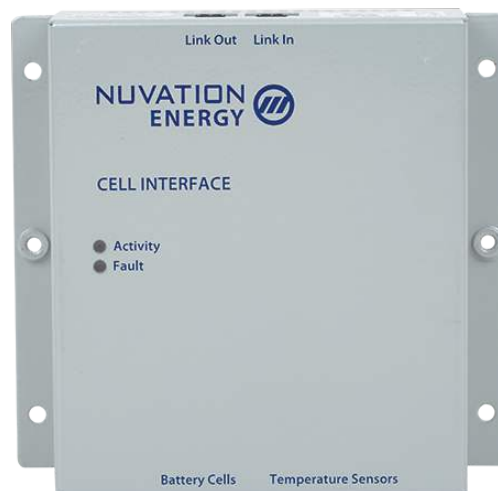


Figure 5. Nuvation Energy G4 Cell Interface Module

The external interfaces to this module are:

- Battery cells connector
- Temperature sensors connector
- 2 Link Bus connectors
- 2 Indicator LEDs



The G4 Cell Interface connects to the battery stack-referenced signals through high voltage rated connectors. Safety precautions are required to handle and connect cables into this module.

4. Installation Instructions



During all stages of the installation, appropriate Personal Protective Equipment (PPE) must be worn. This is especially critical when working with live voltages.

4.1. G4 Stack Switchgear Mechanical Installation

4.1.1. Dimensions and Weight

The G4 Stack Switchgear is 4U (rack-units) tall.

The unit weighs 23 kg [50.7 lbs].

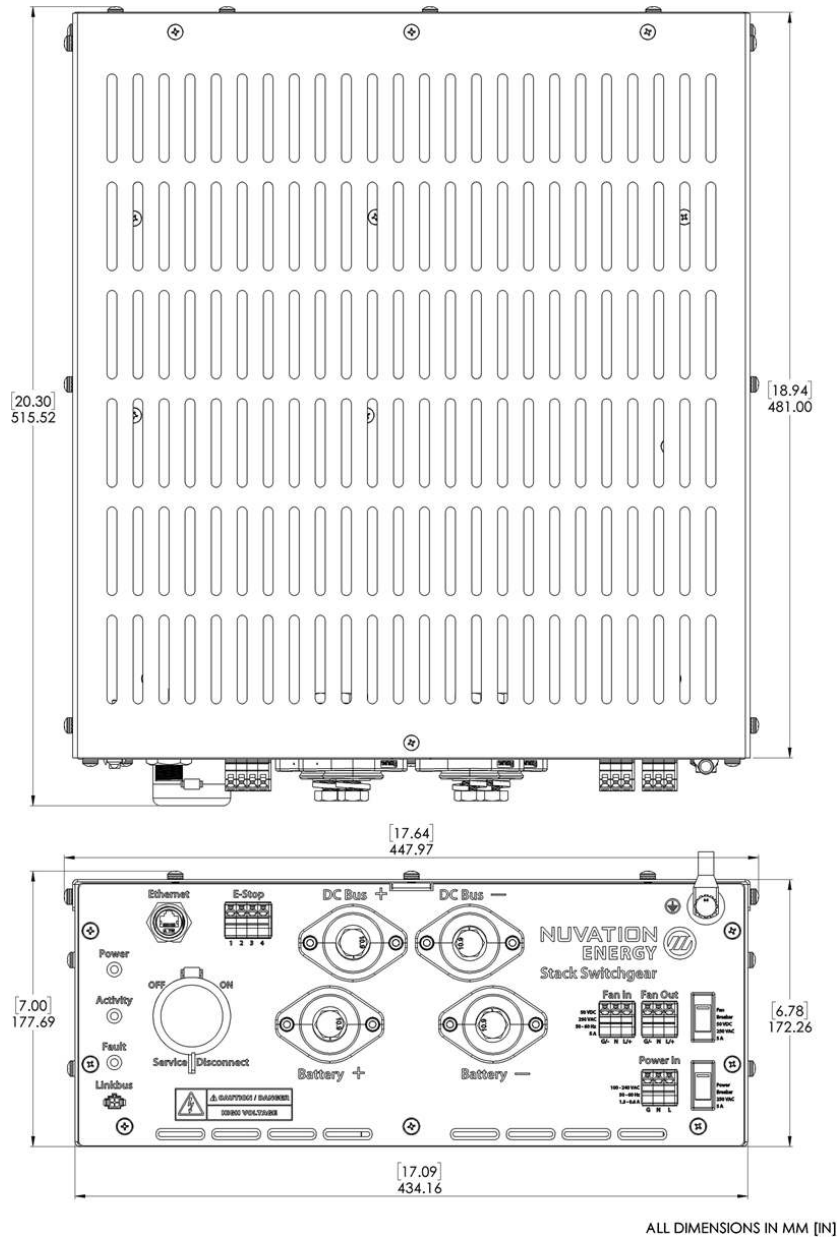


Figure 6. G4 Stack Switchgear Dimensions

4.1.2. Installation Location and Position

The G4 Stack Switchgear is rated to operate in the temperature range of 10 °C to 40 °C. To use the Nuvation Energy G4 Stack Switchgear in the temperature range of -10 °C to 50 °C, the G4 Stack Switchgear must not be accessible in the end product installation. The G4 Stack Switchgear is designed for indoor applications.

The G4 Stack Switchgear is primarily designed to fit in a standard 19" rack with a 23"-deep cabinet. However, other mounting possibilities are supported, as the following subsections discuss. Depending on the desired application, brackets can be ordered with part numbers listed in [G4 Stack Switchgear Ordering Information](#).

The G4 Stack Switchgear must be installed in a horizontal orientation with the vent-slots pointing up to the sky. The G4 Stack Switchgear is not designed to be installed in any other orientation.

4.1.2.1. Mounting Clearances

To maintain safe operating temperatures, it is recommended to leave 1U of space above the unit for airflow. Depending on the environment, airflow, and ambient temperature, some installations may require additional clearance above the unit.

4.1.3. Mounting Instructions

For rack and shelf options, the installation can be done by one person. For 2-post options, the installation requires a minimum of two people.

Fasteners for attaching the brackets to the G4 Stack Switchgear unit (M5 x 8 mm) are included with any mounting bracket order. If fasteners other than the provided hardware is used, the screws cannot extend into the G4 Stack Switchgear more than 8 mm. High-voltage and high-power elements that exist inside the unit could arc to the screw if it intrudes too deep into the unit.

Fasteners for attaching the brackets to the end desired surface are not provided, due to the application-specific nature. In order to source these fasteners however, note that the corresponding bracket slots have widths designed for M5 screws.

After removing the G4 Stack Switchgear from its packaging, perform the following steps based on the mounting brackets purchased.

4.1.3.1. Front-securing Rack-Mount, 19"



Third-party side-support angle brackets are necessary to uphold the weight of the unit, in this mounting application.

Some examples include RASA22BK3 or RAAB2436BK products by Hammond Manufacturing (<https://www.hammg.com/>).

For front-securing 19" rack installations (i.e. using the NUVP-SSG-RB-19)

1. Install the side-support angle brackets (not included) on the rack at the desired location.
2. Install the brackets on the G4 Stack Switchgear.
3. Place the G4 Stack Switchgear onto the installed side-support angle brackets. Ensure the G4 Stack Switchgear is in a horizontal orientation with the vent-slots pointing up to the sky.
4. Secure the G4 Stack Switchgear to the rail of the rack using the brackets installed.



Figure 7. Rack-mount, 19", front-securing

4.1.3.2. 2-Post Rack-Mount, 19" And 23"

For 2-post rack installations (i.e. using the NUVP-SSG-RB-19-2P or NUVP-SSG-RB-23-2P)

1. Install one pair of brackets (i.e. both front or both rear brackets) on the posts at the desired location.
2. Install the other pair of brackets on the G4 Stack Switchgear.
3. Have one person support the G4 Stack Switchgear in the desired position. Ensure the G4 Stack Switchgear is in a horizontal orientation with the vent-slots pointing up to the sky.
4. Attach the G4 Stack Switchgear (with brackets installed) to the posts.



Figure 8. Rack-mount, 2-post, 19"

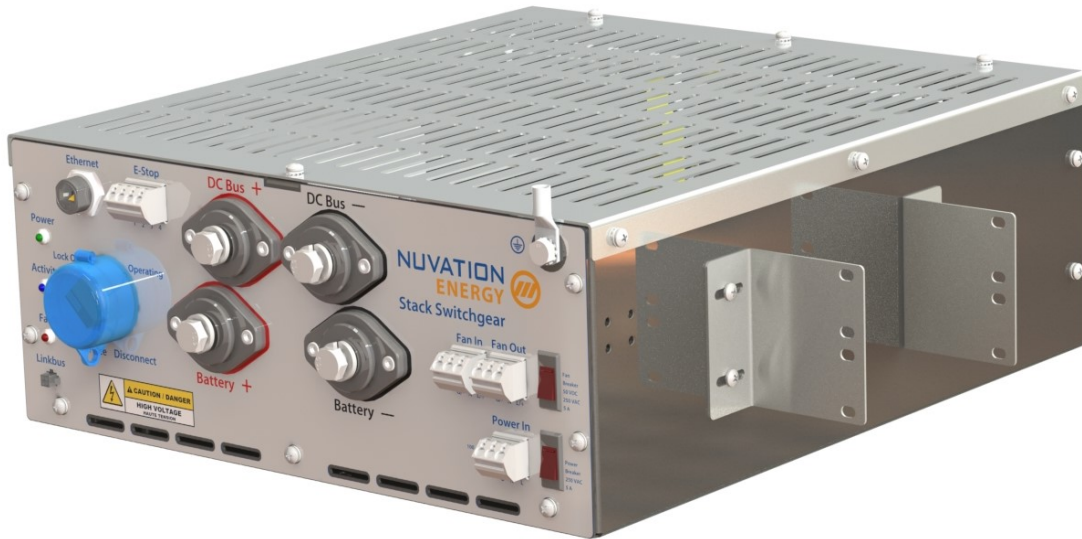


Figure 9. Rack-mount, 2-post, 23"

4.1.3.3. Shelf-Mount

For shelf installations (i.e. using the NUVP-SSG-SB)

1. Install the brackets on the G4 Stack Switchgear.
2. Place the G4 Stack Switchgear on the shelf at the desired location. Ensure the G4 Stack Switchgear is in a horizontal orientation with the vent-slots pointing up to the sky.
3. Attach the G4 Stack Switchgear (with brackets installed) to the shelf.

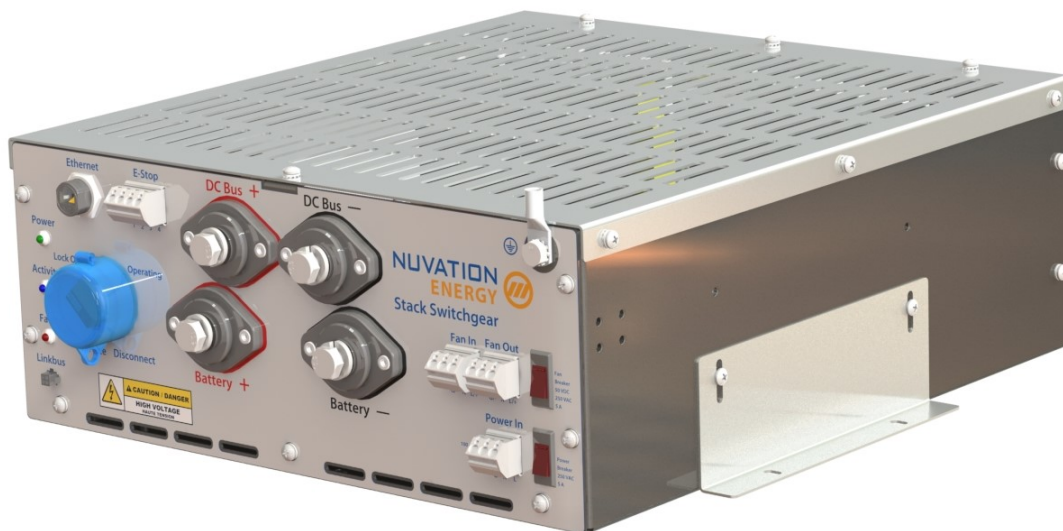


Figure 10. Shelf-mount

4.2. G4 Stack Switchgear Electrical Connections



Before making any connections, ensure that the service disconnect in [Figure 11, "G4 Stack Switchgear external interfaces"](#) is in the **OFF** position.



The G4 Stack Switchgear is configured for a specific battery topology based on the details provided to Nuvation Energy during order fulfillment. Failure to use the same number of G4 Cell Interface modules and/or using a different battery topology will result in undesirable G4 Stack Switchgear behavior.

+ Please contact support@nuvationenergy.com if there is a change in the system design that would require a G4 Stack Switchgear configuration update.

4.2.1. Getting Started

- [Step 1: Ensure system is de-energized](#)
- [Step 2: Ground the G4 Stack Switchgear](#)
- [Step 3: Connect Power In](#)
- [Step 4: Connect Fan Control](#)
- [Step 5: Connect E-Stop](#)
- [Step 6: Connect to external PC](#)
- [Step 7: Connect G4 Cell Interface Link bus](#)
- [Step 8: Connect Battery Stack and DC Bus](#)

Below is a overview image of the external interfaces available on the front of the G4 Stack Switchgear.

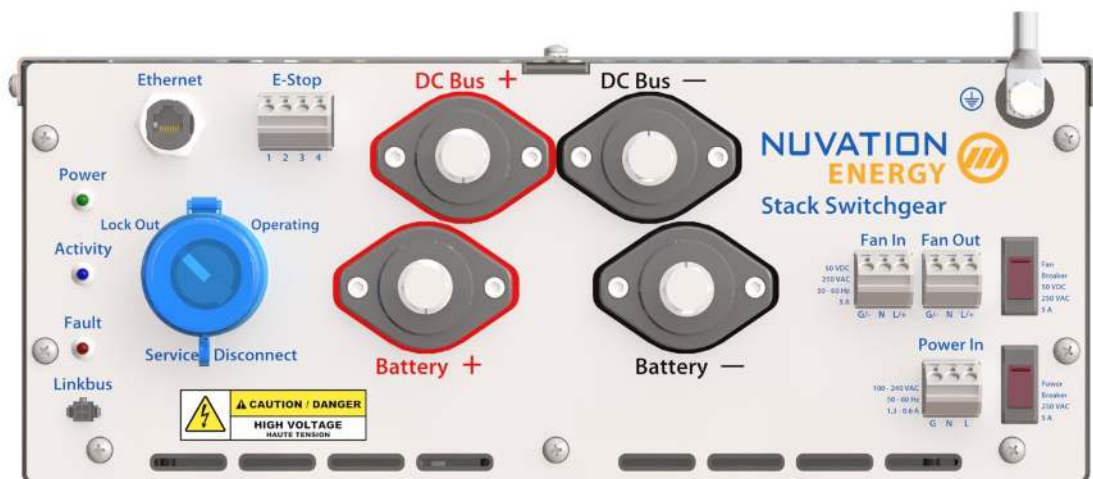


Figure 11. G4 Stack Switchgear external interfaces

4.2.2. Ensure system is de-energized

Ensure that the service disconnect switch, input power breaker, and the fan power breaker are in the **OFF** position.

Service Disconnect

The manual service disconnect switch is accessible on the front of the G4 Stack Switchgear. Use the lock-out/tag-out to ensure that the battery stack does not connect to the DC bus or PCS during installation.

Ensure the service disconnect switch is in the **OFF** position and lock-out/tag-out the switch by locking the cover.



Figure 12. Service Disconnect



The service disconnect switch removes power to the internal contactors—it does not physically break the connection (this is done by the contactors themselves).

In the event of damage to the internal contactors (i.e. a welded contactor), the service disconnect switch cannot guarantee that the DC bus has been disconnected from the battery. It is therefore recommended to check for voltage present on the Battery Stack and DC Bus terminals with a voltmeter before working on the stack to ensure the contactors have opened fully.

Fan Power

An inline breaker provides the ability to turn off fan control for the G4 Stack Switchgear. Ensure the breaker is in the **OFF** position.



Figure 13. Fan Power Breaker

Power In

An inline breaker provides the ability to turn off input power for the G4 Stack Switchgear. Ensure the breaker is in the **OFF** position.



Figure 14. Power In Breaker

Verify system is de-energized

Using a multimeter check the Battery Stack and the DC Bus terminals respectively to verify that the system is de-energized. Be aware that battery itself cannot be de-energized and in some situations, it may not be possible to de-energize the DC bus.

4.2.3. Grounding the G4 Stack Switchgear



Figure 15. Grounding stud

The G4 Stack Switchgear must be bonded to the rack or Earth through a suitably sized conductor by NEC standards. From NFPA 70, Table 250.122, the wire size must be chosen based on the rating of the automatic over-current device in the circuit, as shown in [Table 4, "Minimum grounding wire size"](#).

Table 4. Minimum grounding wire size

G4 Stack Switchgear Current Rating (A)	Grounding Wire (AWG)	
	Copper	Aluminum
100	8	6
200	6	4
300	4	2
350	3	1

An M8 lug (not included) should be used (e.g. Panduit Corp LCMA50-8-L), along with an M8 screw and tooth lock washer (included), as shown in [Figure 15, "Grounding stud"](#).

In order to make the connection:

1. Strip the insulation
2. Crimp the lug
3. Screw the lug onto the terminal

The recommended tightening torque is 15 N-m [130 in-lbs].

4.2.4. Connect Power In

The G4 Stack Switchgear requires 100 V to 240 V AC power to be supplied from an external source. Power is connected via feed-through connectors labeled 'Power In' on the front panel, as shown in [Table 5, "Power In Connector Pin Assignment"](#).

To install a conductor

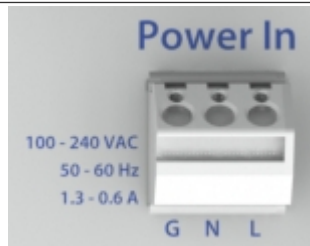
Insert a tool (such as a small flat screwdriver) into the rectangular opening at the top of the connector. This allows the conductor to freely enter into the circular opening at the front of the connector. Remove the tool to secure the conductor in place. For stranded wires, the use of ferrules is recommended.

An inline breaker provides the ability to turn off input power for the G4 Stack Switchgear. It also protects the system by tripping if the input current exceeds 5 A. For specifications of this input, see [G4 Stack Switchgear](#).



For the breaker's safety mechanism to work as expected, the input power wiring must also be rated to at least 5 A.

Table 5. Power In Connector Pin Assignment



Pin	Name	Description	Connected to Device
1	G	Ground	External power source
2	N	Neutral	External power source
3	L	Line	External power source

Input power should be de-energized during installation; this usually involves turning off a breaker at a panel.

4.2.5. Connect Fan Control

Fan control enables the G4 Stack Switchgear to control external AC or DC fans for cooling the battery cells. The fans are enabled by the BMS when battery cell temperatures exceed configurable thresholds.

The power source for the fans must be supplied to the G4 Stack Switchgear. It can be either AC or DC, depending on the fan selection for the system. This can be the same power source used for powering the G4 Stack Switchgear as described in [Section 4.2.4, "Connect Power In"](#).

The signals are connected via feed-through connectors on the front panel, as shown in [Table 6, "Fan Control Connector Pin Assignment"](#).

To install a conductor

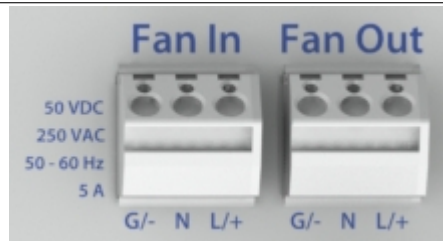
Insert a tool (such as a small flat screwdriver) into the rectangular opening at the top of the connector. This allows the conductor to freely enter into the circular opening at the front of the connector. Remove the tool to secure the conductor in place. For stranded wires, the use of ferrules is recommended.

An inline breaker provides the ability to turn off fan control for the G4 Stack Switchgear. It also protects the system by tripping if the amperage exceeds 5 A. For specifications of this input, see [G4 Stack Switchgear](#).



For the breaker’s safety mechanism to work as expected, the fan control wiring must also be rated to at least 5 A.

Table 6. Fan Control Connector Pin Assignment



Pin	Name	Description		Connected to Device
		AC	DC	
Fan Input				
1	G/-	Ground	Negative	External power source
2	N	Neutral	NC	External power source
3	L/+	Line	Positive	External power source
Fan Output				
1	G/-	Ground	Negative	External fan system
2	N	Neutral	NC	External fan system
3	L/+	Line	Positive	External fan system

[Figure 16, "Battery cooling fan control wiring diagram"](#) provides the internal wiring implementation of the fan control parts shown above.

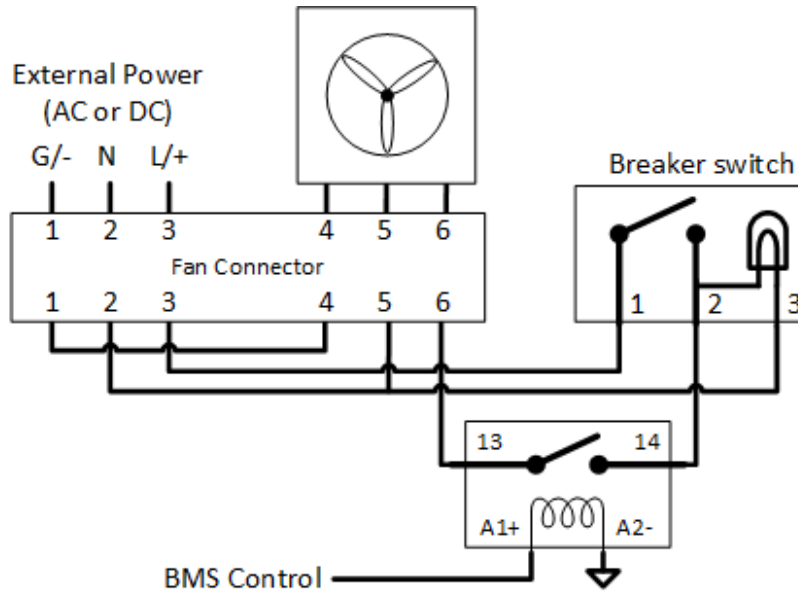


Figure 16. Battery cooling fan control wiring diagram

Fan power should be de-energized during installation; this usually involves turning off a breaker at a panel.

4.2.6. Connect E-Stop

This feature allows a 24 V DC E-Stop signal, provided either by the internal power supply (shown in [Figure 17, "E-Stop circuit \(internal supply\)"](#)) or by a source external to the Nuvation Energy system (shown in [Figure 18, "E-Stop circuit \(external supply\)"](#)), to trigger a BMS fault and disconnect the stack using an internal safety relay. In this event, the BMS will also enter a fault state.

Internally, the E-Stop input is connected to the safety relay coils while the E-Stop output is connected to the internal 24 V DC power supply. One G4 Stack Switchgear unit's E-Stop output is capable of driving the E-Stop inputs for up to two G4 Stack Switchgear units (i.e. one other G4 Stack Switchgear unit in addition to itself); this allows the two G4 Stack Switchgear units to share an E-Stop circuit. For applications requiring more than two G4 Stack Switchgear units on the same E-Stop circuit, an external 24 V DC power source must be used.

For specifications of this input, see [G4 Stack Switchgear](#).

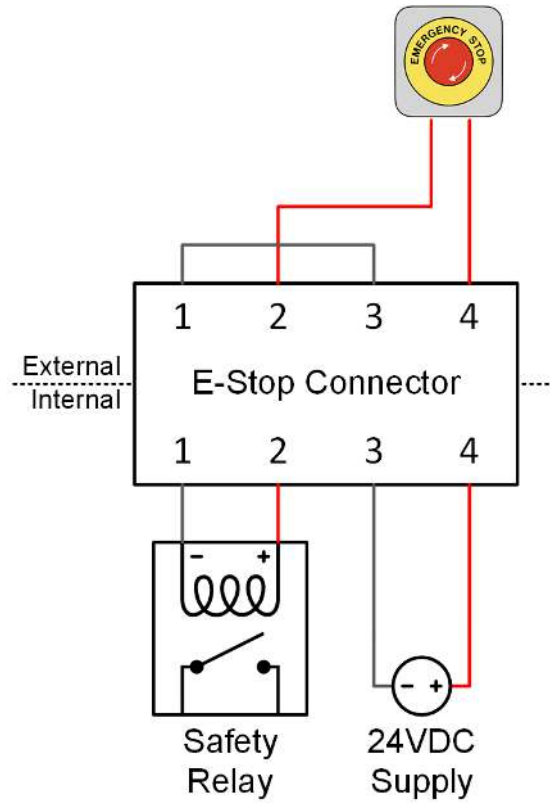


Figure 17. E-Stop circuit (internal supply)

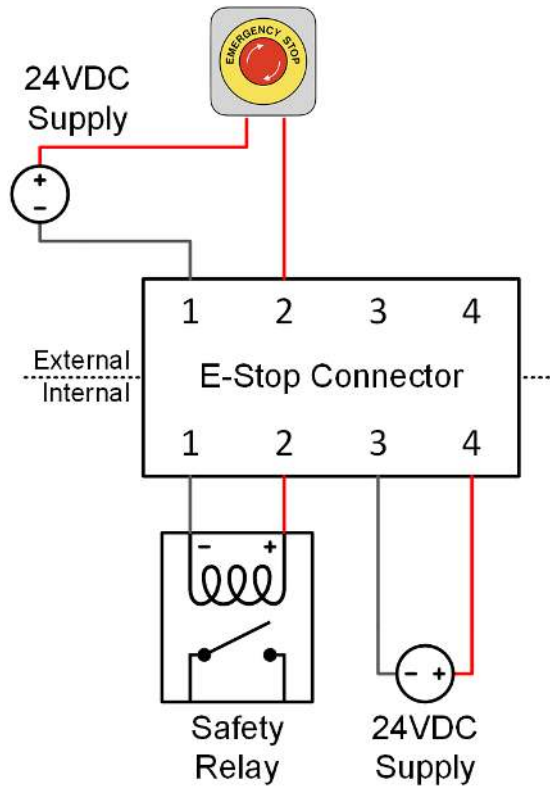


Figure 18. E-Stop circuit (external supply)

The signals are connected via feed-through connectors on the front panel, as shown in [Table 7, “E-Stop Connector Pin Assignment”](#).

To install a conductor

Insert a tool (such as a small flat screwdriver) into the rectangular opening at the top of the connector. This allows the conductor to freely enter into the circular opening at the front of the connector. Remove the tool to secure the conductor in place. For stranded wires, the use of ferrules is recommended.

Table 7. E-Stop Connector Pin Assignment



Pin	Name	Description	Connected to Device
1	E-Stop In-	E-Stop Input (Return)	External E-Stop Circuitry
2	E-Stop In+	E-Stop Input (24 V DC)	External E-Stop Circuitry
3	E-Stop Out-	E-Stop Output (Return)	External E-Stop Circuitry
4	E-Stop Out+	E-Stop Output (24 V DC)	External E-Stop Circuitry

4.2.7. Connect Ethernet

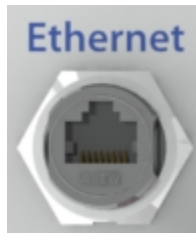


Figure 19. Ethernet Connector

The Ethernet connector is a standard RJ45 Ethernet jack. It may be used to connect the G4 Stack Switchgear to an external system, such as:

- A laptop, to configure operating parameters and observe status
- A local area network (LAN) connection, for wired internet access
- A Nuvation Energy Multi-Stack Controller
- Energy control systems, such as PCSs and energy controllers
- An Ethernet switch, to access any number of the above devices

Any Cat5e-rated or higher Ethernet cable of suitable length may be used to connect to this RJ45 jack.

4.2.8. Connect Link Bus

The Link Bus connector provides power and communication to the G4 Cell Interface modules. The amount of current supplied by this connector is the sum of current consumed by all G4 Cell Interface modules in the system.

Typically, the Link Bus is connected to the G4 Cell Interface module which measures the most negative cell, with each subsequent G4 Cell Interface module measuring increasingly positive cells. Although any order of the G4 Cell Interface modules in the Link Bus chain can be acceptable, the order of the cells in the software registers and the Operator Interface may not be as intuitive as the aforementioned order (i.e. order of increasing potential).

If the G4 Cell Interface modules are not already connected to the battery (e.g. battery cell connection, temperature sensors, and Link Bus cables between the G4 Cell Interface modules), this can be done now. For instructions on connecting the G4 Cell Interface modules to the battery, refer to [Section 4.4, "G4 Cell Interface Electrical Connections"](#).

Install the Link Bus cable between the G4 Stack Switchgear and the first G4 Cell Interface in the Link Bus chain.

4.2.9. Connect Battery Stack and DC Bus



Due to the nature of batteries, live voltages are always present; for this reason, these connections should be completed last. In order to reduce the risk of a short, only install one connection at a time.



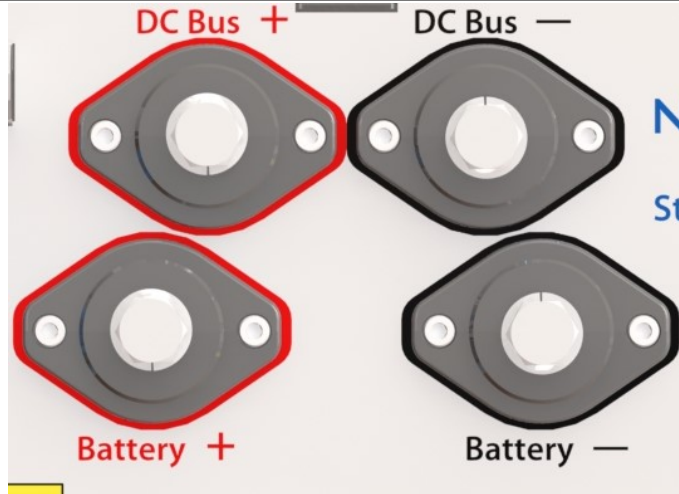
The G4 Stack Switchgear is configured for a specific battery topology based on the details provided to Nuvation Energy during order fulfillment. Failure to use the same number of G4 Cell Interface modules and/or using a different battery topology will result in undesirable G4 Stack Switchgear behavior. Please contact support@nuvationenergy.com if there is a change in the system design that would require a G4 Stack Switchgear configuration update.

The front panel of the G4 Stack Switchgear has four high-power connectors, as illustrated below. Two of these are for the positive and negative terminals of the battery stack; the other two are for the connection to the DC bus (or a PCS in a single stack system). The colors are coordinated such that red is for the positive connections and black is for the negative connections.

The connectors use M10 bolts (included) and are intended for M10 lugs (not included, e.g. Panduit Corp LCMA50-10-L).

Flexible snap-on terminal covers are included. The maximum acceptable terminal lug tongue width is 1.1 inches and the maximum wire size is 4/0. The recommended tightening torque is 6.8 N-m to 9.0 N-m [60 to 80 in-lbs].

Table 8. Battery Stack and DC Bus Connector Assignment



Name	Description	Connected to Device
Battery (-)	Negative terminal of battery stack	Battery stack
Battery (+)	Positive terminal of battery stack	Battery stack
DC Bus (-)	Negative terminal of DC bus	External equipment
DC Bus (+)	Positive terminal of DC bus	External equipment

A typical NUVSSG-1250-350 installation capable of up to 400 A should use 4/0 AWG 90°C copper cable rated 1500 V DC or higher, based on Table 310.15(B)(17) of the NEC (Allowable Ampacities of Single-Insulated Conductors Rated Up to and Including 2000 Volts in Free Air). This should be evaluated on a per-project basis in accordance with site-specific conditions and local codes. The installer shall be responsible for installing cables in accordance with all applicable electrical codes.

In order to make the connection:

1. Feed the wire through the terminal cover
2. Strip the insulation
3. Crimp the lug
4. Screw the lug onto the terminal
5. Torque to the recommended specifications above
6. Slide the terminal cover onto the terminal



The battery stack terminals are always energized and should be handled as such.

Although the DC bus terminals are disconnected from the battery by the G4 Stack Switchgear unit’s contactors, the DC bus can still be energized by other components on the DC bus (e.g. PCS or other stacks). The DC bus terminals should always be treated as though they are energized.

A simple voltage check (i.e. across the positive and negative terminals) is not always sufficient, *especially* with grounded battery stacks. It is recommended to also check for voltage between each conductor and ground.

4.3. G4 Cell Interface Mechanical Installation

4.3.1. Dimensions and Weight

The overall dimensions of the G4 Cell Interface are 104.4 mm × 121.58 mm × 40.6 mm.

The standard G4 Cell Interface (i.e. with bulkhead) weighs approximately 450 g.

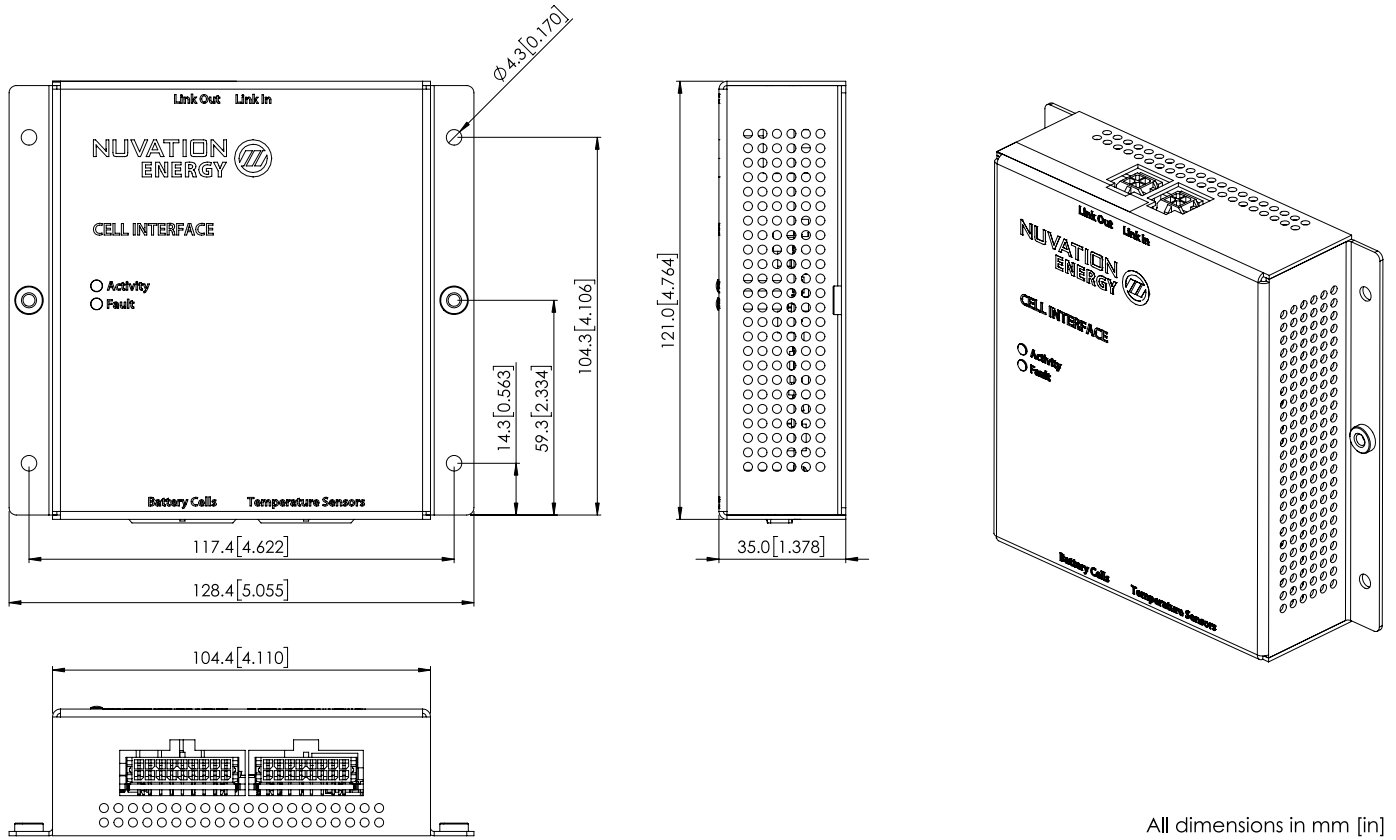


Figure 20. Mechanical Drawing of G4 Cell Interface with Bulkhead Enclosure

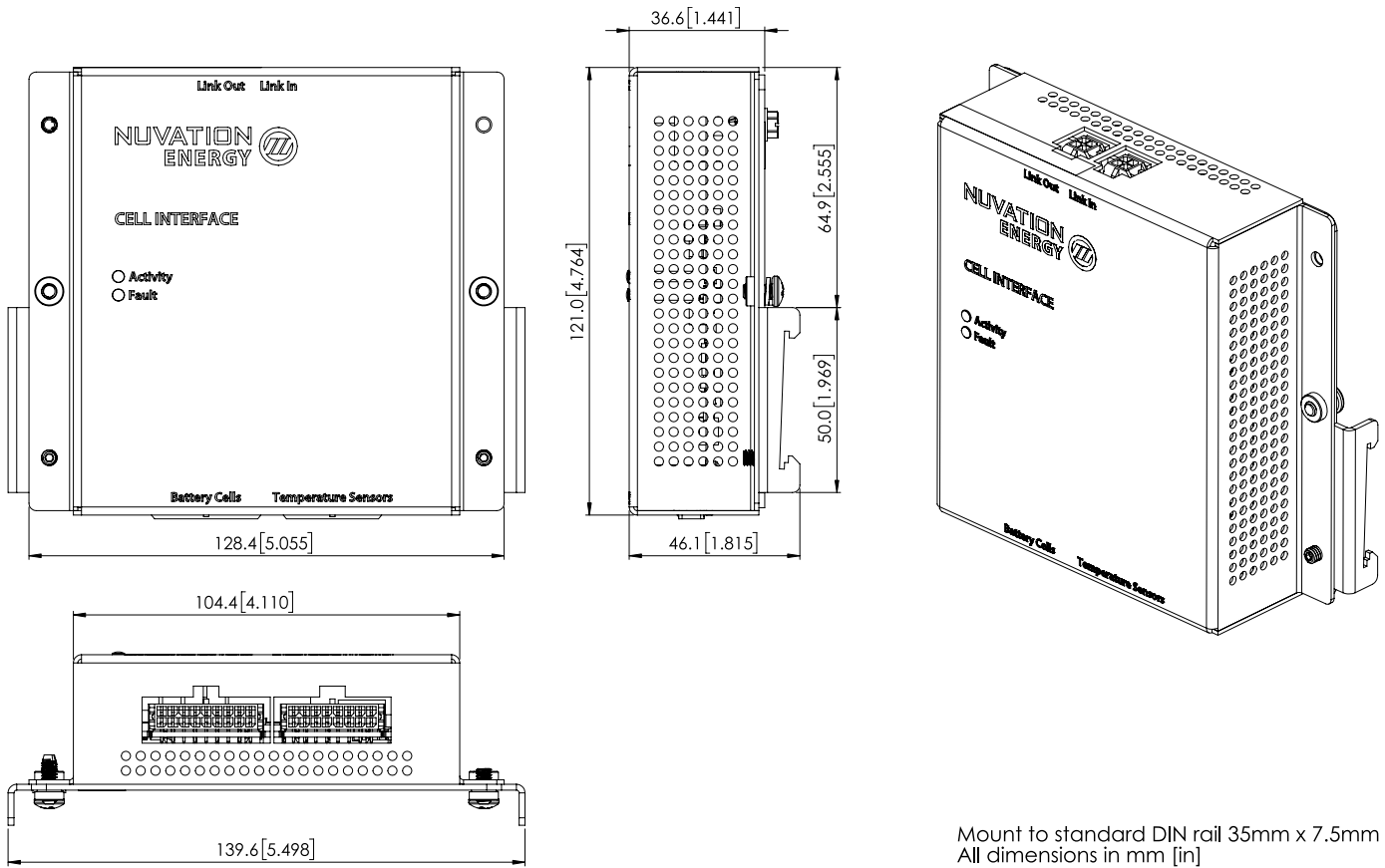
4.3.1.1. DIN rail mounting Kit

For applications requiring DIN rail mounting, the G4 Cell Interface Mounting Bracket (Bulkhead-to-DIN) (sold separately) may be used. This kit includes a metal plate and the necessary hardware to securely mount the bulkhead enclosure of the G4 Cell Interface to EN50022-compliant DIN rails.

