Energy Storage System

System Interface Specification

Butterfly 25Ah-2
PE500-403 Vigor+ Battery Pack
10-20938

Prepared By: Systems Engineering
Initial Release: 12/9/2021

Table of Contents

1. Scope and Conventions of this document

1.1 Scope

This is the technical product specification for the Butterfly 25Ah-2 ESS. This document contains a high-level system overview of system functions, performance & integration.

The document focuses on the individual ESS, not how it integrates into the overall system. The ESS is a system comprised of up to 3 ESS packs connected in parallel in a system. Inputs and outputs are described with respect to the external connection for customer use.

The software configuration allows for operation of 1 up to 3 packs.

1.2 Conventions Used in this Document

Any verbiage written in ITALICS is to be considered rationale or for clarification and is to be considered informational only.

1.2.1 Use of the words 'shall', 'will' or 'must'

The words 'shall', 'will' or 'must' are used to describe a required feature.

1.2.2 Use of the word 'should', 'may' or 'might'

The words 'should', 'may' or 'might' are to be considered a desired or optional feature.

1.2.3 Use of the word or paragraph descriptor "Recommendation"

The word 'Recommendation' is to be considered informational based on the experience of EnerDel or suppliers.

2. Reference Documents

2.1 Order of Precedence

In the event of a conflict between the text of this document and the documents cited herein, the text of this document takes precedence unless otherwise noted in the text of this document. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.2 EnerDel

2.2.1 Software

12V

SW ASSEMBLY-MLEC 1.5_Butterfly_25A-2: (96-20033) comprised of the following:

      Application code: SW APPLICATION_MLEC 1.5_LX_1.1.1.1 (90-20018)
      Bootloader: MLEC (1.5)-Configurable-Bootloader (90-10143)
      SW Configuration: SW CONFIGURATION_Butterfly_25A-2_1.1.1.1 (97-20033)

LX CAN Bus Guide version 1.0 or later

2.2.2 Mechanical

55-20006 recommended spare parts list

12V

        Product Architecture Drawing: 75-20003
        Outline drawings: Gen 3 EV, RH, 12 VOLT (15-20938)

Shipping Model Specification: 67-20010

Pack Labels:

    10001510 - BATTERY, 17.7 KWH, EIME EXECUTIVE
    10001511 - BATTERY, 17.7 KWH, EIME EXPANSION 1
    10001512 - BATTERY, 17.7 KWH, EIME EXPANSION 2

3. Acronyms and Terms

Acronym or Term	Definition
AFE	Active Front End (inverter mode)
ASD	Automatic Service Disconnect
BMS	Battery Management System
BOL	Beginning of Life
BDM	Background Debug Mode
BOB	Break-out Box
BOM	Bill-of-Material
CRD	Customer Requirements Document
DAC	Data Acquisition Card
DOD	Depth of Discharge
EOL	End of Life
EMC	Electromagnetic Compliance
EPO	Emergency Power Off
FAT	Factory Acceptance Test
FIS	Factory Information System
FT	Functional Test
FTP	Functional Test Plan
FTS	Functional Test Station
GES	Grid Energy Storage
GFD	Ground Fault Isolation Detection
GND	Ground (common reference for negative node)
GPIB	General Purpose Interface Bus
GUI	Graphical User Interface
HMI	Human Machine Interface
HV	High Voltage
HVAC	Heating, Ventilation, and Air Conditioning
HW	Hardware
ICT	In-circuit Test
I/O	Inputs and Outputs
LBS	Lithium Battery Systems
LEC	Lithium Energy Controller
LV	Low Voltage
MCA	Master Control Assembly
MLEC	Master LEC
MSD	Manual Service Disconnect
MTS	Manufacturing Test Specification
NFPA	National Fire Protection Association
PAD	Pack Architecture Drawing
PC	Personal Computer

PCB	Printed Circuit Board
PLC	Programmable Logic Controller
PPE	Personal Protective Equipment
PRD	Product Requirements Document
PS	Power Supply
RLEC	Remote LEC
SCA	Slave Control Assembly
SCADA	Supervisory Control and Data Acquisition
SIS	System Interface Specification
SMT	Surface Mount Technology
SOC	State of Charge
SOP	Start of Production
SRS	Software Requirements Specification
SW	Software
UART	Universal Asynchronous Receiver/Transmitter
UCC	Unit Central Controller
UPS	Uninterruptible Power Supply
USB	Universal Serial Bus
UUT	Unit Under Test
V/Hz	Volts/Hertz (inverter mode)
WEG	Water Ethylene Glycol
WIP	Work in Process
XFMR	Transformer

Table 1: Definition of Terms

4. Overview

The product information outlined in this document defines the battery system(s) functionality and associated electrical characteristics.

The Energy Storage System (ESS) through a parallel configuration can combine multiple packs in parallel based on customer requirements and software limitations. The entire configuration supplies the complete system power requirements of high voltage and current. The individual ESS supplies the High Voltage Output connectors. Each pack's two High Voltage (HV+/-) contacts of the battery ESS are used for both charging and discharging.

The Battery Management System (BMS) communicates the status of the ESS to the rest of the system and/or charger (including Maximum Current Limits, State of Charge, Faults, error codes, etc.) via the CAN bus interface through the executive pack BMS Interface. The BMS regulates the HV (+) and HV (-) connections of the batteries by control of multiple contactors internal to the ESS. Refer to the CAN bus user's guide for a comprehensive communications and command listing.

The system can consist of multiple (packs) (96S2P) connected in parallel. See 6.4 Single Pack Characteristics of this document for nominal voltage and overall system capacity. Communication to the customer controller is via CAN. One pack acts as the executive controller and communicates with the customer controller. The other battery packs communicate to the executive pack. Note that the vehicle controller may communicate directly to an expansion pack, but that may needlessly increase the complexity of the vehicle's programming.

The defining features of the system are:

- Vanguard family pack. This pack is part of the design and documentation of the Vanguard series
- An ESS consists of a maximum of (3) battery packs connected in parallel.
- Communication to the vehicle is via CAN. One pack acts as the executive controller and communicates with the vehicle controller. The other packs communicate to the executive pack for command and control.
- Modules built with Gen3 25Ah-2 Energy cells.

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5. **Safety – Warnings and Precautions**

SAFETY FIRST – WARNING / CAUTION – DANGER

WARNING:

This system must be operated solely in accordance with this document. Failure to do so may result in damage to the system and/or equipment connected to its input/output. Any service to the system must be performed by qualified personnel; there are NO user serviceable parts in the system that can be serviced by unqualified personnel.

Safety features of the system are intended to protect the user and service personnel. Bypassing or otherwise forcing the system to operate in a way other than by design may result in injury or death.

DANGER HIGH VOLTAGE SYSTEM:

Any service to the system must be performed by qualified personnel; there are NO user serviceable parts in the system that can be serviced by unqualified personnel. Safety features of the system are intended to protect users from injury. DO NOT TAMPER WITH SYSTEM CONNECTORS OR REMOVE ANY PANELS OR COVERS FROM THE SYSTEM. DO NOT INSERT FINGERS OR ANY OTHER OBJECTS INTO THE SYSTEM THROUGH ANY OPENINGS, PORTALS, OR SEAL AREAS. FAILURE TO COMPLY MAY RESULT IN SEVERE INJURY OR DEATH. ENERDEL IS NOT LIABLE FOR ANY RESULTING INJURIES OR DAMAGES WHATSOEVER AS A RESULT OF A FAILURE TO COMPLY WITH THESE TERMS.

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5.1   Safety First

WARNING:

This system is to be operated solely in accordance with this document and any outlined reference documentation. Failure to do so may result in damage to the ESS, individual battery packs, or vehicle.

Pack safety systems are intended to protect the user, and service personnel. Bypassing or forcing these systems to operate in a way other than by design may result in injury or death. EnerDel bears no responsibility for your failure to operate the system(s) in accordance with this guide and is not liable for any resulting damages whatsoever.

DANGER HIGH VOLTAGE SYSTEM:

Pack safety systems are intended to protect users from injury. DO NOT TAMPER WITH PACK CONNECTORS OR REMOVE ANY PANELS OR COVERS FROM THE SYSTEM. DO NOT INSERT FINGERS OR ANY OTHER OBJECTS INTO THE PACK CASE THROUGH ANY OPENINGS, PORTS, OR SEAL INTERFACES. FAILURE TO COMPLY MAY RESULT IN SEVERE INJURY OR DEATH, AND ENER1 IS NOT LIABLE FOR ANY RESULTING INJURIES OR DAMAGES WHATSOEVER AS A RESULT OF A FAILURE TO COMPLY WITH THESE TERMS.

EnerDel battery systems are designed to provide a HV output capable of driving powerful electric components. The battery systems are a combination of electronic controls, lithium-ion battery technology, and packaging. A fully assembled system has been designed for utmost safety, with robust packaging and built-in system control redundancies to assure enhanced system and user protection.

During installation and service, certain precautions must be in mind and practiced during system handling. In addition to dangerous voltage and current potential at the HV connection external to a fully assembled system, if any disassembly is required to service a system, the danger level for coming into contact with HV internal to the system increases dramatically.

Remember, high voltage with high current capability can be near **400 to 700 VDC** (depending on system configuration).

Though some safety highlights are listed below, additional formal training should be required for personnel with regards to system handling procedures. Never work in an open system alone. Someone must always be aware of your intentions and within eyesight, ready to help in case of an accident. Jewelry and other metallic tools are highly conductive and can easily accidentally and unintentionally short across HV points of potential. Protective shields/covers should be utilized to cover/block system from unintended contact. Safety glasses with side shields should be worn at all times. Rubber gloves with a leather exterior must be worn during direct contact with HV points of potential. If in direct contact with a HV point of potential, only one hand at a time can be in contact with any part of the system at that time.

Only qualified personnel (personnel having been trained appropriately) can be inside a designated approach boundary.

Insulated tools and PPE (**Protective Clothing and PPE Hazard/Risk Category 3, Protective Clothing and PPE Hazard/Risk Category 2 with the midpack contactor open on all packs**) must be utilized by qualified personnel when working inside an approach boundary of exposed energized electrical conduction and circuit parts where tools may make accidental contact.

5.2   Approach Boundary

When servicing the pack outside of the vehicle, an approach boundary should be clearly designated by a form of physical barrier that is clearly visible to onlookers (i.e. fencing, rope, chains, or similar).

6. System Overview

6.1 Description

Through the High Voltage Output connector, the two High Voltage (HV+/-) contacts of each battery pack are used for both charging the battery pack and discharging. The Battery Management System (BMS) communicates the status of the battery pack to the rest of the system and/or charger (including Maximum Current Limits, State of Charge, Faults, error codes, etc) via the CAN bus interface through the BMS Interface connector.

6.2 ESS Overall Vehicle Level Architecture
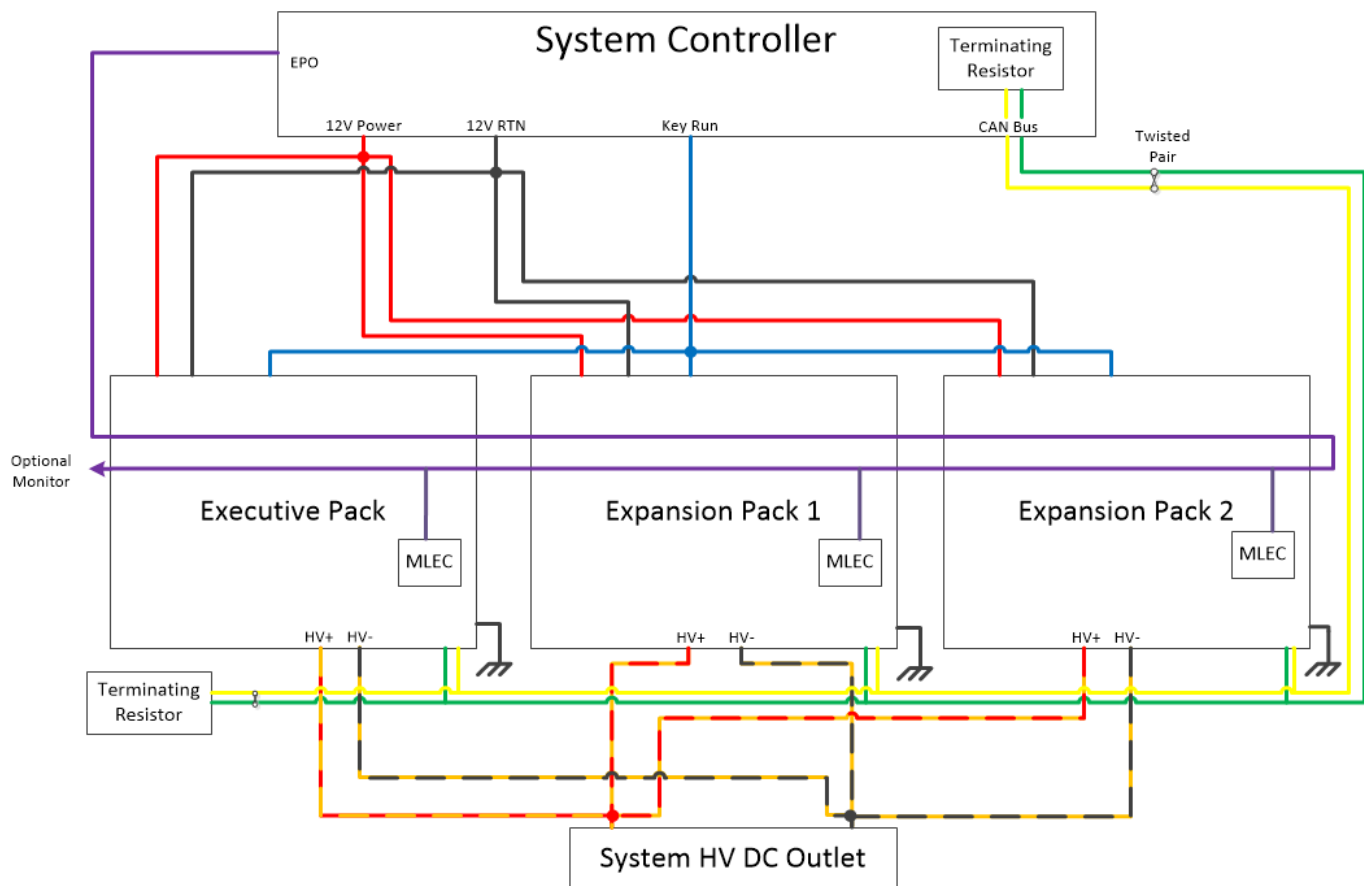
Figure 1: Overall System Of 3 Packs

Figure 1 shows the system connection diagram. The 12V power connections are point to point, not daisy chained. The high voltage DC connections are point to point, not daisy chained. The CAN connection is a bus connection, not point to point or daisy chained.

6.3 Individual Energy Storage System Architecture
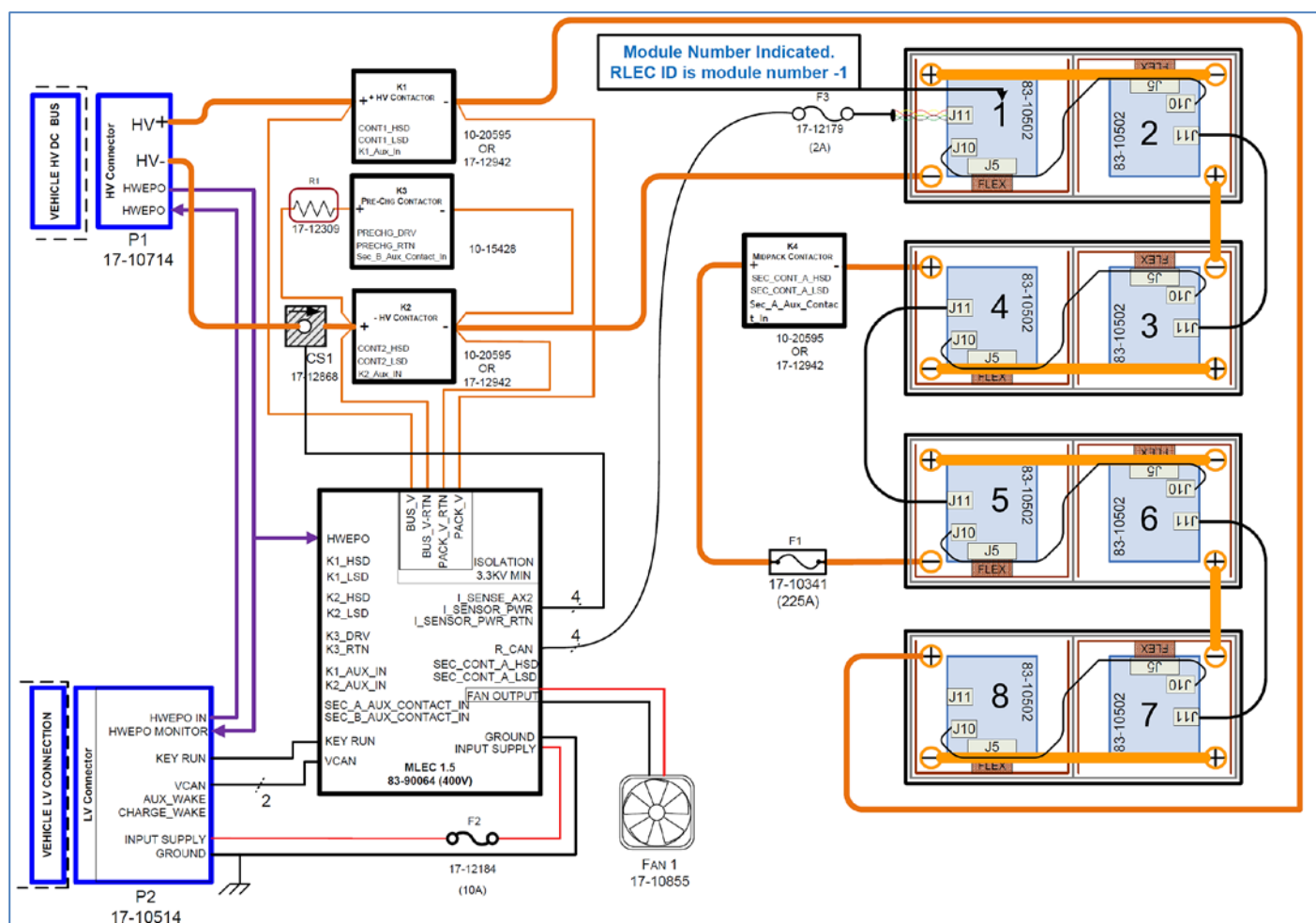
Figure 2: Single Pack Architecture Drawing

6.4 Single Pack Characteristics

Parameter	Units	Specification	Note
Pack Number of Cells	each	192	
Series Elements	n/a	96	The unit of parallel cells is called an element
Number of Cells in Parallel	n/a	2	
Pack Configuration		**96S2P**	
Cell Voltage			
Maximum	V	4.2	at 100% SOC
Nominal	V	3.7	at 50%SOC
Minimum	V	3	at 0% SOC (defined at 1 C-rate)
Minimum	V	2.7	Absolute minimum
Cell Capacity			
Rated	Ah	25	From Cell Specification
Pack capacity beginning of life (BOL)			
Rated	Ah	50	Calculated Value Based on Rated Cell Capacity
Minimum Available Capacity	Ah	48.3	estimated when C/3 rate is used to determine capacity; current taper applied at the end of charge
Pack capacity end of life (EOL)			
Rated	Ah	39.6	EOL defined as 80% of minimum available capacity
Pack Voltage			
Maximum	V	403.2	determined at maximum cell voltage
Nominal	V	355.2	determined at nominal cell voltage at 50% SOC
Minimum	V	288	determined at 0% SOC at 1C
Pack Energy			
Rated energy	kWh	17.8	calculated value based on rated cell capacity
Minimum available energy	kWh	17.1	calculated value based on de-rated cell capacity
Pack Discharge Power			
Typical (continuous)	kW	17.7	at nominal cell voltage
Maximum rate (continuous)	kW	53.2	at nominal cell voltage
Pulse (10S)	kW	88.8	at nominal cell voltage 10 seconds
Pack Charge power			
Typical (continuous)	kW	17.7	at nominal cell voltage
Pack Discharge current			
Typical (continuous)	A	50	between 15% and 100% SOC
Maximum rate (continuous)	A	150	between 15% and 100% SOC
Pulse (10S)	A	250	between 15% and 100% SOC 10 seconds
Pack Charge Current			
Typical (continuous)	A	50	between 0% and 80% SOC
Maximum rate (continuous)	A	100	between 0% and 80% SOC
Pulse (10S)	A	100	between 0% and 80% SOC 10 seconds

Table 2: Product Technical Specifications Single pack

Notes: All limits are subject to BMS broadcasted current limit strategy.   Pulse values are meant for occasional use not repetitive pulse use. Reasonable cool down times are necessary between pulse currents.

6.5   System (2 Packs) Characteristics

Parameter	Units	Specification	Note
System Number of Cells	each	384	
Series Elements	n/a	96	The unit of parallel cells is called an element
Number of Cells in Parallel	n/a	4	
System Configuration		**96S4P**	
Cell Voltage			
Maximum	V	4.2	at 100% SOC
Nominal	V	3.7	at 50%SOC
Minimum	V	3	at 0% SOC (defined at 1 C-rate)
Minimum	V	2.7	absolute minimum
Cell Capacity			
Rated	Ah	25	From Cell Specification
System capacity beginning of life (BOL)			
Rated	Ah	100	Calculated Value Based on Rated Cell Capacity
Minimum Available Capacity	Ah	96.5	estimated when C/3 rate is used to determine capacity; current taper applied at the end of charge
Pack capacity end of life (EOL)			
Rated	Ah	79.2	EOL defined as 80% of minimum available capacity
System Voltage			
Maximum	V	403.2	determined at maximum cell voltage
Nominal	V	355.2	determined at nominal cell voltage at 50% SOC
Minimum	V	288	determined at 0% SOC at 1C
System Energy			
Rated energy	kWh	35.5	calculated value based on rated cell capacity
Minimum available energy	kWh	34.3	calculated value based on de-rated cell capacity
System Discharge Power			
Typical (continuous)	kW	35.1	at nominal cell voltage
Maximum rate (continuous)	kW	105.4	at nominal cell voltage
Pulse (10S)	kW	175.8	at nominal cell voltage 10 seconds
System Charge power			
Typical (continuous)	kW	35.1	at nominal cell voltage
System Discharge current			
Typical (continuous)	A	100	between 15% and 100% SOC
Maximum rate (continuous)	A	300	between 15% and 100% SOC
Pulse (10S)	A	500	between 15% and 100% SOC 10 seconds
System Charge Current			
Typical (continuous)	A	100	between 0% and 80% SOC
Maximum rate (continuous)	A	200	between 0% and 80% SOC
Pulse (10S)	A	200	between 0% and 80% SOC 10 seconds

Table 3: Product Technical Specifications 2 pack system

Notes: All limits are subject to BMS broadcasted current limit strategy.
Pulse values are meant for occasional use not repetitive pulse use. Reasonable cool down times are necessary between pulse currents.