The Mounting Bracket kit assembly adds an extra 14.2 mm to the overall width of the G4 Cell Interface module, bringing it from 104.4 mm to 118.6 mm. The kit assembly holds the module approximately 7 mm away from the inside lip of the DIN rail.

The Mounting Bracket offsets the G4 Cell Interface module from the center of the DIN rail approximately 30 mm upwards as shown in [Figure 21, "Mechanical Drawing of G4 Cell Interface with G4 Cell Interface Mounting Bracket \(Bulkhead-to-DIN\)"](#).

A G4 Cell Interface with the Mounting Bracket weighs approximately 540 g.



Mount to standard DIN rail 35mm x 7.5mm
All dimensions in mm [in]

Figure 21. Mechanical Drawing of G4 Cell Interface with G4 Cell Interface Mounting Bracket (Bulkhead-to-DIN)

4.3.2. Installation Location and Position



Figure 22. Nuvation Energy G4 Cell Interface Module

The G4 Cell Interface is available in a bulkhead-mountable enclosure which has five metal walls,

leaving the back of the unit fully exposed. It is designed to mount to a metal bulkhead panel such that the panel covers the exposed back.

The G4 Cell Interface is rated to operate in the temperature range of -10 °C to 60 °C. It is designed for indoor use.

The G4 Cell Interface should be mounted against a flat surface with the 'Link In' and 'Link Out' ports pointing up to the sky.



Ensure the enclosure is connected securely to Earth, either by grounding the mounting surface or by using a dedicated Earth Bonding Conductor.

4.3.2.1. Mounting Clearances

The NUV100-CI-12-1 and NUV100-CI-16-1 variants produce up to 24 W and 32 W, respectively, during cell balancing. A portion of this heat is transferred to the bulkhead.

Extra space should be provided around the module to allow for sufficient heat dissipation, and cable installation.

If mounting a G4 Cell Interface, PCB assembly only (no enclosure), note that the G4 Cell Interface contains high-voltage signals reaching as high as 1250 V DC. Care must be taken when mounting the PCB into a metal enclosure to ensure that the metal walls remain a safe distance from the exposed conductor on the PCB. Using 1250 V DC as an example, the metal walls of the enclosure must be at least 4.2 mm from the nearest exposed conductor and must not touch the PCB or any component on the PCB, including the connector housings.

4.3.3. Mounting Instructions

Ensure appropriate fasteners (not included) are used to mount the G4 Cell Interface. These fasteners will vary depending on the material and construction of the mounting surface.

It is suggested to use #8-32 screws with a split lock washer for the mounting holes provided on each side flange of the G4 Cell Interface.

4.4. G4 Cell Interface Electrical Connections



The G4 Cell Interface connects to the battery stack-referenced signals through high-voltage rated connectors. Safety precautions are required to handle and connect cables into this module.

4.4.1. Getting Started

To complete the installation of the G4 Cell Interface, the following is required per G4 Cell Interface module:

1. 1x Battery Cells cable
2. 1x Thermistor cable
3. 1x Link Bus cable

These cables are available for purchase as a kit.



Figure 23. Example G4 Cell Interface kit (NUV100-CI-16-KIT-2)

The instructions below are for applications using cable harnesses purchased from Nuvation Energy. To build custom cables, refer to [Section 9.2, "G4 Cell Interface"](#) for connector pin-out and specifications.

Connection sequence

- Step 1: [Connect Temperature cable](#) for temperature measurement of the cells
- Step 2: [Connect Battery Cells cable](#) to battery voltage sense leads
- Step 3: [Connect Link Bus cable](#) to BMS module(s)



The wiring of the battery cell voltage and temperature sensing should be verified **before** connecting to the G4 Cell Interface modules. The temperature sensing must be isolated from the cell voltage sensing and Earth. Although the G4 Cell Interface includes protective circuitry to make it more resilient to brief wiring errors, the same circuitry can result in the battery cells being slowly discharged. Over time, these wiring errors can cause damage to the G4 Cell Interface and/or the cells.

4.4.2. Connect Temperature Cable



The G4 Stack Switchgear is pre-configured to expect a defined number of thermistors based on the information provided to Nuvation Energy during order fulfillment. Failure to use the same number of thermistors will result in undesirable G4 Stack Switchgear behavior. Please contact support@nuvationenergy.com if there is a change requiring a G4 Stack Switchgear configuration update.

The Temperature cable provides 10 kΩ NTC thermistors for temperature measurement of the cells and/or surrounding area. These sensors are used by Nuvation Energy BMS to detect over and under temperature conditions and adjust battery current limits to compensate for cell temperature.



Figure 24. 2 Thermistor cable (NUVW-A18A12-020)



Figure 25. 7 Thermistor cable (NUVW-A19A12-020)



2 to 7 thermistors are supported to accommodate systems requiring Nuvation Energy BMS to meet functional safety requirements.

Cable Isolation

Because the sensors are referenced to the CELL0 or BLOCK0 input on the G4 Cell Interface, care must be taken to ensure that they are electrically isolated from any common or ground potential, and from all other cell voltage terminals of all G4 Cell Interface modules in the system

The thermistors must be isolated from the cell voltage terminals, as well as any metal work or other exposed conductors, in such a way that they will not make an electrical connection to a cell terminal in the event of vibration/failures.

Thermal Consistency

For safety certified systems, there is an additional constraint on thermal consistency for all temperature measurements for each G4 Cell Interface. The constraint is described in detail in the Sensor Fault Detection section within the Nuvation Energy G4 BMS: Safety Manual (available on request).

4.4.2.1. Connection Procedure

Connect to Surface

It is recommended to use thermally conductive/electrically non-conductive epoxy to adhere the thermistors to the cells.

Connect to G4 Cell Interface

'Temperature' cable connects to the 'Temperature Sensors' port at the bottom of the G4 Cell Interface.

4.4.3. Connect Battery Cells Cable

The Battery Cells cable provides cell voltage input and a means for balancing the cells.

Power Requirements

There is no minimum cell voltage requirement when powering the G4 Cell Interface module from the Link Bus.

However, if powering the G4 Cell Interface - 12 channel module from the cells (i.e. not powering from the Link Bus), a minimum of 11V must be present between the most negative and most positive cells.

Similarly, if powering the G4 Cell Interface - 16 channel module or the G4 Cell Interface - 12V 4 channel module from the cells (i.e. not powering from the Link Bus), the cells are connected as two groups and a minimum of 11 V must be present between the most negative and most positive cells of each group.

4.4.3.1. Connection Procedure



The G4 Stack Switchgear is pre-configured to expect a defined battery topology, based on the information provided to Nuvation Energy during order fulfillment. Connecting a differing battery topology will result in undesirable G4 Stack Switchgear behavior. Please contact support@nuvationenergy.com if there is a change in battery topology requiring a G4 Stack Switchgear configuration update.

Connect to Cells

Connect the cables wires to the battery voltage sense leads. The individual wires are labelled to help with identifying the connections. Verify the cell voltages present on the connector are correct. While the G4 Cell Interface module is tolerant of most wiring errors, incorrect connections may cause the cells to discharge.

Refer to the wiring examples below for the specific G4 Cell Interface module used.

Connect to G4 Cell Interface

'Battery Cells' cable connects to the 'Battery Cells' port at the bottom of the G4 Cell Interface.

4.4.3.1.1. Battery Cell Connector for G4 Cell Interface - 12 channel



Figure 26. Battery Cells cable (NUVW-A08Z12-020) for G4 Cell Interface - 12 channel

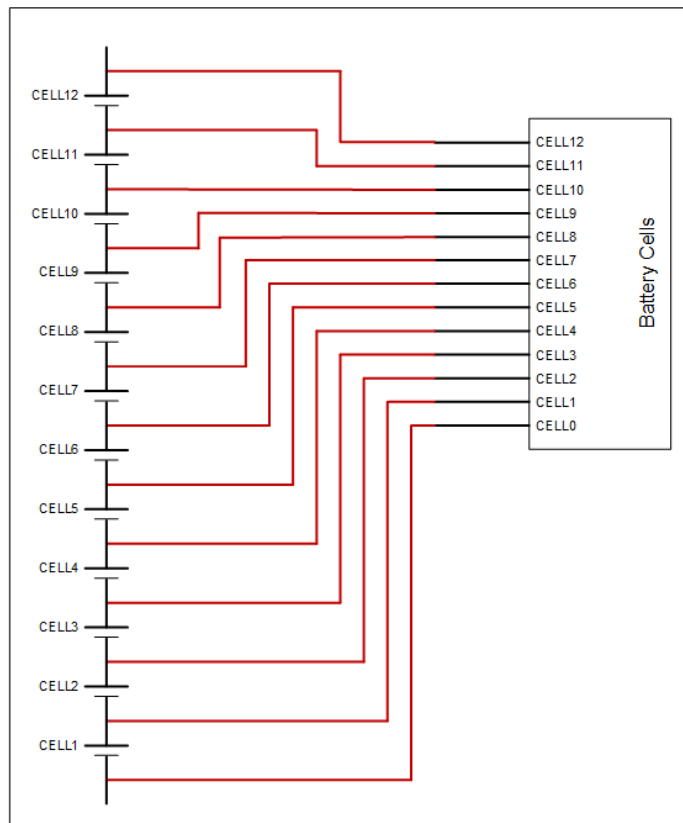


Figure 27. Example wiring 12 cells in a G4 Cell Interface - 12 channel

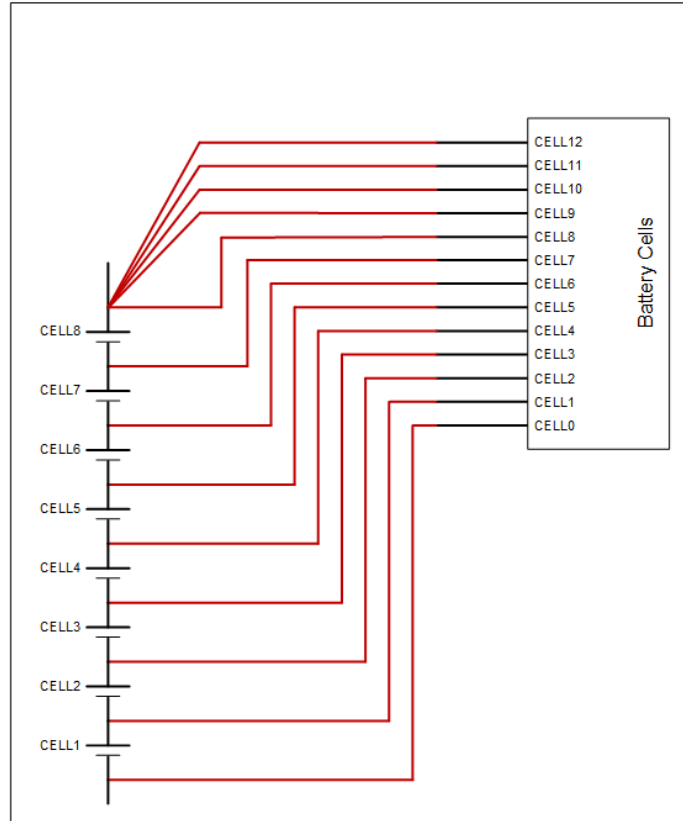


Figure 28. Example wiring 8 cells in a G4 Cell Interface - 12 channel

4.4.3.1.2. Battery Cell Connector for G4 Cell Interface - 16 channel



Figure 29. Battery Cells cable (NUVW-A09Z12-020) for G4 Cell Interface - 16 channel

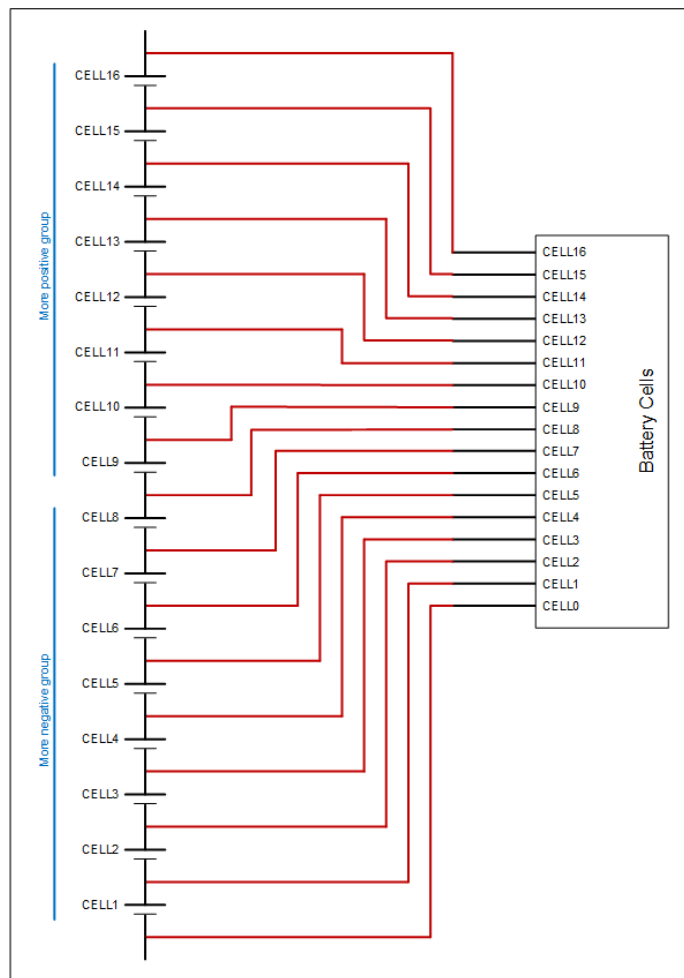


Figure 30. Example wiring 16 cells in a G4 Cell Interface - 16 channel

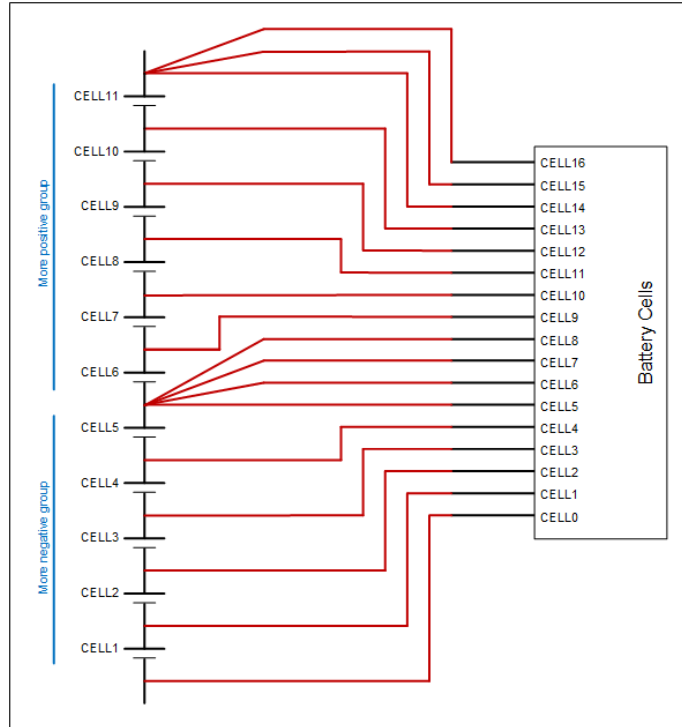


Figure 31. Example wiring 11 cells in a G4 Cell Interface - 16 channel

4.4.3.1.3. Battery Cell Connector for G4 Cell Interface - 12V 4 channel



Balancing is not supported by the G4 Cell Interface - 12V 4 channel variant.



Figure 32. Battery Cells cable (NUVW-A10Z12-020) for G4 Cell Interface - 12V 4 channel

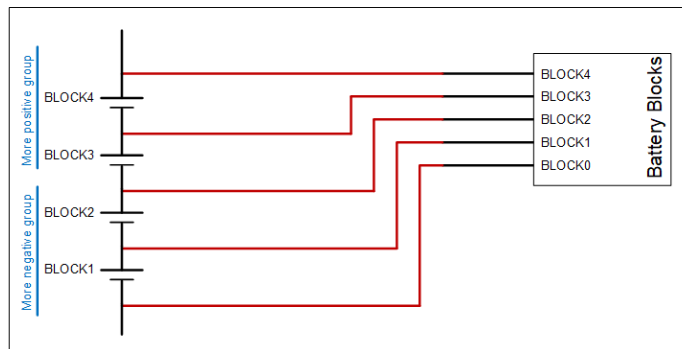


Figure 33. Example wiring 4 blocks in a G4 Cell Interface - 12V 4 channel

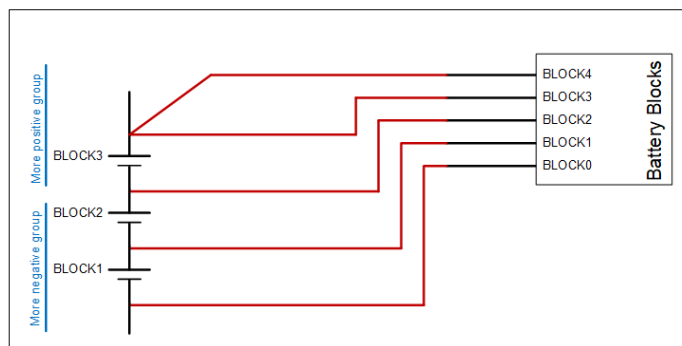


Figure 34. Example wiring 3 blocks in a G4 Cell Interface - 12V 4 channel

4.4.4. Connect the Link Bus Cable



Figure 35. Link Bus cable (NUVW-A01X03-010)

The Link Bus cable is used to connect G4 Cell Interface modules in a daisy chain (called the Link Bus chain) by connecting the 'Link In' of one G4 Cell Interface to the 'Link Out' of the next G4 Cell Interface. In this series-connected chain of modules, each connection is made from the Link In connector of the module with higher potential to the Link Out connector of the module with lower potential.

The Link Bus provides a data channel and a power source to subsequent G4 Cell Interface modules in the Link Bus chain. The amount of current supplied by this connector is the sum of current consumed by all subsequent G4 Cell Interface modules in the Link Bus chain.

Connection Procedure

1. Connect one end of the cable to the 'Link Out' connector on the G4 Stack Switchgear.
2. Connect the other end of the Link Bus cable to the 'Link In' connector on the G4 Cell Interface.
3. For multiple G4 Cell Interface modules, use additional Link Bus cables to connect the 'Link Out' on the current G4 Cell Interface to the 'Link In' of the next G4 Cell Interface in the chain.
4. The 'Link Out' of the last G4 Cell Interface module in the Link Bus chain is to be left unconnected.

4.5. First Power-up

Once the G4 Stack Switchgear is connected to the battery (including the G4 Cell Interface modules chain), it can be powered (internal power and fan power). The two breakers can be put in the closed (non-tripped) position. The power LED (green) should turn ON.

On initial power-up, it is common to see that the fault LED (red) is also ON. This indicates that a fault has been detected; the next step will be to clear this fault.

The service disconnect switch can be put in the **ON** position.

Faults are *latching*, i.e. will remain in faulted state until cleared even if fault condition is removed. Begin by clearing all faults. If any faults remain, investigate the cause of each fault and resolve the issue. The faults are described in the [Section 11.1, "Faults and Self Check Failures"](#). Once all faults are cleared, the G4 Stack Switchgear is able to connect the battery to the DC bus.

4.5.1. Status LEDs

When the G4 Stack Switchgear is powered up, the status LEDs provide an indication of the functional status. A more detailed status may be accessible via the Operator Interface.

4.5.1.1. G4 Stack Switchgear

The three LEDs on the front panel of the G4 Stack Switchgear indicate health and functional status to the user.

Power LED

The **POWER** LED (green) indicates that the system is powered on (AC power is provided and the AC power input breaker is closed).



Figure 36. Power LED

Activity LED

The **ACTIVITY** LED (blue) indicates that the G4 Stack Switchgear is communicating with the Multi-Stack Controller or an external controller and is receiving a heartbeat signal.

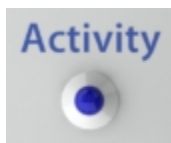


Figure 37. Activity LED

Fault LED

The **FAULT** LED (red) indicates that the system is in a fault state and requires attention to become operational. The Operator Interface's fault page can be used to find the nature of the fault.

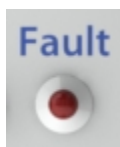


Figure 38. Fault LED

4.5.1.2. G4 Cell Interface

The 2 status LEDs on the face of the G4 Cell Interface indicate the functional status of the module.

Activity

This LED indicates that the G4 Cell Interface module has received a communication packet over the Link Bus.

Fault

This LED is not used in normal operations. It is available to support on-site troubleshooting.

5. Setting up the Operator Interface

5.1. Download and Install the Operator Interface

The Operator Interface is used to access the G4 Stack Switchgear.

The latest Operator Interface release is available online at: <https://ncloud.nuvationenergy.com>. You may create an account to download the software package.

1. Download the High-Voltage BMS package
2. Extract the contents of the package to a suitable location on your computer.
3. Releases follow a naming convention similar to `nuvation-bms-0I-descartes.zip`. The package should be extracted to a folder with the same name to avoid overwriting other releases or files present in the same directory.



Browser Compatibility

The Operator Interface currently supports the most recent versions of Mozilla Firefox and Google Chrome. Other browsers such as Internet Explorer are not supported. Please install a supported browser before attempting to access the Operator Interface.

5.2. Connect to the Operator Interface

Ensure your computer is connected directly to the G4 Stack Switchgear via an Ethernet cable. You will need to configure the network adapter on your computer to match the settings on your G4 Stack Switchgear.

Identify the Battery Management System IP

By default, G4 Stack Switchgear is configured with a static IP address of 192.168.1.21, unless noted otherwise on a label on the G4 Stack Switchgear.

Identify the parts of the Battery Management System's IP Address

The IP address has two parts - the network ID and the host ID.



Figure 39. Parts of an IP address

Write down the network ID and host ID parts of the G4 Stack Switchgear's IP address.

Determine a valid IP address to assign to the PC

The Network ID for the PC IP address must be the same as the G4 Stack Switchgear. The Host ID number can be any number from 2 to 255 as long as it is not the same as the Host ID of the G4 Stack Switchgear. For example if the G4 Stack Switchgear IP address is 192.168.1.21, the IP address of the PC could be 192.168.1.12 or 192.168.1.49 or any 192.168.1.x where x is not 21.



If you have multiple stacks, note down the Host ID from the IP address of each stack's G4 Stack Switchgear. The Host ID number assigned to the PC must be different from this list.

Setup the Static IP address on the PC

Instructions below are for a PC running Windows OS:

1. Go to Control Panel > Network and Sharing Center
2. Right-click your network adapter that connects to your G4 Stack Switchgear and select Properties
3. Click Internet Protocol Version 4 (TCP/IPv4) and click Properties

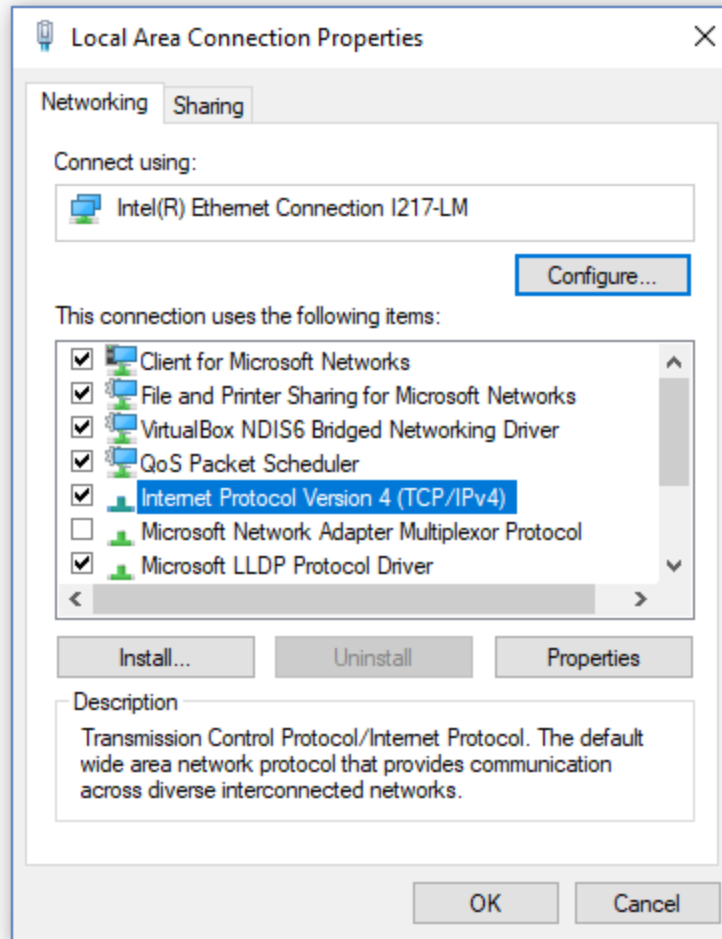


Figure 40. Network Adapter Properties on Windows.

4. Update your network adapter TCP/IPv4 settings to the following:
 - Static IP Address: The IP address must have the same Network ID as the G4 Stack Switchgear and a Host ID that isn't already in use.
 - Refer to the instruction above to determine a valid IP address for the PC.
 - Subnet Mask: 255.255.255.0
 - Default gateway: The Network ID must be the same as the G4 Stack Switchgear and the Host ID should be 1.
 - For example, if the G4 Stack Switchgear IP address is 192.168.1.21, the gateway address would be 192.168.1.1

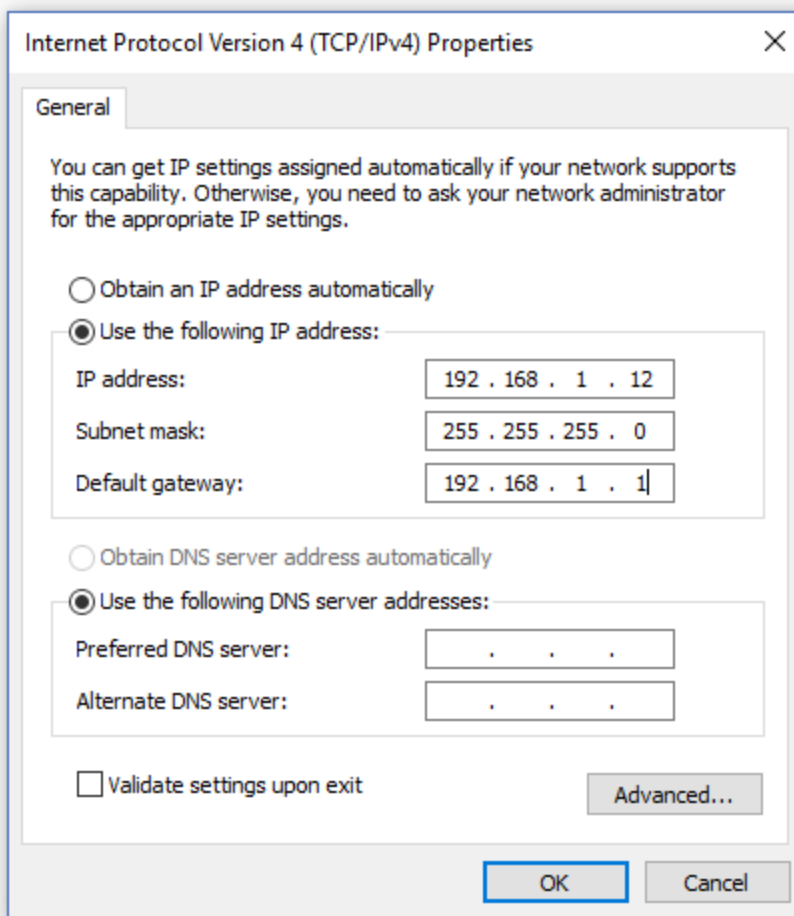


Figure 41. Network Adapter Settings on Windows

5. Ensure your computer is on the same network as your G4 Stack Switchgear.
 - You can connect an Ethernet cable directly between it and the network adapter of your PC.

1. Open the Nuvation-Energy-Operator-Interface.html file in your web browser.
 - This is usually done by double-clicking on the file. If your default browser is not a supported browser, you may need to specify the browser to use.
 - For example, on Windows you may need to right click on the file, select Open with, and then choose Chrome or Firefox from the list.

6. Using the Operator Interface

6.1. The Dashboard Tab

The default tab of the Operator Interface is the Dashboard. The Dashboard contains a high-level overview on the state of the battery stack. This is the only page required for daily monitoring of the battery stack.

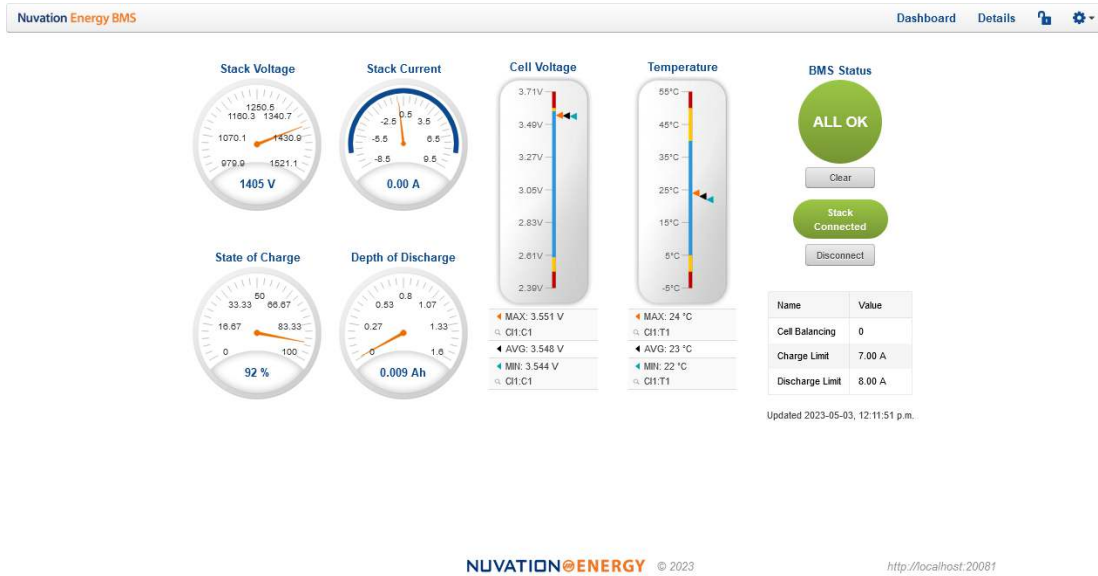


Figure 42. Nuvation Energy BMS Operator Interface Dashboard screenshot

6.1.1. Warnings and Faults

Before going into the details of the gauges and information presented in the dashboard, it is important to understand what a fault and a warning Nuvation Energy BMS status means.



An ALL OK indicates that there are no faults or warning. This is the normal state for Nuvation Energy BMS.



A Warning indicates the state of the battery system has been detected outside of its normal operational range. The cause of the warning should be identified and a corrective action should be performed. For instance, if the warning is a thermistor temperature measurement has become too hot, the battery system should be cooled to bring the measurement back into the normal operational range.

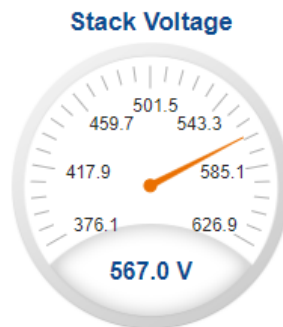


A Fault indicates the state of the battery system has been detected outside of its safe operational range. The cause of the fault must be identified and a corrective action must be performed. For instance, if the fault is a cell voltage measurement has become too low, the cell maintenance manual must be reviewed to identify what remedial actions are required.

A Fault is more severe than a Warning and the source of the fault must be discovered and resolved before attempting to clear and continue operating the battery system.

6.1.2. Stack Voltage

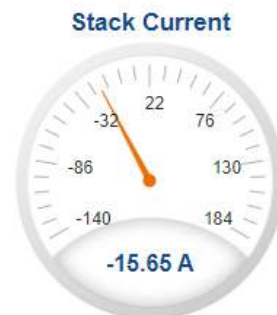
The stack voltage radial meter shows the total battery stack voltage.



6.1.3. Stack Current

The stack current radial gauge shows the battery stack current as well as the maximum charge current limit and the maximum discharge current limit. The acceptable current range is visualized on the gauge by the blue arc. An absence of the blue arc indicates the battery stack cannot be charged or discharged in its present condition.

A negative current value indicates the battery stack is charging. A positive current value indicates the battery stack is discharging.



6.1.4. State-of-Charge

The State-of-Charge radial gauge shows the battery stack's State-of-Charge. The battery stack is empty when the State-of-Charge value is 0% and full when the State-of-Charge value is 100%.

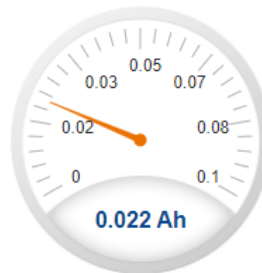
State of Charge



6.1.5. Depth-of-Discharge

The Depth-of-Discharge radial gauge shows how much energy has been taken out of the battery stack. In an ideal Energy Storage System, defined as a system with no power losses, the amount of energy shown in this gauge needs to be added back into the battery stack to fill it back up to 100% State-of-Charge.

Depth of Discharge



6.1.6. Cell Voltage

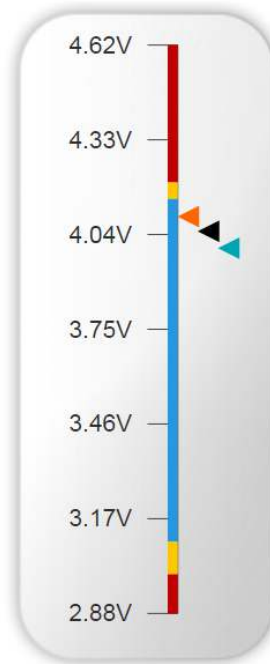
The cell voltage bar gauge shows the maximum, minimum, and average cell voltage measurements within the stack.

The high cell voltage and low cell voltage warning and fault threshold is visualized on the gauge with yellow and red segments. The blue segment depicts the acceptable cell voltage range.

If a triangle enters the yellow segment, a warning has occurred. If a triangle enters the red segment, a fault has occurred.

The maximum and minimum cell location in the stack and their voltage values are shown below the gauge, along with the average cell voltage value.

Cell Voltage



◀	MAX: 4.095 V
🔍	CI1:C3
◀	AVG: 4.05 V
◀	MIN: 3.998 V
🔍	CI1:C1

6.1.7. Temperature

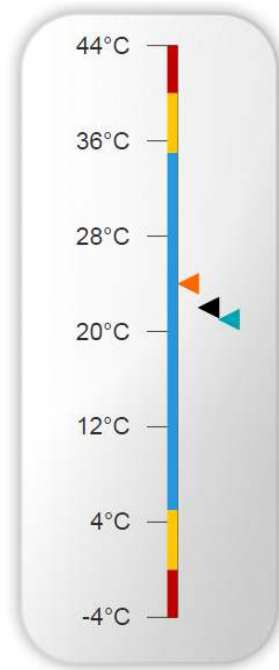
The temperature bar gauge shows the maximum, minimum, and average cell temperature measurements within the stack.

The high cell temperature and low cell temperature warning and fault threshold is visualized on the gauge with yellow and red segments. The blue segment depicts the acceptable cell temperature range.

If a triangle enters the yellow segment, a warning has occurred. If a triangle enters the red segment, a fault has occurred.

The maximum and minimum cell location in the stack and their temperature values are shown below the gauge, along with the average cell temperature value.

Temperature



◀ MAX: 24 °C

🔍 [CI7:T3](#)

◀ AVG: 22 °C

◀ MIN: 21 °C

🔍 [CI10:T4](#)

6.1.8. Nuvation Energy BMS Status

Nuvation Energy BMS status information contains information on the overall safety status of the battery stacks, the battery stack connection state, number of cells balancing, maximum charge current limit, maximum discharge current, and the time and date of the last update of the Dashboard.

6.1.8.1. Operation Status

Nuvation Energy BMS operation state is shown in the big status circular indicator.



Figure 43. Three possible Nuvation Energy BMS operation states

The normal state is All OK and the color of the indicator will be green. The warning state is Warning and the color of the indicator will be orange. The fault state is Fault and the color of the indicator will be red.

Clicking on the indicator will jump to a comprehensive status list of warnings and faults active in the battery stack.

Clicking on the Clear button below the state will cancel any warnings and faults that are not self-clearing.

6.1.8.2. Connection State

The battery stack connection state is shown in the oval indicator.



Figure 44. Three possible connection states

Stack Disconnected in a red oval indicates the SSG contactors are open, and the battery stack is unavailable to be charged or discharged.

Stack Pre-charging in an orange oval indicates the battery stack has connected its pre-charge circuit and is attempting to equalize the battery stack voltage to the system DC bus voltage.

Stack Connected in a green oval indicates the battery stack is available to be charged or discharged.

Clicking the Connect button initiates the stack connection sequence of events. Nuvation Energy BMS must be in the All OK state for the Connect button to be available.

Clicking the Disconnect button will disconnect the battery stack from the system DC bus.

6.1.8.3. Information Table

The information table shows the number of cells that are having excess energy bled off to maintain a balanced battery stack.

Name	Value
Cell Balancing	0
Charge Limit	7 A
Discharge Limit	8 A

The Charge Limit shows the maximum charge current limit value. The Discharge Limit shows the maximum discharge current limit value.

The Charge Limit and Discharge Limit values are visualized on the Stack Current radial gauge as the limits of the blue arc.

6.1.8.4. Last Update

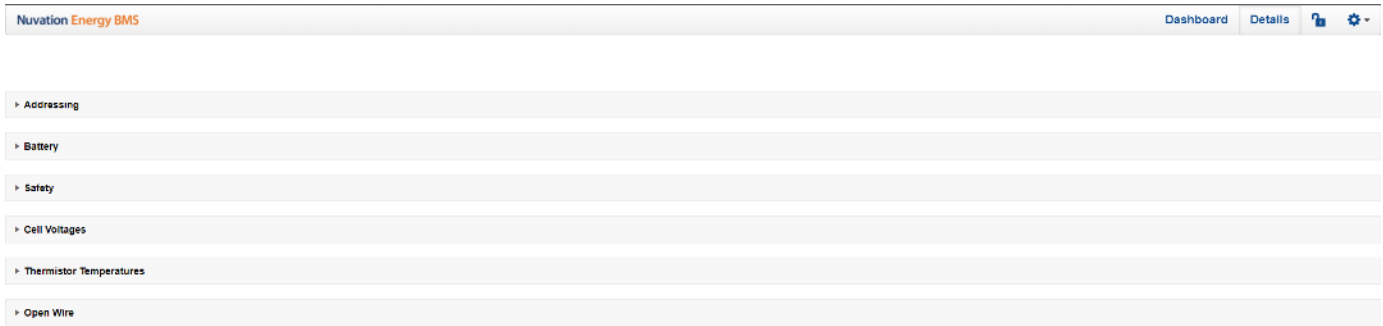
The Updated time and date shows the last time the Operator Interface had successfully communicated with Nuvation Energy BMS and updated all items in the Dashboard with values from Nuvation Energy BMS. The time and date is based on the local computer/tablet; it does not come from Nuvation Energy BMS.

If the communication with a Nuvation Energy BMS is lost, a notification banner appears at the top of the display screen. The information shown on the Dashboard represents the last data received and is no longer recent.

6.2. The Details Tab

The Details tab contains a much more detailed view into the status of Nuvation Energy BMS. The data values shown in this tab can be easily copied into a spreadsheet as a means of capturing the current state of Nuvation Energy BMS for manual data recording purposes.

The Details tab has multiple sub-sections called *accordions* that can be expanded to reveal more information. You can have multiple accordions expanded at the same time.



Faraday Preview 2 NUVATION ENERGY © 2022

http://localhost:20080

Figure 45. Nuvation Energy BMS Operator Interface Details tab screenshot

6.2.1. Addressing

The Addressing accordion presents the addressing information for your Nuvation Energy BMS.

▼ Addressing		Last update: Fri Nov 29 2019 12:42:32 GMT-0500 (Eastern Standard Time)
Network	Address	
IP	192.168.1.21	
Modbus RTU	1	
CAN	10	

Figure 46. Addressing accordion in Details Tab

6.2.2. Battery

The Battery accordion contains values on the overall battery stack and the maximum charge current limit, the maximum discharge current limit, and the number of cells balancing in the battery stack. This information is identical to the values shown in the radial gauges, the bar gauges and the Information Table on the Dashboard.