6.6 System (3 Packs) Characteristics

Parameter	Units	Specification	Note
System Number of Cells	each	576	
Series Elements	n/a	96	The unit of parallel cells is called an element
Number of Cells in Parallel	n/a	6	
System Configuration		**96S6P**	
Cell Voltage			
Maximum	V	4.2	at 100% SOC
Nominal	V	3.7	at 50%SOC
Minimum	V	3	at 0% SOC (defined at 1 C-rate)
Minimum	V	2.7	absolute minimum
Cell Capacity			
Rated	Ah	25	From Cell Specification
System capacity beginning of life (BOL)			
Rated	Ah	150	Calculated Value Based on Rated Cell Capacity
Minimum Available Capacity	Ah	144.8	estimated when C/3 rate is used to determine capacity; current taper applied at the end of charge
Pack capacity end of life (EOL)			
Rated	Ah	118.8	EOL defined as 80% of minimum available capacity
System Voltage			
Maximum	V	403.2	determined at maximum cell voltage
Nominal	V	355.2	determined at nominal cell voltage at 50% SOC
Minimum	V	288	determined at 0% SOC at 1C
System Energy			
Rated energy	kWh	53.3	calculated value based on rated cell capacity
Minimum available energy	kWh	51.4	calculated value based on de-rated cell capacity
System Discharge Power			
Typical (continuous)	kW	52.7	at nominal cell voltage
Maximum rate (continuous)	kW	158.2	at nominal cell voltage
Pulse (10S)	kW	263.7	at nominal cell voltage 10 seconds
System Charge power			
Typical (continuous)	kW	52.7	at nominal cell voltage
System Discharge current			
Typical (continuous)	A	150	between 15% and 100% SOC
Maximum rate (continuous)	A	450	between 15% and 100% SOC
Pulse (10S)	A	750	between 15% and 100% SOC 10 seconds
System Charge Current			
Typical (continuous)	A	150	between 0% and 80% SOC
Maximum rate (continuous)	A	300	between 0% and 80% SOC
Pulse (10S)	A	300	between 0% and 80% SOC 10 seconds

Table 4: Product Technical Specifications 3 pack system

Notes: All limits are subject to BMS broadcasted current limit strategy.
Pulse values are meant for occasional use not repetitive pulse use. Reasonable cool down times are necessary between pulse currents.

6.7 Pack Temperature and Storage Characteristics

Parameter	Units	Specification	Note
Module charge time			
0 to 80% SOC	minutes	24	At module max continuous charge current
Module discharge time			
100% to 20% SOC	minutes	16	At module max continuous discharge current
Maximum module internal resistance (BOL)			
12S2P	mΩ	6	1 kHz AC impedance at 25°C and 50% SOC
Typical module internal resistance (BOL)			
12S2P	mΩ	19	DC resistance, 50% SOC, 25°C, measured with a 10 second, 250 A discharge pulse
Operating temperature			
Optimal	°C	15 to 35	Optimal performance/life
Full performance discharge	°C	15 to 45	Full performance within defined SOC ranges
Full performance charge	°C	15 to 45	Full performance within defined SOC ranges
Reduced performance, discharge	°C	-20 to 15, 45 to 55	Discharge current limiting outside of full performance operating temperature range
Reduced performance, charge	°C	0 to 15, 45 to 55	Charge current limiting outside of full performance operating temperature range
Zero performance, discharge	°C	<-20, >55	Zero current available outside of degraded performance operating temperature range
Zero performance, charge	°C	<0, >55	Zero current available outside of degraded performance operating temperature range
Under temperature fault limit	°C	-30	Based on min. cell temperature
Over temperature fault limit	°C	60	Based on max. cell temperature
Storage temperature	°C	-40 to 60	Recommended module voltage range for long-term storage is 41 to 43 V
Module cycle life	cycles	2500	1C-rate, 100% DOD, 30°C
Module calendar life (storage)	years	>10	At 30% SOC and 30°C. Modules or energy storage units should be reconditioned (charged to at least 80% SOC, discharged to at least 20% SOC, and then charged to 30% SOC) every 6 to 12 months.
Single Module Self-discharge	Wh/day	<0.2 @ 75% SOC and 25°C	Varies with temperature and SOC
Battery module dimensions			
12S2P	mm	198(L) x 178(W) x 290(H)	Estimated envelope including mounting tabs and connectors
RoHS compliance		Yes	

Table 5: Attributes of Moxie+ modules based on cell CE250-370-2

The relevant temperatures listed in Table 8 are the cell temperatures and not the ambient temperatures of pack operation.

7. Pack Mechanical Characteristics

7.1 Mechanical Interface

The pack cannot be suspended by brackets or other means from the M8 fasteners around the base perimeter unless in a stationary application. The ESS is not designed to allow clamping (wedging) of the cover and base as a means of vehicle mounting. The ESS must be held in place by M8 fasteners at all of the mounting locations provided on the battery pack. The base must have a platform or support structure beneath it when used in a dynamic application. With a support structure it can be mounted bottom down upon the greatest X – Y dimensions. With a support structure, it can also be mounted on the rear or long back side. It must be held in place by M8 fasteners to the support structure. It cannot be mounted in any other orientation.

The ESS should be mounted in a location that provides:

- Shielding from direct sunlight
- Shielding from direct contact with water, snow, ice, and other road debris
- Protection from gravel bombardment
- Consideration/mitigation for shock and vibration introduced to the ESS by the terrain and usage.

7.2 Tamper Proof Packaging

The packaging is designed with tamper proof indicators as a deterrent to unauthorized service of the battery pack. The tamper proofing consists of tamper evident EnerDel labels.

7.3   Thermal Management

7.3.1   General

Care should be taken to allow for airflow around the battery packs. Performance will become limited if the pack temperatures rise above 45℃ or go below 15℃ for discharge and 10℃ for charge.

The ESS thermal management of the battery packs is BMS limit controlled, using software algorithms and set-points for current, SOC, and temperature readings. The BMS will ultimately open the contactors to protect the battery cells. (see Section 9.14 for limit strategy).

7.3.2   Cooling

The ESS battery packs utilize an active air flow-based cooling system approach to thermal management. The packs also absorb heat generated during usage and radiate it over time to the surrounding environment.

The ESS battery packs are equipped with an internal fan. The fan specification states that the fan can produce 131 CFM @ 0 in H_2O.

Fan operation is controlled by the ESS Battery Management System.

Fan On Criteria: (If Contactors are closed) AND [(The CAN fan request bit is set) OR (The maximum cell temperature is above 30℃) OR (The maximum RLEC board temperature is above 75℃)] the fan will turn on.

Fan Off Criteria: (If Contactors are open) OR [(The maximum cell temperature is below 20℃) AND (The maximum RLEC board temperature is below 67℃)] the fan will turn off.

The fan will also turn off if the CAN fan request bit was set and is cleared and the temperatures are below the turn on set point temperatures listed in fan on criteria.

Additionally, the code will disallow the fan to be turned on if there is an internal isolation fault.

Customer's ESS Air Supply System should be designed to:

- Consider Humidity Level and the Temperature Delta. Condensation needs to be prevented from building up in the pack.
- Provide enough air volume for the number of packs at the specified fan CFM (Fan curves can be found (Here)
- Consider the multiple combinations of fans that could be active and inactive at any time for a multipack system with an interconnected duct system.
- The ESS inlet and outlet air filters are 45 PPI with hydrophobic mesh. Changing the filter is to be included in the maintenance schedule. Recommended starting point is once a year since the customer vehicle air system is supposed to be closed loop.
- Filter part information: 10-15166 INLET/OUTLET AIR FILTER, ½ THICK, 45 PPI QUADFOAM

7.4 Battery System Model Packaging

7.4.1 Pack Rendered model

Figure 3: The picture shows a general representation of the ESS.

7.4.2 Mechanical Outline Drawing
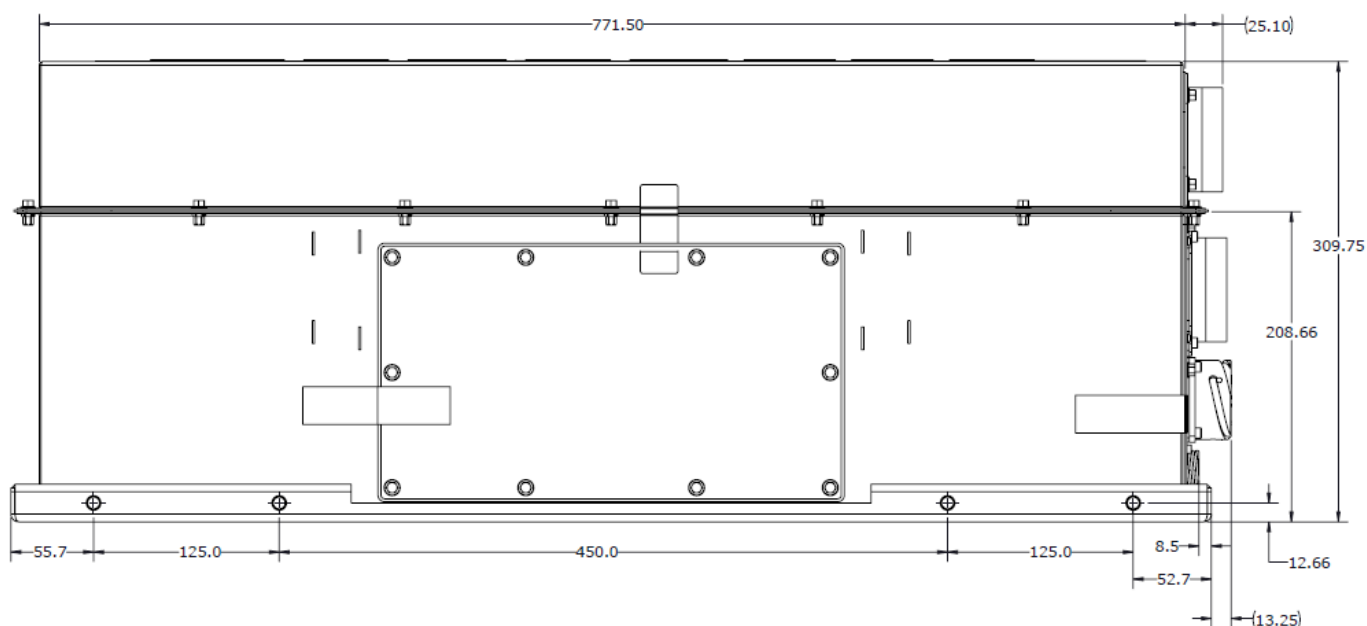
Figure 4: Battery Pack Outline Drawing Front View
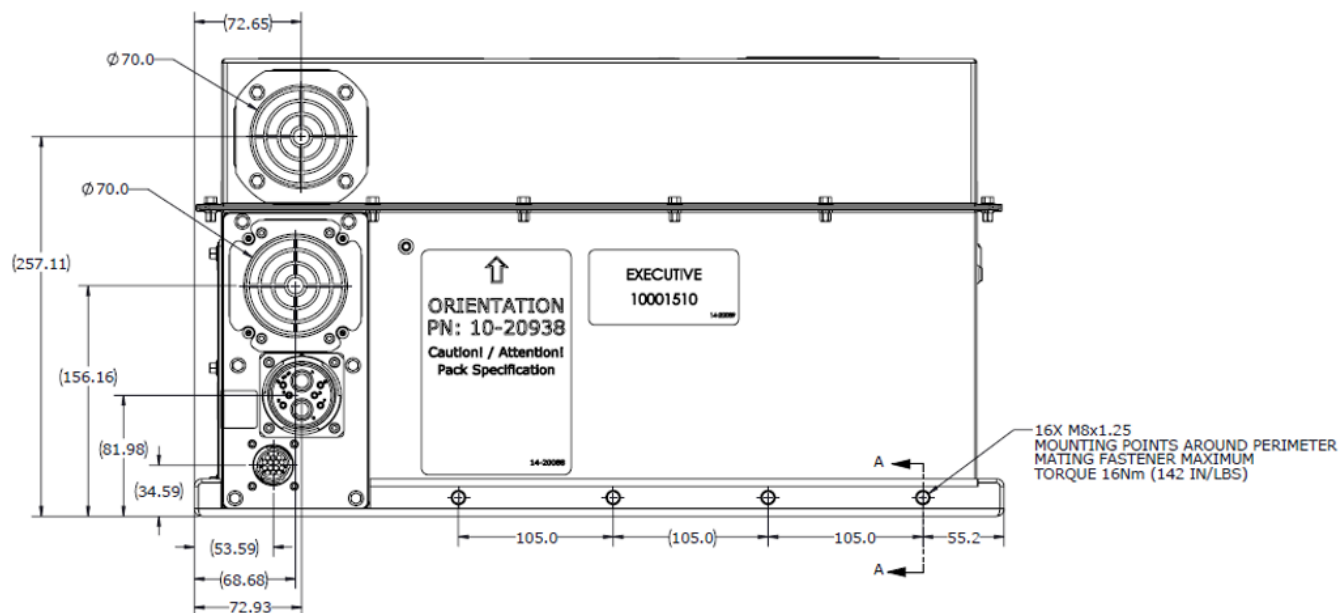
Figure 5: Battery Pack Outline Drawing Right Side View
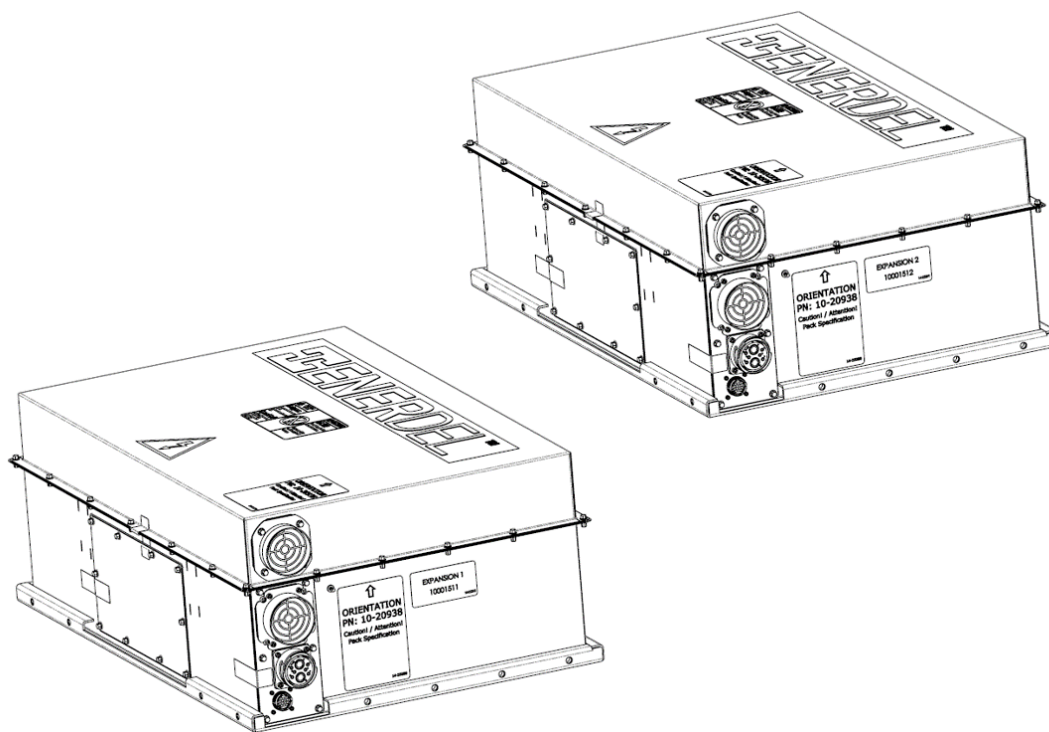
Figure 6: Battery Pack Outline Drawing Expansion Pack View
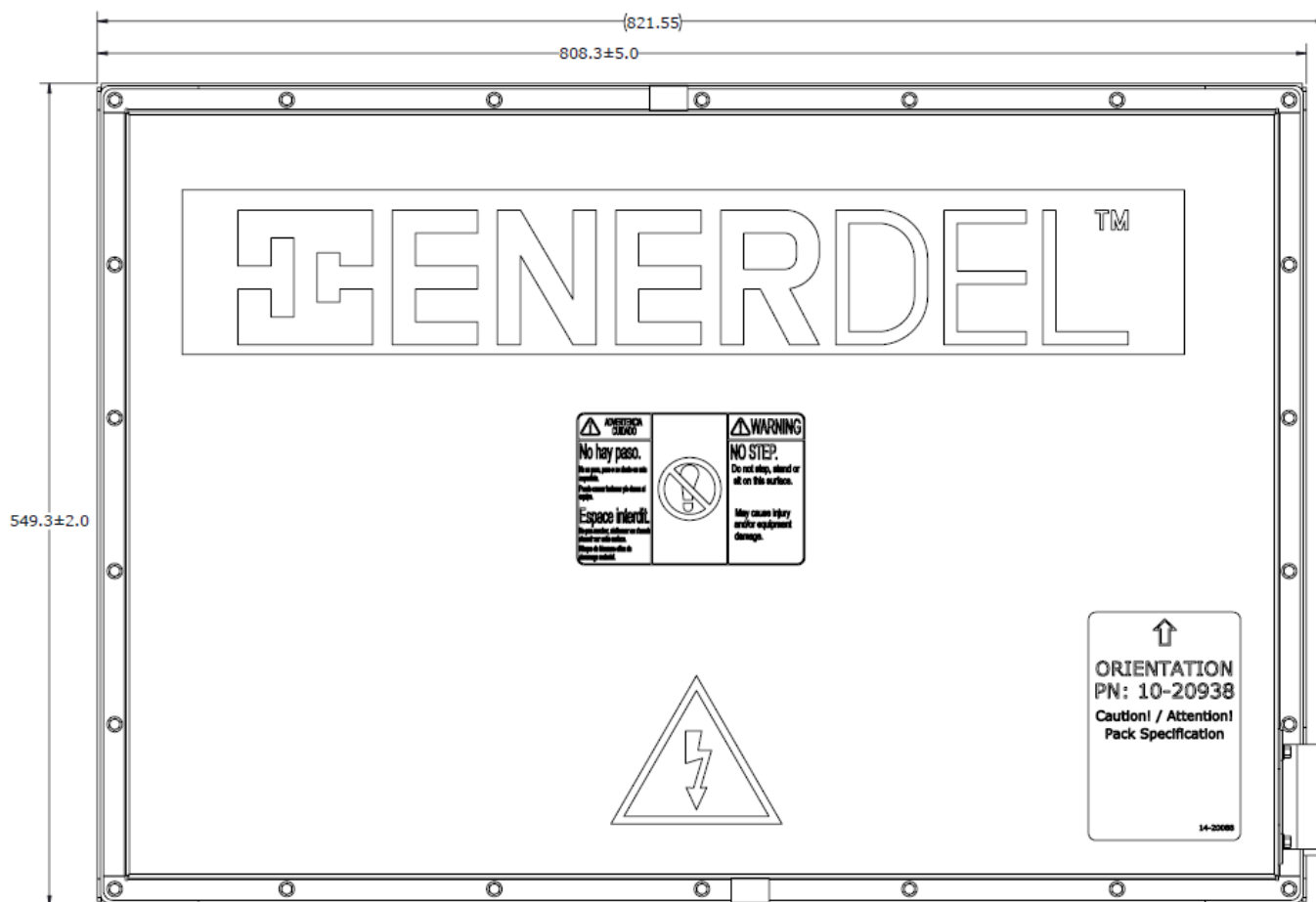
Figure 7: Battery Pack Outline Drawing Top View

Parameter	Unit	Value
X Dimension	mm	808.3
Y Dimension	mm	549.3
Z Dimension	mm	309.75
Mass	kg	164

Table 6: Approximate Pack Outline Dimensions, Mass, and Volume

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8. Electrical Interface

8.1 Pack Interface Connectors

8.1.1 High Voltage (HV) Connector
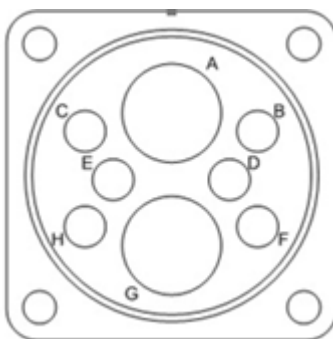
Figure 8: High Voltage Connector Graphic

8.1.1.1 High Voltage Connector Part Numbers

Description	Manufacturer	Part Number
Pack Side Connector	Amphenol	GTC00A32-15S (RDS)
Pack Side Connector	Glenair	ITS4100A32-15SF7GF95
Vehicle Side Connector	Amphenol	GTC06F32-15P (Straight conn.) GTC08F32-15P (Right angle conn.)
Vehicle Side Connector	Glenair	ITS4106F32-15PF7 (Straight conn.) ITS4108F32-15PF7 (Right angle conn.)

Table 7: Battery High Voltage Connector Part Number

8.1.1.2 **High Voltage Connector Signal Assignment and Description**

Pin Name	Signal Name	I/O Type	Voltage Range	Current (Nominal)	Current Max	Wire AWG (Min)	Note
G	High Voltage DC Return **(-)**	Traction Power	-288V to -403V With reference to Pin A	50 A	150A (250 10S Peak)	2	
E	EPO in from vehicle to E Pin on HV connector	Safety Loop	0-36V	0.150 Amps	1 Amps	20	See: Section 8.3 EPO
D	EPO from D Pin out to EPO monitors on BMS and vehicle.	Safety Loop	0-36V	0.150 Amps	1 Amps	20	
A	High Voltage DC Power **(+)**	Traction Power	288V to 403V With Reference to Pin G	50 A	150A (250 10S Peak)	2	

Table 8: High Voltage Connector Signal Assignment

8.1.2 **Low Voltage (LV) Connector**

P2
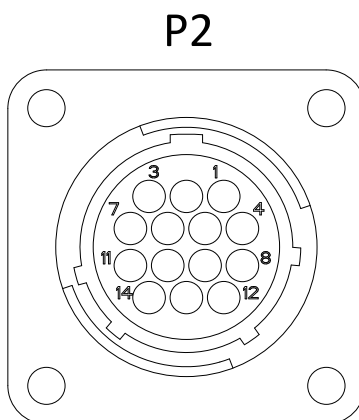
AMP/Tyco 796272-1

View of engagement side

Figure 9: AMP/Tyco connector.