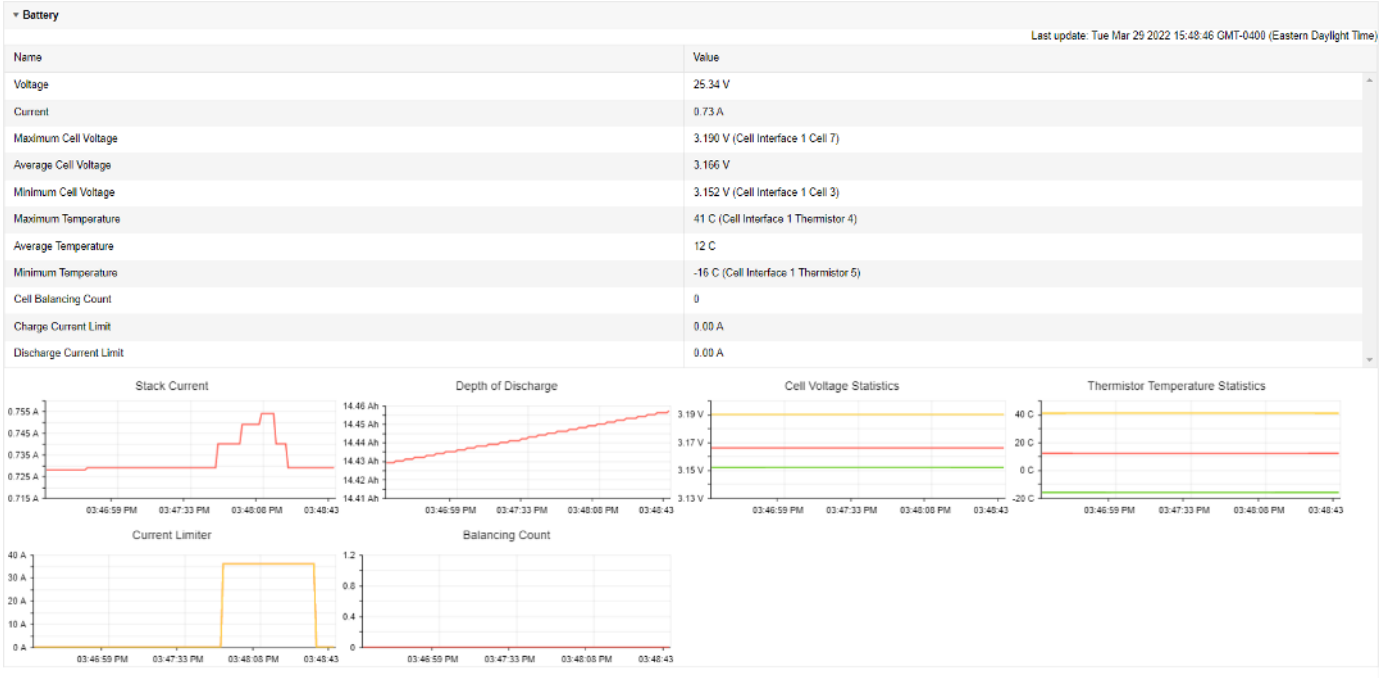


Figure 47. Battery accordion in Details Tab

6.2.3. Safety

The Safety accordion contains a comprehensive list of all possible Nuvation Energy BMS faults, warnings and user triggers as well as the overall status of the battery stack. An active fault is shown as Tripped. An active warning or user trigger is shown as Triggered. A fault, warning or user trigger that has not completed its Self Check is shown as Checking. In normal operation, all user triggers, warnings and faults should be Clear.

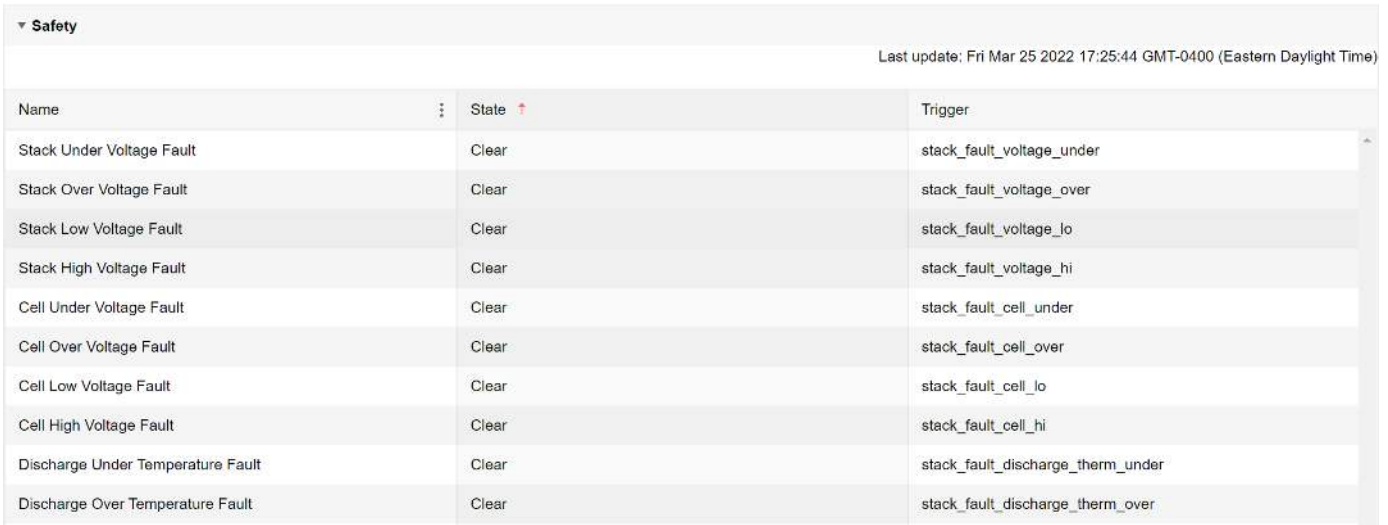


Figure 48. Safety accordion in Details Tab

Clicking on the Clear Faults and Warnings button at the bottom of this accordion will clear any faults and warnings that are not self-clearing. The Clear button on the Dashboard can also be used.

Stack Error / Voltage Lockout	Clear	stack_uvlo_stack_voltage
Cell Under Voltage Lockout	Clear	stack_uvlo_cell_voltage
Discharge High Current User	Clear	stack_trig_discharge_current_hi
Charge High Current User	Clear	stack_trig_charge_current_hi
Discharge Low Temperature User	Clear	stack_trig_discharge_therm_lo
Discharge High Temperature User	Clear	stack_trig_discharge_therm_hi
Charge Low Temperature User	Clear	stack_trig_charge_therm_lo
Charge High Temperature User	Clear	stack_trig_charge_therm_hi
Stack Low Voltage User	Clear	stack_trig_voltage_lo
Stack High Voltage User	Clear	stack_trig_voltage_hi
Cell Low Voltage User	Clear	stack_trig_cell_lo
Cell High Voltage User	Clear	stack_trig_cell_hi
Stack Controller Configuration Consistency Check Fault	Clear	sc_fault_config

Clear Faults and Warnings Generate Report

Figure 49. Bottom of Safety accordion in Details Tab

Clicking on the Generate Report button at the bottom of this accordion will generate a safety report JSON file with a list of the Nuvation Energy BMS faults and warnings and their current state as well as the current firmware versions.

6.2.4. Cell Voltages

The Cell Voltages accordion lists voltage measurements for all Cells configured in the Configuration file. Cells that are not configured are displayed as a - (hyphen). Voltages in red indicate measurements which have triggered a Nuvation Energy BMS fault. Voltages that are highlighted in yellow are open wires. There is no differentiation between cells that are in the normal operating voltage range and cells that have triggered a Nuvation Energy BMS warning. There is also no indication of which particular cells are currently being balanced by the BMS.

Cell Voltages																
	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10	Cell 11	Cell 12	Cell 13	Cell 14	Cell 15	Cell 16
Cl 1	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	-	-	-	-
Cl 2	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	-	-	-	-
Cl 3	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	-	-	-	-
Cl 4	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	-	-	-	-
Cl 5	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	-	-	-	-
Cl 6	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	-	-	-	-
Cl 7	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	-	-	-	-
Cl 8	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	-	-	-	-

Filter: Off Above Below Last update: Fri Mar 25 2022 16:21:03 GMT-0400 (Eastern Daylight Time)

Figure 50. Cell Voltages accordion in Details Tab

Cell Voltages

Filter: Off Above Below

Legend: **Open Wire**

Last update: Wed Nov 20 2019 14:50:16 GMT-0500 (Eastern Standard Time)

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10	Cell 11	Cell 12	Cell 13	Cell 14	Cell 15	Cell 16
CI 1	3.333 V	3.333 V	3.332 V	3.333 V	3.332 V	3.332 V	3.333 V	3.333 V	3.334 V	3.331 V	3.331 V	3.332 V	-	-	-	-
CI 2	3.334 V	3.333 V	3.333 V	3.334 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.334 V	3.334 V	3.334 V	3.334 V	3.334 V	3.334 V	3.334 V
CI 3	3.331 V	3.333 V	3.334 V	3.333 V	3.334 V	3.333 V	3.333 V	3.333 V	3.334 V	3.334 V	3.334 V	3.334 V	3.334 V	3.334 V	3.334 V	3.334 V
CI 4	3.333 V	3.332 V	3.334 V	3.333 V	3.333 V	3.332 V	3.332 V	3.333 V	3.333 V	3.333 V	3.332 V	3.332 V	3.334 V	3.334 V	3.334 V	3.334 V
CI 5	3.334 V	3.333 V	3.334 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V
CI 6	3.333 V	3.333 V	3.332 V	3.333 V	3.333 V	3.332 V	3.333 V	3.333 V	3.334 V	3.333 V	3.333 V	3.333 V	3.332 V	3.332 V	3.332 V	3.332 V
CI 7	3.334 V	3.333 V	3.333 V	3.333 V	3.334 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V
CI 8	3.333 V	3.334 V	3.333 V	3.334 V	3.333 V	3.333 V	3.332 V	3.332 V	3.334 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V	3.333 V

Figure 51. Cell Voltages with open wires accordion in Details Tab

6.2.4.1. Filtering

You can filter the display to highlight cells with voltages above or below a value you specify. The values that match the criteria will be bolded and all other values will be faded.

Filter: Off Above Below

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
CI 1	3.333 V	3.333 V	3.332 V	3.333 V	3.332 V	3.332 V	3.333 V	3.333 V

6.2.5. Thermistor Temperatures

The Thermistor Temperatures accordion lists temperature measurements for all Thermistors configured in the Configuration file. Thermistors that are not configured are displayed as a dash. Temperatures in red indicate measurements which have triggered a Nuvation Energy BMS fault. There is no differentiation between thermistors that are in the normal operating temperature range and thermistors that have triggered a Nuvation Energy BMS warning.

Thermistor Temperatures

Filter: Off Above Below

Last update: Fri Nov 29 2019 12:50:06 GMT-0500 (Eastern Standard Time)

	Index 1	Index 2	Index 3	Index 4	Index 5	Index 6	Index 7	Index 8
CI 1	27 °C	27 °C	27 °C	26 °C	27 °C	27 °C	-	-
CI 2	27 °C	27 °C	28 °C	27 °C	28 °C	27 °C	-	-
CI 3	26 °C	26 °C	27 °C	27 °C	27 °C	27 °C	-	-
CI 4	27 °C	27 °C	27 °C	27 °C	27 °C	27 °C	-	-
CI 5	28 °C	27 °C	27 °C	27 °C	27 °C	27 °C	-	-
CI 6	27 °C	27 °C	27 °C	28 °C	27 °C	27 °C	-	-
CI 7	26 °C	26 °C	26 °C	27 °C	27 °C	27 °C	-	-
CI 8	27 °C	27 °C	27 °C	28 °C	27 °C	27 °C	-	-

Figure 52. Thermistor accordion in Details Tab

6.2.5.1. Filtering

You can filter the display to highlight cells with temperatures above or below a value you specify. The values that match the criteria will be bolded and all other values will be faded.

Filter: Off Above Below

	Index 1	Index 2	Index 3	Index 4	Index 5	Index 6	Index 7	Index 8
CI 1	27 °C	27 °C	27 °C	26 °C	27 °C	27 °C	-	-

6.2.6. Open Wire

The Open Wire accordion lists open wire diagnostics for all Cells configured in the Configuration file. Cells that are not configured are displayed as a - (hyphen). Diagnostic data that is highlighted in yellow indicates an open wire.

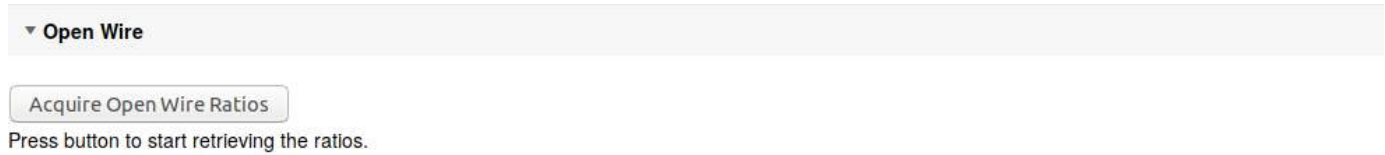


Figure 53. Open Wire accordion in Details Tab

To trigger diagnostics on all cells, click the "Acquire Open Wire Ratios" button. Once clicked, the open wire scanning process begins.

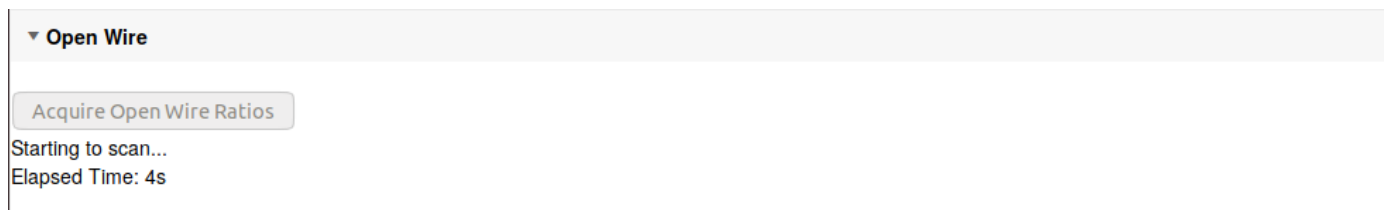


Figure 54. Open Wire acquiring accordion in Details Tab

Once the open wire scanning has completed and all diagnostics data is collected it is displayed in a tabular format with open wires highlighted in yellow.

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10	Cell 11	Cell 12	Cell 13	Cell 14	Cell 15	Cell 16
C11	0.920	0.921	0.922	0.923	0.919	0.919	0.921	0.920	0.920	0.921	0.916	0.920	-	-	-	-
C12	0.969	0.999	0.994	0.994	0.994	0.965	0.995	0.995	0.994	0.995	0.993	0.991	-	-	-	-
C13	0.920	0.920	0.922	0.924	0.924	0.923	0.923	0.924	0.925	0.924	0.922	0.920	-	-	-	-
C14	0.922	0.503	0.921	0.924	0.924	0.923	0.923	0.923	0.922	0.923	0.924	0.923	-	-	-	-
C15	0.920	0.922	0.921	0.921	0.922	0.922	0.920	0.920	0.921	0.921	0.920	0.920	-	-	-	-
C16	0.905	0.905	0.906	0.906	0.909	0.909	0.909	0.908	0.908	0.908	0.908	0.907	-	-	-	-
C17	0.910	0.912	0.912	0.912	0.910	0.910	0.912	0.912	0.912	0.912	0.912	0.910	-	-	-	-
C18	0.910	0.911	0.913	0.914	0.915	0.915	0.914	0.910	0.902	0.918	0.914	0.914	-	-	-	-

Figure 55. Open Wire diagnostics accordion in Details Tab

The diagnostic values displayed are ratios of Voltage. Values very close to one (> 0.97) indicate a short condition. Values approaching zero (0.0 to 0.4) indicate an open wire connection.

Depending on whether you are using G4 Cell Interface - 12 channel or G4 Cell Interface - 16 channel modules or G4 Cell Interface - 12V 4 channel modules, they will display different diagnostics information.

6.2.6.1. Filtering

Use the filter to highlight ratios of Voltage that are above or below the specified value. The values that match the criteria will be bolded and all other values will be faded.

Filter: Off Above Below 0.9

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
Cl 1	0.900	0.920	0.800	0.800	0.920	0.900	0.800	0.800

6.2.7. SoC Calibration

The State of Charge Calibration accordion allows for calibration of SoC and reset of the measured capacity estimate. This accordion is only visible if the OCV is enabled (stack_soc.ocv_enabled). Both of these operations are only enabled when the battery is operational (not in service lockout) but disconnected (stack_control.actual_state == 0).

▼ SOC Calibration

Last update: Fri Mar 25 2022 16:27:06 GMT-0400 (Eastern Daylight Time)

Battery Charge

State of Charge	67 %
Depth of Discharge	0.150 Ah

SOC is calibrated from cell voltages using the open-circuit voltage curve. Battery contactors must be disconnected to calibrate.

Battery Capacity

Measured Capacity	0.000 Ah
Nameplate Capacity	1.500 Ah

Capacity is reset to stack nameplate rating while accounting for cell SOC imbalance. Battery contactors must be disconnected to reset.

Figure 56. SoC Calibration accordion in Details Tab

6.3. The Menu Options

The menu to the right of the Operator Interface provides access to tools and advanced options. Some of these options may be locked to prevent accidental changes.

The following options are available:

- Registers
- Service
- Connection
- Unlock
- About

6.3.1. Registers

This menu option navigates to the Register Browser. This screen allows you to read and write to registers.

When the Operator Interface is locked, the Register Browser is in a view-only mode, restricting the editing of registers.

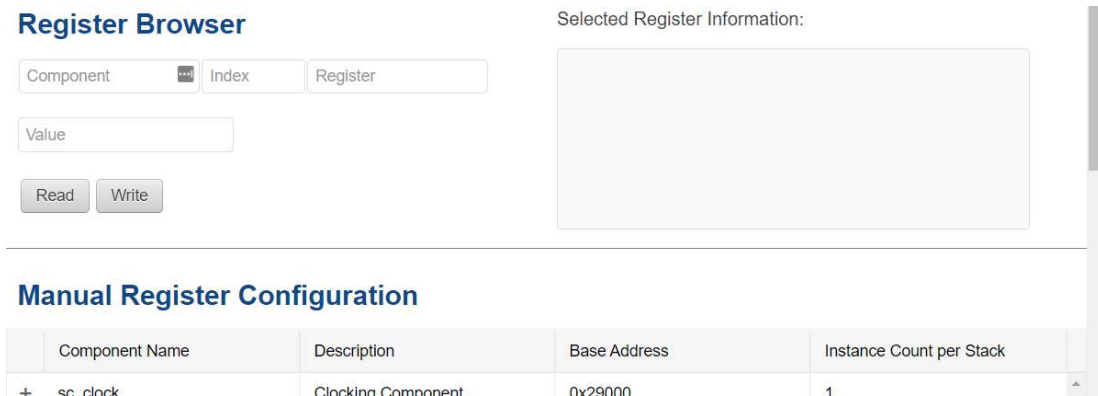


Figure 57. Register Browser

6.3.2. Service

This screen allows you to enter and exit Service Lockout in-order to perform an upgrade or configuration file import.

6.3.2.1. Importing a Configuration File



This is a restricted option requiring the Operator Interface to be unlocked to access this option.

This menu option allows you to import a configuration file.



The G4 Stack Switchgear ships with a configuration file specific for its end application. Serious problems might occur if the configuration settings are incorrectly modified. If you need assistance with modifying the configuration file, please contact support@nuvationenergy.com.

6.3.2.2. Exporting a Configuration File



Nuvation Energy BMS does not preserve the originally imported configuration file with comments and formatting. The export feature will export a configuration file with an alphabetical listing of all registers and their set values.

To export your configuration file:

1. From the menu, select Service
2. Click Export Configuration

6.3.2.3. Upgrade



This is restricted option requiring the Operator Interface to be unlocked to access this option.



The firmware upgrade will erase the configuration file on your Nuvation Energy BMS. Please remember to export and save your current configuration file to save your current configuration file for future reference.



Please contact support@nuvationenergy.com before attempting a firmware upgrade. The current configuration file may not be compatible with different firmware version. Without a valid configuration file, the G4 Stack Switchgear will be rendered non-functional.

6.3.2.4. Updating a Label

A label is the string displayed on the top banner of the Operator Interface. An owner can configure a name for each stack using the label. When the Operator Interface connects to a stack the operator knows immediately what stack they are connected to.



To update a label:

1. From the menu, select Service
2. Click Edit under the label section

Label

The label is used to identify which BMS you are connected to.

Edit **Apply**

3. Enter a suitable name for the stack
4. Click Apply



The Operator Interface automatically saves the label in persistent storage when applied.



A label does not handle spaces. Use hyphens or underscores to delineate words.



6.3.2.5. Editing an IP Address

To edit an IP address:

1. From the menu, select Service
2. Click Edit under the ethernet section

Ethernet

The local IP network configuration used by this BMS.

IP Address	Netmask	Gateway
<input type="text" value="0.0.0.0"/>	<input type="text" value="0.0.0.0"/>	<input type="text" value="0.0.0.0"/>

Edit **Apply**

3. Enter the IP address of your choice
4. Click Apply



The updated IP is saved and in immediate use after the Apply action. Any prior connections via Modbus TCP would have to be reconnected using the updated IP.



Applying changes will disconnect the battery and restart the BMS.

6.3.3. Connection

The connection page allows you to change the IP address and timeout of the Nuvation Energy BMS that you are trying to access.

If you are connecting to a Nuvation Energy BMS that does not use the default IP address (192.168.1.21), you will need to change the connection settings in the Operator Interface to match the BMS.



In scenarios where there are multiple BMS systems, it is possible to direct multiple instances of the Operator Interface at the different BMS IP addresses.

6.3.4. Locking and Unlocking

The Operator Interface can be locked to prevent accidental or unintentional changes that could have serious impacts on the system. To further secure the system, a password can be set to ensure only authorized individuals can access these critical sections of the Operator Interface



The G4 Stack Switchgear ships from the factory with password protection on the Operator Interface. Please contact support@nuvationenergy.com for the factory password and documentation for advanced modifications of the G4 Stack Switchgear.

When the Operator Interface is unlocked, the lock indicator will be replaced with an unlocked indicator.



Figure 58. Operator Interface Locked indicator



Figure 59. Operator Interface Unlocked indicator

6.3.4.1. Lock the Operator Interface

To lock the Operator Interface, simply click the Unlocked indicator or bring up the settings menu and select Lock.



To prevent accidental changes to your Nuvation Energy BMS, always lock the Operator Interface after making your changes.

It is possible to require a password to unlock the Operator Interface.

6.3.4.2. Unlock the Operator Interface

To Unlock the Operator Interface, simply click the Locked indicator or bring up the settings menu and select Unlock. If a password has been set, the correct password will need to be entered to complete the unlocking process.

6.3.5. About

This screen displays version details for the underlying software for your Nuvation Energy BMS. The name and number of the current software release are displayed at the top of the About screen.

In the screenshot below, the release name is at the top in large blue letters. The version number following the release name has a format of yy.mm with yy representing the year and mm representing the month within that year that this Nuvation Energy BMS package was released.

The version numbers below the release name are the version numbers of the individual software packages running on your Nuvation Energy BMS.

When contacting support, please include the details in your About screen.

About This BMS

Software Version	
OI:	0.57.0
SC:	4.109.1:01f91781 (4.109.1) (CRC 60404)
SC BL:	4.109.1 (CRC 19929)
SC Revision ID:	A2
PI:	4.109.1 (4.109.1) (CRC 16898)
PI BL:	4.109.1 (CRC 57871)
PI Revision ID:	Y

Factory Lockdown	
SC Factory Persist:	CRC 58422
PI Factory Persist:	CRC 5938

Figure 60. Sample About Screen



Not all information is displayed unless the BMS is factory locked. Additional information for identifying the configuration and images is provided to ensure the correct version of firmware and configuration is being used as specified at the factory.

6.4. The Status Banner

The banner at the top of the screen is used to indicate high level changes in system status. During typical operation nothing is displayed and this indicates the Operator Interface is communicating with the BMS and the BMS is fully operational with no major diagnostics problems.

6.4.1. Service Lockout Indication



In normal operating scenarios the G4 Stack Switchgear should never be in service lockout. In the un-likely scenario that the G4 Stack Switchgear is in service lockout, please contact support@nuvationenergy.com.

When the system is either entering or is in service lockout, a banner is displayed indicating this to the user.



Figure 61. Operator Interface Service Lockout indicator



Figure 62. Operator Interface Entering Service Lockout indicator

6.4.2. Self Check Indication

When the system is either exiting service lockout or has just booted, the system will execute a Self Check to verify a safe operation. A banner is displayed indicating the Self Check execution to the user.



Figure 63. Operator Interface Self Check indicator

6.4.3. Communication Loss

When the Operator Interface can no longer communicate with the Battery Management System, a communication lost banner is displayed at the top of the display. It will provide the amount of time since disconnected and updates each second.



Figure 64. Operator Interface Communication lost indicator

6.5. Understanding the Service Lockout and Self Check

Service Lockout allows you to put your Nuvation Energy BMS into a Lockout state while you perform maintenance on your energy storage installation such as loading new configurations, or upgrading the firmware.

If you are making physical wiring changes, you should enter Service Lockout before powering down Nuvation Energy BMS.

When in Service Lockout, Nuvation Energy BMS will set all faults and warnings as tripped.

A Self Check is a self-test that is executed when:

1. Exiting Service Lockout
2. When booting the Battery Management System

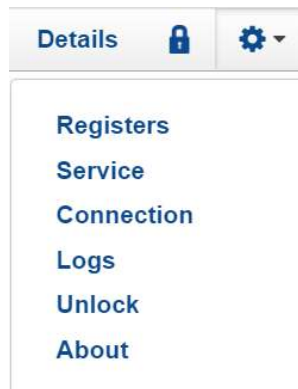
A Self Check is a verification to make sure that the configured Battery Management System is ready for operation. A Battery Management System remains in Self Check until the issues preventing a successful Self Check are corrected. Refer to [Section 6.5.3, "Self Check"](#) for further details about the Self Check.




The status for the Service Lockout and Self Check are displayed in the status banner of the Operator Interface as indicated in [Section 6.4, "The Status Banner"](#)

6.5.1. Entering Service Lockout

1. Unlock the Operator Interface by clicking the Lock indicator and enter the password if prompted.
2. From the menu, select Service to bring up the Service page



3. Click Enter Service Lockout to enter Service Lockout

 **Service Lockout**

Enter Service Lockout
Exit Service Lockout

Warning: Service Lockout will disconnect the battery and prevent operation.



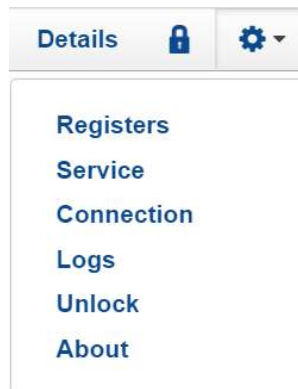
Entering Service Lockout will open all contactors and GPOs and halt all cell voltage/temperature and stack voltage/current data acquisition.



When in Service Lockout, you will not be able to access the Operator Interface dashboard.

6.5.2. Exiting Service Lockout

1. Unlock the Operator Interface by clicking the Locked indicator and enter the password if prompted.
2. From the menu, select Service to bring up the Service page



3. Exit the Service Lockout by clicking Exit Service Lockout



Exiting Service Lockout may close contactors

4. A Self Check will be initiated and its banner will be displayed on the Operator Interface. Refer to [Section 6.4.2, "Self Check Indication"](#) for banner details.

6.5.3. Self Check

The Self Check verifies that all configured data inputs for the faults and warnings of the Battery Management System are being received. The Battery Management System will remain in Self Check until all these data inputs are received. The Self Check is executed continuously unless the Battery

Management System is returned back to Service Lockout. If the issue(s) that were preventing a successful Self Check are corrected, the Battery Management System will enter operation. You will be able to access the dashboard controls once Nuvation Energy BMS has successfully completed the Self Check.

6.5.4. Self Check Troubleshooting

If Nuvation Energy BMS fails its Self Check, you will receive an error notification. The reason for the failure is that some form of input to the Battery Management System was not received. This means that the Battery Management System was expecting some measurement (e.g. cell voltage, current) but it never was received by the software. Because of this lack of data, the Battery Management System should not be operated and the issue(s) needs to be resolved. There are two main causes for a lack of Self Check failures:

- Misconfiguration: The current configuration does not match the Battery Management System deployment.
- Incomplete setup: There is an issue in the setup of the Battery Management System (e.g. cables are missing or faulty)

You can identify the parts of the Battery Management System that have not completed their Self Check by referring to the Details > Safety accordion section. The faults/warnings that are currently failing Self Check are indicated by the red text "Checking" on the right side of the display.

Refer to [Section 11.1, "Faults and Self Check Failures"](#) for details on on how to address the Self Check failures.

If you just imported a configuration file, re-import a known-good configuration file.



If the failures persist, please submit a support ticket with as much detail as possible to support@nuvationenergy.com.

7. Configuration Settings

The following sections break down a complete system configuration into the major areas of responsibility.

7.1. Background and Terminology

Terminology and technical concepts critical to the operation and configuration of Nuvation Energy BMS are presented in this section.

7.1.1. Register Data Model

Understanding the Register Data Model is key to understanding how to configure Nuvation Energy BMS.

Nuvation Energy BMS implements all data storage and processing using two important software building blocks.

Register

A register is the fundamental unit of data storage within the system. Each register has a unique name and associated type that defines how the value is interpreted. Registers range in size from as small as one byte up to as large as eight bytes.

Component

A component combines a set of related registers with processing rules that operate on those registers to implement a particular BMS function for the system. A given component may have many instances throughout the system. In this case, its associated registers will have the same number of instances.

Complex behavior within the system is achieved by connecting multiple components together, either through configuration or through hard-wired connections in the firmware itself.

Configuration for a system is completely determined by the state of all configuration registers present within the system. Configuration registers are persisted in non-volatile memory and are loaded automatically upon reset.

External protocols are implemented by mapping (and in some cases aggregating) the appropriate BMS registers to Modbus registers.

7.1.1.1. Index versus Location

Internally to Nuvation Energy BMS firmware, all register indexing is zero-based. That is, if multiple instances of the same register are present, the first instance is always indexed at zero. This convention is reflected in all register expressions and configuration files.

Operator-facing tools such as Nuvation Energy BMS Operator Interface or the MESA Modbus models use one-based location identifiers to refer to physical, countable entities.

For example, the location of the first cell within a stack is defined as Cell Interface 1, Cell 1—i.e. it is

the first cell in the first G4 Cell Interface. The index of this first cell is defined as zero within the firmware.

7.1.1.2. Register Expressions

Registers are accessed by name in Nuvation Energy BMS tools and configuration. Each register also has a unique address that is used internally within the BMS.

7.1.1.2.1. Single Register Instance

This expression is used when assigning to or reading from a single register in the system and is of the form:

```
component_name.register_name
```

where:

- **component_name** is the name of the component within the system
- **register_name** is the name of the register within the component

7.1.1.2.2. Range of Register Instances

These expressions build on the single register references by adding an additional range expression in square brackets:

```
component_name[range_expression].register_name
```

The **range_expression** may take any of the following forms:

- **index** - A single instance of component_name.register_name at index. Note that cell[0].voltage is equivalent to cell.voltage.
- **start_index:end_index** - All instances from start_index through end_index. The expression cell[0:3].voltage expands into:

```
cell[0].voltage
cell[1].voltage
cell[2].voltage
cell[3].voltage
```

- **start_index:end_index:block_length** - All instances from start_index through end_index within a repeating block of block_length across all instances of the register. For example if there were N instances of the register cell.voltage, the expression cell[0:3:16].voltage expands into:

```
cell[0].voltage
cell[1].voltage
cell[2].voltage
```

```
cell[3].voltage
cell[16].voltage
cell[17].voltage
cell[18].voltage
cell[19].voltage
cell[32].voltage
cell[33].voltage
cell[34].voltage
cell[35].voltage
...
cell[N-16].voltage
cell[N-15].voltage
cell[N-14].voltage
cell[N-13].voltage
```

- **start_index:end_index:block_length:block_count** - All instances from start_index through end_index within a repeating block of block_length repeated block_count times. The expression cell[0:3:16:2].voltage expands into:

```
cell[0].voltage
cell[1].voltage
cell[2].voltage
cell[3].voltage
cell[16].voltage
cell[17].voltage
cell[18].voltage
cell[19].voltage
```

In this case, only the first 2 blocks of 16 instances are included, rather than all blocks of 16 instances.

7.1.1.2.3. All Register Instances

A compact syntax can be used to expand to all instances of a given register within the system. The expression:

```
component_name[*].register_name
```

expands to all instances of **component_name.register_name** within the system. For example, the expression cell[*].voltage expands into:

```
cell[0].voltage
cell[1].voltage
cell[2].voltage
cell[3].voltage
cell[4].voltage
cell[5].voltage
```

```
cell[6].voltage
cell[7].voltage
cell[8].voltage
cell[9].voltage
cell[10].voltage
cell[11].voltage
cell[12].voltage
cell[13].voltage
cell[14].voltage
cell[15].voltage
cell[16].voltage
.
.
.
cell[N-3].voltage
cell[N-2].voltage
cell[N-1].voltage
```

where N is the total number of instances of the register `cell.voltage` within the system.

7.1.1.2.4. Register Address

In some cases, it is necessary to use the address of a register as a configuration value for another register in the system. This is required when assigning input and output pins to functions within the BMS, for example.

The expression:

```
@component_name.register_name
```

expands to the address of the register in the system. The single-instance range expression may be used for register addresses. For example:

```
@component_name[index].register_name
```

expands to the address of **component_name.register_name** at index in the system.

7.1.2. Units

A standard set of types/units has been adopted for use within Nuvation Energy BMS for the measurements and configuration settings. Unless otherwise noted, the units used within the firmware should be assumed as defined below.

Table 9. Standard Types and Units

Type	Units	Variable Type	Application
Address	none	uint32	BMS register address

Type	Units	Variable Type	Application
Boolean	false=0, true=1	uint8	Logic value
Charge	mAh	int32	Depth of discharge and throughput
Count	number	uint32	A positive count of some event
Crc16	none	uint16	Used to verify persistent data
Current	mA	int32	Stack and pack currents
CurrentNano	nA	int32	Current in nano amps
Energy	Wh	uint32	Energy capacity of a stack
Farads	μFarads	uint32	Capacitance of cells
Float	value	float	Single precision floating point
Int64	value	int64	Signed 64 bit integer
Impedance	Ω	uint32	Resistance of a stack
ImpedanceMili	mΩ	uint32	Resistance of a stack
IpAddress	IP	uint32	IP4 address for a stack
LogLevel	none	uint32	Log level applied the BMS firmware
MicroOhms	μΩ	uint32	Resistance of a cell
Microseconds	μs	uint64	Time measurement or period
Percentage	%	uint8	Percentage of a full scale value (e.g. SoC)
PowerW	W	int32	Rated power of a stack
SoftwareId	enum	uint32	Enumeration for type of G4 Cell Interface
Temperature	°C	int16	Thermistor temperatures
String	none	char[8]	Storage for 8 characters
UInt8	value	uint8	Unsigned 8 bit integer
UInt16	value	uint16	Unsigned 16 bit integer
UInt64	value	uint64	Unsigned 64 bit integer
Voltage	mV	int32	Cell and stack voltages

Every register within the firmware has an associated type that defines the expected units for that register.



A negative value for *Current* represents a charge direction while a positive value represents a discharge direction with respect to the cell/stack. Some *Current* registers represent the magnitude of the current and are never negative in value. These register exceptions include the following:

- `stack_current_limit.min_charge_current`
- `stack_current_limit.max_charge_current`
- `stack_current_limit.max_discharge_current`
- `stack_charge_status.hold_current`
- `stack_control.precharge_max_current`

- `stack_control.precharge_bias_current`
- `stack_fault_precharge_over_current.thresh`

7.1.3. Storage Types

Each register in Nuvation Energy BMS can be one of five storage types.

Volatile

- Data that is not persisted across a system reset

Configuration

- Data that is persisted on the [service page](#) via loading a configuration file.

Persistent

- Data that is persisted and regularly saved

Factory

- Data that is persisted when requested and is typically set at the factory

Manufacturing

- Data that is persisted and saved at manufacturing time

These types of storage can be read directly from the Operator Interface *Registers* menu option as discussed in [Section 6.3.1, “Registers”](#).

7.1.4. Configuration File

Configuration is stored externally to Nuvation Energy BMS in a plain-text file. This file defines the state of configuration registers as required for a particular system.



The G4 Stack Switchgear ships with a configuration file specific for its end application.
To update the configuration file, please contact support@nuvationenergy.com.

The Operator Interface provides tools for importing and exporting configuration files to and from Nuvation Energy BMS as a way to set or retrieve the state of all configuration registers.

The configuration file format is plain ASCII text with the following syntax:

- Any lines starting with a leading # are treated as comments.
- Each non-comment line is treated as a register assignment statement.

A register assignment takes on the form `register_expression = value` where:

- `register_expression` is one of the valid [Register Expressions](#) previously defined.
- `value` is either a numerical constant, quoted string, IP address, or a valid [Register Address](#).

Any standard text editor can be used to edit configuration files (e.g. Notepad++, etc.).



A configuration file cannot be used to configure the IP settings of a stack.

Stack IP configuration is detailed in the [Appendix C](#).



When a Battery Management System has been configured for [Factory Lockdown](#) there are a set of components that will have all their register protected from most write operations. Attempting to perform a write operation via a register addressing (for example using a [Digital Inputs](#)) will silently fail. Please refer to [Section 7.2.4, "Restricted Register Write Operations"](#) for further details.

7.2. Factory Lockdown

Factory Lockdown is a mechanism for users to lock registers with *Factory* storage type as read-only. This is typically used to protect safety related configurations for safety certification purposes.

7.2.1. Configuring Factory Registers

Factory registers can be configured in the same way normal configuration registers can be set. They can be set through the Operator Interface *Registers* menu option ([Section 6.3.1, "Registers"](#)) or applied by uploading a configuration file. Factory registers can only be configured when the system is not in *Factory Lockdown*.

7.2.2. Enabling Factory Lockdown

Factory Lockdown can be enabled by writing to specific registers from the Operator Interface. The user must follow the process below for the Nuvation Energy BMS to be considered factory-locked.

1. Ensure all factory registers are configured to their desired value
2. Write 1 to `sc_factory_lockdown.requested_state`
3. Write 1 to `sc_factory_persist.save`
4. Wait until `sc_factory_persist.save` is equal to 0
5. Verify `sc_factory_lockdown.actual_state` is equal to 1
6. Write 1 to `pi_factory_lockdown.requested_state`
7. Write 1 to `pi_factory_persist.save`
8. Wait until `pi_factory_persist.save` is equal to 0
9. Verify `pi_factory_lockdown.actual_state` is equal to 1

7.2.3. Clearing Factory Lockdown

A system can only exit *Factory Lockdown* through a firmware upgrade .

For performing a factory reset, refer to your *Product Manual*.

7.2.4. Restricted Register Write Operations

When *Factory Lockdown* has been enabled, all register writes are restricted through external interfaces (e.g. Modbus-TCP, HTTP) with some exceptions. A 'whitelist' of registers which can be written to when in *Factory Lockdown* and are excluded from write protection are listed in [Table 10, "Factory Lockdown Whitelist"](#).