(Enerdel PN: 17-10514)

8.1.2.1 **LV Connector Part Numbers**

Description	Manufacturer	Part Number
Pack Side Connector	TE Connectivity/AMP	796272-1
Vehicle Side Connector	TE Connectivity/AMP	796271-1

Table 9: Battery Low Voltage Connector Part Numbers

8.1.2.2 **Low Voltage Connector Signal Assignment and Description (SINGLE PACK) 12V system.**

Pin	Signal Name	I/O Type	Voltage Range	Current (Nominal)	Current (Max Source/Sink)	Function
1	12V Ground (Return)	Power (Chassis Ground)	0V	<1 Amps	16 Amps	Chassis Ground
2	Aux CAN HIGH (Not used)	CAN	Differential (w/Aux CAN Low)	CAN Bus Standard	CAN Bus Standard	AUX Vehicle communication Bus.
3	Ignition/Key Run	Signal (Input)	0 to 14V (12V is active state)	80uAmps	300uAmps	Primary system start discrete signal.
4	N/C	-	-	-	-	-
5	Vehicle CAN Low	CAN	Differential (w/Vehicle Can High)	CAN Bus Standard	CAN Bus Standard	Vehicle communication bus.
6	AUX Wake (Optional)	12V Input signal	0 to 14V (12V is active state)	80uAmps	300uAmps	Pack Startup
7	Aux CAN Low (Not used)	CAN	Differential (w/Aux CAN High)	CAN Bus Standard	CAN Bus Standard	12V power
8	Vehicle CAN High	CAN	Differential (w/Vehicle Can Low)	CAN Bus Standard	CAN Bus Standard	Vehicle communication bus.
9	Emergency Stop/ Hardware Interlock IN (HWEPO)	EPO Supply (Input)	0 to 14V (12V is active state)	0.150 Amps	1 Amp	Pack Shutdown
10	Charge Wake (Optional)	Signal (Input)	0 to 14V (12V is active state)	80uAmps	300uAmps	Charge initiation
11	12V Input Voltage Supply	Power (+12)	10V – 14V (14V max)	<1 Amps	16 Amps	12V power
12	Vehicle CAN Shield (Optional)	Shield Connection	0V	-	-	Noise shield to chassis
13	HW EPO Loop Monitor (Optional)	Signal (Output)	10V – 14V (14V max)	0.150 Amps	1 Amp	Monitor HW EPO Loop
14	N/C	-	-	-	-	-

Table 10: Low Voltage Connector Signal Assignment 12 V System

12V from vehicle to EPO loop is monitored by the BMS. Absence of this EPO signal on BMS will open the contactors to isolate the voltage from the bus side. Ignition/Key Run is for activating the BMS. All AUX designations not used but available. Charge wake is not used in this system. Optional vehicle CAN shield is a ground path for the communication cable to pin 12 which is connected to the pack chassis through a J1939 RC ground termination.

9. System Features and Operating Instructions

9.1 Pack Startup

The battery pack requires +12V PWR, GND, HWEPO (ENABLED), and CAN messages at time of startup. When the KEYRUN signal is asserted (ENABLED), the BMS will perform diagnostics as it closes the contactors to the system interface and after it receives CAN messages from the system controller. A "key cycle" is considered the reassertion of the KEYRUN signal after the BMS has shut down the battery pack (a **6s** delay between "key cycles" is REQUIRED).

9.2 Emergency Power Off (EPO)

The battery pack has been designed to include an Emergency Power OFF (EPO) feature. The EPO signals that are present at the HV Output connector MUST be looped back on the harness-side. Contactors are DISABLED when the connection is missing or otherwise removed. The disabling of contactors is a function of hardware.

To cause all contactors to open on all packs when one HV connector is removed, the EPO connections shall be wired as shown below. Any pack can be used in any position in the below diagram.

The EPO MONITOR pins shall not be connected to each other. Their intended use is for individual inputs to a controller to help locate any breaks in the EPO wiring.
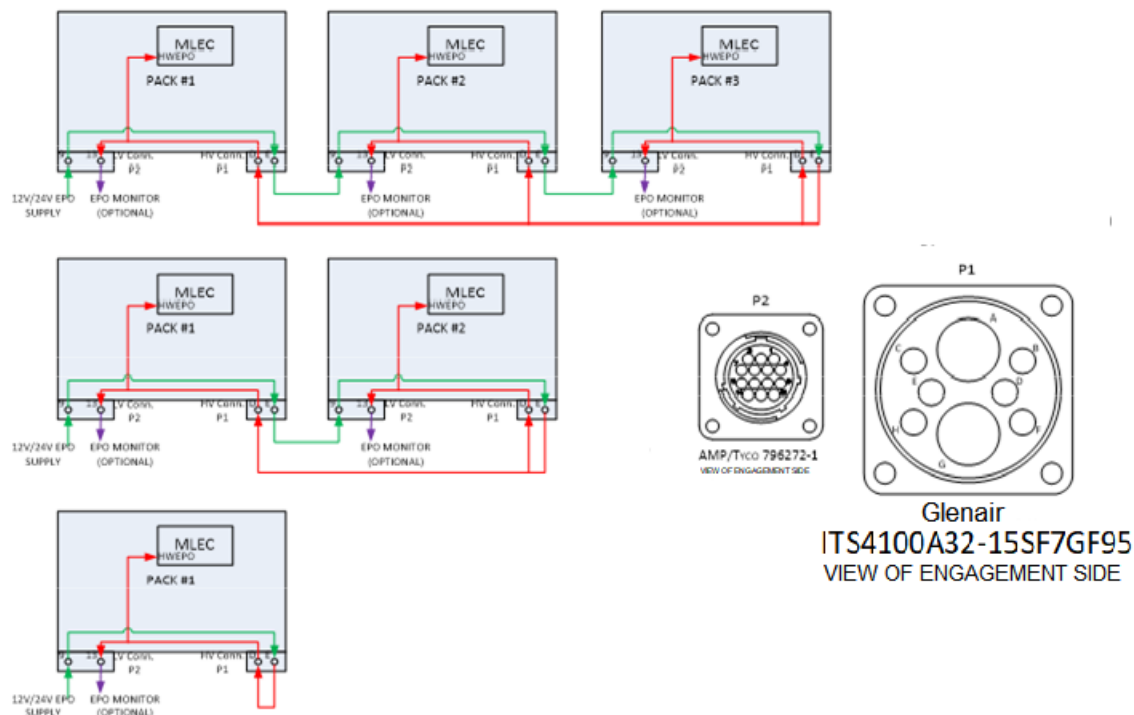

Figure 10: EPO Loop Pack Connection Requirement 1 through 3 packs.

9.3   BMS Consumed Current from External 12V Supply

The constant current consumed by the battery pack electronics through the BMS Interface connector is <1 A (typical) with a ≈7.5A inrush (estimated) when the following simultaneously ACTIVE conditions exist: BMS electronics ON, contactors CLOSED. The constant current consumed by the battery pack electronics is ≈5A the 12V system. (estimated max. – single pack) when the Fan is active and the contactors are closed.

9.4   BMS Power Consumption from Battery Pack

As per the BMS design, RLEC (Remote Lithium Energy Controller) is self-powered by the battery module. RLEC consumes the total power from the battery in two categories: 1. Power consumption by RLEC Electronics and 2. Power consumption by the passive balancing circuit.

Estimated power consumption by RLEC Electronics is ~0.44W per RLEC from a 12S2P module. Which will be 8 * 0.44=3.5W for a 96S2P pack.

Estimated power consumption by passive balancing circuit when all 12 elements in a module are being balanced is given in table below at different levels of cell voltage.

Cell Voltage (V)	Power consumed from a module for balancing (W)
4.2	5.4
3.6	4.0
3.5	3.8

Table 11: Power consumed from a module for balancing

This will provide an estimation on how long a battery pack can be kept ON without using it. Care should be taken to not let the battery drain itself from power consumption by BMS.

9.5   Pre-Charge

In addition to any pre-charge considerations for the overall system that may exist external to the battery pack, a pre-charge protection circuit is also internal to the battery pack and is controlled by the BMS for the system application. The protection circuit is primarily a resistive load that is placed in series with the pre-charge contactor that connects to the HV (-) output in parallel to HV(-), the primary contactor. The pre-charge contactor will actuate moments before the HV (-) primary contact is engaged. The battery pack is designed and contains considerations for protection from possible load capacitance that could blow the HV fuse and/or damage the battery cells. Each pack has a 50 Ω pre-charge resistor. Each pack connected to the system performs a pre-charge sequence.

Pre-charge Completion Criteria: Bus Voltage (external HV measurement) is within 95 % Of Pack Voltage (internal HV measurement) within 1 second.

Pre-charge timing is not controlled in terms of pack sequence.   If the system needs to limit the inrush current, staggering the first pack contactor request from the rest of the pack contactor requests is required.

Number of Packs	Maximum pre charge current (100% SOC)
1	8.1 amps
2	16.2 amps
3	24.3 amps

Table 12: Potential Pre-charge current

9.6   Auxiliary Contacts

The battery pack has been designed to include diagnostics that can determine if a contact has opened or closed appropriately as commanded by the BMS. The BMS utilizes the "auxiliary contact" internal to each contactor to read the open or closed position accordingly. In this system, each pack will have and monitor auxiliary contacts for the K1 HV (+), K2 HV (-), K3 pre-charge and K4 mid-pack contactors.

9.7   Grounding Scheme

The BMS negative return (GND) at the BMS Interface connector is isolated from HV (-) within the battery pack.

9.8   Chassis Ground

The pack enclosure shall be connected to chassis ground of the system by the customer. There is one M6-1X10 ground stud on right side of the pack. The customer should use this to connect to chassis ground. The torque specification for this M6 stud is 2.82 Nm (25 in-lbs).

Figure 11: Location of Ground Stud

NOTE: The pack must be grounded by connecting to this M6-1x10 Dog Point ground stud.

9.9   Ground Fault Isolation Detection (GFD)

Ground Fault Isolation Detection (GFD) is a feature internal to the battery pack and is diagnosed by the BMS for the system application.

Internal Isolation detection: Enabled non-switched. Internal isolation check is run before contactors are closed.

External Isolation detection: Non-Switched continuous update, approximately 6 S.

External isolation detection limit: Not less than 226,600 Ω (403.2 max pack voltage + 50 volts * 500 Ω / volts).

The number of packs connected affects the isolation detection calculated resistance value. As the number of packs connected increases, the variability in the calculated resistance value increases. The resistance trigger is set to trip before the isolation detection limit is reached in a system with three packs.

Number of packs	External resistance trigger (Example: HV+ to gnd)
1	270 kΩ
2	250 kΩ
3	230 kΩ

Table 13: Example external isolation trigger vs. # of packs

If the Internal isolation detection triggers, the pack will abort the pre-charge / closure sequence.

If the external isolation detection triggers, there is a 60 second delay between the fault bit being set and the contactors opening.

9.10   High Voltage Fuse

The battery pack has been designed such that the HV fuse is NOT *serviceable*, in that the fuse is internal to the battery pack enclosure and can NOT be replaced except by highly trained technical personnel. No fuse compartment cover exists. Blown HV fuses are not covered under the warranty.

9.11   Cell Balancing

Cell balancing is active in the battery pack whenever the battery pack is awake (BMS is powered) and during both charge and discharge. Cell balancing is active when elements are above 3.5 volts.

9.12   Charge/Discharge

Whether the battery pack is discharging into a load or charging from a source, the BMS continuous current limits reported on the communication bus must be obeyed at all times during operation to prevent the BMS from opening the contactors in an attempt to protect the battery cells. *Current, NOT voltage, is the primary control parameter of power in the battery pack system. It should be noted to the end user that if the maximum charge current is not equal to zero, it is acceptable to charge at the level indicated by the maximum charge current limit. Likewise, the end user may discharge and the rate that is indicated by the maximum discharge current limit is not equal to zero.*

9.13 Charging strategy

Packs charged at a low rate can be charged to a high SOC without current tapering. For example, a pack charged at a current of 33 A can be charged to 93% SOC with no current tapering. Higher SOCs are accessed by tapering the current.

Packs charged at a high rate will experience current tapering at SOCs starting at 80%. In this case, a lower current should be selected when the pack reaches 80% SOC.

In either case, the pack can be float charged at a constant voltage after constant current charging to attain a full charge, but this may not be necessary.

9.13.1 Fleet charging life recommendation

The duration that the battery packs spend at high SOC should be minimized to extend lifetime. The order in which the packs are charged should be rotated so that the batteries will experience even wear due to time spent at high SOCs. For example, a pack that is always charged first and spends 12 hours at 100% SOC compared to a pack that is always charged last and spends 1 hour at 100% SOC will age faster by a factor of approximately 30%.

9.14 Current Limit Strategy (Temperature)

The current limits are affected by the internal pack temperature as reported by the average cell temperature in the battery pack CAN messages.

Reduction in allowed charge current and allowed pulse charge current can be expected when the internal pack temperature is above 45°C and below 15°C.

Reduction in allowed discharge current and allowed pulse discharge current can be expected when the internal pack temperature is above 45°C and below 15°C.

The BMS will not allow the battery pack to be discharged when the internal pack temperature is above 55°C or below -20°C.

The BMS will not allow the battery pack to be charged when the internal pack temperature is above 55°C or below 0°C.
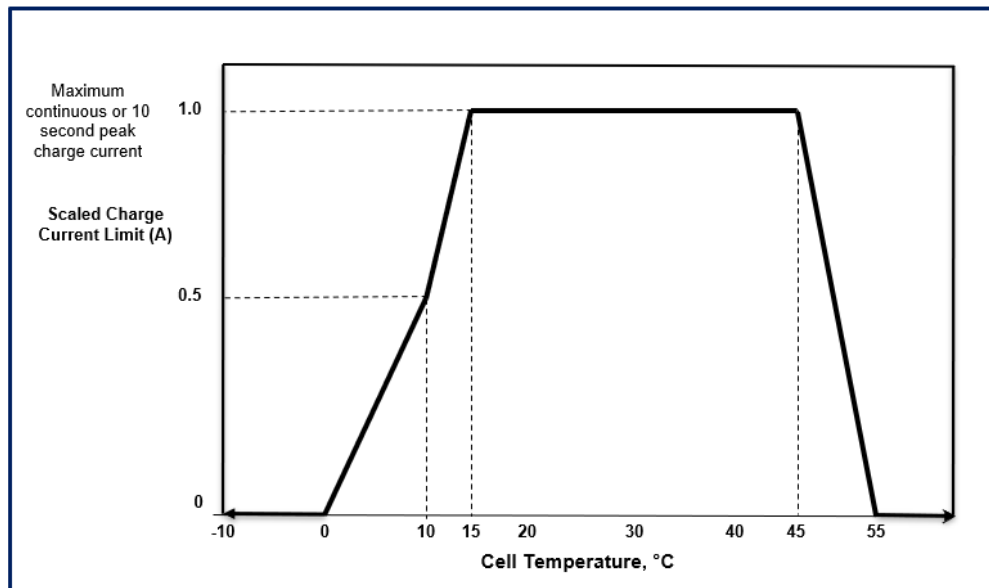
The BMS will operate between 80°C and -40°C.

Figure 12: Single pack Current Limit Strategy for Temperature - Charge
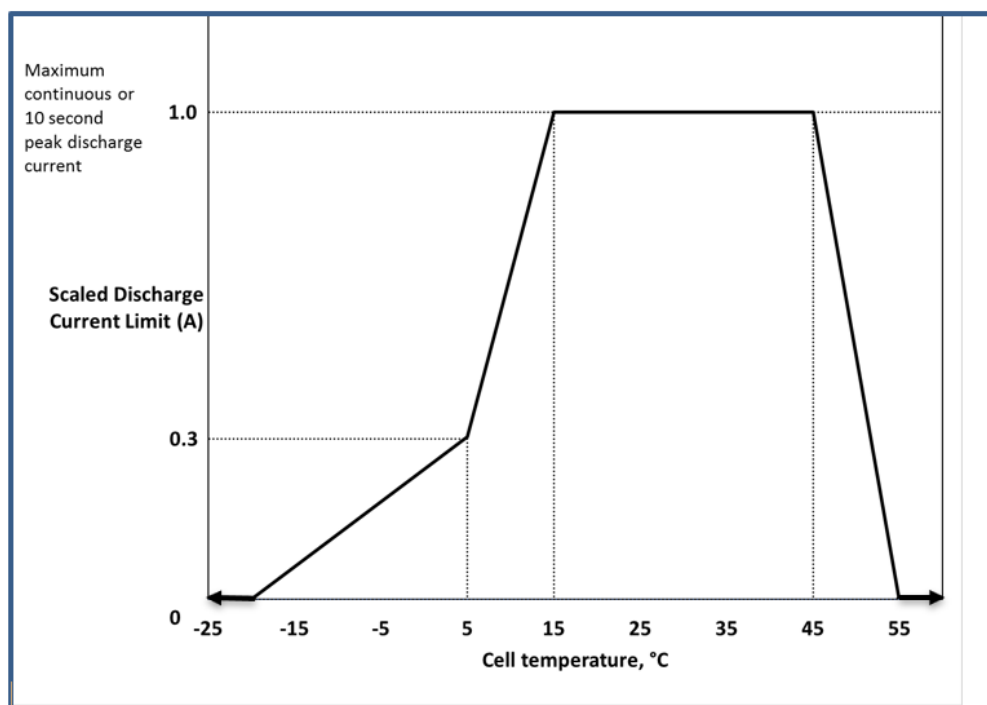
Figure 13: Single pack Current Limit Strategy for Temperature - Discharge

9.15   Current Limit Strategy (SOC)

The current limits are affected by the pack SOC and minimum and maximum cell voltage.

Reduced allowed discharge current and pulse discharge current can be expected when the SOC is below 15%.

Reduced allowed charge current and pulse charge current can be expected when the SOC is above 80%.

The BMS will not allow the battery pack to be discharged when the SOC is 0%.

The BMS will not allow the battery pack to be charged when the SOC is 100%.

Figure 14: Single pack SOC Based Current Limits – Charge

Figure 15: Single pack SOC Based Current Limits – Discharge

9.16 Pack fault strategy and Limit Tolerances

Current limits are calculated by each pack and aggregated by the executive pack to generate the system limits.
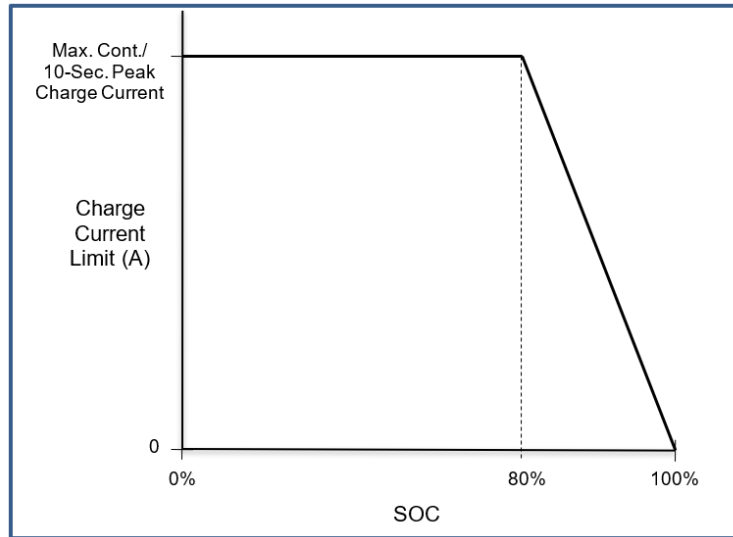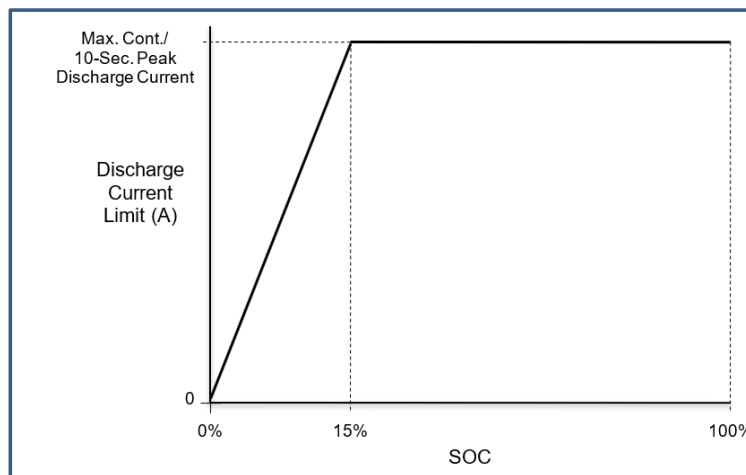
Allowed limits discussed below are for each pack. Each pack individually calculates and determines its fault conditions.

The BMS will protect itself by communicating malfunction codes and by lowering the current limits via the vehicle CAN communication bus. If these warnings are not heeded within 3 seconds, the BMS will protect the ESS by opening the pack contactors.

To charge the battery pack, it is necessary for the charger or the vehicle system controller to receive and to follow the charge current limits communicated by the BMS on the vehicle CAN bus. If the charging system (external charger or the vehicle system controller) can follow the charge current limit, then the battery pack will command the charging system to taper the charge current appropriately when approaching 100% SOC.

The battery pack can be operated in any SOC range between 0% and 100%.

The vehicle controller can stop the charge or discharge process at any point in the cycling of the battery pack.

The battery pack SOC operating range can vary freely based on the application.

9.16.1 Current related faults and Limits.

If the current faults are triggered the pack will lower the current limits to zero and set the contactors opening bit to true.

9.16.1.1   Current regulation fault

The current regulation fault is a ≈15 second fault. If the broadcast current limits are not obeyed for 15 seconds based upon the following criteria the fault will be set and the contactors will open.

Current regulation fault – charge limit:

The current regulation fault is set if the pack charge current is greater than the maximum of (105% of the broadcast charge current or 3A) for more than 15 seconds.

Current regulation fault – discharge limit:

The current regulation fault is set if the pack discharge current is greater than the maximum of (110% of the broadcast discharge current or 1.5A) for more than 15 seconds.

9.16.1.2   Overcurrent fault

The Overcurrent fault is a ≈2 second fault. If the pulse current limits are not obeyed for 2 seconds based upon the following criteria the fault will be set and the contactors will open.

Overcurrent fault – charge limit:

The Overcurrent fault is set if the pack charge current is greater than the maximum of (110% of the broadcast charge current or 4A) for more than 2 seconds.

Overcurrent fault – discharge limit:

The Overcurrent fault is set if the pack discharge current is greater than the maximum of (178% of the broadcast discharge current or 2A) for more than 2 seconds.