Table 10. Factory Lockdown Whitelist

Register Name	Register Address
sc_op_state.requested_state	279776
sc_boot.requested_state	229376
stack_trigger_summary.clear_faults	131081
stack_trigger_summary.clear_warnings	131082
stack_factory_trigger_summary.clear_faults	221449
stack_factory_trigger_summary.clear_warnings	221450
sc_linkbus.cell_open_wire_manual_scan	69650
sc_linkbus.diagnostics	69653
stack_control.requested_state	200705
stack_contactor.requested_value	102401
stack_breaker.request_state	196610
stack_breaker.reset	196622
sc_gpo.value	94209
sc_client_id.uuid_lsb	279312
sc_client_id.uuid_msb	279313
sc_controller_wdt.expired	221184
sc_controller_heartbeat.value	278784
sc_pcs.state	279296
sc_modbus_rtu.transaction_complete	279041
sc_stackbus_packets.tx_count	77840
sc_stackbus_packets.tx_err_count	77841
sc_stackbus_packets.rx_count	77842
sc_stackbus_packets.rx_err_count	77843
sc_canbus_packets.tx_count	73984
sc_canbus_packets.tx_err_count	73985
sc_canbus_packets.rx_count	73986
sc_canbus_packets.rx_err_count	73987
sc_persist.save	18432
sc_persist.load	18433
sc_persist.error	18434
sc_aux_persist.save	18456

Register Name	Register Address
sc_aux_persist.load	18457
sc_aux_persist.error	18458
sc_ci_persist.save	24576
sc_ci_persist.load	24577
sc_ci_persist.error	24578
sc_val_persist.save	18464
sc_val_persist.load	18465
sc_val_persist.error	18466
cell_val_persist.save	18480
cell_val_persist.load	18481
cell_val_persist.error	18482
sc_locked_cfg_persist.save	18496
sc_locked_cfg_persist.load	18497
sc_locked_cfg_persist.error	18498
sc_clock_err_stats.reset	168019
sc_stackbus_stat.reset	212995
sc_stack_stat.reset	213251
sc_linkbus_stat.reset	213507
sc_rom_test_stat.reset	213763
sc_ram_test_stat.reset	214019
stack_cell_soc_stat.update	298573
stack_cell_soc_variance_stat.update	298583
stack_cell_soh_stat.update	274437
stack_balance_stat.update	281349
stack_soc.reset	90115
stack_soc.reset_soc	90116
stack_soc.reset_capacity	90117
stack_soc.measured_capacity	90125
stack_soc.adaptive_soc	90120
stack_soc.accumulative_soc	90119
cell_states.soc	293659
cell_states.vp	293658
cell_states.soc_variance	293661
cell_states.vp_variance	293660
cell_model.instantaneous_resistance	281376
cell_model.polarization_resistance	281378
cell_charge.throughput_reset	233475

Register Name	Register Address
cell_model.ohmic_resistance	281377
pi_op_state.requested_state	7712
pi_boot.requested_state	32
pi_fsm_stat.reset	7427
pi_afe_stat.reset	7939
pi_rom_test_stats.reset	7763
pi_stackbus_stat.reset	7683
pi_contactor_stats.reset	7795
pi_clock_err_stats.reset	7779
pi_aux_persist.save	4448
pi_aux_persist.load	4449
pi_aux_persist.error	4450
pi_stackbus_packets.tx_count	7808
pi_stackbus_packets.rx_count	7810
pi_stackbus_packets.tx_err_count	7809
pi_stackbus_packets.rx_err_count	7811



Configuration storage typed registers can be written to and are exempt from this rule. Refer to [Section 7.1.3, "Storage Types"](#) for information on register storage types.

7.3. Battery Parameters

These following settings are used to configure State-of-Charge (SoC) and State-of-Health (SoH) algorithms for operation with a particular battery chemistry.

7.3.1. Stack Capacity

Battery stack capacity is defined as the total amount of charge that can be extracted from a battery stack when discharging from full to empty, assuming current limits are properly followed. Nominal (or design) capacity is configured as follows:

`stack_soc.nominal_capacity`

- Nominal capacity of the battery stack
- Set to the capacity that would correspond to a full discharge



The nominal capacity of the stack is identical to that of the cells used within the stack, where a cell may be one or more electro-chemical cells directly connected in parallel. The actual capacity of the battery stack maybe less than this nominal capacity due to imbalances in SoC and capacity fade of the cells with usage. Correct configuration of the nominal capacity is essential for accurate SoC and SoH

estimation.

7.3.2. Stack Cycle Count

In addition to the nominal capacity, the nominal cycle count for the battery stack is required for SoH estimation based upon cycle count.

`stack_soc.nominal_cycle_count`

- Set to the expected cycle life of the battery stack assuming full discharge cycles at the configured maximum operating current
- Set to zero to ignore cycle count for SoH

7.3.3. State-of-Health

The State-of-Health (SoH) is a value that can be used to describe the battery's current performance relative to its performance at beginning of life. Nuvation Energy BMS estimates SoH by using one or both of the following two metrics:

1. **Cycle count:** SoH for a specific cell can be defined as the ratio of the number of equivalent cycles to the nominal cycle count. At the stack level, the SoH will be the minimum of the cell SoH values.
2. **Battery capacity:** Capacity based SoH can be defined as the ratio of the current measured capacity to the nominal capacity value. Note that this SoH value will also include charge imbalance.

There are two ways State-of-Health can be configured using the above two metrics:

1. Capacity based SoH:
 - a. Configure the nominal capacity as describe in the [battery capacity](#) section.
 - b. Set the `stack_soc.nominal_cycle_count` register to zero.
2. Capacity and cycle count based SoH:
 - a. Configure both the [battery capacity](#) and [cycle count](#).
 - b. The SoH estimate will be the minimum of the stack capacity SoH and the stack cycle count SoH.



Currently, we cannot configure SoH based only on cycle count. SoH will always have a capacity based component to it.

7.3.4. State of Charge (SoC)

The state of charge of a battery is a measure of the percentage of charge contained in the battery that is available for discharge. The BMS can be configured to measure the state of charge using two different methods:

1. **Accumulated SoC:** Continuously measures and accumulates the charge that is charged/discharged to/from the battery.

2. **Adaptive SoC:** Augments the accumulated measurements with an adaptive SoC algorithm. This latter technique compensates for errors due to integration over long periods of time and for factors such as self discharge which can not be directly measured by a BMS. The algorithm requires a configuration of the [open circuit voltage](#) for the battery.

The following parameters are used to select and enable which state of charge for the Nuvation Energy BMS.

Table 11. Current Full Condition Configuration

Register	Type	Units	Description
stack_soc.enable	config	bool	Enables the state of charge measurement when set to one. Applies to both SoC techniques
stack_soc.output_select	config	enum	Selects which technique of state of charge is used for output on the following registers. Zero selects the accumulated SoC measurement and one selects the adaptive SoC algorithm.
stack_soc.soc	output	percentage	The current state of charge of the battery
stack_soc.dod	output	mAhr	The current depth of discharge of the battery



The adaptive state of charge algorithm does require more detailed configuration settings for proper use. Please contact support@nuvationenergy.com for help in configuring this algorithm for your battery chemistry. This algorithm is not currently recommended for LFP chemistries.



The Sunspec Modbus point definition for SoC and DoD uses the data from the registers noted above for output.

The end limits for the state of charge (i.e. 0% and 100%) are defined by the full and empty conditions of a battery. The following subsections provide details on these end conditions and how they are configured.

7.3.4.1. Battery Empty Condition

Nuvation Energy BMS supports the definition of the empty condition using either or both min/max and average cell voltages, as configured using the following registers.

stack_soc.vempty

- Defines fully discharged minimum cell voltage for operation
- Set as per application requirements, or set to zero to disable

stack_soc.vemptyavg

- Defines fully discharged average cell voltage for operation
- Set as per application requirements, or set to zero to disable

When discharging near the bottom of the battery, if the empty conditions are not met the battery will remain at 1% SoC.



For battery chemistries that do not tolerate overcharge and make use of electrical balancing circuits to keep cells balanced (e.g. Lithium-Ion), the empty conditions are typically applied against the minimum cell voltages. But for chemistries that make use of overcharge during the charging process as a way to balance the stack (e.g. lead acid), the empty conditions are typically applied against the average cell voltage.



These voltage settings must be carefully aligned with the minimum [Cell Voltage Thresholds](#) and [Stack Voltage Thresholds](#) for proper SoC operation.

7.3.4.2. Battery Full Condition

A battery can reach the full condition while charging (i.e. when the BMS reads negative current measurements) Nuvation Energy BMS supports the definition of the full condition using a combination of cell voltage and battery current measurements. This condition is configurable using the following register settings.

`stack_soc.vfull`

- Defines fully charged maximum cell voltage for operation
- Set as per application requirements, or set to zero to disable

`stack_soc.vfullavg`

- Defines fully charged average cell voltage for operation.
- Set as per application requirements, or set to zero to disable.

`stack_soc.ifull`

- Defines the largest negative current before the battery is considered full.
- Value must be negative to represent a current in the charge direction.
- Set to a large negative value (default) if this condition is not applicable.

`stack_charge_status.hold_current`

- Defines the upper bound for the current full condition.
- Configured as a positive value.
- Software will use the negative value of this setting for the full condition.
- Should be larger than the noise measurement of the current.

`stack_soc.ifull_period`

- Defines the period a current must between the prior thresholds before the full current condition is met.
- Configured as a positive value in microseconds.
- Set to a value of zero if no period is desired.

A battery is full (reaches 100% SoC) if all three of the following conditions are met:

1. The full voltage condition is met (either/both maximum or average setting).

2. The battery current is between the full current threshold and the negative hold current.
3. The battery current is maintained between the prior thresholds for the duration of the ifull period.

For example, assume the following:

```
vfull      = 3600 mV
vfullavg   = 0
ifull      = -1000 mA
hold_current = 5 mA
ifull_period = 1000000 microseconds
```

The full condition would be met when the first cell voltage equals or was greater than 3.6 V AND when the current was between -1000 and -5 mA for a duration of one second.

When charging at the top end of the battery, if the full conditions are not met the battery will remain at 99% SoC.



For battery chemistries that do not tolerate overcharge and make use of electrical balancing circuits to keep cells balanced (e.g. Lithium-Ion), the full conditions are typically applied against the maximum cell voltages. But for chemistries that make use of overcharge during the charging process as a way to balance the stack (e.g. lead acid), the empty conditions are typically applied against the average cell voltage.



These voltage settings must be carefully aligned with the maximum [Cell Voltage Thresholds](#) and [Stack Voltage Thresholds](#) for proper SoC operation.

7.3.5. Open Circuit Voltage Curve

Nuvation Energy BMS supports the use of an open-circuit voltage (OCV) table for the battery cells. The component `stack_ocv_lut` stores the voltages unique for each SoC percentage (total of 101 entries). The first table entry represents 0 percent and the last entry represents 100 percent. The voltages must be consistent with the defined the cell voltage range of [empty to full](#).

The OCV curve can be used to estimate the SoC of a stack when it is at rest. Contact support@nuvationenergy.com for details on how to perform this estimation.

7.3.6. Cell Resistance Estimation

The Nuvation Energy BMS can be configured to estimate the per cell resistance of every installed cell during charge/discharge usage. To learn more about this feature and how to configure and use it, please contact support@nuvationenergy.com.

7.3.7. Nameplate Information

Nuvation Energy BMS can be configured to display nameplate information about the battery stack.

`stack_nameplate.label0`

- First 8 characters of the battery stack's name which will be displayed as a banner on the Operator Interface

`stack_nameplate.label1`

- Next 8 characters of the battery stack's name after `stack_nameplate.label0`

`stack_nameplate.label2`

- Next 8 characters of the battery stack's name after `stack_nameplate.label1`

`stack_nameplate.label3`

- Next 8 characters of the battery stack's name after `stack_nameplate.label2`

`stack_nameplate.battery_type`

- Type of battery, corresponding to Sunspec s802 point: `BatTyp`

`stack_nameplate.energy_capacity`

- The nameplate energy capacity of the battery stack in Wh, corresponding to Sunspec s801 point: `WHRtg`

`stack_nameplate.max_charge_rate`

- The nameplate maximum rate of energy transfer into the battery stack in W, corresponding to Sunspec s801 point: `WMaxChaRte`

`stack_nameplate.max_discharge_rate`

- The nameplate maximum rate of energy transfer out of the battery stack in W, corresponding to Sunspec s801 point: `WMaxDisChaRte`

`stack_nameplate.max_soc`

- The nameplate maximum state of charge expressed as a percentage, corresponding to Sunspec s801 point: `SoCNpMaxPct`

`stack_nameplate.min_soc`

- The nameplate minimum state of charge expressed as a percentage, corresponding to Sunspec s801 point: `SoCNpMinPct`

7.4. Stack Topology

Configuring the battery stack topology requires that the following be specified:

- Which cell voltage taps are actually connected to cells
- Which thermistor inputs are actually connected to thermistors

7.4.1. Cell Inputs

The G4 Cell Interface modules may be connected to fewer cells than the maximum supported number of cell inputs.

The following registers are used to indicate which cells are actually present in the system. The index `n` is the zero-based index of the cell input.

`cell[n].installed`

- Indicates a cell is physically connected
- Set to 1 if connected
- Set to 0 if not connected

Cell indexing is statically assigned in such a way that `cell[0]` always refers to the first cell on the first G4 Cell Interface in the Link Bus chain.

When using multiple G4 Cell Interface modules, `cell[16]` refers to the first cell in the second G4 Cell Interface in the Link Bus chain, `cell[32]` refers to the first cell in the third G4 Cell Interface in the Link Bus chain, and so on.

7.4.2. Thermistor Inputs

The G4 Cell Interface modules may be connected to fewer than the maximum supported number of thermistors. The following registers are used to indicate which thermistors are actually present in the stack. The index `n` is the zero-based index of the thermistor input.

`therm[n].installed`

- Indicates a thermistor is physically connected
- Set to 1 if connected
- Set to 0 if not connected

Thermistor indexing is statically assigned in such a way that `therm[0]` always refers to the first thermistor on the first G4 Cell Interface in the Link Bus chain.

When using multiple G4 Cell Interface modules, `therm[8]` refers to the first thermistor in the second G4 Cell Interface in the Link Bus chain, `therm[16]` refers to the first thermistor in the third G4 Cell Interface in the Link Bus chain, and so on.

7.5. Operational Limits

The operational limits of a battery stack are captured in the form of voltage, temperature, and current thresholds. These thresholds must be set correctly for your battery cells and DC bus system so that the BMS can:

1. Control current during charging and discharging to keep the battery within normal operating limits.
2. Warn operators and external systems if the battery is not within normal operating limits
3. Disconnect the battery from the DC bus under a fault condition if the battery is approaching unsafe limits

Nuvation Energy BMS can either be in an operating or non-operating zone. The operating zone is also known as the *All Clear* zone while the non-operating zone is further divided into the *Warning* and *Fault* zones. All three zones are illustrated below graphically.

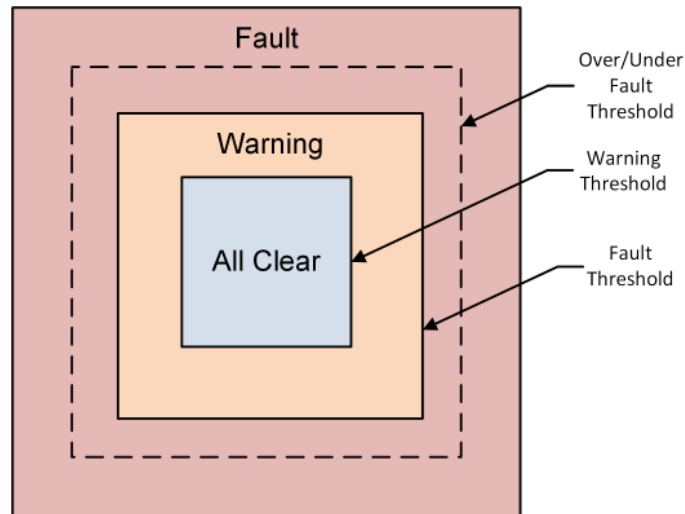


Figure 65. Battery Management System Zones

All Clear

- The *All Clear* zone represents the subset of all system states that can be reached under normal, fully controlled operation. With proper configuration and functional control, a system should never leave this zone.

Warning

- The *Warning* zone describes the region where the battery cells are not within their normal operating limits and Nuvation Energy BMS is taking action to try and bring the system back into the operating zone.

Fault

- The *Fault* zone describes the region where the battery cells are approaching unsafe limits. There are two thresholds within this zone: the *Fault Threshold* and the *Over/Under Fault Threshold*. At least one of the two thresholds should be enabled.
 - At the *Fault Threshold*, Nuvation Energy BMS will gracefully disconnect the battery from the DC bus and shut down the inverter. When the battery cells return to an operable state, Nuvation Energy BMS can be configured to automatically reconnect the battery to the DC bus.
 - At the *Over/Under Fault Threshold*, Nuvation Energy BMS will disconnect the battery cells as quick as possible. An explicit user action is required to bring the system back into an operating state at this point. These faults must be enabled for functional safety compliance for UL 1973 or UL 9540.

7.5.1. Triggers

The fundamental building block used to define thresholds throughout Nuvation Energy BMS are trigger components. There are four types of trigger components, each described in the following sections.

7.5.1.1. Basic Triggers

A Basic Trigger is the most fundamental type of trigger in Nuvation Energy BMS. This trigger is

latching meaning a tripped trigger will not self-clear when the trigger condition is cleared. The trigger will remain tripped until explicitly cleared through an external request via the Operator Interface or a supported protocol.

`trigger_name.thresh`

- The input must meet or exceed this threshold to trip the trigger.

`trigger_name.disabled`

- Set to 0 to enable the trigger
- Set to 1 to disable the trigger

7.5.1.2. Boolean Triggers and Standalone Triggers

Boolean and Standalone Triggers are specific types of Basic Triggers where the trigger is tripped based on either a 1 or 0 value. The two triggers are identical except for how they are tripped. Both triggers are latching. The following register is used to configure these types of triggers.

`trigger_name.disabled`

- Set to 0 to enable the trigger
- Set to 1 to disable the trigger

7.5.1.3. Hysteresis Triggers

A Hysteresis Trigger provides a means of hysteresis to the triggering condition. This trigger can be configured to be latching or non-latching. The following registers are used to configure this type of trigger.

`trigger_name.thresh`

- The input must meet or exceed this threshold to trip the trigger

`trigger_name.time_hyst`

- The elapsed time that the input must meet or exceed the threshold in order to trip the trigger
- Set to 0 to configure a trigger that trips instantly

`trigger_name.end_time_hyst`

- The elapsed time that the input must recover (i.e. remain below the threshold) before the trigger will clear
- Set to 0 to configure a trigger that clears instantly
- Set to > 0 to configure a trigger that clears after the defined period of time

`trigger_name.latched`

- Set to 1 for latching trigger behavior
- Set to 0 for non-latching trigger behavior

`trigger_name.disabled`

- Set to 0 to enable the trigger
- Set to 1 to disable the trigger

7.5.1.4. User-Defined Triggers

A user-defined trigger provides a separate way to create a high/low signal based on BMS measurements. The user-defined triggers are not connected into any of the prior warning or fault reporting and operate independently. A user-defined trigger is will not open contactors when triggered.

A user-defined trigger is configured identically as the [hysteresis trigger](#).

All user defined triggers have the following two naming formats:

- stack_trig_<measurement>_<condition>

7.5.2. Cell Voltage Thresholds

The following diagram illustrates how cell voltage trigger thresholds are configured in typical applications.

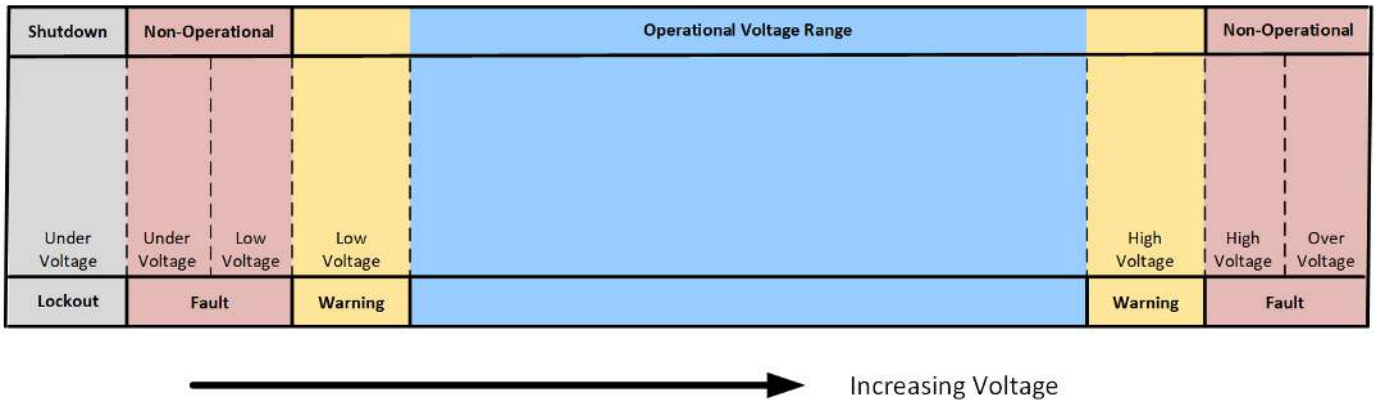


Figure 66. Typical Arrangement of Cell Voltage Thresholds

These thresholds also affect the current limits of the system as shown below.

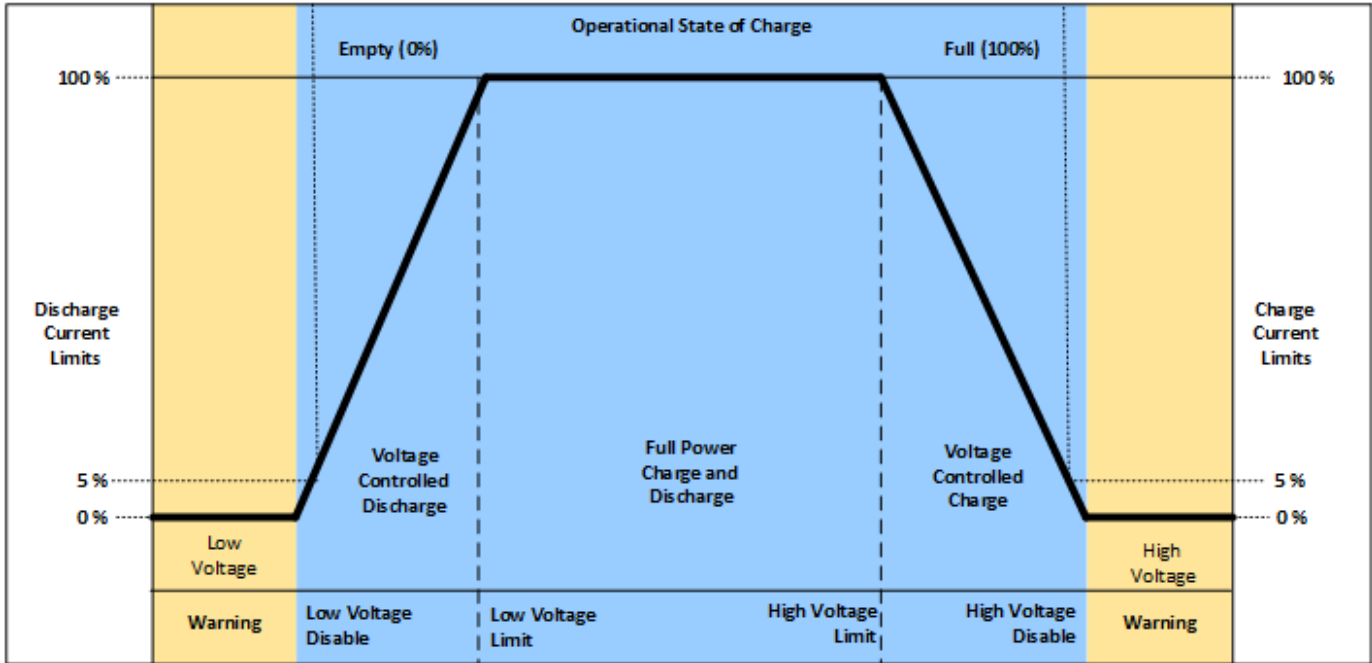


Figure 67. Typical Arrangement of Cell Voltage Current Limits

Most systems will make use of thresholds configured in the following order of decreasing cell voltage.

Table 12. Cell Voltage Operational Limits

Register	Setting
stack_fault_cell_over.thresh	The limit within the fault zone above which an explicit user operation is required to bring the system back into an operating state.
stack_fault_cell_hi.thresh	The upper limit of the warning zone as per cell specifications. Set just below stack_fault_cell_over.thresh to allow a self-clearing range within the fault zone.
stack_warn_cell_hi.thresh	The upper limit of the operating zone. Set just above stack_current_limit.voltage_cell_max.
stack_current_limit.voltage_cell_max	The voltage at which charge limits approach 0%. Set just above stack_soc.vfull.
stack_current_limit.voltage_cell_high	The voltage at which charge current limits are reduced from 100%. Set as per application requirements.
stack_current_limit.voltage_cell_low	The voltage at which discharge current limits are reduced from 100%. Set as per application requirements.
stack_current_limit.voltage_cell_min	The voltage at which discharge limits approach 0%. Set just below stack_soc.vempty.
stack_warn_cell_lo.thresh	The lower limit of the operating zone. Set just below stack_current_limit.voltage_cell_min.
stack_fault_cell_lo.thresh	The lower limit of the warning zone as per cell specifications. Set just above stack_fault_cell_under.thresh to allow a self-clearing range within the fault zone.

Register	Setting
stack_fault_cell_under.thresh	The limit within the fault zone below which an explicit user operation is required to bring the system back into an operating state.
stack_uvlo_cell_voltage.thresh	The under-voltage lockout threshold for system shutdown.



The under-voltage lockout trigger itself does not shut down the BMS when a cell voltage drops below this level.

stack_fault_cell_over.thresh may or may not be different from stack_fault_cell_hi.thresh, depending upon system requirements. For example, if a battery system is expected to implement self-clearing (non-latching) faults during operation, the stack_fault_cell_hi.thresh must be set slightly below stack_fault_cell_over.thresh. This allows the stack_fault_cell_hi trigger to prevent the stack_fault_cell_over trigger from engaging, which would require an explicit clear action. If the stack_fault_cell_over.thresh and stack_fault_cell_hi.thresh are identical, it is impossible to implement self-clearing behavior on high voltage conditions. The same applies to under-voltage conditions.

The stack_fault_cell_[over/under] or the stack_fault_cell_[hi/lo] trigger can be disabled if only one behavior is necessary. The stack_fault_cell_[over/under] triggers must be enabled for safety compliance to UL 1973 or UL 9540.

User-defined triggers are also available for high and low cell voltages.

Table 13. User-Defined Cell Voltage Triggers

Register	Setting
stack_trig_cell_hi.thresh	User-defined high cell voltage trigger
stack_trig_cell_lo.thresh	User-defined low cell voltage trigger

7.5.3. Thermistor Temperature Thresholds

Separate configuration thresholds are provided for charging and discharging as many cells have different temperature limits in these two modes of operation. Charge triggers will only trip while the stack is charging, while discharge triggers will only trip while the stack is discharging or resting.

The following diagrams illustrates how temperature trigger thresholds are configured in typical applications.

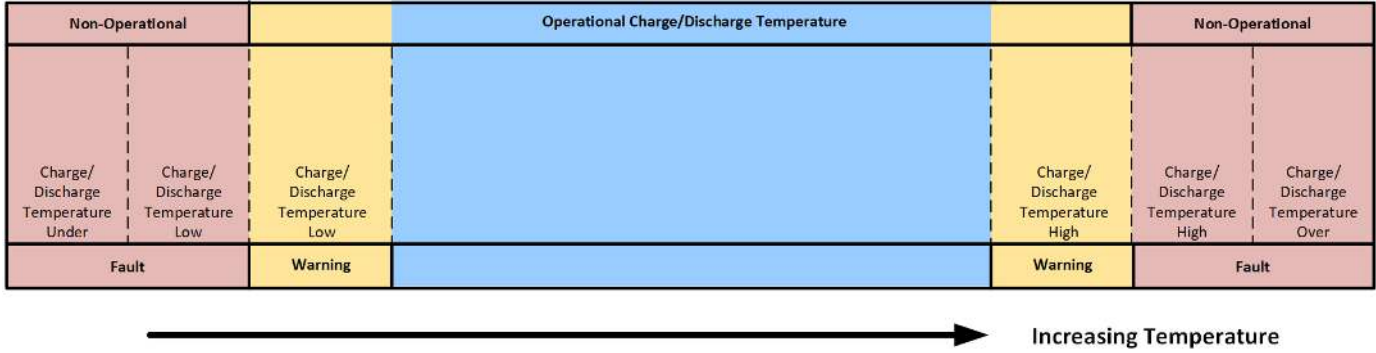


Figure 68. Typical Arrangement of Temperature Thresholds

These thresholds also affect the current limits of the system as shown below.

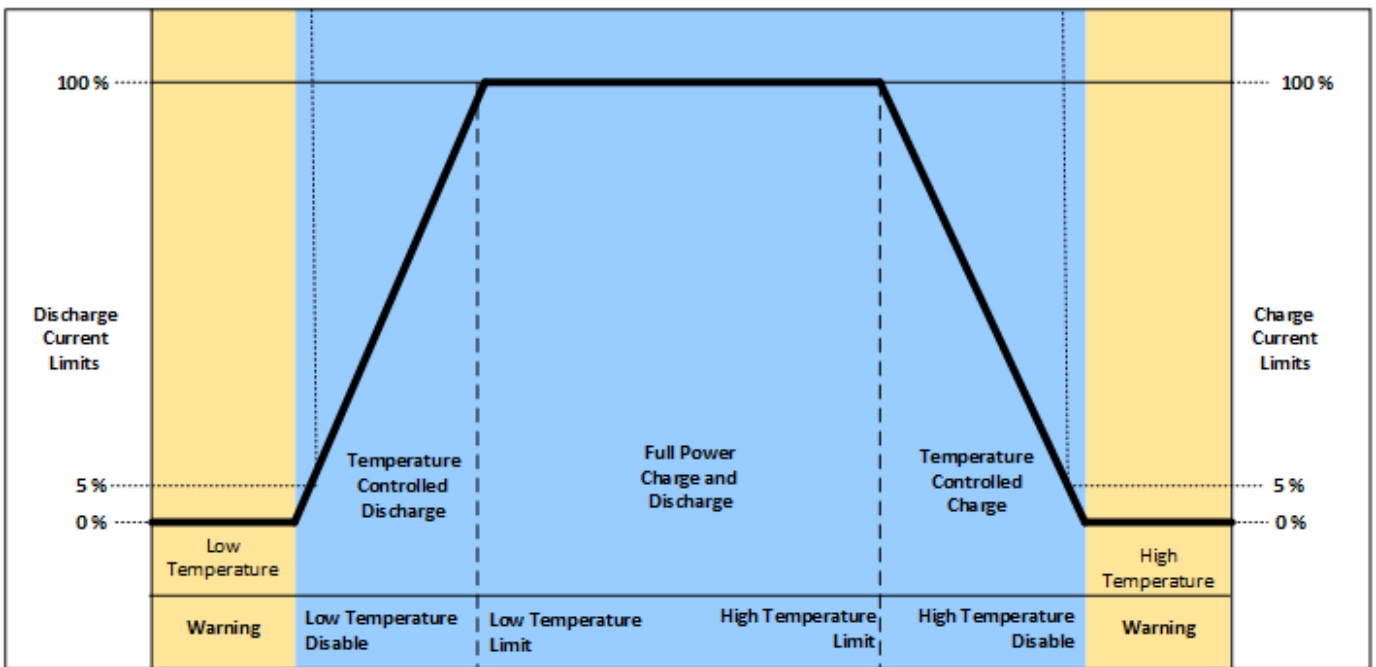


Figure 69. Typical Arrangement of Temperature Current Limits

Most systems will make use of thresholds configured in the following order of decreasing thermistor temperature.

Table 14. Charge Temperature Operational Limits

Register	Setting
stack_fault_charge_therm_over.thresh	The limit within the fault zone above which an explicit user operation is required to bring the system back into an operating state.
stack_fault_charge_therm_hi.thresh	The upper limit of the warning charging zone as per cell specification.
stack_warn_charge_therm_hi.thresh	The upper limit of the operating charging zone. Set just above stack_current_limit.temperature_charge_max.

Register	Setting
stack_current_limit.temperature_charge_max	The temperature at which current limits approach 0% during charging.
stack_current_limit.temperature_charge_high	The temperature at which current limits are reduced from 100% during charging.
stack_current_limit.temperature_charge_low	The temperature at which current limits are reduced from 100% during charging.
stack_current_limit.temperature_charge_min	The temperature at which current limits approach 0% during charging.
stack_warn_charge_therm_lo.thresh	The lower limit of the operating charging zone. Set just below stack_current_limit.temperature_charge_min.
stack_fault_charge_therm_lo.thresh	The lower limit of the warning charging zone as per cell specification.
stack_fault_charge_therm_under.thresh	The limit within the fault zone below which an explicit user operation is required to bring the system back into an operating state.

Table 15. Discharge Temperature Operational Limits

Register	Setting
stack_fault_discharge_therm_over.thresh	The limit within the fault zone above which an explicit user operation is required to bring the system back into an operating state.
stack_fault_discharge_therm_hi.thresh	The upper limit of the warning discharging zone as per cell specification.
stack_warn_discharge_therm_hi.thresh	The upper limit of the operating discharging zone. Set just above stack_current_limit.temperature_discharge_max.
stack_current_limit.temperature_discharge_max	The temperature at which current limits approach 0% during discharging.
stack_current_limit.temperature_discharge_high	The temperature at which current limits are reduced from 100% during discharging.
stack_current_limit.temperature_discharge_low	The temperature at which current limits are reduced from 100% during discharging.
stack_current_limit.temperature_discharge_min	The temperature at which current limits approach 0% during discharging.
stack_warn_discharge_therm_lo.thresh	The lower limit of the operating discharging zone. Set just below stack_current_limit.temperature_discharge_min.
stack_fault_discharge_therm_lo.thresh	The lower limit of the warning discharging zone as per cell specification.
stack_fault_discharge_therm_under.thresh	The limit within the fault zone below which an explicit user operation is required to bring the system back into an operating state.

The temperature charge and discharge thresholds can be configured in a similar manner to how the cell voltage thresholds ([Section 7.5.2, “Cell Voltage Thresholds”](#)) are configured.

User-defined triggers are also available for high and low thermistor temperature during both charge and discharge.

Table 16. User-Defined Charge Temperature Triggers

Register	Setting
stack_trig_charge_therm_hi.thresh	User-defined threshold for charge high temperature trigger.
stack_trig_charge_therm_lo.thresh	User-defined threshold for charge low temperature trigger.

Table 17. User-Defined Discharge Temperature Triggers

Register	Setting
stack_trig_discharge_therm_hi.thresh	User-defined threshold for discharge high temperature trigger.
stack_trig_discharge_therm_lo.thresh	User-defined threshold for discharge low temperature trigger.

7.5.4. Stack Current Thresholds

The following diagrams illustrate how current trigger thresholds are configured in typical applications.

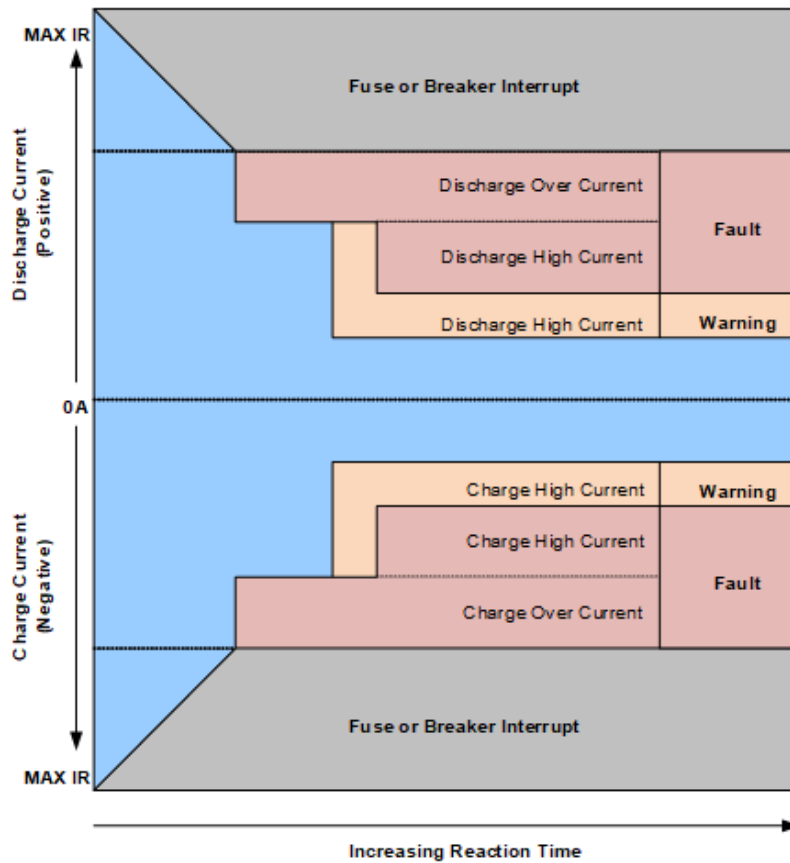


Figure 70. Typical Arrangement of Current Thresholds

The stack current thresholds are used to define the limits of the operating zone and non-operating zone for charge and discharge currents. These limits must factor in the specifications of the battery cells as well as the limits of any DC current-carrying paths in the stack.

Table 18. Stack Current Operational Limits

Register	Setting
stack_fault_charge_current_over.thresh	The limit within the fault zone above which an explicit user operation is required to bring the system back into an operating state.
stack_fault_charge_current_hi.thresh	The limit of the warning charging zone as per cell specification and stack design limits.
stack_warn_charge_current_hi.thresh	The limit of the operating charging zone as per application requirements.
stack_warn_discharge_current_hi.thresh	The limit of the operating discharging zone as per application requirements.
stack_fault_discharge_current_hi.thresh	The limit of the warning discharging zone as per cell specification and stack design limits.
stack_fault_discharge_current_over.thresh	The limit within the fault zone below which an explicit user operation is required to bring the system back into an operating state.

The stack current thresholds can be configured in a similar manner to how the cell voltage thresholds ([Section 7.5.2, “Cell Voltage Thresholds”](#)) are configured. The stack_fault_[charge/discharge]_current_hi faults are typically configured with a small amount of trip time hysteresis (e.g. approximately 100–200 ms).

User-defined triggers are also available for charge and discharge currents.

Table 19. User-Defined Stack Current Triggers

Register	Setting
stack_trig_charge_current_hi.thresh	User-defined charge current trigger.
stack_trig_discharge_current_hi.thresh	User-defined discharge current trigger.



Charge current thresholds are specified as negative values and discharge current thresholds are specified as positive values.

7.5.5. Stack Voltage Thresholds

The following diagrams illustrate how stack voltage trigger thresholds are configured in typical applications.

Shutdown	Non-Operational		Operational Voltage Range				Non-Operational			
Under Voltage	Under Voltage	Low Voltage	Low Voltage					High Voltage	High Voltage	Over Voltage
Lockout	Fault		Warning					Warning	Fault	

Increasing Voltage

Figure 71. Typical Arrangement of Stack Voltage Thresholds

These thresholds also affect the current limits of the system as shown below.

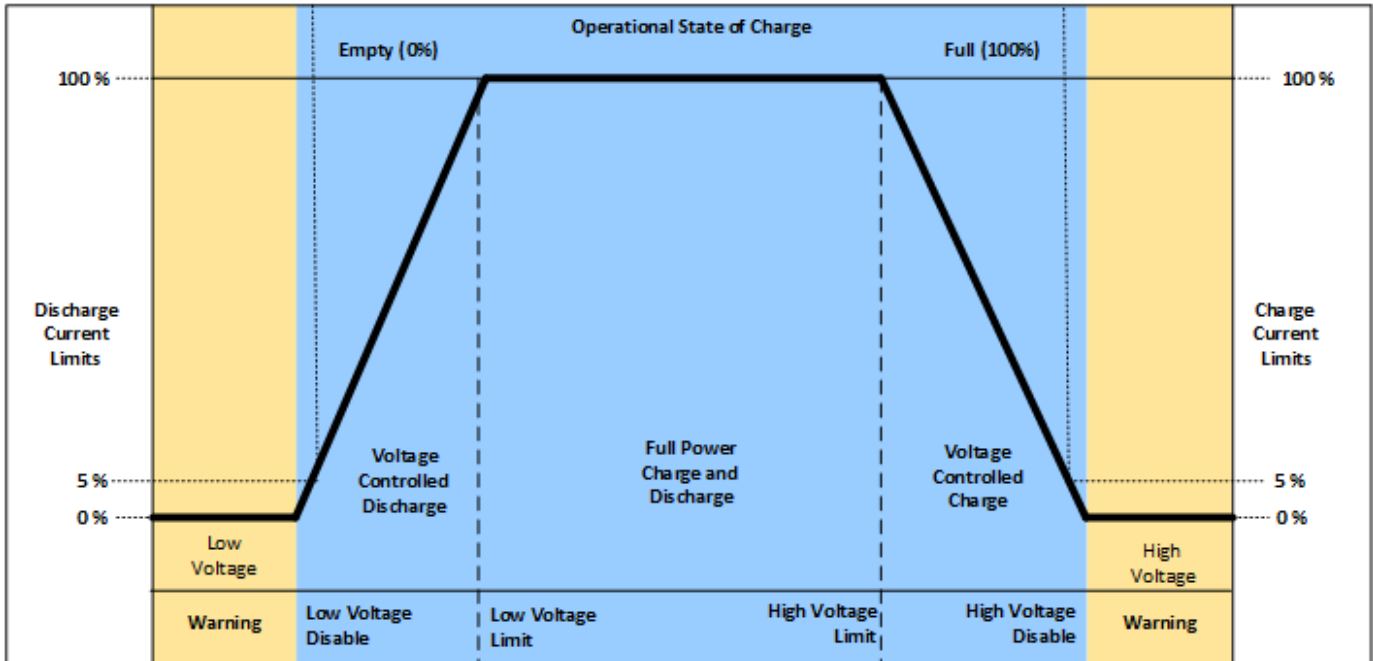


Figure 72. Typical Arrangement of Stack Voltage Current Limits

Stack voltage thresholds are used to define the operating voltage limits of the overall battery stack design. These thresholds are used to enforce the design limits of the battery stack or DC bus as a whole. For example, it may be necessary to limit the overall stack voltage within a certain limited range to maintain compatibility with a specific charger or inverter. Stack voltage limits also are used to ensure that average cell voltage is maintained within specified limits.

Most systems will make use of thresholds configured in the following order of decreasing stack voltage.

Table 20. Stack Voltage Operational Limits

Register	Setting
stack_fault_voltage_over.thresh	The limit within the fault zone below which an explicit user operation is required to bring the system back into an operating state.
stack_fault_voltage_hi.thresh	The upper limit of the warning zone as per application requirements.
stack_warn_voltage_hi.thresh	The upper limit of the operating zone. Set just above stack_current_limit.voltage_stack_max.
stack_current_limit.voltage_stack_max	The voltage at which charge limits approach 0%. Set as per application requirements.
stack_current_limit.voltage_stack_high	The voltage at which charge current limits are reduced from 100%. Set as per application requirements.
stack_current_limit.voltage_stack_low	The voltage at which discharge current limits are reduced from 100%. Set as per application requirements.
stack_current_limit.voltage_stack_min	The voltage at which discharge limits approach 0%. Set as per application requirements.
stack_warn_voltage_lo.thresh	The lower limit of the operating zone. Set just below stack_current_limit.voltage_stack_min.
stack_fault_voltage_lo.thresh	The lower limit of the warning zone as per application requirements.
stack_fault_voltage_under.thresh	The limit within the fault zone below which an explicit user operation is required to bring the system back into an operating state.
stack_uvlo_stack_voltage.thresh	The under-voltage lockout threshold for system shutdown.



The under-voltage lockout trigger itself does not shut down the BMS when the stack voltage drops below this level.

The stack voltage thresholds can be configured in a similar manner to how the cell voltage thresholds ([Section 7.5.2, “Cell Voltage Thresholds”](#)) are configured.

User-defined triggers are also available for high and low stack voltages.

Table 21. User-Defined Stack Voltage Triggers

Register	Setting
stack_trig_voltage_hi.thresh	User-defined high stack voltage trigger.
stack_trig_voltage_lo.thresh	User-defined low stack voltage trigger.

Since stack voltage is measured independently from individual cell voltages in Nuvation Energy BMS, another important configuration threshold is the limit for mismatch between the overall stack voltage measurement and the sum of individual cell voltages.

stack_fault_voltage_sum.thresh

- The upper limit of the operating voltage mismatch zone
- Set as per application requirements (typically at least 5–10% of stack_fault_voltage_over.thresh)

7.5.6. External Controller Heartbeat

Nuvation Energy BMS can be configured to require a heartbeat signal from an external controller in order to keep the stack online and out of fault state. A write to the MESA controller heartbeat register is expected at least once during the watchdog period. If a multi-stack controller—such as the Nuvation Energy Multi-Stack Controller—is in use, it can periodically write to this register to keep the stack out of fault state.

`sc_controller_wdt.period`

- Trip time for watchdog if heartbeat disappears
- Set to 5 seconds or as per application requirements

`sc_fault_controller_wdt.disabled`

- Set to 0 to enable controller watchdog
- Set to 1 to disable controller watchdog

If this feature is not used, the watchdog fault should be disabled.

7.6. Control Settings

7.6.1. Current Control

Nuvation Energy BMS controls the current flowing through a battery stack:

1. During connection or disconnection of the battery to prevent harmful transient current events
2. During operation of a connected battery to keep the battery within its operational limits
3. During operation of a battery to keep the individual cells at a balanced state of charge
4. During a fault condition in order to protect the battery

Control for cases (1) and (4) is achieved through external switching devices that are under the control of Nuvation Energy BMS. This control is limited to hard switching. Control for case (2) is achieved through current limiting signals that are used by chargers and inverters to throttle current dynamically. Control for case (3) is implemented within Nuvation Energy BMS itself through passive balancing loads that are under control of a configurable balancing algorithm.

7.6.1.1. Stack Switch Functions

Nuvation Energy BMS defines three contactor switch functions for use within typical battery configurations:

- **Pre-charge Switch:** Connected during pre-charge operation only. Disconnected under fault condition.
- **Main Switch:** Connected after any pre-charge operation completes. Disconnected under fault condition.
- **Stack Switch:** Connected whenever either the pre-charge switch or the main switch is connected. Disconnected under fault condition.

While a *pre-charge contactor* is optional, virtually all systems require a *main contactor* to protect the battery from unsafe conditions.

A *stack contactor* is often used in conjunction with a main contactor, i.e. at the other end of the stack to isolate the battery stack completely from the DC bus and provide a level of contactor redundancy.

Stack connection and disconnection sequencing is illustrated in the state diagram below.

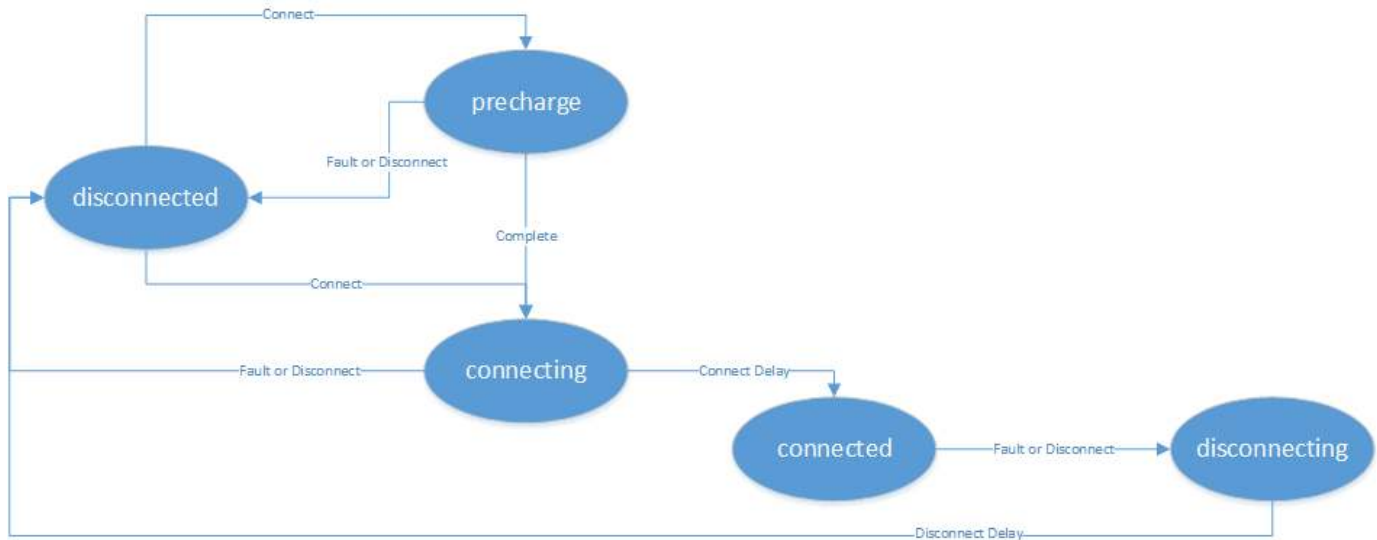


Figure 73. Battery Stack States and Transitions

As a system is connected and disconnected from the DC bus, a configurable sequencing delay is inserted before and after the connected state. During the connected state, the BMS uses current limits to control current flowing into and out of the stack. During all other states, current limits are set to zero. This allows for graceful switching behavior with no current flow under normal connect and disconnect requests.



The switch functions defined here must be mapped to appropriate outputs for use in an actual system. This process is covered in detail in [Section 7.7, “Input / Output Assignment”](#).

7.6.1.1.1. Auto-Connection Setting

It is sometimes desired for the Nuvation Energy BMS to automatically initiate a connection of a battery stack when:

- The BMS powers on
- After all faults have been cleared

This operation can be configured with the following register setting.

`stack_control.auto_connect`

- When set to a value of one, the BMS will initiate a connection of the battery stack if there are no faults triggered

- When set to a value of zero, the BMS waits for a connection request from the Operator Interface or through one of its external interface. Note a stack will not connect if there is any faults triggered.

7.6.1.1.2. Pre-Charge Switch Settings

If enabled, the pre-charge switch is engaged for a fixed (but configurable) amount of time during the pre-charge state.

A bias current can be read prior to engaging the pre-charge contactor. The bias current measured is subtracted from subsequent pre-charge current measurements. If the pre-charge over-current fault is configured, the pre-charge will terminate if the fault is triggered. At the end of the pre-charge period, the following conditions are evaluated:

- At least one stack current sample was received
- The absolute value of the stack current minus the bias current is compared to be smaller than a maximum threshold value

If all of the above conditions are true then the pre-charge operation was successful. Otherwise a pre-charge timeout fault is tripped. Upon successful pre-charge completion, the stack connection sequence continues. During the remaining connection sequence, both the main and pre-charge contactors are engaged. At the end of the connection sequence the pre-charge contactor is de-energized.

Pre-charge behavior is configured through the following registers as required for a particular application.

`stack_control.precharge_bias_delay`

- Determines the fixed amount of time prior to pre-charge to measure any bias current in the battery stack
- The bias current is stored in the register `stack_control.precharge_bias_current` at the end of this delay
- The bias current is removed from subsequent pre-charge current measurements before applying pre-charge fault limits.
- If enabled set to a minimum of 1 second otherwise set to 0 seconds

`stack_control.disable_precharge`

- If set to 1 then pre-charge is disabled
- If pre-charge is disabled the system will skip the pre-charge step and immediately enter the next part of the connection sequence

`stack_control.precharge_delay`

- Determines the fixed amount of time the pre-charge path is energized if enabled
- Set based upon pre-charge hardware power and thermal ratings
- This delay is limited to a minimum duration of 1 second and a maximum duration of 10 seconds



`stack_control.disable_precharge` must be set to 0 for this register to have an effect

`stack_control.disable_connecting`

- If value is set to 1, the system will immediately enter the connected state after pre-charge completes

`stack_control.connect_delay`

- Determines the minimum time both the pre-charge and main contactors are energized during connection
- This connection delay occurs after the pre-charge delay has successfully completed
- Set to a minimum of 1 second to ensure both contactors are energized at the end of the duration
- This delay is limited to a maximum duration of 10 seconds



`stack_control.disable_connecting` must be set to 0 for this register to have an effect

`stack_control.precharge_max_current`

- Determines the maximum current flow at the end of `stack_control.precharge_delay` under which pre-charge can complete successfully
- Set to ensure any in-rush currents upon main switch connection are within system ratings
- Set to zero to disable pre-charge

`stack_control.voltage_mismatch_thresh`

- Determines the maximum absolute voltage difference between the stack voltage and the DC Bus voltage at the end of `stack_control.precharge_delay` under which pre-charge can complete successfully
- Set to ensure that the stack and DC bus have sufficiently equalized before continuing the connection sequence.

`stack_fault_precharge_over_current.thresh`

- Sets the over-current limit at any time during pre-charge
- If the fault is triggered, pre-charge will terminate immediately
- Limits the power dissipated of a pre-charge resistor during a short condition allowing for a smaller resistor

`stack_fault_precharge_timeout.disabled`

- Must be set to zero if pre-charge is enabled

A pre-charge operation only completes successfully if the stack current magnitude falls below the maximum pre-charge current within the configured delay time and the `stack_fault_precharge_over_current` does not trip.



If pre-charge is enabled the fault `stack_fault_precharge_timeout` must also be enabled.

7.6.1.1.3. Sequencing Delays

The following registers are used to configure the sequencing delays used before a stack enters the connected or disconnected state.

`stack_control.connect_delay`

- The delay between the contactors connecting and current limits engaging after a connect request
- This delay is important for systems using pre-charge
- When pre-charge is used the delay must be a minimum of one second and is limited to 10 seconds maximum



`stack_control.disable_connecting` must be set to 0 for this register to have an effect, otherwise the system will behave as if this delay is 0s

`stack_control.disconnect_delay`

- The delay between current limits disengaging and the contactors disconnecting after a disconnect request
- This delay is important to allow a PCS time to ramp down before the BMS opens the contactors
- This delay should not be less than one second and is limited to 10 seconds maximum



The [Section 7.10.4, "Fault Pilot"](#) is expected to be configured to allow stack connection to be maintained for `stack_control.disconnect_delay` period and have the PCS ramp power down before contactors. Please refer to this section for details when that fault pilot period is not maintained. This delayed response to disconnection will help in reducing the number of events that could degrade [Section 7.10.9, "Contactor Life Tracking"](#).

7.6.2. Contactor Configuration

Contactors that are used internally to the G4 Stack Switchgear must have a specific configuration to match its design and wiring.

Contactors are also configured as directional or non-directional. A directional contactor has a preferred direction for breaking current. Nuvation Energy BMS will open any non-directional contactors or directional contactors aligned with stack current flow first. Directional contactors that are opposed to stack current flow will be opened after a configurable delay. An optional feedback mechanism can be configured for contactors with a feedback line. Once a contactor's feedback output is wired into a GPI and configured, if the contactor fails to open/close, the feedback line will indicate the problem and the BMS can flag a fault.

The following registers are used to configure the internal contactors.

7.6.2.1. Contactor Configuration

Main Contactor

- `stack_contactor[0].installed = 1`

- `stack_contactor[0].inverted = 0`
- `stack_contactor[0].feedback_enable = 1`
- `stack_contactor[0].address_enable = 1`
- `stack_contactor[0].address = @stack_control[0].main_switch_state`
- `stack_contactor[0].delay = 1000`
- `stack_contactor[0].direction = 1`

Pre-Charge Contactor

- `stack_contactor[1].installed = 1`
- `stack_contactor[1].inverted = 0`
- `stack_contactor[1].feedback_enable = 1`
- `stack_contactor[1].address_enable = 1`
- `stack_contactor[1].address = @stack_control[0].precharge_switch_state`
- `stack_contactor[1].delay = 0`
- `stack_contactor[1].direction = 0`

Stack Contactor

- `stack_contactor[2].installed = 1`
- `stack_contactor[2].inverted = 0`
- `stack_contactor[2].feedback_enable = 1`
- `stack_contactor[2].address_enable = 1`
- `stack_contactor[2].address = @stack_control[0].stack_switch_state`
- `stack_contactor[2].delay = 1000`
- `stack_contactor[2].direction = 2`

Unused Contactor

- `stack_contactor[3].installed = 0`
- `stack_contactor[3].feedback_enable = 0`
- `stack_contactor[3].address_enable = 0`
- `stack_contactor[3].address = 0`

7.6.3. Current Limits

The Nuvation Energy BMS supplies configurable current limits for the charge and discharge directions of a battery stack. The current limits provide a feedback to an external control system to gradually taper the current demanded from the battery as the stack approaches its full (100% SOC) and empty (0% SOC) states.

The current limits are calculated by taking the minimum of the following input variables:

1. Cell Voltage (refer to [Figure 67, "Typical Arrangement of Cell Voltage Current Limits"](#))
2. Cell Temperature (refer to [Figure 69, "Typical Arrangement of Temperature Current Limits"](#))
3. Stack Voltage (refer to [Figure 72, "Typical Arrangement of Stack Voltage Current Limits"](#))

The charge/discharge current limits can be accessed via the following outputs:

BMS Registers

`stack_current_limit.charge_current_limit`

- The charge current limit in milliamperes.

`stack_current_limit.discharge_current_limit`

- The discharge current limit in milliamperes.

Sunspec Modbus Points

SunSpec 802 Model: Maximum Charge Current (MaxBatACha)

- Modbus address 40106 at unit identifier 1
- Single point of unsigned data
- Units of Amperes once scaled

SunSpec 802 Model: Maximum Discharge Current (MaxBatADischa)

- Modbus address 40107 at unit identifier 1
- Single point of unsigned data
- Units of Amperes once scaled



A scaling factor has to be applied to the current limits read from the Sunspec 802 model. The scaling factor can be read from Modbus address 404014. The scaling factor is an exponent of a base 10 adjust applied to the data read. (e.g. a scaling factor of -3 means the current limits are divided by 1000). The scaling factor is constant for the Battery Management System operation.

7.6.3.1. Current Limit Behavior

The calculated current limits are only updated to the [outputs](#) only when the Nuvation Energy BMS is in the [connected state](#). Outside of this state, the current limits are set to zero to indicate that the external power controller should not be charging or discharging the battery stack. This behavior is most important during the [Disconnecting](#) state. When the current limits do go to zero, there will be a time granted to the external controller to ramp down power before the contactors are opened. Such behaviour allows the [contactor life](#) to be protected and avoid opening Battery Management System contactors at elevated currents.

7.6.3.2. Current Limit Configuration

The configuration for the limits of the current limits for each contributing measurement was provided in earlier sections:

- Cell Voltage (refer to [Table 12, "Cell Voltage Operational Limits"](#))
- Cell Temperature (refer to both [Table 14, "Charge Temperature Operational Limits"](#) and [Table 15, "Discharge Temperature Operational Limits"](#))
- Stack Voltage (refer to [Table 20, "Stack Voltage Operational Limits"](#))

The following sections detail additional configuration of current limits.

7.6.3.2.1. Maximum Operating Currents

The maximum continuous operating charge and discharge currents must be configured for current limiting to function properly. These values correspond to the current limit values that will be used during normal wide-open operation (i.e. no throttling).

`stack_current_limit.max_charge_current`

- Magnitude of maximum continuous operating charge current

`stack_current_limit.max_discharge_current`

- Magnitude of maximum continuous operating discharge current



The current limits given above are magnitudes only—i.e. both charge and discharge current limits are positive.

7.6.3.2.2. Minimum Charge Current

The minimum charge current is the constant charging current that should be applied as the battery reaches the end of its charge cycle. The BMS will ensure that the charge current limit does not fall below this minimum value until the battery has reached its maximum charging voltage.

`stack_current_limit.min_charge_current`

- Minimum charge current to be applied at the end of charge cycle
- Set as per battery manufacturer recommendations (typically below C/20)

This setting must be configured in conjunction with the full thresholds defined by [Stack Capacity](#). For example, the stack can be considered full once the current limit reaches the minimum charge current.



The current limit given above is magnitude only—i.e. charge current limit is positive.

7.6.3.2.3. Current Limiting Response Times

The current limiting control loop can be tuned for stable and responsive behavior in a variety of systems. Two independent settling times are provided to allow independent adjustment of the response to decreases in current limits (attack time) and increases in current limits (decay time).

`stack_current_limit.attack_settling_time`

- Settling time for decreases in current limits
- Typically this is between 1 and 5 seconds

`stack_current_limit.decay_settling_time`

- Settling time for increases in current limits
- Typically this is on the order of 10x larger than `stack_current_limit.attack_settling_time`

`stack_current_limit.nonlinear_rolloff`

- Enables a non-linear roll-off of the current limits when set to True (i.e. a value of one)
- Current limits will follow a linear response when set to False (i.e. a value of zero)

Since the attack time determines how quickly the current limits can respond before a potential fault conditions opens a switch, it is critical to have sufficient control bandwidth here to avoid tripping faults.

A non-zero settling time is critical in most applications to avoid oscillations in the presence of noise and other imperfections in high-power control of the DC current in the charger and/or inverter.

When the nonlinear roll-off is enabled, the slope of the current limits at the end of the charge/discharge regions will be smaller (closer to zero) than the linear response. A nonlinear roll-off will reduce large changes in variables (such as the cell voltage) on the current limit output.

7.6.4. Passive Cell Balancing

When multiple cells are connected in series to form a larger battery stack, it is important to ensure each cell is giving equal contributions to the system. The effects of a single low State-of-Charge or a single high State-of-Charge cell will dominate the performance of the large battery stack. The act of equalizing State-of-Charge of multiple series-connected cells is called *balancing* and there are many types of balancing.

Nuvation Energy BMS implements a *passive* balancing solution. Cells with high State-of-Charge are discharged via internal bleed resistors which are enabled on a per-cell basis. Properly adjusting the algorithm settings for your cells is necessary to achieve a well-performing system.



Balancing is not supported on G4 Cell Interface - 12V 4 channel.

A number of configurable settings are used to fine-tune the passive balancing algorithm for voltage, temperature, current, and duty cycle.

Cell balancing is achieved by monitoring the cell voltages and apply balancing to the cells with the highest voltages. The balancer must be first enabled for balancing to take place.

`stack_cell_balancer.enabled`

- Enables or disables balancing operation
- Set to 1 to enable
- Set to 0 to disable

7.6.4.1. Voltage Based Cell Balancing

7.6.4.1.1. Settings for Voltage Based Cell Balancing

Both absolute and relative cell voltage thresholds are used to safely balance a stack of batteries.

min_enable_voltage is the absolute threshold that determines the voltage below which a cell will not be balanced. This prevents over discharging in a system even with large imbalances.

voltage_delta is the relative threshold that is used to determine when a system is balanced. Balancing for a given cell will take place when that cell's voltage is at least `voltage_delta` millivolts higher than the minimum cell voltage.

`stack_cell_balancer.min_enable_voltage`

- Minimum voltage threshold for balancing (mV). The minimum cell voltage threshold for balancing must be greater than, or equal to, 1.1 V.
- Typically this is set higher than `stack_current_limit.voltage_cell_high`

`stack_cell_balancer.voltage_delta`

- Delta voltage threshold for balancing (mV)
- Delta between a given cell's voltage and the minimum cell voltage
- Typically this is set between 5 and 25 mV



If `stack_cell_balancer.voltage_delta` is set to zero, the system will continue balancing down all cells (even if the difference between min and max is zero) until they reach `stack_cell_balancer.min_enable_voltage`. This mode can be used to passively balance all cells in a stack to a specific open-circuit voltage.

7.6.4.1.2. Cell Balancing Temperature Settings

Temperature limits are used to prevent the cells and the BMS module from overheating. If the following temperature threshold is exceeded, balancing is disabled for all cells in the stack.

`stack_cell_balancer.max_enable_temperature`

- The upper cell temperature limit, in degrees °C, as measured by thermistors external to the BMS
- Set per application requirements.

7.6.4.1.3. Cell Balancing Current Settings

Thresholds based on stack current allow the balancer to be fine-tuned to run during specific portions of the charge and discharge cycle.

`stack_cell_balancer.min_enable_current`

- The minimum current at which balancing remains enabled (mA)
- This is typically set to a negative value to enable balancing below certain charge currents
- For example, a value of -10000 causes balancing to be **disabled** when charging at greater than 10 A

`stack_cell_balancer.max_enable_current`

- The maximum current at which balancing remains enabled (mA)
- This may be a negative or positive value depending upon application requirements
- For example, a value of 200 causes balancing to be **disabled** when discharging at greater than 200 mA

The two most common use cases are:

1. **Balance only while charging:** In this case, both the minimum and maximum current thresholds are set to negative values that correspond to the range of charge currents under which balancing should take place.
2. **Balance while charging and holding:** In this case, the maximum current threshold is set to a slightly positive value so that the stack will balance when it is idle or disconnected. The level of discharge current flow tolerated during idle balancing is application-specific and is thus configurable.

7.6.4.2. Cell Balancing Duty Cycle

All the energy that is removed from a cell by passive balancing is dissipated as heat. If the amount of heat dissipated is too great, its desirable to reduce the amount of balancing applied to the cells. Passive balancing is applied for the majority of a cell voltage scan period defined by the register `sc_linkbus[0].scan_period`. Balancing is disabled every linkbus scan cycle to measure the cell voltages. The register `sc_linkbus[0].balance_settle_period` provides the period of time balancing is turned off before measuring cell voltages. The duration of balancing applied to all cells can be reduced by increasing this delay period.



The `sc_linkbus[0].balance_settle_period` register value must be between a minimum of 50 ms and must be smaller then the linkbus scan period.

7.7. Input / Output Assignment

The G4 Stack Switchgear unit’s internal Stack Controller implements the following inputs and outputs:

- Fault Pilot output signal (sent on the Stack Bus)
- Four general purpose digital outputs
- Four general purpose digital inputs

The Fault Pilot signaling mechanism is a dedicated hardware signaling path between the G4 Stack Switchgear unit’s internal Stack Controller and G4 Stack Switchgear unit’s internal Power Interface that is used to rapidly open the contactors in the case of a fault condition or processor failure. It is configurable for advanced applications that may require customized behavior ([Section 7.10.4, “Fault Pilot”](#)).

The G4 Stack Switchgear unit’s internal Power Interface implements the following inputs and outputs:

- Fault Pilot input signal (received from the Stack Bus)

- Four contactor output drivers

Contactor outputs and general purpose digital inputs and outputs present on Nuvation Energy BMS are implemented to allow for assignment of pin functions through configuration rather than through hard-wired implementation. This means that the pins connected to any external contactors, switches, or other digital inputs or outputs must be mapped in configuration to the appropriate BMS function for that system.



The G4 Stack Switchgear unit's internal Stack Controller and Power Interface inputs and outputs have specific assignments and configuration which can not be changed/modified.

7.7.1. General Purpose Digital Outputs

The most commonly used *General Purpose Digital Output* functions are:

- **Charge current disable:** A control signal that is asserted when charging should be disabled
- **Discharge current disable:** A control signal that is asserted when discharging should be disabled
- **Fault state:** A signal that is asserted when faults are present within the system
- **Trigger state:** A trigger signal for external devices that is asserted when a specific trigger within the system is tripped

General Purpose Digital Output functions are assigned through the following configuration registers. The index **n** is the zero-based index of the *General Purpose Digital Output* hardware pin.

`sc_gpo[n].address_enabled`

- Set this to 1 to enable the function specified in `sc_gpo[n].address`

`sc_gpo[n].inverted`

- When set to 0, GPO output switch is **closed** when assigned function value is 0
- When set to 1, GPO output switch is **closed** when assigned function value is 1

`sc_gpo[n].address`

- Determines the function mapped to output

The configuration settings for the most common functions are illustrated in the table below.

Table 22. Common Assignments for General Purpose Digital Output

Function	<code>sc_gpo[n].address</code>	<code>sc_gpo[n].inverted</code>
Charge Current Enable	@stack_current_limit.charge_current_disable	0
Discharge Current Enable	@stack_current_limit.discharge_current_disable	0
Fault State	@stack_trigger_summary.fault	1
Trigger State	@trigger_name.trig	1

For advanced applications, *General Purpose Digital Outputs* may be configured to be driven from any

Boolean register within the BMS.



The G4 Stack Switchgear unit’s internal Power Interface also has GPOs via the pi_gpo but these should not be configured for general usage.

7.7.2. General Purpose Digital Inputs

The most commonly used *General Purpose Digital Input* functions are:

- **Clear faults:** Hardware input to clear any latched fault conditions
- **Connect request:** Request to connect the battery stack to the DC bus
- **Auxiliary contactor feedback:** Provides feedback to compare an auxiliary contactor state with current contactor state.

General Purpose Digital Input functions are assigned through the following configuration registers. The index **n** is the zero-based index of the *General Purpose Digital Input* hardware pin.

sc_gpi[n].address_enabled

- When set to 1, the state of the input pin is propagated to the destination register address

sc_gpi[n].inverted

- When set to 0, GPI input value is 1 if hardware GPI is asserted
- When set to 1, GPI input value is 0 if hardware GPI is asserted

sc_gpi[n].address

- The destination register address to populate with the state of the input pin

sc_gpi[n].rising_edge_triggered

- When set to 1, the input value will be populated to the destination upon detection of a rising edge

sc_gpi[n].falling_edge_triggered

- When set to 1, the input value will be populated to the destination upon detection of a falling edge

If the *General Purpose Digital Input* is configured as neither rising nor falling edge triggered, the input value is continuously populated into the destination address. The configuration settings for the most common functions are illustrated in the table below.

Table 23. Common Assignments for General Purpose Digital Input

Function	sc_gpi[n].address	sc_gpi[n].inverted	sc_gpi[n].rising_edge_triggered
Clear Faults	@stack_trigger_summary.clear_faults	0	1
Connect Request	@stack_control.requested_state	0	1
Contactor Feedback	@stack_contactor[m].feedback_value	0	0

For advanced applications, *General Purpose Digital Input* may be configured to drive any Boolean register within the BMS.

7.8. External Communication Interface Settings

The G4 Stack Switchgear supports a 10/100 Ethernet interface for Modbus TCP and Operator Interface connectivity with external systems. Although its internal Stack Controller module supports CAN Bus as well as RS485 for Modbus RTU, these interfaces are not exposed on the G4 Stack Switchgear.

7.9. Measurement Calibration

The Nuvation Energy BMS provide calibration settings which allow the system to be fine-tuned for integration with a variety of measurement sensors. The preset values that ship with the BMS can be adjusted as required.

7.9.1. Thermistor Calibration

Nuvation Energy BMS can be configured to use any thermistor. A function that converts measured voltage into temperature must be determined and configured for the particular thermistor in use.

A sixth-order polynomial is used within the BMS to model this transfer function:

$$T(v) = C_0 + C_1 \cdot v + C_2 \cdot v^2 + C_3 \cdot v^3 + C_4 \cdot v^4 + C_5 \cdot v^5 + C_6 \cdot v^6$$

`stack_therm_poly.coeff0` (Factory)

- Set to C_0 (Floating-point value)

`stack_therm_poly.coeff1` (Factory)

- Set to C_1 (Floating-point value)

`stack_therm_poly.coeff2` (Factory)

- Set to C_2 (Floating-point value)

`stack_therm_poly.coeff3` (Factory)

- Set to C_3 (Floating-point value)

`stack_therm_poly.coeff4` (Factory)

- Set to C_4 (Floating-point value)

`stack_therm_poly.coeff5` (Factory)

- Set to C_5 (Floating-point value)

`stack_therm_poly.coeff6` (Factory)

- Set to C_6 (Floating-point value)

The thermistor voltage is read by a 10 k Ω pull-up to 3.00 V DC. The first step in calculating coefficients for a thermistor is to create a table in Microsoft Excel™ or equivalent spreadsheet application with the following columns:

Temperature (°C)	Resistance (Ω)	V _{adc} (V)
-40	334274	2.91286
-35	241323	2.88063
....
125	336.75	0.09773

Temperature and resistance values are taken from the datasheet of the thermistor. V_{adc} is calculated using the following formula:

$$V_{adc} = 3.0 \left(\frac{R}{R + 10000} \right)$$

Using the line plot feature, create a graph of V_{adc} vs Temperature and turn on the trend line. Then modify the trend line to be a 6th order polynomial type, and display the equation on the chart. The equation will look like:

$$T(V) = (151.68) + (-352.94)V + (549.33)V^2 + (-482.08)V^3 + (223.69)V^4 + (-51.518)V^5 + (4.5693)V^6$$

These polynomial coefficients can then be used to configure Nuvation Energy BMS for this thermistor. An example plot of these measurements is shown in the next figure.

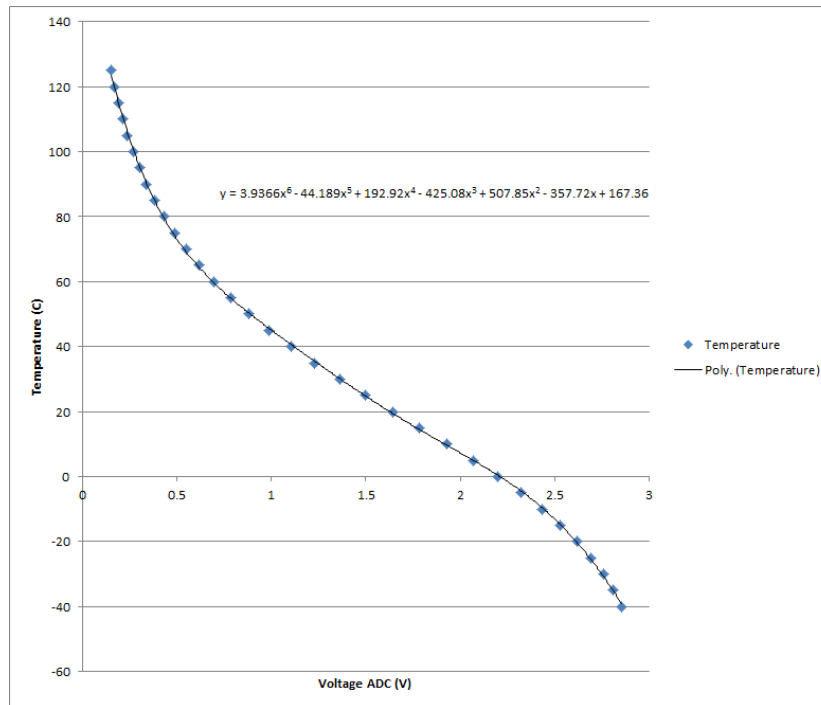


Figure 74. Typical Voltage ADC vs Thermistor Plot

7.9.2. Stack Current Calibration

Current measurements are made using a current sensing analog front-end (AFE) .

7.9.2.1. Stack Current Factory Calibration

The factory calibration of current readings is implemented according to the following formula that converts ADC readings into a current:

$$I(\mathit{currentadc}) = \mathit{currentadc} \left(\frac{\mathit{multiplier}}{\mathit{divider}} \right)$$

The multiplier and divider are set in configuration as follows.

`pi_afe_iadc.multiplier` (Factory)

`pi_afe_iadc.divider` (Factory)

=== Stack Current Field Calibration

Units that have been factory locked may still require tuning for variability in shunts on a per-unit basis. The equation for Stack Current Field Calibration adjustment is:

$$I(\mathit{rawcurrent}) = \mathit{rawcurrent} \left(1 + \frac{\mathit{gain}}{100000} \right)$$

The gain is set in the configuration as follows.

`stack_power.current_gain` (Configuration)

- Fine tuning gain for raw current values.
- A value of 1000 = +1% adjustment ($\mathit{rawcurrent} * 1.01$)
- A value of -1000 = -1% adjustment ($\mathit{rawcurrent} * 0.99$).

At the factory, appropriate limits for the gain are defined to ensure a user does not misconfigure the system. The gain limit is set in the configuration as follows:

`stack_power.current_gain_limit` (Factory)

- Absolute value of the limit for gains on raw current values.
- If the `stack_power.current_gain` register is set to outside of this limit, the gain applied will be limited to this value.



Nuvation has pre-calibrated each G4 Stack Switchgear with its own gain and limit. Each unit will have its own set of calibrations which must be maintained when applying an upgrade or configuration update. Make sure to capture and record the calibration of each unit for this purpose. If you have lost this calibration information, please contact support@nuvationenergy.com with the serial number(s) to retrieve this data.

7.9.2.2. Charge Deadband Setting

In addition to calibrating current readings, it is also necessary to define the deadband that will be used to determine whether the battery stack is charging, discharging, or at rest (holding).

`stack_charge_status.hold_current` (Factory)

- The battery stack is considered at rest unless the absolute value of current exceeds this threshold
- Set as required by application (typically between 50 and 100 mA)

While this threshold is used to qualify certain aspects of SoC estimation, Coulomb counting takes place continuously regardless of the configured hold current value. Other functions that require knowledge of the charge or discharge state of the stack (e.g. the thermistor temperature thresholds) also make use of this threshold.

7.9.3. Stack Voltage Calibration

Stack voltage measurements are made using a voltage sensing analog front-end (AFE) that must be configured for Nuvation Energy BMS.

7.9.3.1. Stack Voltage Factory Calibration

Factory calibration operates according to the following formula that converts an ADC reading to a voltage:

$$I(\text{voltageadc}) = \text{voltageadc} \left(\frac{\text{multiplier}}{\text{divider}} \right)$$

`pi_afe_vadc.multiplier` (Factory)::

- Default calibration: set to 1

`pi_afe_vadc.divider` (Factory)

- Default calibration: set to 1414

7.9.3.2. Stack Voltage Field Calibration

Units that have been factory locked may still require tuning for variability on a per-unit basis. The equation for Stack Voltage Field Calibration adjustment is:

$$V(\text{rawvoltage}) = \text{rawvoltage} \left(1 + \frac{\text{gain}}{100000} \right)$$

The gain is set in the configuration as follows.

`stack_power.voltage_gain` (Configuration)

- Fine tuning gain for raw voltage values. A value of 1000 = +1% adjustment ($\text{rawvoltage} * 1.01$). A value of -1000 = -1% adjustment ($\text{rawvoltage} * 0.99$).

At the factory, appropriate limits for the gain are defined to ensure a user does not misconfigure the system. The gain limit is set in the configuration as follows:

`stack_power.voltage_gain_limit` (Factory)

- Absolute value of the limit for gains on raw voltage values.
- If the `stack_power.voltage_gain` register is set to outside of this limit, the gain applied will be limited to this value.



Nuvation has pre-calibrated each G4 Stack Switchgear with its own gain and limit. Each unit will have its own set of calibrations which must be maintained when applying an upgrade or configuration update. Make sure to capture and record the calibration of each unit for this purpose. If you have lost this calibration information, please contact support@nuvationenergy.com with the serial number(s) to retrieve this data.

7.10. Hardware Settings

For G4 High-Voltage BMS systems, the following configuration registers must be set as per the G4 Cell Interface variant in use for your application.

`sc_linkbus.softwareid`

- Set to 0 for NUV100-CI-12
- Set to 1 for NUV100-CI-16
- Set to 2 for NUV100-CI-4M12

`sc_linkbus.cicount`

- Set to the total number of G4 Cell Interface modules connected to the Stack Controller

The power required by the G4 Cell Interface may be sourced either from the battery cells themselves or from the 24 V DC supply of the BMS through the *Link Bus*.

`sc_linkbus.power_mode`

- Set to 0 to power G4 Cell Interface modules from battery cell power
- Set to 1 to power G4 Cell Interface modules from the Stack Controller through the *Link Bus*

7.10.1. Link Bus Scan Period

The rate at which cell voltage and temperature measurements are updated is determined by a configurable *Link Bus* scan period. All cell voltages are measured every scan cycle. Thermistor temperature measurement is multiplexed across eight consecutive scan cycles. One thermistor in each group of cells (monitored by a single BMS module) is measured during each cycle, so the effective scan period of any given thermistor in the system is 8 times the *Link Bus* scan period.

`sc_linkbus.scan_period`

- Measurement period for cell voltages
- This is typically set to 1 second

Performance of passive balancing is also closely related to the scan period. In Nuvation Energy BMS, a single wiring harness is used to measure cell voltage as well as bleed off passive cell balancing current. It is not possible to make accurate voltage measurements while simultaneously balancing cells. To ensure accurate measurement, balancing current flow must stop before measurement can start (and any transient effects associated with that current flow must be allowed to settle). This is handled automatically by Nuvation Energy BMS. This means that passive balancing has some duty cycle that is less than 100% in practical systems.

The *Link Bus* has a configurable settling period for balancing that corresponds to the amount of time balancing is left off before voltage measurements are taken.

`sc_linkbus.balance_settle_period`

- Settling period during which balancing is disabled before cell voltage measurement.
- Typically set between 50 and 100 ms

For most systems, values between 50 and 100 ms yield accurate, stable measurements. When coupled with a scan period of 1000 ms, balancing duty cycles above 90% are achievable.