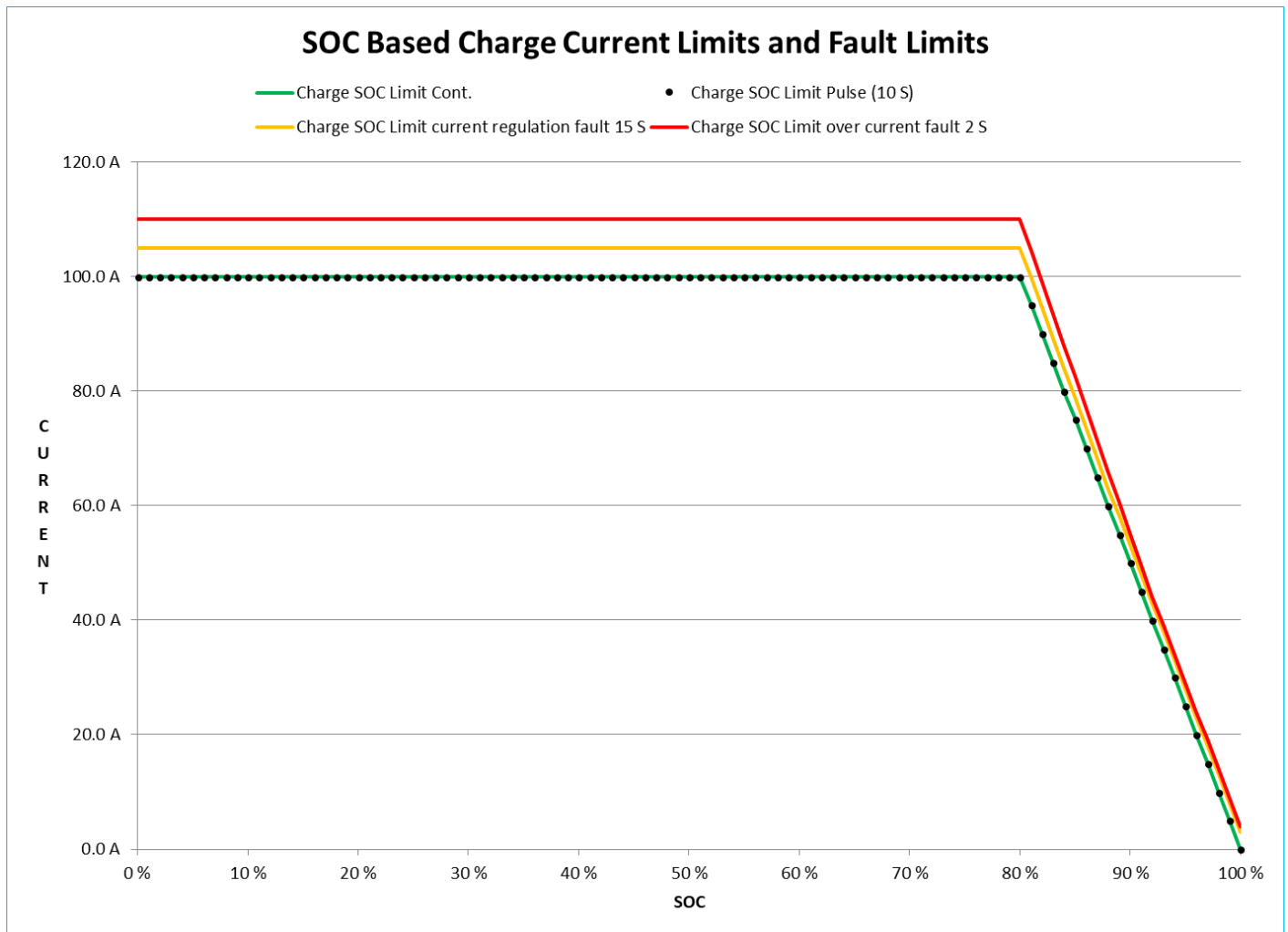### 9.16.2 Detailed Operational Limit and Fault Limit Graphs

Figure 16: Single pack SOC Based Charge Limits
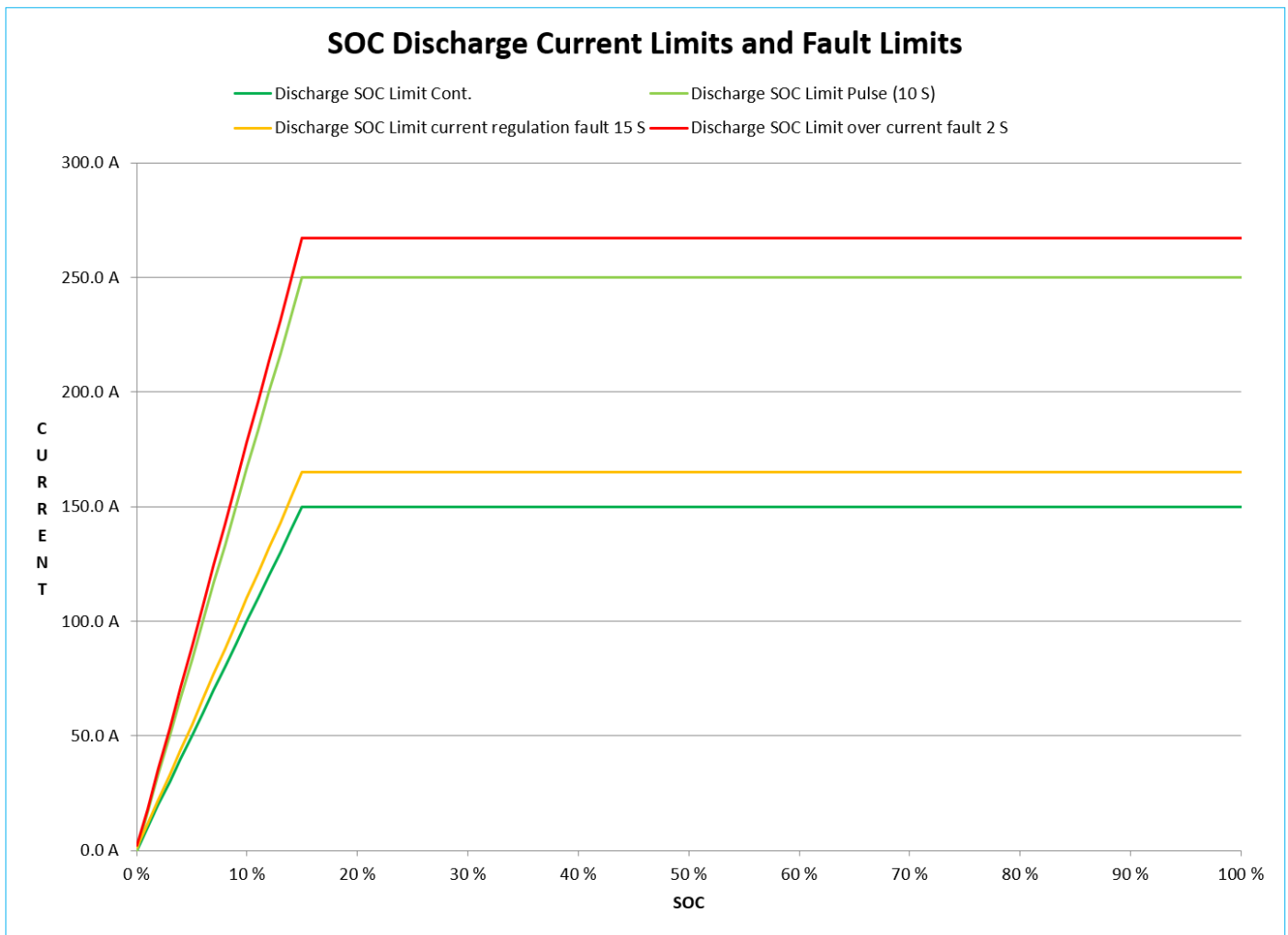
Figure 17: Single Pack SOC Based Discharge Limits

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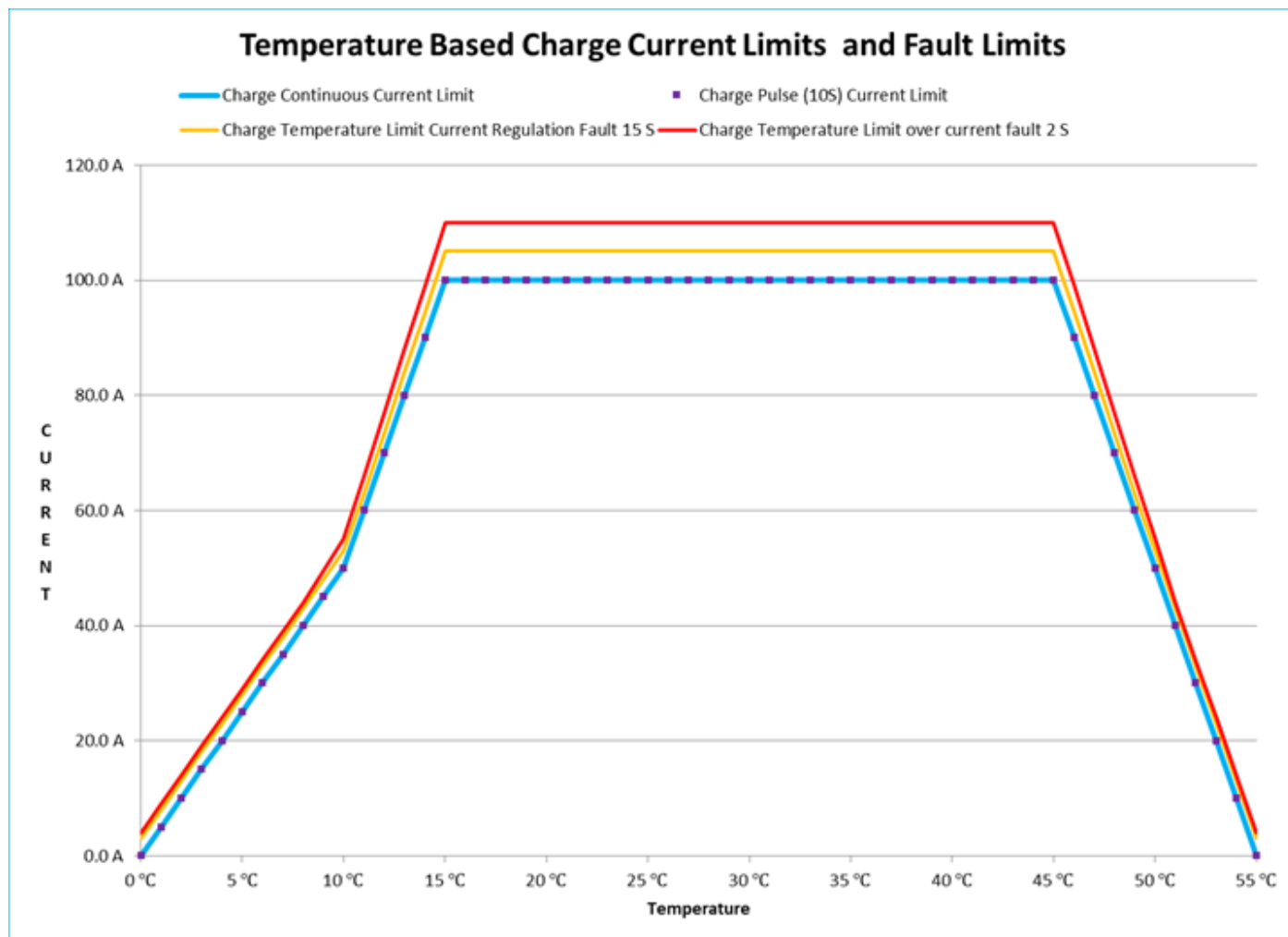
Figure 18: Single pack Temperature Based Charge Limits