For some applications, it may be desirable to de-rate the effective passive balancing current by increasing the balancing settling period as a way to decrease the balancing duty cycle. If the balancing settling period is increased beyond the scan period, the actual scan rate of the system will start to decrease below the configured value.

The actual *Link Bus* scan period can be observed by reading the register:

`sc_linkbus.actual_scan_period`

- Actual measured scan period of the *Link Bus*
- Value should be approximately equal to the desired scan period configured in `sc_linkbus.scan_period`

7.10.2. Cell Voltage Low-Pass Filter

One of two low-pass filters (LPF) are available for cell voltage measurement. This cell voltage low-pass filter is also referred to as the 'Measurement Anti-Aliasing Filter'. The filters are implemented in hardware and are selected via the following configuration.

`sc_linkbus.cell_voltage_lpf_bw`

- A value of 0 selects a 7 kHz LPF (i.e OFF)
- A value of 1 selects a 26 Hz LPF (i.e. ON)



The 26 Hz LPF results in slower cell voltage scan rates. Refer to the measurement rates listed in [Maximum Stack Deployment](#).



The 26 Hz LPF cannot be used with the G4 Cell Interface - 12V 4 channel

7.10.3. Cell Open Wire Detection and Diagnostics

The Battery Management System is capable of detecting wiring and circuit problems on each cell voltage channel. The following scenarios are detectable:

- Open circuits
- Short circuits
- High impedance connections/wiring
- Internal Battery Management System hardware failures

All installed channels are scanned for wiring and circuit problems when the Battery Management System is not in [Service Lockout](#) and its contactors are closed. Open wires and circuit problems are reported for each cell through the `cell.open_wire` flag. The common configurable settings for open wire detection on all modules are listed and described below.

`sc_linkbus.cell_open_wire_disabled`

- Typically this is set to 0
- Setting this to 1 will disable all open wire reporting

`sc_linkbus.cell_open_wire_period`

- The configurable period for scanning all channels for open wires
- Typically this is set to 3600000000 (one hour)



Open wires are only scanned according to this period when the batteries are connected to the DC bus during typical operation.

`sc_linkbus.cell_open_wire_thresh`

- The configurable count for positive open wire detections before the `cell.open_wire` flag is set
- This is to ensure noise triggered false positives are filtered
- Typically this is set to 3

`sc_linkbus.cell_open_wire_max`

- The configurable maximum count for positive open wire detections
- This variable is used to prevent windup of each channel's counter
- It also dictates how many *Link Bus* scan cycles should be used to collect enough samples to detect open wires
- Typically set to 10 and cannot be less than `sc_linkbus.cell_open_wire_thresh`

For systems using G4 Cell Interface - 12 channel or G4 Cell Interface - 16 channel modules, the configurable settings are listed and described below.

`sc_linkbus.cell_open_wire_ratio_lower`

- The ratio below which the channel has an error, represented as an integer between 0 and 1000, (0 = 0.0, and 1000 = 1.0)
- Channels that have low ratios are indicative of high impedance connections between the cell and channel input, possibly due to loose connections or bad terminals.
- Very low ratios indicate an open wire or a Battery Management System hardware failure
- Typically set to 800, representing 0.8

`sc_linkbus.cell_open_wire_ratio_upper`

- The ratio above which the channel has an error, represented as an integer between 0 and 1000, (0 = 0.0, and 1000 = 1.0)
- Channels that have high ratios are indicative of either short circuits or a Battery Management System hardware failure
- This is typically 970, representing 0.97

For G4 High-Voltage BMS systems using G4 Cell Interface - 12V 4 channel modules, the configurable settings are listed and described below.

`sc_linkbus.cell_open_wire_bal_tol`

- The maximum voltage spread within a CI4M12 cell measurement
- A high voltage spread within a CI4M12 channel indicates an open wire
- This is typically set to 500 for 500 mV

`sc_linkbus.cell_open_wire_low_thresh`

- Voltage below which a CI4M12 cell is considered to have an error
- Low voltages can indicate either an open or short circuit
- This is typically 100 for 100 mV

7.10.4. Fault Pilot

The *Fault Pilot* refers to internal hardware control for the Nuvation Energy BMS that is used to open the contactors through a secondary control path in the case of a fault condition. When the system is faulted, the *Fault Pilot* will guarantee that the contactor coils are de-energized, regardless of the state of the coil control software.

In most applications, the *Fault Pilot* operates as a delayed version of the overall fault state of the BMS. This small delay allows for the opening of contactors according to any delays configured as part of the contactor output settings ([Section 7.6.2, "Contactor Configuration"](#)).

In Nuvation Energy G4 Stack Switchgear systems, the fault pilot is an internal signal generated by the G4 Stack Switchgear unit's internal Stack Controller module and sent to the G4 Stack Switchgear unit's internal Power Interface module.

`sc_gpo_fault_pilot.fault_enabled`

- Set to 1 to enable Fault Pilot to assert when `stack_factory_trigger_summary.fault` is tripped

`sc_gpo_fault_pilot.fault_delay`

- Set according to application (typically, between 100 and 5000 ms)

7.10.5. Clock Verification

The G4 Stack Switchgear unit's internal Stack Controller and Power Interface modules each have an independent clock and these are checked against each other regularly to ensure proper operation. The following components are associated with clock checking diagnostics.

`sc_fault_clocks.disabled`

- Setting to 1 enables clock checking on the G4 Stack Switchgear unit's internal Stack Controller
- Disabling this fault will prevent the BMS from tripping a fault if the G4 Stack Switchgear unit's internal Stack Controller detects that the G4 Stack Switchgear unit's internal Power Interface clock is out of sync
- Typically set to 1

`pi_clock_check.enabled`

- Setting to 1 enables clock checking on the G4 Stack Switchgear unit's internal Power Interface
- No fault is associated with this feature and the G4 Stack Switchgear unit's internal Power Interface will directly disconnect the contactors if a clock error is detected
- Typically set to 1 The G5 Stack Switchgear will perform periodic self checks for its internal clocks to ensure proper operation. The following components are associated with clock checking diagnostics.

`sc_fault_clocks.disabled`

- Setting to 1 enables clock checking on the G5 Stack Switchgear
- Disabling this fault will prevent the BMS from opening contactors if the G5 Stack Switchgear detects that the unit's internal clock is not operating properly.

7.10.6. Open Shunt Detection and Diagnostics

Nuvation Energy BMS is capable of detecting improperly installed, loose, or disconnected sense wires that are used to measure the stack voltage and stack current by tracking the correlation between the two measurements.

`stack_open_shunt_detector.enabled`

- Set to 1 to enable the open shunt detection algorithm

`stack_open_shunt_detector.current_activity_threshold`

- Current measurements above this threshold are used for tracking the correlation between stack voltage and stack current
- Typically set to the same value as the `stack_short_shunt_detector.current_activity_threshold` register

`stack_open_shunt_detector.minimum_resistance_threshold`

- The threshold value below which resistance estimates are considered faulty

- The threshold value (R_T), calculated in Ω , can be determined using the equation below, where (R_c) is the cell resistance in Ω and (N_{cell}) is the number of cells connected in series for a stack
- The value of the BMS register `minimum_resistance_threshold` in $\mu\Omega$ can be calculated by multiplying the value of R_T by 1000000

$$R_T = \frac{R_c \cdot N_{cell}}{10000}$$

`stack_open_shunt_detector.filter_sample_count`

- This register is used to adjust how much noise is filtered out to prevent false trips due to noisy signals
- A higher value will result in a greater amount of filtering
- Typically set to 10

`stack_fault_open_shunt.thresh`

- The minimum percent of faulty samples required to trip an open shunt fault
- These faulty samples are current and voltage measurements that do not correlate with each other
- Typically set to 50

7.10.7. Shorted Shunt Detection and Diagnostics

Nuvation Energy BMS can detect shorts in the stack current and stack voltage sensing circuit by tracking the correlation between the stack voltage and stack current.

`stack_short_shunt_detector.enabled`

- Set to 1 to enable the short shunt detection algorithm

`stack_short_shunt_detector.current_activity_threshold`

- If a short circuit exists, the measured current would fall below this threshold value
- The threshold value (I_a), calculated in A, can be determined using the equation below, where (I_{fuse}) is the fuse rating of the stack in A
- The value of the BMS register `current_activity_threshold` in mA can be calculated by multiplying the value of I_a by 1000

$$I_a = 0.0056 \cdot I_{fuse}$$

`stack_short_shunt_detector.voltage_activity_threshold`

- If voltage activity is detected above this threshold value, the detector looks for correlation between the stack voltage and stack current.
- The threshold value (V_a), calculated in V, can be determined using the equation below, where I_a is current activity threshold value calculated above and R_{stack} is the stack resistance in Ω
- The value of the BMS register `voltage_activity_threshold` in mV can be calculated by multiplying

the value of V_a by 1000

$$V_a = 10 \cdot I_a \cdot R_{stack}$$

If the value of the stack resistance is not known, it can be calculated using the cell resistance (R_c) in Ω and the number of cells in the stack (N_{cell}).

$$R_{stack} = N_{cell} \cdot R_c$$

`stack_short_shunt_detector.current_time_constant`

- The time constant of the filter used to remove noise in the current signal
- Typically set to 1000000

`stack_short_shunt_detector.voltage_time_constant`

- The time constant of the filter used to remove noise in the voltage signal
- Typically this is set to 1000000

`stack_short_shunt_detector.activity_detection_time`

- The settling time of the filter used to detect gradual changes in stack voltage The value also represents the time required to detect these changes.
- Typically set to 1800000000

`stack_short_shunt_detector.ramp_detection_time`

- The time constant of the filter used to detect rapid changes in stack voltage. The value also represents the time required to detect these changes.
- Typically set to 10000000

`stack_short_shunt_detector.filter_sample_count`

- Used to adjust how much noise is filtered out to prevent false trips due to noisy signals
- A higher value will result in a greater amount of filtering
- Typically set to 100

`stack_fault_short_shunt.thresh`

- The minimum percent of faulty samples required to trip a short shunt fault
- These faulty samples are current and voltage measurements that do not correlate with each other
- Typically this is set to 50



If the short shunt fault has tripped, it cannot be cleared by pressing Clear Faults until the activity falls below its threshold. It may take several minutes for this transition to occur.

Refer to [Section 11.1.7.1.2, "Clearing the Short Shunt Fault Is Not Immediate"](#) on how to work around this issue.

7.10.8. Temperature Consistency Check

For each G4 Cell Interface module in the stack, the temperature consistency check will calculate the maximum deviation between the smallest and largest measured temperature.

If the deviation exceeds a configurable threshold value, a fault will be tripped.

`stack_fault_ci_therm_consistency.thresh`

- The maximum temperature deviation, in units of °C, that is allowed between thermistors of a single G4 Cell Interface module
- Typically this is set to 15

In order to minimize this temperature deviation and prevent false trips, consider the following recommendations below.

7.10.8.1. Recommendation for Temperature Consistency Check

There are two main factors that need to be considered when connecting the thermistors. First, it is important to ensure that the thermal cooling environment for each of thermistors is similar. One approach is to place the thermistors orthogonal to the cooling air direction.

Consider the following scenario where the cooling air flow is in the same direction as the installed thermistors.

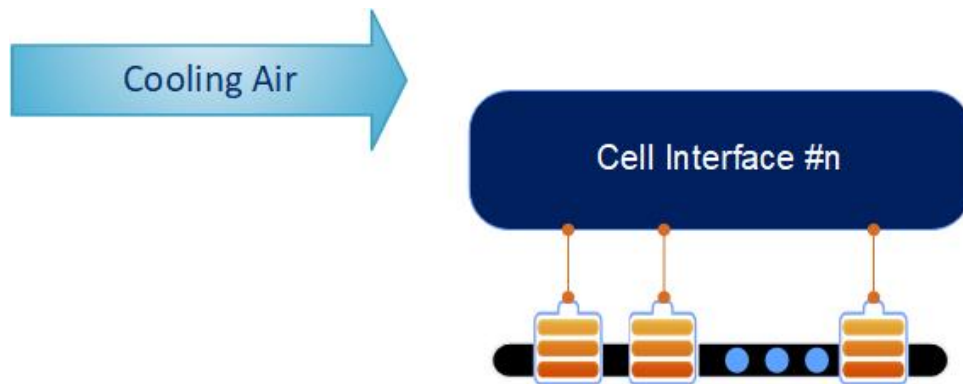


Figure 75. Thermistor arrangement scenario one

A temperature gradient will develop in the direction of the air flow, where the cells to the far left will be cooled more than the ones to the right. This can result in a large temperature deviation within the cell grouping. To minimize this, the cells can be rearranged as shown in below.

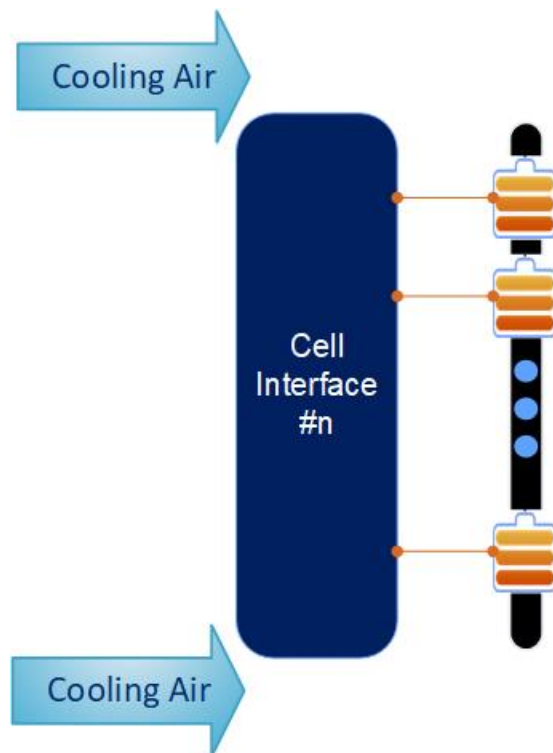


Figure 76. Thermistor arrangement scenario two

The effect of the temperature gradient can be attenuated by grouping thermistors orthogonal to the gradient. During operation, the temperature measurements within this group increase and decrease and therefore, when a failure occurs, the problematic thermistor will begin to deviate from the rest of the group.

A second factor that can be considered to minimize the temperature deviation within cell grouping is battery State-of-Health. It is advantageous to group cells with similar State-of-Health values together since they would have similar thermal responses to current activity.

7.10.9. Contactor Life Tracking

Nuvation Energy BMS provides a mechanism to track the life of each contactor and to trigger a fault when it is end-of-life. The life of each contactor at any given time is determined by the various opening currents the contactor has experienced. Each contactor can be individually configured for contactor life tracking where `ssg_contactor_monitor[n]` and `ssg_contactor_life_tracker[n]` corresponds to `stack_contactor[n]`.

Typically, a contactor will specify the number of make/break cycles it is rated for within a current range. For example, if contactor XYZ has the following ratings:

- 1000V, 200A max, 50 cycles make/break
- 1000V, 100A max, 6000 cycles make/break

Depending on the application, it may be safe to assume that above a number of rated make/break cycles, contactor life tracking is not required. In this example, we will assume that anything above

6000 cycles does not need to be tracked.

This will translate to the following contactor life tracking configuration:

- `ssg_contactor_monitor[0].enabled = 1`
- `ssg_contactor_life_tracker[0].enabled = 1`
- `ssg_contactor_life_tracker[0].min_opening_current = 100`
- `ssg_contactor_life_tracker[0].max_opening_current = 200`
- `ssg_contactor_life_tracker[0].max_rated_current = 199`
- `ssg_contactor_life_tracker[0].max_life = 50`



Consult the Nuvation Energy G4 High-Voltage BMS: Datasheet for specifications on contactor life ratings of your product model.

A complete list of all contactor life tracking registers is shown below.

`ssg_contactor_monitor[n].enabled`

- Set to 1 to enable monitoring of contactor n for contactor life tracking

`ssg_contactor_life_tracker[n].enabled`

- Set to 1 to enable contactor life tracking for contactor n

`ssg_contactor_life_tracker[n].is_precharge`

- Set to 1 if the contactor is configured as the pre-charge contactor

`ssg_contactor_life_tracker[n].current_capture_window`

- Window of current samples to consider for an opening current, centered around when the contactor opens. The largest value in this window is used
- Typical value is 2000000 (2 seconds). This would mean current measurements taken 1 second before and 1 second after the contactor opening event will be considered

`ssg_contactor_life_tracker[n].min_opening_current`

- Minimum opening current, above which the contactor life will increment
- This is typically set to the minimum current at which the contactor make/break cycles is limited

`ssg_contactor_life_tracker[n].max_opening_current`

- Maximum opening current, above which the contactor is immediately considered end-of-life

`ssg_contactor_life_tracker[n].max_rated_current`

- Current to assume the contactor opened at if the opening event could not be monitored
- Typically set to between `ssg_contactor_life_tracker[n].min_opening_current` and `ssg_contactor_life_tracker[n].max_opening_current`

`ssg_contactor_life_tracker[n].max_life`

- Maximum life of the contactor, above which the contactor is considered end-of-life
- This should be set to the number of make/break cycles the contactor is rated for between

ssg_contactor_life_tracker[n].min_opening_current and
ssg_contactor_life_tracker[n].max_opening_current

ssg_warn_contactor_end_of_life.thresh

- The threshold below which a warning is triggered around the contactor’s remaining life
- This value is a Percentage, indicating the remaining life of the contactor

ssg_fault_contactor_end_of_life.thresh

- The threshold below which a fault is triggered around the contactor’s remaining life
- This value is a Percentage, indicating the remaining life of the contactor. This should be set to 0

Please contact support@nuvationenergy.com if this feature is required for your application’s functional safety.

7.11. Watchdogs and Freshness

Watchdog timers are employed in Nuvation Energy BMS to ensure specific functions execute regularly. If a watchdog timer is not periodically reset, the timer will expire and an associated fault will trip and disconnect the contactors. The watchdog timers are exposed by the BMS through multiple watchdog components.

wdt.expired

- 1 indicates that the timer has not been reset within the configured time and is considered expired
- 0 indicates the timer has not expired.

wdt.period

- The time period within which the timer needs to be reset before it expires

The watchdogs configurations are described below.

Table 24. Nuvation Energy BMS Watchdog Components

Watchdog Component	Notes
sc_ram_test_wdt	Configures the watchdog timer for the RAM testing. Typically period is 60000000 (60 s).
sc_rom_test_wdt	Configures the watchdog timer for the ROM testing. Typically period is 60000000 (60 s).
sc_controller_wdt	Configures the watchdog timer for the external controller update. The period is dependant on the responsiveness to external controller to periodically update the BMS watchdog.

7.11.1. Freshness

Freshness is a mechanism in Nuvation Energy BMS to guarantee data within the system is up to date.

Measurements such as cell voltage, cell temperatures, and stack voltage are captured on the G4 Cell Interface modules and the G4 Stack Switchgear unit’s internal Power Interface and are aggregated on

the G4 Stack Switchgear unit’s internal Stack Controller. Points of failures on the G4 Cell Interface or Power Interface modules, or on the Link Bus or Stack Bus can result in data reported by the BMS to be stale.

Regardless of how and where data stops being propagated, freshness provides a mechanism for the system to detect these failures and perform the necessary procedures to keep the system safe.

The freshness mechanism is exposed by the BMS through multiple freshness component.

fresh.stale

- 1 indicates that the associated data has not been updated within the configured time and is considered stale
- 0 indicates the data is still fresh

fresh.period

- The time period within which the associated data needs to be updated before it is considered to be stale

Freshness components are mapped to certain types of data such as cell data, stack data, and so on. When a freshness component becomes stale, it means that its associated data has not been updated within the configured time period.

Table 25. Nuvation Energy BMS Freshness Components

Freshness Component	Associated Data	Notes
stack_cell_fresh	cell.voltage cell.open_wire	Ensures cell information is updated. Only installed cells are checked for freshness. The period must be longer than <code>sc_linkbus.scan_period</code> , typically 3000000 (3 seconds).
stack_therm_fresh	therm.temperature therm.circuit_fail	Ensures thermistor information is updated. Only installed thermistors are checked for freshness. The period must be longer than 8x <code>sc_linkbus.scan_period</code> , typically 10000000 (10 seconds).
sc_ci_fresh	ci.supply_error ci.mux_error	Ensures Cell Interface operational information is updated. Only installed Cell Interface modules are checked for freshness. The period must be longer than <code>sc_linkbus.scan_period</code> , typically 3000000 (3 seconds).
stack_cell_open_wire_fresh	stack_cell_summary_stat.cell_open_wir e_executions	Ensures open-wire detection occurs periodically. The period must be set longer than <code>sc_linkbus.cell_open_wire_period</code> , typically 120000000 (120 seconds).

Freshness Component	Associated Data	Notes
stack_power_fresh	stack_power.voltage stack_power.current	Ensures stack power information is updated. The period must be set longer than pi_afe.sample_period, typically 60000000 (60 seconds).
stack_linkbus_fresh	sc_linkbus.power_error	Ensures Link Bus checks occur periodically. The period must be longer than sc_linkbus.scan_period, typically 3000000 (3 seconds).
sc_factory_verify_fresh	sc_factory_persist.verification_error	Ensures factory configuration verification of the stack controller subsystem occurs periodically. The period is typically 60000000 (60 seconds).
pi_factory_verify_fresh	pi_fault_config_factory_verify.error	Ensures factory configuration verification of the power interface subsystem occurs periodically. The period is typically 60000000 (60 seconds).
ssg_contactor_life_verify_fresh	ssg_contactor_life_persist.verification_error	Ensures verification of the contactor life data occurs periodically. The period is typically 60000000 (60 seconds)
ssg_contactor_end_of_life_fresh	ssg_contactor_life_tracker_summary.min_life_remaining	Ensures contactor life is evaluated periodically. The period is typically 60000000 (60 seconds)
ssg_contactor_monitor_fresh	ssg_contactor_monitor.status	Ensures contactor monitoring occurs periodically. The period is typically 10000000 (10 seconds)

8. Communication Protocols

8.1. Modbus Protocol Support

Nuvation Energy BMS implements the SunSpec battery models defined in the Modular Energy Storage Architecture (MESA) as the top-level Modbus interface to the product. Specifically the BMS implements the MESA Draft 3 Storage models (800 Series).

The specifications for these models are available for download at <https://www.nuvationenergy.com/technical-resources>.



MESA Draft 3 is currently implemented on Nuvation Energy BMS.

8.1.1. Modbus TCP

This protocol is used for communications over TCP/IP networks. A single Modbus TCP connection is supported over port 502 for read and write access. All register data is transmitted as big endian (most significant byte first).

8.1.2. Implemented MESA Models

The MESA standards contain a number of 'models' that can be implemented by vendors to describe a storage device at various levels of detail. The models implemented by Nuvation Energy BMS are described in the sections below.

Detailed register maps for all Draft 3 models are found in the document *MESA-Energy-Storage-Information-Models_Draft_3.xlsx* found at the Nuvation Energy technical resources located at <https://www.nuvationenergy.com/technical-resources>.

8.1.2.1. Common Model

This model primarily contains information to identify the device (e.g. manufacturer, model, serial number) as well as the version of software running on the device. The Modbus address of this model is 40000. [Table 26, "Common Model Points"](#) describes the points of the Common Model as implemented in the BMS. A full description of the Common Model can be found in the SunSpec specification bundle.

Table 26. Common Model Points

Point Name	Address	Description	Note
SunSpec_ID	40000	Identifies this as a SunSpec Modbus Map	Set to 0x53756e53
ID	40002	Identifies Common Model Block	Set to 0x0001
L	40003	Length of block	Set to 66
Mn	40004	Device Manufacturer	Set to "Nuvation Engineering"

Point Name	Address	Description	Note
Md	40020	Device Model Number	Contents of BMS registers sc_mfg_info.manufacturing<0-3>
Opt	40036	Options	Set to "Fully Loaded"
Vr	40044	Version Information	Contents of the sc_fw_image.build_version and sc_fw_image.build_id BMS registers separated by a colon
SN	40052	Device Serial Number	Contents of BMS registers sc_mfg_info.serialnumber<0-1>
DA	40068	Device Address	Set to 0x1234

8.1.2.2. S801

This model describes an energy storage device at the highest possible level. State-of-Charge and overall alarm and warning states are found here. All mandatory points are implemented. The Modbus address of this model is 40070.

8.1.2.3. S802

This model describes a battery storage device. At this level, the critical operational information includes the charge and discharge current limits. All mandatory points are implemented. The Modbus address of this model is 40094.

8.1.2.4. S803

This model describes a lithium-ion battery in detail. Voltage, temperature, and current statistics are available at the pack and stack level within this model. All mandatory and most optional points are implemented. The Modbus address of this model is 40116.

8.1.2.5. End Model

This model marks the end of the implemented Modbus address space.

8.1.3. MESA Model Structure and Nomenclature

This section is a clarification of terms used to describe a MESA model. It is used to understand the terminology in the spreadsheet presented in the previous section.

8.1.3.1. Points

All MESA models are a collection of points (i.e. Modbus registers). These points can be one or more Modbus registers in length. By definition, each Modbus register is 16 bits wide. For points that are larger than one Modbus register, partial read accesses are not allowed. A modbus request to a MESA point must read all registers that make up the point. Otherwise, a Modbus read/write error is returned on such an access.

For example, the MESA s802 model has the Evt1 point which is of type bitfield32. In this case, the point spans 2 Modbus register and so a request to read this point must read 2 modbus registers.

8.1.3.2. Fixed/Repeating Blocks

MESA models are described as collections of Fixed and Repeating blocks of points. A Fixed block is a set of points that is always defined and never changes in its size. A Repeating block describes a set of related points (i.e. usually for a string of batteries) of which there could be multiple instances of the Repeating blocks. The points within a repeating block are the same but these sets of blocks are concatenated sequentially.

For example in the 803 model, there is a set of repeating blocks that describe data for a particular stack/string of batteries. Accessing the 803 repeating block corresponds to using a stack/string index (0, 1, 2, ...) to access the desired repeating block.

For a single-stack Nuvation Energy BMS there is only one 803 repeating block.

If a stack/string is configured in Nuvation Energy BMS software to be installed, then accessing its 803 repeating block will provide a valid Modbus response.

Repeating blocks are taken into account in the length indicated in the model header.

8.1.3.3. Unimplemented Points

Any MESA point that is not implemented by a vendor will generate an unimplemented response. The response will be a valid Modbus read response but all point data returned will report unimplemented values. The unimplemented values vary by type as listed in the following table.

Table 27. Unimplemented Point Values

Type	Width (bits)	Unimplemented Value (hexadecimal)
signed int	16	0x8000
unsigned int	16	0xFFFF
signed int	32	0x80000000
unsigned int	32	0xFFFFFFFF
enumeration	16	0xFFFF
enumeration	32	0xFFFFFFFF

A write to a writeable MESA point that is unimplemented will generate a Modbus write error.

The MESA implementation on Nuvation Energy BMS has unimplemented points as follows:

Table 28. Unimplemented MESA Points

Model	Point Name	Description
801	Evt	Event status bitfield
801	DisChaRate	Self Discharge Rate

Model	Point Name	Description
801	MaxRsvPct	Maximum Reserve Percent
801	MinRsvPct	Minimum Reserve Percent
801	ChaSt	Charge Status
801	DerAlarmReset	Alarm Reset (read is unimplemented)
802	CycleCt	Cycle Count
802	WMaxDisChaRte	NamePlate Max Discharge Rate
802	SoH	State of Health (reported in 803 model per string)
802	BatReqPCSSt	PCS State Request
802	BatReqW	Battery Power Request
802	SoH_SF	State of Health Scale Factor
802	BatReqW_SF	Battery Power Request Scale Factor
803	StrEvt2	String Event 2
803	StrConFail	String Connection Fail

8.1.3.4. Scale Factors

All MESA points are integer values (signed or unsigned). To account for different range values beyond the data size (i.e. greater than 65535 for an unsigned 16 bit value) or some fractional value (i.e. 1.1), some MESA points have scale factors associated with them. The scale factor is another point within the model which contains a signed integer exponent of base 10 that scales a corresponding point value. For example, a scale factor of 2 would result in multiplying the corresponding point by 100. Likewise a scale factor of -3 would result in a scale factor of 0.001. Refer to the prior MESA Draft 3 spreadsheet for the relationship between MESA points and their scale factors. All scale factors are fixed for a model and do not change in value.

8.1.4. Operational Cases for MESA

There are two main operational cases for the control of Nuvation Energy BMS over its MESA interface:

1. An external controller (sometimes called "Energy Storage Controller") is used to coordinate power control functions of the BMS in conjunction with some other equipment (such as an inverter). This controller requires periodic and rapid responses of MESA point reads as well as some control over the operation of the BMS (such as stack connectivity). If there is a loss of communication between this controller and the BMS, the BMS will disconnect the stack(s) as a safety precaution.
2. An owner/operator of a battery system requires control of the BMS to monitor the activity of the batteries and track battery usage and its charge/discharge activities. This information can then be used to characterize the usage of the Battery Management System and to validate battery warranties of a vendor.

Read and write Modbus TCP operations can be performed over the standard Modbus port 502 (only a single connection is supported on this port).

The shortest polling periods expected for the MESA models during operation are listed below:

- All fixed model blocks: 100ms
- 801: less than 100ms
- 802: less than 100ms
- 803 Fixed Block: less than 100ms
- 803 Repeating Block(s): less than 100ms (single block)

Depending on BMS system load and size, some requests could take up to 1000ms. The BMS typically samples data at between 250ms to 1000ms depending on configuration, so reading the data faster than this will not improve system behaviour and incurs unnecessary overhead.

These two operational cases will be discussed in detail in the following sections.

8.1.4.1. External Controller Communicating Over MESA Interface

An external controller typically polls Nuvation Energy BMS battery control points at a rate of 2–4 Hz. This controller reads data points required to manage current flow in the system. The following table summarizes the most important points an external controller may want to read from the BMS.

Table 29. MESA Points Read by an External Controller

Model	Block	Point Name	Address	Scale Factor	Purpose
801	Fixed	DERHb	40086	No	BMS Heartbeat counter incremented every second
802	Fixed	Evt1	40101	No	Bit field of all faults/warnings of a the BMS
802	Fixed	Vol	40105	Yes	External DC voltage of the battery system
802	Fixed	MaxBatACha	40106	Yes	Charge current limit calculated by the BMS
802	Fixed	MaxBatADischa	40107	Yes	Discharge current limit calculated by the BMS
803	Fixed	BTotDCCur	40127	Yes	Total DC current of the battery system

A controller may also want to command Nuvation Energy BMS to perform certain actions, such as connecting/disconnecting the battery. The following table provides the different writeable points in the MESA interface for different control functions:

Table 30. MESA Points Written to by an External Controller

Model	Block	Point Name	Address	Purpose
801	Fixed	ControllerHb	40087	Heartbeat register for external controller
801	Fixed	DERAlarmReset	40088	Clears all latched alarms in the BMS
802	Fixed	BSetOperation	40110	Commands Nuvation Energy BMS to connect/disconnect the battery

When configured, the heartbeat controller can be used to update the watchdog timer of Nuvation Energy BMS on single-stack and multi-stack implementations. If the heartbeat point is not updated within the watchdog timer period, a fault will be generated on the BMS stack and its corresponding contactors will be opened. The value written to the heartbeat point must increase in value and roll

over to zero when the 16 bit range limit is reached.

The clearing of alarms of Nuvation Energy BMS is accomplished by writing a value of 1 to the DERAlarmReset point. This point is erroneously identified as read-only in the MESA Draft 3 spreadsheet referenced earlier. Note that the alarm will not be cleared if the alarm condition is still present.



Only BMS Faults are cleared using this point. BMS Warnings are not cleared.

Commanding the Nuvation Energy BMS stack/string to connect/disconnect is accomplished through the BSetOperation point. This point accepts the enumerated values for these connect/disconnect operations. Additional connection logic (such as separate pre-charge circuitry) is managed automatically by the BMS when it is configured for such an operation.

8.1.4.2. External Nuvation Energy BMS Monitoring Over MESA Interface

An external data logger may want to access a variety of data from the BMS. In general, a data logger will not actively manage Nuvation Energy BMS; normally, it will not initiate actions such as connecting a battery stack to the DC voltage bus or clearing faults. A data logger should connect to one of the read-only Modbus connections (if available) to allow the writable Modbus connection to be available for separate external control functions. The following table contains the MESA data points exposed by the BMS that could be collected for logging purposes.

Table 31. MESA Points Read by External Data Logger

Model	Block	Point Name	Address	Scale Factor	Purpose
801	Fixed	SoC	40081	Yes	BMS State of Charge
801	Fixed	DERHb	40086	No	BMS Heartbeat counter incremented every second
802	Fixed	Evt1	40101	No	Bit field of all faults/warnings of a BMS
802	Fixed	Vol	40105	Yes	External DC voltage of the battery system
802	Fixed	MaxBatACha	40106	Yes	Charge current limit calculated by BMS
802	Fixed	MaxBatADischa	40107	Yes	Discharge current limit calculated by BMS
802	Fixed	BSetOperation	40110	No	BMS requested connection state of all stacks/strings
803	Fixed	BConStrCt	40118	No	Number of stacks/strings with contactor closed
803	Fixed	BMaxCellVol	40119	Yes	Maximum cell voltage measured
803	Fixed	BMaxCellVolLoc	40120	No	Module/String location of maximum cell voltage
803	Fixed	BMinCellVol	40121	Yes	Minimum cell voltage measured
803	Fixed	BMinCellVolLoc	40122	No	Module/String location of minimum cell voltage
803	Fixed	BMaxModTmp	40123	Yes	Maximum module temperature
803	Fixed	BMaxModTmpLoc	40124	No	Module/String location for maximum module temperature

Model	Block	Point Name	Address	Scale Factor	Purpose
803	Fixed	BMinModTmp	40125	Yes	Minimum module temperature
803	Fixed	BMinModTmpLoc	40126	No	Module/String location for minimum module temperature
803	Fixed	BTotDCCur	40127	Yes	Total DC current of the battery system
803	Fixed	BMaxStrCur	40128	Yes	Largest DC current reported by a stack/string
803	Fixed	BMinStrCur	40129	Yes	Smallest DC current reported by a stack/string
803	Repeat	StrSoC	40135 +Index	No	State of charge for a stack/string
803	Repeat	StrSoH	40136 +Index	Yes	State of health for a stack/string
803	Repeat	StrCur	40137 +Index	Yes	Current of a stack/string
803	Repeat	StrMaxCellVol	40138 +Index	Yes	Maximum cell voltage of a stack/string
803	Repeat	StrMinCellVol	40139 +Index	Yes	Minimum cell voltage of a stack/string
803	Repeat	StrCellVolLoc	40140 +Index	No	Location of min/max cell voltages of a stack/string
803	Repeat	StrMaxModTmp	40141 +Index	Yes	Maximum module temperature of a stack/string
803	Repeat	StrMinModTemp	40142 +Index	Yes	Minimum module temperature of a stack/string
803	Repeat	StrModTmpLoc	40143 +Index	No	Location of min/max module temperatures of a stack/string
803	Repeat	StrEvt1	40144 +Index	No	Alarms warnings and status bitfield of a stack/string



The term Index in the Repeating block addresses used in the above table refers to a calculation of $\text{Index} = \text{Stack Index} * \text{Length of Repeating block}$. By definition, the 803 Repeating block is 16 Modbus registers in length.

8.1.5. Accessing MESA Models

MESA models are located contiguously in the Modbus address space starting at a base address of 40000. The Common Model is always located first in this space. The End Model is always last and is used to denote the end of MESA Modbus registers. Each model located between the Common Model and the End Model has a numeric identifier as well as a length. A handy tool that can be used to explore the MESA Modbus registers for Nuvation Energy BMS is modpoll.exe. It is available for free download at <http://www.modbusdriver.com/modpoll.html>.

Using modpoll.exe, the Common Model can be polled from a using the following command (assuming the device has an IP address of 192.168.1.21)

Polling example with BMS IP address of 192.168.1.21

```
modpoll.exe -m tcp -0 -r 40000 -c 70 192.168.1.21

modpoll 3.4 - FieldTalk(tm) Modbus(R) Master Simulator
Copyright (c) 2002-2013 proconX Pty Ltd
Visit http://www.modbusdriver.com for Modbus libraries and tools.

Protocol configuration: MODBUS/TCP
Slave configuration...: address = 1, start reference = 40000 (PDU), count = 70
Communication.....: 192.168.1.21, port 502, t/o 1.00 s, poll rate 1000 ms
Data type.....: 16-bit register, output (holding) register table

-- Polling slave... (Ctrl-C to stop)
[40000]: 21365
[40001]: 28243
[40002]: 1
[40003]: 66
.
.
.
[40068]: 4660
[40069]: -32768
```

As another example, the complete S802 model for a system with one stack could be polled using the following command:

Example with BMS IP address of 192.168.1.21

```
modpoll.exe -m tcp -0 -r 40094 -c 22 192.168.1.21

modpoll 3.4 - FieldTalk(tm) Modbus(R) Master Simulator
Copyright (c) 2002-2013 proconX Pty Ltd
Visit http://www.modbusdriver.com for Modbus libraries and tools.

Protocol configuration: MODBUS/TCP
Slave configuration...: address = 1, start reference = 40094 (PDU), count = 22
Communication.....: 192.168.1.21, port 502, t/o 1.00 s, poll rate 1000 ms
Data type.....: 16-bit register, output (holding) register table

-- Polling slave... (Ctrl-C to stop)
[40094]: 802
[40095]: 20
.
.
.
[40114]: -2
[40115]: -32768
```

9. External Interfaces

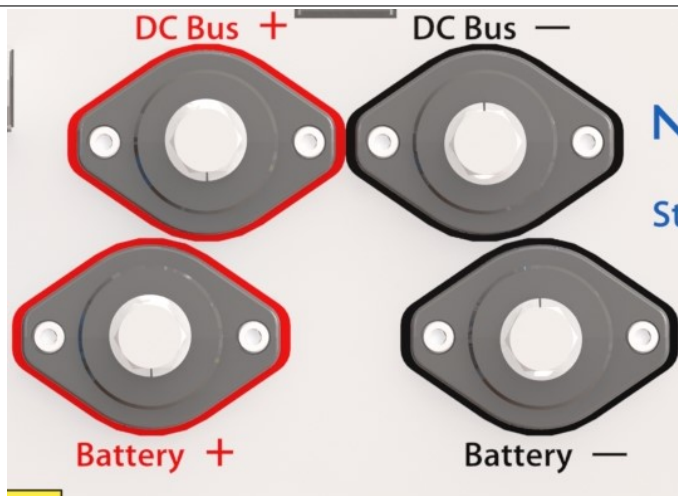
9.1. G4 Stack Switchgear

9.1.1. Battery Stack and DC Bus

The connectors use M10 bolts (included) and are intended for M10 lugs (not included, e.g. Panduit Corp LCMA50-10-L).

Flexible snap-on terminal covers are included. The maximum acceptable terminal lug tongue width is 1.1 inches and the maximum wire size is 4/0. The recommended tightening torque is 6.8 N-m to 9.0 N-m [60 to 80 in-lbs].

Table 32. Battery Stack and DC Bus Connector Assignment



Name	Description	Connected to Device
Battery (-)	Negative terminal of battery stack	Battery stack
Battery (+)	Positive terminal of battery stack	Battery stack
DC Bus (-)	Negative terminal of DC bus	External equipment
DC Bus (+)	Positive terminal of DC bus	External equipment

9.1.2. Ethernet

The Ethernet jack is a standard RJ45 Cat5e rated jack.

Table 33. Ethernet Connector Pin Assignment

Pin	Connection	Description	Connected to Device
1	TD_P	Transmit differential pair positive	External Equipment
2	TD_N	Transmit differential pair negative	External Equipment
3	RD_P	Receive differential pair positive	External Equipment
4	NUL45	Unused; connected to Pin 5 and terminated	External Equipment

Pin	Connection	Description	Connected to Device
5	NUL45	Unused; connected to Pin 4 and terminated	External Equipment
6	RD_N	Receive differential pair negative	External Equipment
7	NUL78	Unused; connected to Pin 8 and terminated	External Equipment
8	NUL78	Unused; connected to Pin 7 and terminated	External Equipment

9.1.3. Link Bus

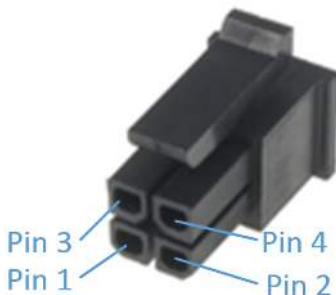
Supported Wire Diameter: 22 AWG - 12 AWG

Table 34. Link Bus Connector Pin Assignment



Pin	Name	Description	Connected to Device
1	VBUS	DC power from G4 Stack Switchgear	G4 Cell Interface
2	COM	Power return from G4 Stack Switchgear	G4 Cell Interface
3	IPA	Link Bus differential pair plus	G4 Cell Interface
4	IMA	Link Bus differential pair minus	G4 Cell Interface

Table 35. Link Bus: Molex Micro-Fit 3.0 Connector



Molex 43025-0400	
Manufacturer	Molex Incorporated
Housing	43025-0400
Housing material	Nylon UL94V-0
Circuits	4
Crimp terminal	43030-0002
Wire gauge range	AWG20-24 stranded

9.1.4. E-Stop

Supported Wire Diameter: 22 AWG - 12 AWG

Table 36. E-Stop Connector Pin Assignment

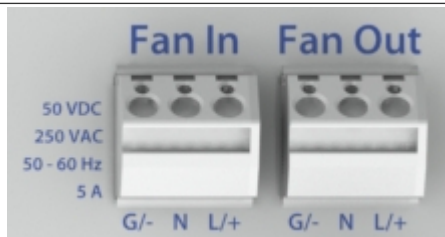


Pin	Name	Description	Connected to Device
1	E-Stop In-	E-Stop Input (Return)	External E-Stop Circuitry
2	E-Stop In+	E-Stop Input (24 V DC)	External E-Stop Circuitry
3	E-Stop Out-	E-Stop Output (Return)	External E-Stop Circuitry
4	E-Stop Out+	E-Stop Output (24 V DC)	External E-Stop Circuitry

9.1.5. Fan Control

Supported Wire Diameter: 22 AWG - 12 AWG

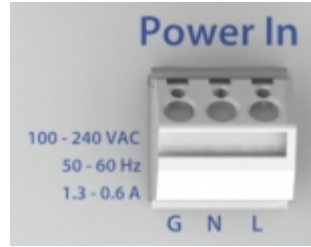
Table 37. Fan Control Connector Pin Assignment



Pin	Name	Description		Connected to Device
		AC	DC	
Fan Input				
1	G/-	Ground	Negative	External power source
2	N	Neutral	NC	External power source
3	L/+	Line	Positive	External power source
Fan Output				
1	G/-	Ground	Negative	External fan system
2	N	Neutral	NC	External fan system
3	L/+	Line	Positive	External fan system

9.1.6. Power In

Table 38. Power In Connector Pin Assignment



Pin	Name	Description	Connected to Device
1	G	Ground	External power source
2	N	Neutral	External power source
3	L	Line	External power source

9.2. G4 Cell Interface

9.2.1. Battery Cells

The Battery Cells connector provides cell voltage input and a means for balancing the cells. The cable wire should be rated for at least 750 mA to survive worse-case currents.

Pins 8, 16, 17, and 18 are No Connect in the G4 Cell Interface - 12 channel model. Pins 2, 4, 6, 8, 10, 11, 12, 13, 14, 15, 16, and 17 are No Connect in the G4 Cell Interface - 12V 4 channel model.

All unused voltage inputs should be tied to the next highest potential voltage sense input. In this way, all pins should be connected with the exception of pins 8, 16, 17 and 18 in the G4 Cell Interface - 12 channel model and pins 2, 4, 6, 8, 10, 11, 12, 13, 14, 15, 16, and 17 in the G4 Cell Interface - 12V 4 channel model.



The wiring of the battery cell voltage and temperature sensing should be verified **before** connecting to the G4 Cell Interface modules. The temperature sensing wires must be isolated from the cell voltage sensing leads. Although the G4 Cell Interface includes protective circuitry to make it more resilient to brief wiring errors, the same circuitry can result in the battery cells being slowly discharged. Over time, these wiring errors can cause damage to the G4 Cell Interface and/or the cells.



The G4 Stack Switchgear is pre-configured to expect a defined battery topology, based on the information provided to Nuvation Energy during order fulfillment. Connecting a differing battery topology will result in undesirable G4 Stack Switchgear behavior. Please contact support@nuvationenergy.com if there is a change in battery topology requiring a G4 Stack Switchgear configuration update.

Table 39. Battery Cells: Molex Micro-Fit 3.0 Connector



Molex 43025-1800	
Manufacturer	Molex Incorporated
Housing	43025-1800
Housing material	Nylon UL94V-0
Circuits	18
Crimp terminal	43030-0002
Wire gauge range	AWG20-24 stranded

9.2.1.1. Battery Cell Connector for G4 Cell Interface - 12 channel

Table 40. G4 Cell Interface - 12 channel Battery Cell Connector Pin Assignment

Pin	Connection	Description	Connected to Device
1	CELL0	Bottom reference of G4 Cell Interface	Connect to negative terminal of the lowest cell (Cell 1)
2	CELL2	Cell 2 voltage sense	Connect to positive terminal of Cell 2
3	CELL4	Cell 4 voltage sense	Connect to positive terminal of Cell 4
4	CELL6	Cell 6 voltage sense	Connect to positive terminal of Cell 6
5	CELL8	Cell 8 voltage sense	Connect to positive terminal of Cell 8
6	CELL10	Cell 10 voltage sense	Connect to positive terminal of Cell 10
7	CELL12	Cell 12 voltage sense	Connect to positive terminal of Cell 12
8	No Connect	Not Connected	No Connect
9	No Connect	Not Connected	No Connect
10	CELL1	Cell 1 voltage sense	Connect to positive terminal of the lowest cell (Cell 1)
11	CELL3	Cell 3 voltage sense	Connect to positive terminal of Cell 3
12	CELL5	Cell 5 voltage sense	Connect to positive terminal of Cell 5
13	CELL7	Cell 7 voltage sense	Connect to positive terminal of Cell 7
14	CELL9	Cell 9 voltage sense	Connect to positive terminal of Cell 9
15	CELL11	Cell 11 voltage sense	Connect to positive terminal of Cell 11
16	No Connect	Not Connected	No Connect
17	No Connect	Not Connected	No Connect
18	No Connect	Not Connected	No Connect

9.2.1.2. Battery Cell Connector for G4 Cell Interface - 16 channel

Table 41. G4 Cell Interface - 16 channel Battery Cell Connector Pin Assignment

Pin	Connection	Description	Connected to Device
1	CELL0	Bottom reference of G4 Cell Interface	Connect to negative terminal of the lowest cell (Cell 1)
2	CELL2	Cell 2 voltage sense	Connect to positive terminal of Cell 2
3	CELL4	Cell 4 voltage sense	Connect to positive terminal of Cell 4
4	CELL6	Cell 6 voltage sense	Connect to positive terminal of Cell 6
5	CELL8	Cell 8 voltage sense	Connect to positive terminal of Cell 8
6	CELL10	Cell 10 voltage sense	Connect to positive terminal of Cell 10
7	CELL12	Cell 12 voltage sense	Connect to positive terminal of Cell 12
8	CELL14	Cell 14 voltage sense	Connect to positive terminal of Cell 14
9	No Connect	Not Connected	No Connect
10	CELL1	Cell 1 voltage sense	Connect to positive terminal of the lowest cell (Cell 1)
11	CELL3	Cell 3 voltage sense	Connect to positive terminal of Cell 3

Pin	Connection	Description	Connected to Device
12	CELL5	Cell 5 voltage sense	Connect to positive terminal of Cell 5
13	CELL7	Cell 7 voltage sense	Connect to positive terminal of Cell 7
14	CELL9	Cell 9 voltage sense	Connect to positive terminal of Cell 9
15	CELL11	Cell 11 voltage sense	Connect to positive terminal of Cell 11
16	CELL13	Cell 13 voltage sense	Connect to positive terminal of Cell 13
17	CELL15	Cell 15 voltage sense	Connect to positive terminal of Cell 15
18	CELL16	Cell 16 voltage sense	Connect to positive terminal of Cell 16

9.2.1.3. Battery Cell Connector for G4 Cell Interface - 12V 4 channel

Table 42. G4 Cell Interface - 12V 4 channel Battery Cell Connector Pin Assignment

Pin	Connection	Description	Connected to Device
1	BLOCK0	Bottom reference of G4 Cell Interface	Connect to negative terminal of the lowest cell (Cell 1)
2	No Connect	Not Connected	No Connect
3	BLOCK1	Cell 1 voltage sense	Connect to positive terminal of the lowest cell (Cell 1)
4	No Connect	Not Connected	No Connect
5	BLOCK2	Cell 2 voltage sense	Connect to positive terminal of Cell 2
6	No Connect	Not Connected	No Connect
7	BLOCK3	Cell 3 voltage sense	Connect to positive terminal of Cell 3
8	No Connect	Not Connected	No Connect
9	No Connect	Not Connected	No Connect
10	No Connect	Not Connected	No Connect
11	No Connect	Not Connected	No Connect
12	No Connect	Not Connected	No Connect
13	No Connect	Not Connected	No Connect
14	No Connect	Not Connected	No Connect
15	No Connect	Not Connected	No Connect
16	No Connect	Not Connected	No Connect
17	No Connect	Not Connected	No Connect
18	BLOCK4	Cell 4 voltage sense	Connect to positive terminal of Cell 4

9.2.2. Temperature Sensors

The Temperature Sensors connector provides NTC thermistor inputs for temperature measurement of the cells and/or surrounding area. Because the sensors are referenced to the CELL0 (or BLOCK0 on CI-4M12) input on the G4 Cell Interface, care must be taken to ensure that they are electrically isolated from any common or ground potential, and from all other cell voltage terminals of all G4 Cell Interface modules in the system. The thermistors must be isolated from the cell voltage terminals in such a way that they will not make an electrical connection to a cell terminal in the event of vibration/failures.

Connect up to eight 10 kΩ NTC thermistors to this connector.



The G4 Stack Switchgear is pre-configured to expect a defined number of thermistors based on the information provided to Nuvation Energy during order fulfillment. Failure to use the same number of thermistors will result in undesirable G4 Stack Switchgear behavior. Please contact support@nuvationenergy.com if there is a change requiring a G4 Stack Switchgear configuration update.



2 to 7 thermistors are supported to accommodate systems requiring Nuvation Energy BMS to meet functional safety requirements.

Table 43. Temperature Sensors: Molex Micro-Fit 3.0 Connector



Molex 43025-1600	
Manufacturer	Molex Incorporated
Housing	43025-1600
Housing material	Nylon UL94V-0
Circuits	16
Crimp terminal	43030-0002
Wire gauge range	AWG20–24 stranded

Table 44. Temperature Sensors Connector Pin Assignment

Pin	Connection	Description	Connected to Device
1	VBOT	External Temperature Probe Reference 1	10 kΩ NTC Thermistor
2	VBOT	External Temperature Probe Reference 2	10 kΩ NTC Thermistor
3	VBOT	External Temperature Probe Reference 3	10 kΩ NTC Thermistor
4	VBOT	External Temperature Probe Reference 4	10 kΩ NTC Thermistor

Pin	Connection	Description	Connected to Device
5	VBOT	External Temperature Probe Reference 5	10 kΩ NTC Thermistor
6	VBOT	External Temperature Probe Reference 6	10 kΩ NTC Thermistor
7	VBOT	External Temperature Probe Reference 7	10 kΩ NTC Thermistor
8	VBOT	External Temperature Probe Reference 8	10 kΩ NTC Thermistor
9	TEMP1_R	External Temperature Probe Input 1	10 kΩ NTC Thermistor
10	TEMP2_R	External Temperature Probe Input 2	10 kΩ NTC Thermistor
11	TEMP3_R	External Temperature Probe Input 3	10 kΩ NTC Thermistor
12	TEMP4_R	External Temperature Probe Input 4	10 kΩ NTC Thermistor
13	TEMP5_R	External Temperature Probe Input 5	10 kΩ NTC Thermistor
14	TEMP6_R	External Temperature Probe Input 6	10 kΩ NTC Thermistor
15	TEMP7_R	External Temperature Probe Input 7	10 kΩ NTC Thermistor
16	TEMP8_R	External Temperature Probe Input 8	10 kΩ NTC Thermistor



For safety certified applications there must be at least 2—but no more than 7—thermistors installed per G4 Cell Interface module in a specific pattern. The following table lists the expected pattern of thermistor installation approved for safety certification.

Table 45. Safety Certified Thermistor Installation

Total Thermistors per G4 Cell Interface	TEMP1_R	TEMP2_R	TEMP3_R	TEMP4_R	TEMP5_R	TEMP6_R	TEMP7_R	TEMP8_R
7	Installed	Installed	Installed	Installed	Installed	Installed	Installed	Not Installed
6	Installed	Installed	Installed	Installed	Not Installed	Installed	Installed	Not Installed
5	Installed	Installed	Not Installed	Installed	Not Installed	Installed	Installed	Not Installed
4	Not Installed	Installed	Installed	Installed	Installed	Not Installed	Not Installed	Not Installed
3	Not Installed	Installed	Installed	Installed	Not Installed	Not Installed	Not Installed	Not Installed
2	Not Installed	Installed	Installed	Not Installed	Not Installed	Not Installed	Not Installed	Not Installed

9.2.2.1. Thermal Consistency

For safety certified systems, there is an additional constraint on thermal consistency for all temperature measurements for each G4 Cell Interface. The constraint is described in detail in the Sensor Fault Detection section within the Nuvation Energy G4 BMS: Safety Manual (available on request).

9.2.3. Link In



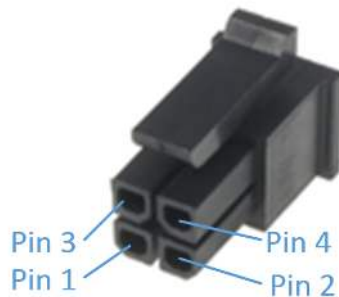
The G4 Stack Switchgear is pre-configured to expect a defined battery topology, based on the information provided to Nuvation Energy during order fulfillment. Connecting a differing battery topology will result in undesirable G4 Stack Switchgear behavior. Please contact support@nuvationenergy.com if there is a change in battery topology requiring a G4 Stack Switchgear configuration update.

This interface is used, with Link Bus cables, to connect each G4 Cell Interface in series to the G4 Cell Interface of the next lowest potential, and the G4 Cell Interface of the lowest potential to the G4 Stack Switchgear. In this series-connected chain of modules, each connection is made from the Link In connector of the module with higher potential to the Link Out connector of the module with lower potential.

The G4 Cell Interface also accepts power from its Link In connector to power itself, as well as subsequent G4 Cell Interface modules in the Link Bus chain (i.e. connected to its Link Out connector). The amount of current sourced into this connector is the sum of current consumed by this G4 Cell Interface and the subsequent G4 Cell Interface modules in the Link Bus chain.

Connect this interface to the [Link Out connector](#) on the previous G4 Cell Interface module in the Link Bus chain or to the [Link Bus connector](#) on the G4 Stack Switchgear.

Table 46. Link In: Molex Micro-Fit 3.0 Connector



Molex 43025-0400	
Manufacturer	Molex Incorporated
Housing	43025-0400
Housing material	Nylon UL94V-0
Circuits	4
Crimp terminal	43030-0002
Wire gauge range	AWG20–24 stranded

Table 47. Link In Connector Pin Assignment

Pin	Connection	Description	Connected to Device
1	VBUS	DC power from the G4 Stack Switchgear, with Fault Pilot Signal	Previous G4 Cell Interface in the Link Bus chain or G4 Stack Switchgear
2	COM	Power return from the G4 Stack Switchgear	Previous G4 Cell Interface in the Link Bus chain or G4 Stack Switchgear
3	IPA	Link Bus differential pair plus	Previous G4 Cell Interface in the Link Bus chain or G4 Stack Switchgear
4	IMA	Link Bus differential pair minus	Previous G4 Cell Interface in the Link Bus chain or G4 Stack Switchgear

9.2.4. Link Out

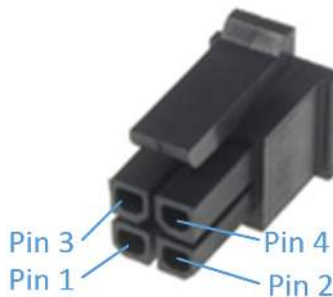
This interface is used to provide a data channel and power source to subsequent G4 Cell Interface modules in the Link Bus chain. The amount of current supplied by this connector is the sum of current consumed by all subsequent G4 Cell Interface modules in the Link Bus chain (up to 25 mA per CI-12 or 31 mA per CI-16/CI-4M12).



The G4 Stack Switchgear is pre-configured to expect a defined battery topology, based on the information provided to Nuvation Energy during order fulfillment. Connecting a differing battery topology will result in undesirable G4 Stack Switchgear behavior. Please contact support@nuvationenergy.com if there is a change in battery topology requiring a G4 Stack Switchgear configuration update.

Connect this interface to the [Link In connector](#) on the subsequent G4 Cell Interface module in the Link Bus chain. The Link Out interface of the last G4 Cell Interface module in the Link Bus chain is to be left unconnected.

Table 48. Link Out: Molex Micro-Fit 3.0 Connector



Molex 43025-0400	
Manufacturer	Molex Incorporated
Housing	43025-0400
Housing material	Nylon UL94V-0

Circuits	4
Crimp terminal	43030-0002
Wire gauge range	AWG20-}24 stranded

Table 49. Link Out Connector Pin Assignment

Pin	Connection	Description	Connected to Device
1	VBUS	DC power from G4 Stack Switchgear , with Fault Pilot Signal	Subsequent G4 Cell Interface module in the Link Bus chain
2	COM	Power return from G4 Stack Switchgear	Subsequent G4 Cell Interface module in the Link Bus chain
3	IPA	Link Bus differential pair plus	Subsequent G4 Cell Interface module in the Link Bus chain
4	IMA	Link Bus differential pair minus	Subsequent G4 Cell Interface module in the Link Bus chain

10. Servicing



The order of these steps must be followed in order to maximize the life of the components (the contactors in particular).

In order to service the stack (including the battery itself), perform the following steps:

1. Allow the battery to come to rest (no current).
 - This may involve sending commands to the PCS.
2. Using the Operator Interface, disconnect the stack by clicking the **Disconnect** button.
 - Refer to the [Section 6.1.8, "Nuvation Energy BMS Status"](#) for instructions on connecting/disconnecting a stack.
 - This initiates the disconnection sequence.
 - Wait for the connection state to show **Stack Disconnected**.
3. Put the Service Disconnect switch in the **OFF** position and insert a lock-out / tag-out.

The battery stack can now be serviced. To bring the stack back into operation, perform the following steps:

1. Remove the lock-out / tag-out and put the Service Disconnect switch in the **ON** position.
2. Address any faults if necessary (using the Operator Interface).
 - All faults must be cleared for G4 Stack Switchgear to close contactors.
3. Using the Operator Interface, connect the stack by clicking the **Connect** button.
 - Refer to the [Section 6.1.8, "Nuvation Energy BMS Status"](#) for instructions on connecting/disconnecting a stack.
 - This initiates the connection sequence.
 - Wait for the connection state to show **Connected**.

The stack is now connected to the DC bus.



The battery stack terminals are always energized and should be handled as such.

Although the DC bus terminals are disconnected from the battery by the G4 Stack Switchgear unit's contactors, the DC bus can still be energized by other components on the DC bus (e.g. PCS or other stacks). The DC bus terminals should always be treated as though they are energized.

A simple voltage check (i.e. across the positive and negative terminals) is not always sufficient, *especially* with grounded battery stacks. It is recommended to also check for voltage between each conductor and ground.

11. Troubleshooting

11.1. Faults and Self Check Failures

During initial setup and usage of a Nuvation Energy BMS, there are two main classes of failures that prevent stack connection:

1. 'Self Check' failures
2. Triggering of faults

When either of these failures occur, an operator of the Operator Interface can open the Details > Safety accordion ([Section 6.2.3, "Safety"](#)). That screen presents a list of faults, warnings and user triggers which can have the following states:

Table 50. States for Faults, Warnings and User Triggers

Self Check State	Faults, Warnings, User Triggers	States of Faults, Warnings, User Triggers
Incomplete Self Check	Faults, Warnings, User Triggers	Checking
Completed Self Check	Faults	Clear or Tripped
Completed Self Check	Warnings or User Triggers	Clear or Triggered

All faults, warnings and user triggers that are in a **Checking** state indicate that the Self Check operation is still executing. All fault, warning, and user triggers in this state are not receiving all of their configured input data. The Self Check will continue to execute when there is still at least one fault, warning or user trigger in the **Checking** state. The contactors are not allowed to close while the Self Check is executing.

After the Self Check has completed and when one or more faults are in the **Tripped** state, the Nuvation Energy BMS enters its faulted state and opens all contactors. The contactors can not be commanded to close again until all faults are back in the **Clear** state.

This section will describe the condition the fault monitors and the meaning when that fault has triggered. In addition this section describes how the Self Check failures can occur for the different classes of faults/warnings/user.

In general, all warnings and user triggers have a similar trigger condition as their corresponding fault. The following discussion will focus on the term fault and all descriptions can be applied to the compatible warning or user trigger. Each fault has a descriptive name (e.g. Cell Over Voltage) and a name for the corresponding trigger component (e.g. stack_fault_cell_over). Both names are shown on the details tab of the OI, refer to [Section 6.2.3, "Safety"](#) for details.

11.1.1. Cell Voltage Faults

Cell Over Voltage | stack_fault_cell_over

- Fault that is triggered when an installed cell voltage is above the *over* fault threshold.

Cell High Voltage | `stack_fault_cell_hi`

- Fault that is triggered when an installed cell voltage is above the *high* fault threshold.

Cell Low Voltage | `stack_fault_cell_lo`

- Fault that is triggered when an installed cell voltage is below the *low* fault threshold.

Cell Under Voltage | `stack_fault_cell_under`

- Fault that is triggered when an installed cell voltage is below the *under* fault threshold.

11.1.1.1. Self Check Issues



The G4 Stack Switchgear is configured for a specific battery topology based on the details provided to Nuvation Energy during order fulfillment. Failure to use the same number of G4 Cell Interface modules and/or using a different battery topology could result in initialization issue and other undesirable behavior. Please contact support@nuvationenergy.com if there is a change in the system design that would require a G4 Stack Switchgear configuration update.

These faults could fail Self Check through a number of possible conditions such as:

1. Missing or misconfigured G4 Cell Interface modules, preventing the software from completing a full scan of the cell voltage and temperature measurements.
2. Misconfiguration on the number of G4 Cell Interface modules. Refer to the register `sc_linkbus.cicount`.
3. Incorrect G4 Cell Interface configuration. For example if the type of G4 Cell Interface defined in `sc_linkbus.softwareid` is incorrect, it may prevent the cell voltage measurement.
4. Failure in the Link Bus communication. Any interruptions of the bus can prevent the cell voltages from completing a Self Check. Such a failure could happen if:
 - Not all G4 Cell Interface modules are connected.
 - Link Bus cables are connected to the wrong port (i.e. Link Out instead of Link In).
 - Link Bus cables are damaged.

11.1.2. Stack Voltage Faults

Stack Over Voltage | `stack_fault_voltage_over`

- Fault that is triggered when the stack voltage is above the *over* fault threshold.

Stack High Voltage | `stack_fault_voltage_hi`

- Fault that is triggered when the stack voltage is above the *high* fault threshold.

Stack Low Voltage | `stack_fault_voltage_lo`

- Fault that is triggered when the stack voltage is below the *low* fault threshold.

Stack Under Voltage | `stack_fault_voltage_under`

- Fault that is triggered when the stack voltage is below the *under* fault threshold.

Voltage Sum Check | stack_fault_voltage_sum

- Fault that is triggered when the absolute difference between the measured stack voltage and sum of all cell voltages in the stack exceeds the fault threshold.

11.1.2.1. Self Check Issues

These faults have the following Self Check issues:

Fault	Self Check Issues
stack_fault_voltage_hi stack_fault_voltage_lo	Contact support@nuvationenergy.com . G4 Stack Switchgear unit’s internal Power Interface module’s AFE is disabled.
stack_fault_voltage_sum	Same issues regarding cell voltage Self Check issues (Section 11.1.1.1, “Self Check Issues”)

11.1.3. Thermal Faults

Discharge Under Temperature | stack_fault_discharge_therm_over

- Fault that is triggered when any thermistor measurement is above the *over* fault threshold during discharge.

Discharge High Temperature | stack_fault_discharge_therm_hi

- Fault that is triggered when any thermistor measurement is above the *high* fault threshold during discharge.

Discharge Low Temperature | stack_fault_discharge_therm_lo

- Fault that is triggered when any thermistor measurement is below the *low* fault threshold during discharge.

Discharge Under Temperature | stack_fault_discharge_therm_under

- Fault that is triggered when any thermistor measurement is below the *under* fault threshold during discharge.

Charge Over Temperature | stack_fault_charge_therm_over

- Fault that is triggered when any thermistor measurement is above the *over* fault threshold during charge.

Charge High Temperature | stack_fault_charge_therm_hi

- Fault that is triggered when any thermistor measurement is above the *high* fault threshold during charge.

Charge Low Temperature | stack_fault_charge_therm_lo

- Fault that is triggered when any thermistor measurement is below the *low* fault threshold during charge.

Charge Under Temperature | stack_fault_charge_therm_under

- Fault that is triggered when any thermistor measurement is below the *under* fault threshold during charge.

11.1.3.1. Self Check Issues

All of the temperature measurements are communicated through over the Link Bus using the same mechanism as the cell voltages. Thus, the Self Check failures for the temperature measurements are exactly the same. Refer to [Section 11.1.1.1, "Self Check Issues"](#) for further details.

11.1.4. Stack Current Faults

Discharge Over Current | `stack_fault_discharge_current_over`

- Fault that is triggered when the stack current is above the *over* discharge fault threshold.

Discharge High Current | `stack_fault_discharge_current_hi`

- Fault that is triggered when the stack current is above the *high* discharge fault threshold.

Charge High Current | `stack_fault_charge_current_hi`

- Fault that is triggered when any stack current is above the *high* charge fault threshold.

Charge Over Current | `stack_fault_charge_current_over`

- Fault that is triggered when any stack current is above the *over* charge fault threshold.

11.1.4.1. Self Check Issues

The stack current is measured from the G4 Stack Switchgear unit’s internal Power Interface module’s Analog Front End (AFE). The following issues can contribute to these faults not initializing:

1. G4 Stack Switchgear unit’s internal Power Interface module’s AFE is not enabled.
 - This may occur if the G4 Stack Switchgear configuration file is incorrectly modified. Contact support@nuvationenergy.com for a valid configuration file for the G4 Stack Switchgear.
2. Communication failure between the G4 Stack Switchgear unit’s internal Stack Controller and Power Interface modules

11.1.5. Pre-charge Faults

Pre-charge Timeout | `stack_fault_precharge_timeout`

- Fault that is triggered at the end of the pre-charge period. Reasons for fault include:

Pre-charge Error Code	Error Code Description
1	The delay set by <code>stack_control.precharge_delay</code> expired before a current is measured.
2	The measured current exceeds <code>stack_control.precharge_max_current</code> .

- The value of `stack_control.precharge_error` (listed above) can be used to determine the reason for triggering the fault.

Pre-charge Over Current | `stack_fault_precharge_over_current`

- Fault that is triggered at any time during the pre-charge connection period if the stack current exceeds the fault threshold.

11.1.5.1. Self Check Issues

These faults are directly related to the current faults detailed previously. Refer to [Section 11.1.4.1, "Self Check Issues"](#) for details.

11.1.6. Contactor Faults

Contactor Coil Drive Check | `stack_fault_coil_fail`

- Fault that is generated when there is a difference between the commanded state of the contactor coil and the observed state read from the hardware. This fault is a consistency check on the drive state of the coil. This fault will trigger when contactors are unconnected or have a short in their circuit. If the fault pilot signal is asserted, this fault will trigger and can not be used to determine if there is a inconsistent contactor drive state.

Contactor Feedback Check | `stack_fault_contactor_feedback_fail`

- Fault that is generated when there is a mismatch between the contactor state and the contactor feedback signal provided. Please check that the Service Disconnect Switch is set to the operating position.

Interlock Check | `sc_fault_pi_interlock`

- Fault that is generated when the interlock function of the G4 Stack Switchgear unit's internal Power Interface module has been activated. In the G4 Stack Switchgear unit, this is connected to fuse indicator switches on the fuses. This fault should only occur if the fuses have blown.



The G4 Stack Switchgear unit's e-stop circuit is unrelated to this interlock.

Fault Pilot Check | `sc_fault_fault_pilot_state_mismatch`

- Fault that is generated when the fault pilot state set by the G4 Stack Switchgear unit's internal Stack Controller module does not match the detected state on the G4 Stack Switchgear unit's internal Power Interface module.



`sc_fault_fault_pilot_state_mismatch.time_hyst` must be set to at least 500ms.

11.1.6.1. Self Check Issues

All of these faults are dependent on the stack bus communication between the G4 Stack Switchgear unit's internal Stack Controller and Power Interface modules.

The following table summarizes these Self Check issues:

Fault	Self Check Issues
<code>sc_fault_pi_interlock</code>	Stack Bus failure
<code>sc_fault_fault_pilot_state_mismatch</code>	Stack Bus failure
<code>stack_fault_coil_fail</code>	G4 Stack Switchgear unit's internal Power Interface module's AFE disabled.
<code>stack_fault_contactor_feedback_fail</code>	GPI not configured G4 Stack Switchgear unit's internal Power Interface module's AFE disabled Stack Bus failure.

* Note that these faults may occur if the G4 Stack Switchgear configuration file is incorrectly modified. Contact support@nuvationenergy.com for a valid configuration file for the G4 Stack Switchgear.

11.1.7. Diagnostics Faults

Cell Open Wire Test | stack_fault_cell_open_wire

- Fault indicating there is an open wire on an installed cell channel.
- This can also trip due to misconfigured or incorrectly installed cells.

Cell Open Wire Test | stack_warn_cell_open_wire

- Warning triggering on the same data as stack_fault_cell_open_wire.

Thermistor Circuit Test | stack_fault_therm_circuit_fail

- Fault indicating there is a circuit failure on a thermistor channel on a G4 Cell Interface.
- This can also trip due to misconfigured or incorrectly installed thermistors.

Thermistor Consistency Check | stack_fault_ci_therm_consistency

- Fault indicating the difference between thermal readings on a G4 Cell Interface is too large.

Cell Interface Measurement Check | sc_fault_ci

- Fault indicating there was an internal hardware failure on a G4 Cell Interface.

Current Shunt Open Wire Check | stack_fault_open_shunt

- Fault indicating the current shunt is open circuit.

Current Shunt Short Circuit Check | stack_fault_short_shunt

- Fault indicating the current shunt has become a short circuit.
- When experiencing difficulty clearing this fault, please refer to [Section 11.1.7.1, "Known Issues"](#).

Contactors End-Of-Life | ssg_fault_contactor_end_of_life

- Fault indicating a contactor is end-of-life.
- Contact support@nuvationenergy.com if this fault has tripped.

Stack Switchgear Contactor Life Sanity Check | ssg_fault_contactor_life_sanity_check

- Fault indicating a sanity check error on the contactor life data.

Stack Switchgear Contactor Life Memory Error | ssg_fault_config_contactor_life

- Fault indicating an error saving or loading the contactor life data.

Stack Switchgear Contactor Life Memory Check | ssg_fault_config_contactor_life_verify

- Fault indicating a validation error on the contactor life data.

11.1.7.1. Known Issues

11.1.7.1.1. Short Shunt Fault on Self Check

Issue

In rare occasions, the `stack_fault_short_shunt` can accidentally trip when powering on the G4 Stack Switchgear. If the contactors remain open and no current has flowed through the batteries, the fault does not indicate a short on the current shunt. Note that this issue only occurs within a minute of powering on the G4 Stack Switchgear and faults that happen outside this window should be investigated further.

Workaround

The operator of the Operator Interface can attempt to clear the fault as described in [Section 6.2.3, "Safety"](#).

11.1.7.1.2. Clearing the Short Shunt Fault Is Not Immediate

Issue

Clearing the `stack_fault_short_shunt` fault might not occur immediately.

Workaround

To determine when the fault can be cleared, read the values of the `stack_short_shunt_detector.voltage_activity_threshold` and `stack_short_shunt_detector.inactivity_envelope` registers. Wait until the value in the inactivity envelope is smaller than the voltage activity threshold. At this point the `stack_fault_short_shunt` fault can be cleared. The maximum time required for the inactivity envelope to fall below the threshold can be determined by reading the `stack_short_shunt_detector.activity_detection_time` register, with the value given in μs .

11.1.7.2. Self Check Issues

The `stack_fault_cell_open_wire`, `stack_fault_therm_circuit_fail`, `stack_fault_ci_therm_consistency`, and `sc_fault_ci` can fail a Self Check due to problems with the Link Bus. Refer to [Section 11.1.1.1, "Self Check Issues"](#) for further details.

The `stack_fault_open_shunt` and `stack_fault_short_shunt` can fail a Self Check if the associated algorithms are not enabled, the G4 Stack Switchgear unit's internal Power Interface module's AFE is not enabled, or there is Stack Bus communication errors. This is typically caused by incorrectly modifying the G4 Stack Switchgear factory configuration file. Contact support@nuvationenergy.com for a valid configuration file for the G4 Stack Switchgear.

11.1.8. Breaker Faults

Breaker Tripped Check | `stack_fault_breaker_tripped`

- Fault that is triggered to indicate that the breaker has tripped.(i.e. opened)

Breaker Conflict Check | `stack_fault_breaker_conflict`

- Fault that is triggered to indicate that the breaker state differs from the expected state of the breaker.

11.1.8.1. Self Check Issues

Most Self Check failures for these faults are caused by an invalid configuration of the GPI(s) used to read the breaker state. This is typically caused by incorrectly modifying the G4 Stack Switchgear factory configuration file. Contact support@nuvationenergy.com for a valid configuration file for the G4 Stack Switchgear.

11.1.9. Watchdog Faults

Power Interface Measurement Watchdog | stack_fault_power_wdt

- Fault indicating stack voltage and current data has not been updated periodically.

Cell Voltage Measurement Watchdog | stack_fault_cell_wdt

- Fault indicating all cell data has not been updated periodically for every installed cell.

Temperature Measurement Watchdog | stack_fault_therm_wdt

- Fault indicating all thermistor data has not been updated periodically for every installed thermistor.

Cell Interface Measurement Watchdog | stack_fault_ci_wdt

- Fault indicating G4 Cell Interface data has not been updated periodically for every installed G4 Cell Interface.

Cell Open Wire Measurement Watchdog | stack_fault_open_wire_wdt

- Fault indicating open wire scanning has not been occurring periodically when connected to the DC bus.

Controller Heartbeat Watchdog | sc_fault_controller_wdt

- Fault indicating that an external controller to the Battery Management System was not updating its watchdog timer (via the MESA heartbeat).

Controller Heartbeat Watchdog | sc_warn_controller_wdt

- Warning triggered from the same data as sc_fault_controller_wdt.

StackBus Receive Watchdog | sc_fault_stackbus_rxwdt

- Fault indicating that there was a receive communication failure over the Stack Bus.

StackBus Transmit Watchdog | sc_fault_stackbus_txwdt

- Fault indicating that there was a transmit communication failure over the Stack Bus.

Power Interface AFE Watchdog | sc_fault_pi_afe_wdt

- Fault indicating that there was a communication failure between the AFE and the G4 Stack Switchgear unit's internal Power Interface module.

LinkBus Communication Watchdog | sc_fault_linkbus_wdt

- Fault indicating that there was an internal communication failure relating to Link Bus data. Please contact Nuvation Energy at support@nuvationenergy.com if you are experiencing this fault.

Stack Controller RAM Test Watchdog | sc_fault_ram_test_wdt

- Fault indicating the internal RAM testing has not been executing periodically.

Stack Controller ROM Test Watchdog | sc_fault_rom_test_wdt

- Fault indicating the internal ROM testing has not been executing periodically.

Stack Controller Factory Configuration | `sc_fault_factory_verify_wdt`

- Fault indicating the factory registers on the G4 Stack Switchgear unit's internal Stack Controller module have not been periodically validated against non-volatile memory.

Power Interface Factory Memory Watchdog | `pi_fault_factory_verify_wdt`

- Fault indicating the factory registers on the G4 Stack Switchgear unit's internal Power Interface module have not been periodically being validated against non-volatile memory.

Contactactor Monitor Watchdog | `ssg_fault_contactor_monitor_wdt`

- Fault indicating contactor monitoring has not been executing periodically.

Contactactor End-Of-Life Watchdog | `ssg_fault_contactor_end_of_life_wdt`

- Fault indicating contactor life has not been evaluated periodically.

Stack Switchgear Contactactor Life Memory Watchdog | `ssg_fault_contactor_life_verify_wdt`

- Fault indicating contactor life data has not been validated periodically.

11.1.9.1. Self Check Issues

The `stack_fault_cell_wdt`, `stack_fault_therm_wdt`, `stack_fault_ci_wdt`, and `stack_fault_open_wire_wdt` can fail a Self Check due to problems with the Link Bus communication. Refer to [Section 11.1.1.1, "Self Check Issues"](#) for further details.

The watchdog faults `sc_fault_ram_test_wdt`, `sc_fault_rom_test_wdt`, `sc_fault_factory_verify_wdt`, `pi_fault_factory_verify_wdt`, `sc_fault_stackbus_rxwdt` and `sc_fault_stackbus_txwdt` should always pass their Self Check as they are core to the Nuvation Energy BMS and are not configurable.

Please contact Nuvation Energy at support@nuvationenergy.com if you are experiencing these faults.

The `sc_fault_pi_afe_wdt` and `stack_fault_power_wdt` can fail a Self Check due to disabling the G4 Stack Switchgear unit's internal Power Interface module's AFE or a high amount of noise on the DC bus.

This is typically caused by incorrectly modifying the G4 Stack Switchgear factory configuration file. Contact support@nuvationenergy.com for a valid configuration file for the G4 Stack Switchgear.

The `sc_fault_controller_wdt` can fail a Self Check if there is no external controller updating the heartbeat. Disable this fault if there is no external controller periodically updating the watchdog as described in [Section 7.5.6, "External Controller Heartbeat"](#).

11.1.10. Miscellaneous Faults

Stack Controller Configuration Consistency Check | `sc_fault_config`

- Fault indicating that there was an error reading the non-volatile storage of the Battery Management System configuration. A default configuration is used when this fault occurs and the Battery Management System will fail to exit Service Lockout. Once a configuration has been successfully imported into the Battery Management System and saved, this fault should not occur. Note that during an upgrade of the Battery Management System, the configuration is deleted to avoid incompatibility with the upgraded version.

Stack Controller Factory Consistency Check | `sc_fault_config_factory`

- Fault indicating that there was an error reading the non-volatile storage of the Battery Management System factory configuration. This is similar to `sc_fault_config`; refer to that fault for more details.

Stack Controller Factory Memory Check | `sc_fault_config_factory_verify`

- Fault indicating that verification of factory configuration settings against non-volatile storage has failed on the G4 Stack Switchgear unit's internal Stack Controller module. This typically means either a setting was changed after saving or non-volatile memory has been corrupted.

Power Interface Factory Memory Check | `pi_fault_config_factory_verify`

- Fault indicating that verification of factory configuration settings against non-volatile storage has failed on the G4 Stack Switchgear unit's internal Power Interface module. This typically means either a factory setting was changed after saving or non-volatile memory has been corrupted.

Firmware Version Mismatch Check | `sc_fault_fw_mismatch`

- Fault indicating that the internal Stack Controller and Power Interface modules firmware versions are different. Contact support@nuvationenergy.com if this fault occurs.

Clock Check | `sc_fault_clocks`

- Fault indicating that the internal Stack Controller and Power Interface modules clocks are ticking at different rates. This may indicate an overloaded system or malfunction in the hardware or software. Also if one of the processors resets, this fault can trip since its clock also resets.

LinkBus Power Mode Check | `sc_fault_linkbus_power`

- Fault indicating that there was a hardware problem with the Link Bus power or an incorrect power mode in `sc_linkbus.power_mode`.

Internal Software Error | `sc_fault_register_link`

- Fault indicating an internal communication failure in the BMS firmware. Contact support@nuvationenergy.com if this fault occurs and record the values in the following registers `sc_gpo.link_error`, `sc_gpo_shutdown.link_error`, `stack_contactor.link_error` and `sc_gpi.link_error`.

11.2. Lost/Forgotten IP Address

If a Nuvation Energy BMS has been configured with a static IP address and it has been forgotten, follow the steps below to recover it.



Depending on the network interface used on the PC, this process may not work due to differing security and IP configurations. If the only IP discovered is the IP of the PC, the network interface is not suitable and another one will need to be used. This issue is most common with USB to Ethernet dongles.

11.2.1. Wireshark (Windows/Linux)

1. Download/install Wireshark on a PC (<https://www.wireshark.org/>)

2. Connect the PC directly to the Ethernet port on the G4 Stack Switchgear
3. Start a Wireshark capture on the network interface connected to the G4 Stack Switchgear
4. In the 'filter' field, enter in `arp.isgratuitous` and press enter
5. Either reboot the G4 Stack Switchgear, or unplug/plug the Ethernet cable
6. The device should send a 'Gratuitous ARP' on the Ethernet network. In Wireshark the 'Info' field looks like: Gratuitous ARP for <IP> (Request) where the <IP> is the address for the G4 Stack Switchgear
7. Once that is complete, update the PC network settings to match the G4 Stack Switchgear and connect the Operator Interface.
 - Refer to [Section 5.2, "Connect to the Operator Interface"](#) for instructions.

11.2.2. Netdiscover (Linux only)

1. Install netdiscover on a PC (on Debian based systems use: `sudo apt install netdiscover`)
2. Connect the PC directly to the Ethernet port on the G4 Stack Switchgear
3. Run `sudo netdiscover -i <interface> -p` where <interface> is the network interface connected to the G4 Stack Switchgear
4. Either reboot the G4 Stack Switchgear, or unplug/plug the Ethernet cable
5. The device address and MAC will show up in netdiscover once an ARP packet is sent
6. Once that is complete, update the PC network settings to match the G4 Stack Switchgear and connect the Operator Interface.
 - Refer to [Section 5.2, "Connect to the Operator Interface"](#) for instructions.



In the event the IP address cannot be discovered, contact support@nuvationenergy.com for assistance.

Appendix A: Operating Limits

G4 Stack Switchgear



Exceeding the ratings will damage the system.

External Specifications

Symbol	Parameter	Min	Typ	Max	Units
V_{input}	Input Voltage	100	-	240	V AC
P_{input}	Input Power	-	33.7	60	W
f_{input}	Input Frequency	45	50/60	65	Hz
V_{fan_DC}	Cooling Fan DC Voltage	-	-	50	V DC
V_{fan_AC}	Cooling Fan AC Voltage	-	-	250	V AC
I_{fan}	Cooling Fan Current	-	-	5	A DC/AC
I_{E-Stop}	E-Stop Input Current Rating	-	-	9.6	mA DC
V_{E-Stop}	E-Stop Input Voltage Rating	19.2	24	28.8	V DC

Electrical Characteristics

The part number of the G4 Stack Switchgear captures its product rating. Refer to [G4 Stack Switchgear Ordering Information](#) for the relevant voltage, current and fuse ratings available for the G4 Stack Switchgear part numbers. The voltage rating is an absolute maximum rating, and the current rating is a continuous rating (also referred to as the 'nominal' rating).

Voltage and Temperature Specifications

NUVSSG-1250-x

Symbol	Parameter	Min	Typ	Max	Units
Stack Voltage Specifications					
V_{stack_ov}	Stack Over-Voltage Threshold (triggers contactors to open)	0	Configurable	1250	V DC
V_{stack_uv}	Stack Under-Voltage Threshold (triggers contactors to open)	0	Configurable	-	V DC
Battery Cell Specifications					
C_{ov}	Cell Over-Voltage Threshold (triggers contactors to open)	-	Configurable	-	V
C_{uv}	Cell Under-Voltage Threshold (triggers contactors to open)	-	Configurable	-	V
Temperature Sensors Specifications					

Symbol	Parameter	Min	Typ	Max	Units
T_{ut}	Under-Temperature Threshold (triggers contactors to open)	-	Configurable	-	°C
T_{ot}	Over-Temperature Threshold (triggers contactors to open)	-	Configurable	-	°C
T_{fan_en}	Fan Enable Temperature Threshold	-	Configurable	-	°C
Overvoltage Category Specifications					
CAT_{II}	Phase to Ground Rated System Voltage (RMS or DC)	-	-	300	V
CAT_{III}	Phase to Ground Rated System Voltage (RMS or DC)	-	-	150	V

Continuous and Maximum Current Ratings

Symbol	Parameter	Continuous	Absolute Max	Units
G4 Stack Switchgear Configuration: 1250 V DC, 100 A				
$I_{discharge_oc}$	Stack Discharging Over-Current (triggers contactors to open)	100	150	A DC
I_{charge_oc}	Stack Charging Over-Current (triggers contactors to open)	100	150	A DC
G4 Stack Switchgear Configuration: 1250 V DC, 200 A				
$I_{discharge_oc}$	Stack Discharging Over-Current (triggers contactors to open)	200	250	A DC
I_{charge_oc}	Stack Charging Over-Current (triggers contactors to open)	200	250	A DC
G4 Stack Switchgear Configuration: 1250 V DC, 300 A				
$I_{discharge_oc}$	Stack Discharging Over-Current (triggers contactors to open)	300	350	A DC
I_{charge_oc}	Stack Charging Over-Current (triggers contactors to open)	300	350	A DC
G4 Stack Switchgear Configuration: 1250 V DC, 350 A				
$I_{discharge_oc}$	Stack Discharging Over-Current (triggers contactors to open)	350	400	A DC
I_{charge_oc}	Stack Charging Over-Current (triggers contactors to open)	350	400	A DC



The G4 Stack Switchgear can handle short current overages above the continuous rating. Any charge or discharge current above the continuous rating must not exceed 5 minutes per hour and must not exceed the specified absolute max rating. Sufficient time to allow the system to cool down afterward is required.

Contactors Life Ratings

Table 51. Contactor Life Ratings : NUVSSG-1250-100-x

Symbol	Parameter	Min	Max	Absolute Max	Units
$I_{min_breaking}$	Minimum breaking current of contactors	100	-	-	A DC
N_{min}	Number of contactor opening cycles below the minimum breaking current	6000	-	-	cycles
$I_{max_breaking}$	Maximum breaking current of contactors	-	150	-	A DC
N_{life}	Number of contactor opening cycles between the minimum and maximum breaking currents	-	100	-	cycles

Symbol	Parameter	Min	Max	Absolute Max	Units
N_{max}	Number of contactor opening cycles above the maximum breaking current	-	1	-	cycle
I_{max}	One time contactor maximum breaking current	-	-	1260	A DC

Table 52. Contactor Life Ratings : NUVSSG-1250-200-x

Symbol	Parameter	Min	Max	Absolute Max	Units
$I_{min_breaking}$	Minimum breaking current of contactors	100	-	-	A DC
N_{min}	Number of contactor opening cycles below the minimum breaking current	6000	-	-	cycles
$I_{max_breaking}$	Maximum breaking current of contactors	-	250	-	A DC
N_{life}	Number of contactor opening cycles between the minimum and maximum breaking currents	-	100	-	cycles
N_{max}	Number of contactor opening cycles above the maximum breaking current	-	1	-	cycle
I_{max}	One time contactor maximum breaking current	-	-	1260	A DC

Table 53. Contactor Life Ratings : NUVSSG-1250-300-x

Symbol	Parameter	Min	Max	Absolute Max	Units
$I_{min_breaking}$	Minimum breaking current of contactors	100	-	-	A DC
N_{min}	Number of contactor opening cycles below the minimum breaking current	6000	-	-	cycles
$I_{max_breaking}$	Maximum breaking current of contactors	-	350	-	A DC
N_{life}	Number of contactor opening cycles between the minimum and maximum breaking currents	-	100	-	cycles
N_{max}	Number of contactor opening cycles above the maximum breaking current	-	1	-	cycle
I_{max}	One time contactor maximum breaking current	-	-	1260	A DC

Table 54. Contactor Life Ratings : NUVSSG-1250-350-x

Symbol	Parameter	Min	Max	Absolute Max	Units
$I_{min_breaking}$	Minimum breaking current of contactors	100	-	-	A DC
N_{min}	Number of contactor opening cycles below the minimum breaking current	6000	-	-	cycles
$I_{max_breaking}$	Maximum breaking current of contactors	-	400	-	A DC
N_{life}	Number of contactor opening cycles between the minimum and maximum breaking currents	-	100	-	cycles
N_{max}	Number of contactor opening cycles above the maximum breaking current	-	1	-	cycle
I_{max}	One time contactor maximum breaking current	-	-	1260	A DC



To extend the lifetime of the G4 Stack Switchgear, a disconnect delay can be configured to allow time for the PCS controller to reduce the current flowing through

the battery stack before the G4 Stack Switchgear will open contactors, which will avoid exposing the contactors to high breaking currents.



Contactors will open immediately for the following conditions which will bypass the disconnection delay:

1. Unpowering the G4 Stack Switchgear

Environmental Conditions

Symbol	Parameter	Min	Typ	Max	Units
Thermal Specifications					
T _a	Operating Temperature: G4 Stack Switchgear Accessible*	10	25	40	°C
	Operating Temperature: G4 Stack Switchgear Inaccessible*	-10	25	50	°C
	Storage Temperature	-10	25	50	°C
Humidity Specifications					
RH	Operating Relative Humidity	5	-	85	%
	Storage Relative Humidity	5	-	85	%
Shock and Vibration Specifications					
Vertical	Vertical shock/vibration	-	-	10	m/s ²
Longitudinal	Longitudinal shock/vibration	-	-	10	m/s ²
Transverse	Transverse shock/vibration	-	-	10	m/s ²
Pulse vibration	On each axis	-	-	245	m/s ²

*To use the Nuvation Energy G4 Stack Switchgear in the temperature range of -10 to 50 °C, the G4 Stack Switchgear must not be accessible in the end product installation. In an installation where the G4 Stack Switchgear is accessible, the operating temperature is reduced to 10 to 40 °C.

For transportation, it is recommended that the G4 Stack Switchgear be shipped in its original packaging via pallet whenever possible.

Standards and Certifications

Certification/Report	
Stationary Battery Safety	UL Recognized (internal Power Interface and Stack Controller modules) - UL 1973 (file no. MH64071)
Functional Safety (components)	UL Recognized (internal Power Interface and Stack Controller modules) - UL Recognized - UL 991 (file no. MH64071) - UL Recognized - UL 1998 (file no. MH64071)

Certification/Report

Electrical Safety (components)	Internal Power Interface and Stack Controller modules - IEC 62368-1:2014 (Second Edition) - IEC 62368-3:2017
Shock and Vibration	Designed to meet the requirements of SAE J2464 and SAE J2380

UL 1973 recognition ensures safe battery operation and significantly reduces the effort of certifying the energy storage solution to meet UL 1973 and UL 9540.

G4 Cell Interface



Exceeding the maximum ratings will damage the G4 Cell Interface module.

Electrical Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Units
Link In Specifications						
+V _{BUS}	Input Voltage	-	9	24	60	V DC
	Input Current, CI-12	+VBUS = 24 V DC, Link Out disconnected	-	-	25.5	mA DC
	Input Current, CI-16 and CI-4M12	+VBUS = 24 V DC, Link Out disconnected	-	-	31.7	mA DC
I _{P_LINK}	Output Current	-	-	-	20	mA DC
I _{N_LINK}	Output Current	-	-	-	20	mA DC
Link Out Specifications						
+V _{BUS}	Output Voltage	-	-	+VBUS	-	V DC
	Output Current per CI-12	+VBUS = 24 V DC	-	-	25.5	mA DC
	Output Current per CI-16 and CI-4M12	+VBUS = 24 V DC	-	-	31.7	mA DC
I _{P_LINK}	Output Current	-	-	-	20	mA DC
I _{N_LINK}	Output Current	-	-	-	20	mA DC
Battery Cells Specifications						
C _(n) - C _(n-1)	Input Cell Voltage Range	CI-12, CI-16	0	-	5	V DC
B _(n) - B _(n-1)	Input Block Voltage Range	CI-4M12	5	-	20	V DC
V _{sum}	Voltage between C0 and C12	CI-12, +VBUS = 0 V DC	11	-	60	V DC
	Voltage between C0 and C8	CI-16, +VBUS = 0 V DC	11	-	40	V DC
	Voltage between C8 and C16	CI-16, +VBUS = 0 V DC	11	-	40	V DC
	Voltage between B0 and B2	CI-4M12, +VBUS = 0 V DC	11	-	40	V DC
	Voltage between B2 and B4	CI-4M12, +VBUS = 0 V DC	11	-	40	V DC
TME	Total Measurement Error	CI-12, CI-16, +VBUS = 24 V DC	±0.1	±1.2	±1.6	mV DC
	Total Measurement Error	CI-4M12, +VBUS = 24 V DC	±2.0	±8.0	±10.0	mV DC
I _(n)	Cell Balancing Current (only for CI-12 and CI-16)	C _(n) - C _(n-1) = 4 V DC	304	307	310	mA DC
V _{bal}	Cell Voltage for Balancing	CI-12 and CI-16	1.1	-	-	V DC

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{ins}	Internal reinforced insulation rating from Chassis/COM	-	-	-	1250	V DC
CAT _{II}	Overvoltage category	Phase to Ground Rated System Voltage (RMS or DC)	-	-	300	V
CAT _{III}	Overvoltage category	Phase to Ground Rated System Voltage (RMS or DC)	-	-	150	V
Temperature Sensors Specifications						
$I_{(n)}$	Output Current to Temperature Sensor	-	-	-	300	μ A
$R_{t(n)}$	Temperature Sensor Resistance at 25 °C	-	-	10	-	k Ω
$T_{(n)}$	Input Temperature Sensor Voltage Range	Cell 0 or Block 0 = 0 V	0	-	3	V
V_{ins}	Internal reinforced insulation rating from Chassis/COM	-	-	-	1250	V DC
CAT _{II}	Overvoltage category	Phase to Ground Rated System Voltage (RMS or DC)	-	-	300	V
CAT _{III}	Overvoltage category	Phase to Ground Rated System Voltage (RMS or DC)	-	-	150	V

Environmental Conditions

Symbol	Parameter	Min	Typ	Max	Units
Thermal Specifications					
T_a	Operating Temperature	-10	25	60	°C
	Storage Temperature	-20	25	60	°C
Humidity Specifications					
RH	Operational RH	5	-	85	%
	Storage RH	5	-	85	%
Shock and Vibration Specifications					
Vertical	Vertical shock/vibration	-	-	10	m/s ²
Longitudinal	Longitudinal shock/vibration	-	-	10	m/s ²
Transverse	Transverse shock/vibration	-	-	10	m/s ²
Pulse vibration	On each axis	-	-	245	m/s ²

Standards and Certifications

The G4 Cell Interface meets industry standards CISPR 22 Class A and IEC/EN 61000-4-2 for EMC/EMI and ESD respectively. It has been designed to meet EN 60950 high voltage creepage/clearance distances for reinforced insulation rated to 1250 V DC. All components are EU RoHS / China RoHS compliant.

Certification/Report	
Stationary Battery Safety	UL Recognized - UL 1973 (file no. MH64071)
Functional Safety	- UL Recognized - UL 991 (file no. MH64071) - UL Recognized - UL 1998 (file no. MH64071)
Electrical Safety	IEC 62368-1:2014 (Second Edition), IEC 62368-3:2017
Industrial Immunity	EN/IEC 61000-6-2 2019
Shock and Vibration	Designed to meet the requirements of SAE J2464 and SAE J2380

UL 1973 recognition ensures safe battery operation and significantly reduce the effort of certifying the energy storage solution to meet UL 1973 and UL 9540.

Maximum Stack Deployment

G4 Cell Interface modules are deployed as a daisy chain to monitor the cells of a stack. The maximum number of modules that are supported in a stack depend on two metrics:

- the maximum number of modules that can be powered over Link Bus power (if required)
- the required scan rate of the cell voltage measurements

Limits Due to Link Bus Power

Max CI-12	Max CI-16	Max CI-4M12
50	40	40

Limits Due to Cell Voltage Scan Rate

The following are approximate cell voltage scan rates for different lengths of G4 Cell Interface daisy chains where all cells are installed. On the G4 Stack Switchgear, the Measurement Anti-Aliasing Filter is set to OFF.

Table 55. Cell Voltage Scan Rates for CI-16 and CI-4M12

Measurement Anti-Aliasing Filter	G4 Cell Interface Chain Length	Scan Rate [Hz]
Off	1	5.53
Off	5	3.32
Off	10	2.22
Off	15	1.74
Off	20	1.38
Off	25	1.15
Off	30	0.91

Table 56. Cell Voltage Scan Rates for CI-12

Measurement Anti-Aliasing Filter	G4 Cell Interface Chain Length	Scan Rate [Hz]
Off	1	6.01
Off	5	3.94
Off	10	3.03
Off	15	2.59
Off	20	1.97
Off	25	1.63
Off	30	1.44
Off	35	1.30
Off	40	1.08

Appendix B: Ordering Information

G4 Stack Switchgear

This section provides orderable part numbers for Nuvation Energy’s offerings of G4 Stack Switchgear units and mounting accessories.

These options are suffixed to the product part number in the format: NUVSSG-1250-<current-rating>-<fuse-rating-code>.

Table 57. G4 Stack Switchgear Unit Ordering Information

Part Number	Product Name	Compatible Fuse Rating
NUVSSG-1250-100-x	G4 Stack Switchgear, 1250 V, 100 A	200 A
NUVSSG-1250-200-x	G4 Stack Switchgear, 1250 V, 200 A	250 A, 315 A, 350 A
NUVSSG-1250-300-x	G4 Stack Switchgear, 1250 V, 300 A	350 A, 400 A, 450 A, 500 A
NUVSSG-1250-350-x	G4 Stack Switchgear, 1250 V, 350 A	400 A, 450 A, 500 A

* x = fuse rating code.

Fuse Rating Code

The fuse rating code is denoted by the x at the end of the product part number. The G4 Stack Switchgear fuse rating is determined by the application power profile, which is based on continuous power, cycle duration, and cycle frequency.

A Nuvation Energy Application Engineer will assist with determining a suitable fuse rating when an order is placed.

Table 58. Fuse rating and code

Fuse Rating	Code
200 A	1
250 A	2
315 A	3
350 A	4
400 A	5
450 A	6
500 A	7

For e.g., a NUVSSG-1250-100-1 is a "1250 V DC, 100 A" G4 Stack Switchgear, with a 200 A fuse rating.

Mounting Bracket

By default, the G4 Stack Switchgear ships with bracket NUVP-SSG-SB for shelf-mounting. The following mounting bracket options are available upon request.

Table 59. Mounting Bracket Ordering Information

Part Number	Product Name
NUVP-SSG-SB	Part, Stack Switchgear, Brackets for shelf-mounting
NUVP-SSG-RB-19	Part, Stack Switchgear, Front-securing Brackets for 19" Rack
NUVP-SSG-RB-19-2P	Part, Stack Switchgear, Brackets for 2-post 19" Rack
NUVP-SSG-RB-23-2P	Part, Stack Switchgear, Brackets for 2-post 23" Rack

Fasteners for attaching the brackets to the unit are included.



Bracket CAD files are available online at <https://www.nuvationenergy.com/technical-resources>.

G4 Cell Interface

Product part numbers for ordering a G4 Cell Interface are listed in [Table 60, "G4 Cell Interface Ordering Information"](#). Accessory kits are listed in [Table 61, "G4 Cell Interface Accessory Kits Ordering Information"](#).



G4 Cell Interface kits—which include the G4 Cell Interface module and cables—are available to get you started quickly. Please visit <https://nstore.nuvationenergy.com> for more details.

Table 60. G4 Cell Interface Ordering Information

Part Number	Product Name
NUV100-CI-12-1	G4 Cell Interface - 12 channel, Bulkhead
NUV100-CI-12-U	G4 Cell Interface - 12 channel, PCB assembly only (no enclosure)
NUV100-CI-12-KIT	G4 Cell Interface Kit - 12 channel
NUV100-CI-16-1	G4 Cell Interface - 16 channel, Bulkhead
NUV100-CI-16-U	G4 Cell Interface - 16 channel, PCB assembly only (no enclosure)
NUV100-CI-16-KIT	G4 Cell Interface Kit - 16 channel
NUV100-CI-4M12-1	G4 Cell Interface - 12V 4 channel, Bulkhead
NUV100-CI-4M12-U	G4 Cell Interface - 12V 4 channel, PCB assembly only (no enclosure)
NUV100-CI-4M12-KIT	G4 Cell Interface Kit - 12V 4 channel



If mounting a G4 Cell Interface, PCB assembly only (no enclosure), note that the G4 Cell Interface contains high-voltage signals reaching as high as 1250 V DC. Care must be taken when mounting the PCB into a metal enclosure to ensure that the metal walls remain a safe distance from the exposed conductor on the PCB. Using 1250 V DC as an example, the metal walls of the enclosure must be at least 4.2 mm from the nearest exposed conductor and must not touch the PCB or any component on the PCB, including the connector housings.

Table 61. G4 Cell Interface Accessory Kits Ordering Information

Part Number	Product Name
NUVP-CI-DIN-MB	G4 Cell Interface Mounting Bracket (Bulkhead-to-DIN)

Appendix C: Changing the Nuvation Energy BMS Network Configuration

Nuvation Energy BMS is flexible and allows changing its network configuration if you need the IP address of Nuvation Energy BMS to match your existing network settings.



Improperly modifying the network settings can result in a Nuvation Energy BMS that cannot communicate over Ethernet.

Be sure to record the updated IP address, netmask, and gateway settings if you decide to make changes to these settings.

Modifying the Network Settings



The G4 Stack Switchgear ships from the factory with password protection on the Operator Interface. Please contact support@nuvationenergy.com for the factory password and documentation for advanced modifications of the G4 Stack Switchgear.

1. Unlock the Operator Interface by clicking the menu and UnLock
 - You will need the Operator Interface password if the Operator Interface is password-protected
2. Follow the instructions in [Section 6.3.2.5, "Editing an IP Address"](#) to update the IP.

Appendix D: Best Practices

This section describes important concepts which need special attention to achieve a reliable installation.

Excess Cable Management

During the first prototype system build, it is possible to encounter cable lengths that are too long for your system. Leaving the excess cable length unmanaged can result in a messy system installation.

If reducing the cable length is not feasible or if there is no time to physically modify the lengths, a common solution is to wrap the excess cable length in a coil and fasten the wire loop in the cabinet. This basic tactic has the undesirable effect of creating an air-core transformer which will couple EMI into the cable extremely well.

The best solution to cable length management is to bundle the excess length in a figure-8 pattern. This prevents the bundle from turning into an air-core transformer since the direction of current in one side of the figure-8 turns opposite to the current in the other side. It is recommended to use the figure-8 method if physically reducing the cable length is not possible.

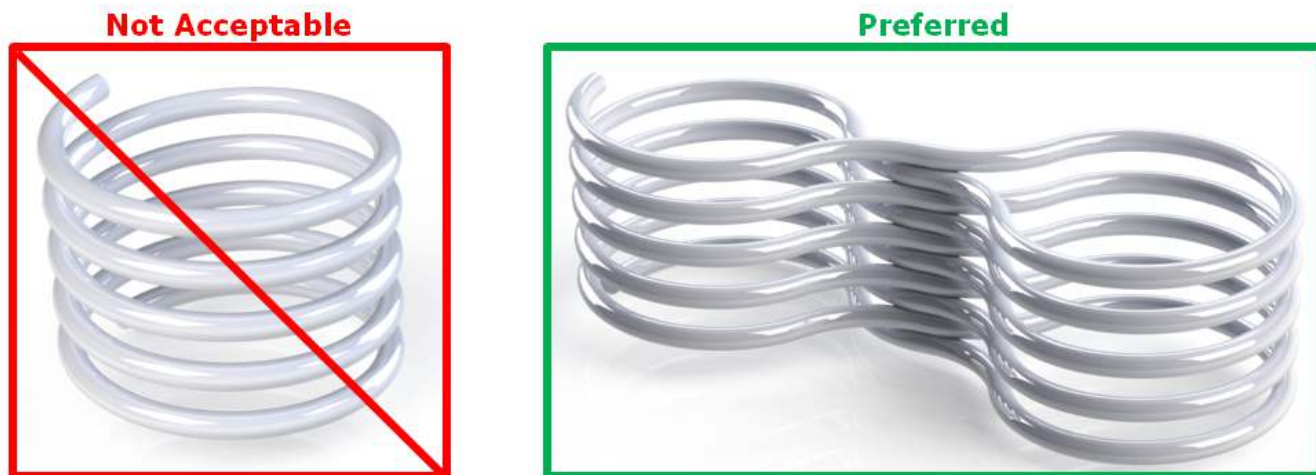


Figure 77. Excess Cable Management Examples

System Noise

High-power inverters generate a lot of system noise, especially on the DC bus. This is due to the industry standards for AC harmonics and EMC on the grid-side which require the DC bus to help filter out the harmful emissions. Unfortunately, that means the battery cells and the G4 High-Voltage BMS experience extreme levels of noise.

The most harmful emissions on the DC bus are between the DC bus and earth. This is due to the slew-rate of the switching devices implemented in the inverter (usually IGBTs). The slew-rate is impacted by many elements, and the emissions can be minimized by carefully grounding the installation so that the return-path for the high-frequency switching noise can be kept small.

The G4 High-Voltage BMS has various faults and informative registers to determine if the system has a high level of noise that is impacting the Battery Management System.

The communication faults are:

```
sc_fault_linkbus_wdt.trig
sc_fault_stackbus_rxwdt.trig
sc_fault_stackbus_txwdt.trig
sc_fault_pi_afe_wdt.trig
sc_fault_controller_wdt.trig
```

The informative communication error registers are:

```
sc_linkbus_packets.operation_read_errors
sc_linkbus_packets.operation_validate_errors
sc_stackbus.rxerrrate
sc_stackbus.txerrrate
pi_afe.rx_err_rate
pi_afe.tx_err_rate
```

The system controller heartbeat should also be coming through as expected, and can be verified by reading the register:

```
sc_controller_heartbeat.value
```

In a correctly wired system, a communication fault points to elevated system noise that is disrupting communications. If the system grounding scheme cannot be improved, there are still a few techniques within G4 High-Voltage BMS or the battery area to try to decrease the amount of noise.

DC Filtering

A DC filter can be installed between the DC bus and the inverter or between each DC battery stack and the common DC bus in a multi-stack system. Schaffner FN 2200 is an example DC filter which has been known to decrease the amount of harmful emissions on the DC bus. An example filter installation is shown below:

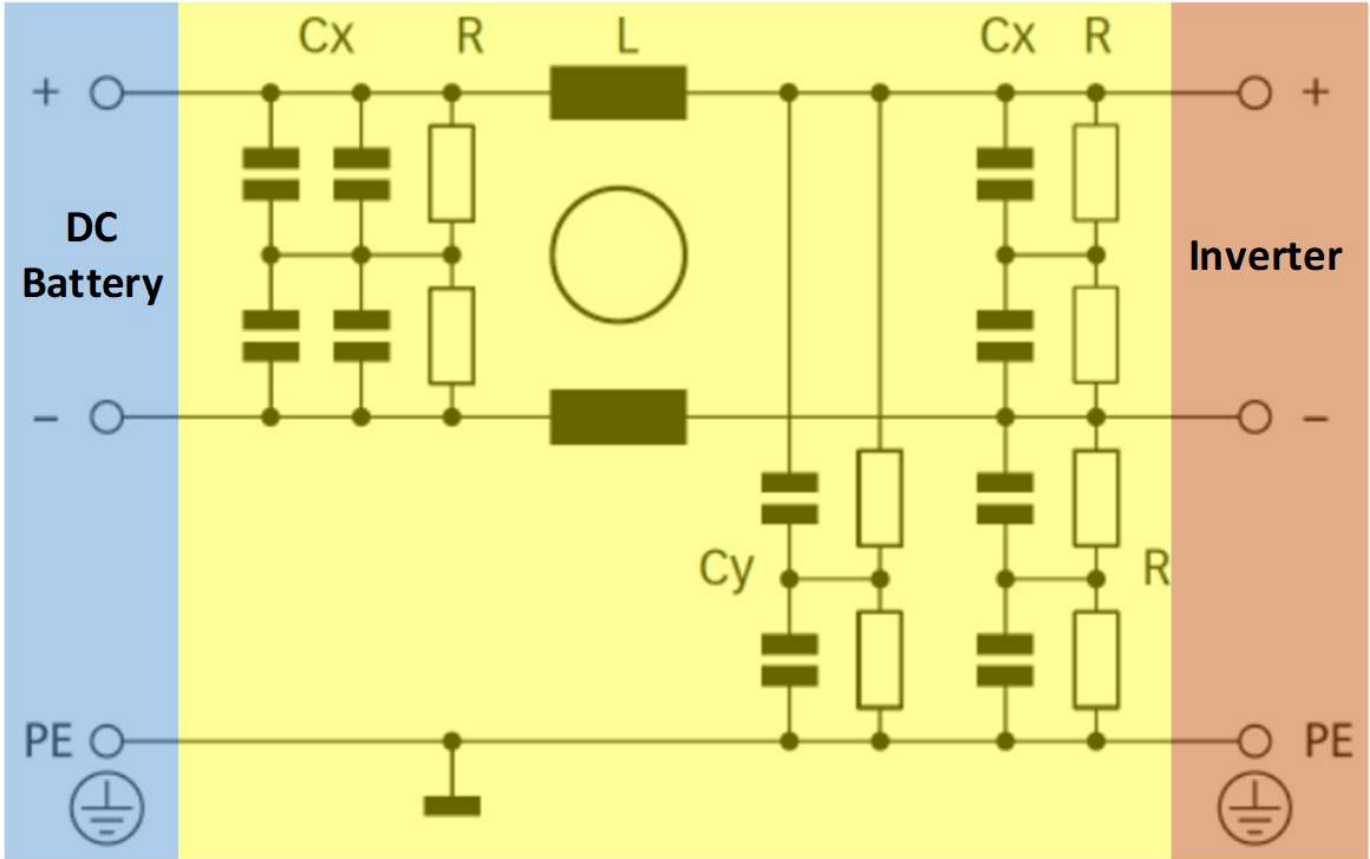


Figure 78. Example DC Filter Schematic

When using DC filters, please be aware that it shunts high-frequency noise to earth. If the inverter is not driving an insulated neutral system, there will be high current pulses flowing in the system earth which can trip ground fault detectors. It might be necessary to install an isolation transformer between the inverter and the grid to remove the high current pulses.

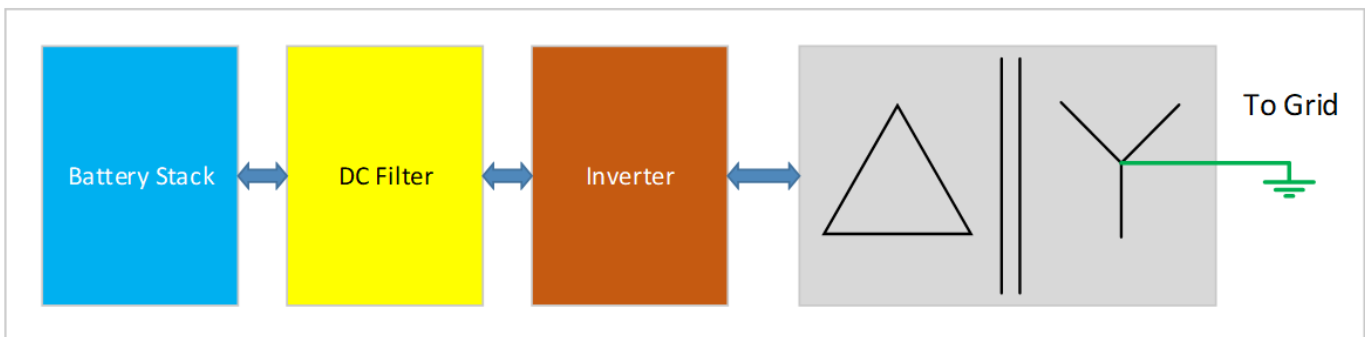


Figure 79. Example Isolation Transformer Installation Diagram

Link Bus Power

While the communication interface between the G4 Stack Switchgear and the G4 Cell Interface is a daisy-chain, the power supplied to the G4 Cell Interface from the G4 Stack Switchgear is a bus. This results in the power twisted pair in the Link Bus cable carrying power up the entire length of the

chain. This provides a decent medium to couple system noise into the Link Bus which can result in `sc_linkbus` communication faults.

In systems where the cells can provide the necessary minimum operating voltage to the G4 Cell Interface, Link Bus power can be disabled if the observed impact on performance is acceptable. The power twisted pair must be disconnected in the Link Bus cable, so all Link Out and Link In connectors on the G4 Stack Switchgear and the G4 Cell Interface modules must have pins 1 and 2 unpopulated.

Security



This section is provided as guidance only and experts in security and the broader system must be consulted on any security decisions.



Security for the entire system and site must be considered, not just for individual Nuvation Energy products.

It is recommended evaluating each site and system to assess the risk level and impacts of the system not operating properly. Security restrictions protect against both accidental misuse and intentional attacks. Each added layer of security will impact the ability to diagnose and resolve system problems and analyze system performance. The costs of system security should be proportional to the risk level of that system.

The sections below outline the best practices for maintaining a secure system.

Physical Security

Physical security measures are designed to deny unauthorized physical access to Nuvation Energy products and the larger systems. Physical security can include barriers, locks, access control, surveillance, guards, intrusion detection/alarms, and other physical security systems.

Ensuring all equipment is physically secure is the first and most important step in protecting the system. Below are some recommended best practices for the physical security of the products:

- Nuvation Energy products should be physically secured in a locked enclosure, room, or building to restrict access. This physically secured area will be referred to as the 'secure zone'.
- The 'secure zone' access should be restricted to authorized personnel only.
- Authorized personnel should be trained to operate the equipment and follow the security process.
- Any unauthorized personnel should be supervised at all times.

Outside the products themselves, access to equipment and connections should also be secured, such as:

- Cells/battery modules
- PCS/inverters
- SCADA systems

- UPS/emergency power equipment
- High and low power cables and measurement wires
- Communication cables (i.e. Ethernet, USB, Linkbus, Stackbus, etc.)
- Networking equipment (i.e. routers, switches, transceivers, etc.)
- Buttons/control panels (i.e. E-stop, touchscreens, etc.)
- Any other critical equipment/connections that might compromise the site

Network Security

The networking on Nuvation Energy products uses Ethernet-based TCP/IP communications. Throughout this section, references to the nController apply to both Nuvation Energy Multi-Stack Controller and Energy Management System products. A network security analysis for any third party equipment on the network should be conducted in consultation with the equipments' manufacturer. Below are some recommended best practices for network security of Nuvation Energy products:

- Nuvation Energy products should be on an isolated network where only trusted equipment can operate, and trusted personnel can access. This network will be referred to as the 'secure network'.
- The 'secure network' should be within the 'secure zone' (see the [Physical Security](#) for details)
- The 'secure network' should be established through either a:
 - Physically isolated network (i.e. no connection to any other network, otherwise known as 'air gapped')
 - Firewall isolated network (i.e. router, smart switch, or other equipment with packet filtering to the 'secure network')
- The nController should be used to isolate the stack BMSs from the site network through the nController 'Internal/Bridge' network. These two networks must be isolated on separate subnetworks with separated IP address ranges.

An example of a 'secure network' topology with a router based firewall, Multi-Stack Controller, and Stack Switchgear units isolated on the 'Internal/Bridge' network is below:

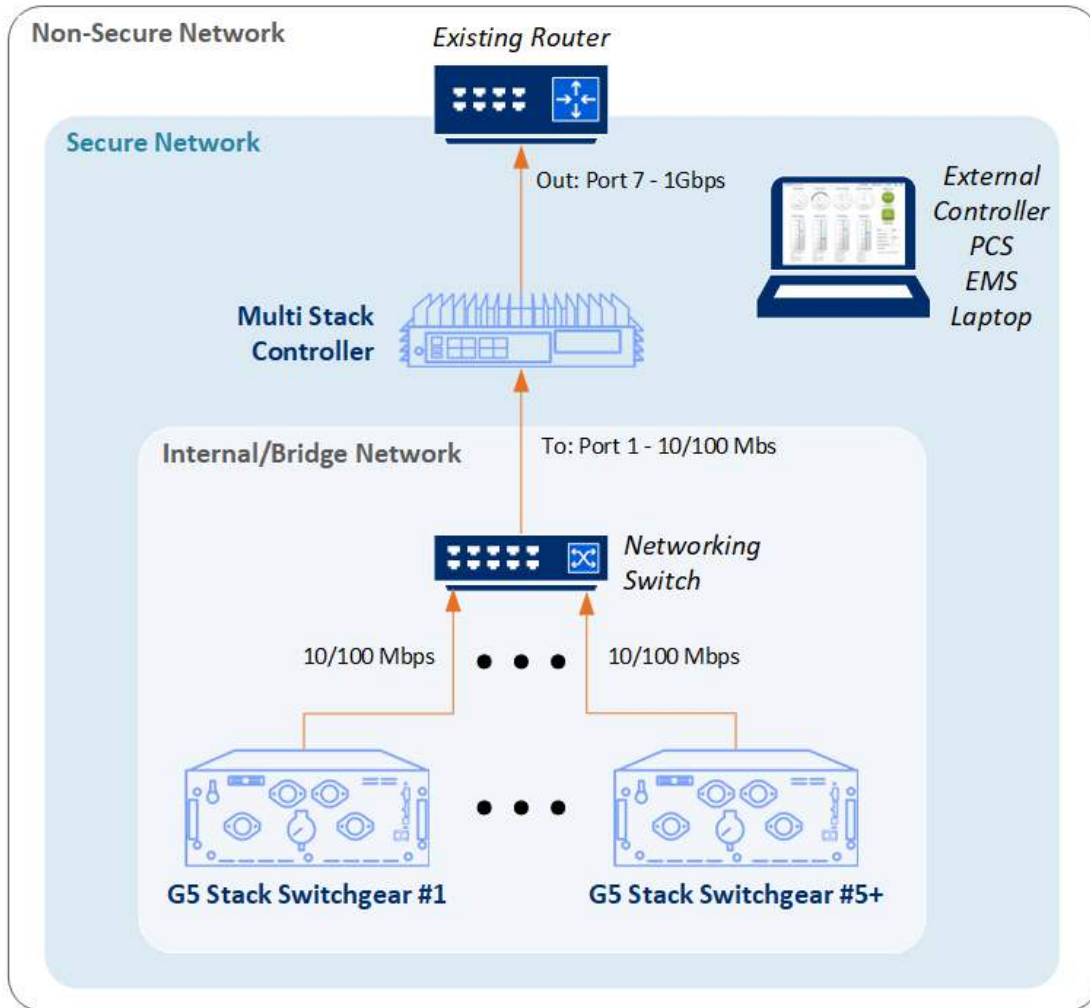


Figure 80. Networking configuration for a Multi-Stack Controller with secure and internal network

Inbound Protocols and Ports

All the open ports listening on Nuvation Energy products with the network protocols are listed below. Unless specified, the protocols are not encrypted or authenticated.

G4 High-Voltage BMS/Low-Voltage BMS **TCP Port 80 (HTTP)** TCP Port 502 (Modbus) ** TCP Ports 8080/8081 (Multi-Stack Controller Bridge)

Outbound Protocols

All Nuvation Energy products implement the essential outbound services for proper operation with modern networking equipment, listed below. Unless specified, the protocols are not encrypted or authenticated.

- Broadcast on network segment (ARP, STP)
- UDP Port 67/68 (DHCP)

Blocking outbound protocols can be done in a similar way to inbound protocols (i.e. firewalls). For more information on the above services and to configure or disable services, contact support@nuvationenergy.com. Some services such as mDNS cannot be disabled.

Operator Interface Unlock Password

The Operator Interface for both single and multi-stack systems can be configured with a password which restricts some features in the products. The unlock password protects against accidental misuse of the products during normal operation.



The Operator Interface uses HTTP which does not encrypt connections and requires a secured network to protect against malicious intent.

From time to time Nuvation Energy will make updates to products in response to changes in available technologies, client requests, emerging energy storage standards, and other industry requirements. The product specifications in this document, therefore, are subject to change without notice.

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