![ENERDEL logo]
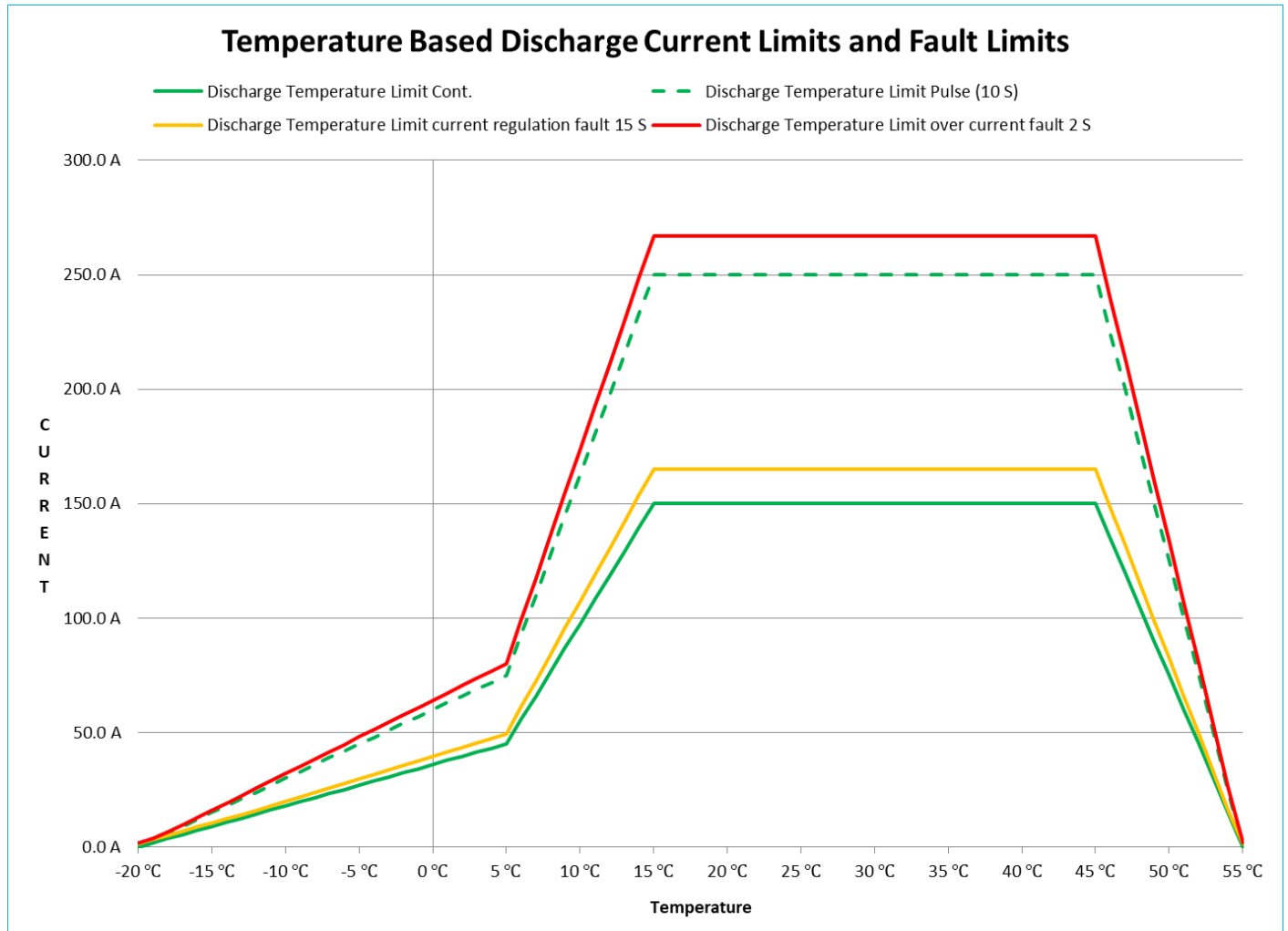
Figure 19: Single pack Temperature Based Discharge Limits

9.16.3 Voltage related faults and limits

The BMS will set the charge current limit to **0A** if any single cell voltage during charge exceeds **4.2V**.

The BMS will open the contactors if any single cell voltage exceeds **4.2V**.

The BMS will prevent discharge from the battery pack when the pack SOC is at or below **0%** by setting the current limit to **0A**. The BMS will set the discharge current limit to **0A** if any single cell voltage is below **3V or lower**.

The battery pack will accept charge if all single cell voltages are greater than **3V**.

The BMS will open contactors if any cell falls below 3V, and no charging will be possible by the end user (no operation below 2.0V). NOTE: The battery pack may be permanently damaged if any single cell voltage is **below 2V**.

9.17　BMS input voltage supply related faults.

12V Supply Fault/Warning Parameter	Value	Note:
Undervoltage Fault- Reset	10.0 V	The undervoltage fault is set if the supply voltage is <=8.5V OR If the supply voltage is <= 9.5V for 5 S.
Undervoltage Fault- Upper Limit	9.5 V	
Undervoltage Fault- Lower Limit	8.5 V	The undervoltage fault is reset when the supply voltage is > 10 V.
Undervoltage Fault- Delay	5.0 S	
Undervoltage Warning- Reset	10.5 V	The undervoltage warning is set if the supply voltage is <= 10 V for 4 S.
Undervoltage Warning- Limit	10.0 V	
Undervoltage Warning- Delay	4.0 S	The undervoltage warning is reset when the supply voltage is > 10.5 V.

Table 14: BMS input supply related faults

9.18　Pack Diagnostic Fault Table

Fault Name	Fault ID	Fault Applicable (Y/N)	Disables HV Contactors (Y/N)	Latched Until Next Key Cycle (Y/N)	Latched Until Manually Cleared (Y/N)
BUS VOLT AD FLT	0	Y	N	N	N
PACK VOLT AD FLT	1	Y	N	N	N
PACK CUR B HI AD FLT	2	N	-	-	-
PACK CUR B LO AD FLT	3	N	-	-	-
PACK CUR A HI AD FLT	4	Y	Y	Y	N
PACK CUR A LO AD FLT	5	Y	Y	Y	N
BD UNDER TEMP FLT	6	Y	Y	Y	N
SEC STUCK ON FLT	7	Y	Y	Y	N
INT ISO FLT	8	Y	Y	Y	N
EXT ISO FLT	9	Y	Y	Y	N
SEC CONTA OPEN FLT	10	Y	Y	Y	N
CONT PCHG SHORT FLT	11	Y	Y	Y	N
CONT1 DROPOUT FLT 2ND FLT	12	Y	Y	Y	N
CONT1 DROPOUT FLT 1ST FLT	13	Y	Y	Y	N
CONT PCHG RETRY FLT	14	Y	Y	Y	N
CONT FIRST PCHG FAILED	15	Y	N	N	N
REDUNDANT CELLV COMPARE FLT	16	Y	Y	Y	N
CONT2 STUCK ON FLT	17	Y	Y	N	Y
NO CHARGE CUR FLT	18	N	-	-	-
BD OVER TEMP FLT	19	Y	Y	Y	N
UNDER TEMP FLT	20	Y	Y	Y	N
OVER TEMP FLT	21	Y	Y	Y	N
FAN CUR LOW FLT	22	Y	N	N	N
FAN CUR HIGH FLT	23	Y	N	N	N
MODULEV TO CELLV COMPARE FLT	24	Y	Y	Y	N
CONT1 STUCK ON FLT	25	Y	Y	N	Y
UNDER VOLT FLT B	26	N	-	-	-
UNDER VOLT FLT A	27	Y	Y	Y	N
OVER VOLT FLT B	28	N	-	-	-
OVER VOLT FLT A	29	Y	Y	Y	N
OVER CURRENT FLT	30	Y	Y	Y	N
SPI FLT	31	Y	N	N	N
CONT2 DROPOUT 2ND FLT	32	Y	Y	Y	N
CONT2 DROPOUT 1ST FLT	33	Y	Y	Y	N
CONT1 STUCK OPEN FLT	34	Y	Y	Y	N

Table 15: Faults used in this pack

Fault Name	Fault ID	Fault Applicable (Y/N)	Disables HV Contactors (Y/N)	Latched Until Next Key Cycle (Y/N)	Latched Until Manually Cleared (Y/N)
CONT2 STUCK OPEN FLT	35	Y	Y	Y	N
SEC CONTB OPEN FLT	36	N	-	-	-
NO PCU DATA FLT	37	Y	Y	Y	N
OVER CURRENT REG FLT	38	Y	Y	Y	N
SUPPLY V UNDER VOLT FLT	39	Y	Y	N	N
LO DCHG DURING CHG FLT	40	N	-	-	-
HI DCHG DURING CHG FLT	41	N	-	-	-
SLAVE COMM FLT	42	Y	Y	N	N
SUPPLY V UV WARNING	44	Y	N	N	N
HI CONT COIL CUR FLT	45	Y	Y	Y	N
CV CONNECTION FLT	46	Y	Y	Y	Y
EXTREME UNDER VOLT FLT	47	Y	Y	N	Y
LO CUR CORRELATION FLT	48	N	-	-	-
HI CUR CORRELATION FLT	49	N	-	-	-
MAIN CONT OPEN UNDER LOAD FLT	50	Y	N	N	N
FUSE BLOWN FLT	51	N	-	-	-
PACK TEMPERATURE AD FLT	52	Y	N	N	N
MODULE V OUTLIER FLT	53	Y	Y	Y	N
UNREASONABLE TEMP FLT	54	Y	N	N	N
HIGH TEMP DELTA FLT	55	Y	N	N	N
HIGH CV DELTA FLT	56	Y	N	N	N
NO EPO FLT	57	Y	Y	Y	N
INVALID AIN CAL	58	Y	N	N	N
INVALID CONFIG	59	Y	Y	N	N
EXT FAULT	60	Y	Y	N	N
CONT PCHG STUCK ON FLT	61	Y	Y	Y	N
CONT PCHG STUCK OPEN FLT	62	Y	Y	Y	N

Table 16: Faults used in this pack part 2

9.19 CAN Communications

9.19.1 Pack CAN interface specification

CAN is supported on the battery with the following specification:

- Protocol CAN 2.0B
- 500 Kbps
- 29-bit identifiers (traditional MLEC addressing)
- Motorola format
- Refer to *MLEC LX CAN Bus User's Guide* and the ".dbc" file for complete information.

9.19.2 Pack Interface Tools

A CAN Interface Tool (PCAN-USB Adapter (isolated) IPEH-002022) can be connected to V_CANH and V_CANL of the CAN Bus at the Pack Interface connector. Pack interface tools for software service and installation are described as follows (diagnostics and programming):

PCAN Tool w/Viewer and/or Explorer – off-the-shelf hardware and software application(s) that provides a method for CAN bus connectivity and communication (DBC files are associated with Explorer).

Recommended tools for interfacing with the battery pack are listed below, including details for obtaining the various specialty and custom/proprietary items:

CAN Interface Tool (hardware and software)
Desc: PCAN-USB Adapter with optical isolation, p/n IPEH-002022
Distributor: Phytools (https://phytools.com/products/pcan-usb-adapter-isolated)
Mfr: PEAK-System (www.peak-system.com)

Appendix A: Summary of 25Ah-2 Performance Relative to 25Ah-1

25 Ah naming convention.

      The first version of the 25 Ah cell sold by EnerDel is referred to with a -1 reference, which is the same as CE250-370-1. The second offering of the 25 Ah cell is delineated by the -2 suffix, which is the same as CE250-370-2.

Charge capability vs temperature.

      The performance parameter that is different is the charge capability at lower temperatures.

Parameter	Units	Specification	Note
Operating temperature			
Optimal	°C	15 to 35	Optimal performance/life
Full performance discharge	°C	15 to 45	Full performance within defined SOC ranges
Full performance charge 25 Ah-**1**	°C	10 to 45	Full performance within defined SOC ranges
Full performance charge 25 Ah-**2**	°C	15 to 45	Full performance within defined SOC ranges
Degraded performance, discharge	°C	-20 to 15, 45 to 55	Discharge current limiting outside of full performance operating temperature range
Degraded performance, charge 25 Ah-**1**	°C	0 to 10, 45 to 55	Charge current limiting outside of full performance operating temperature range
Degraded performance, charge 25 Ah-**2**	°C	0 to 15, 45 to 55	Charge current limiting outside of full performance operating temperature range

Table 17: 25Ah-1 vs 25Ah-2 Operating Temperature Capability
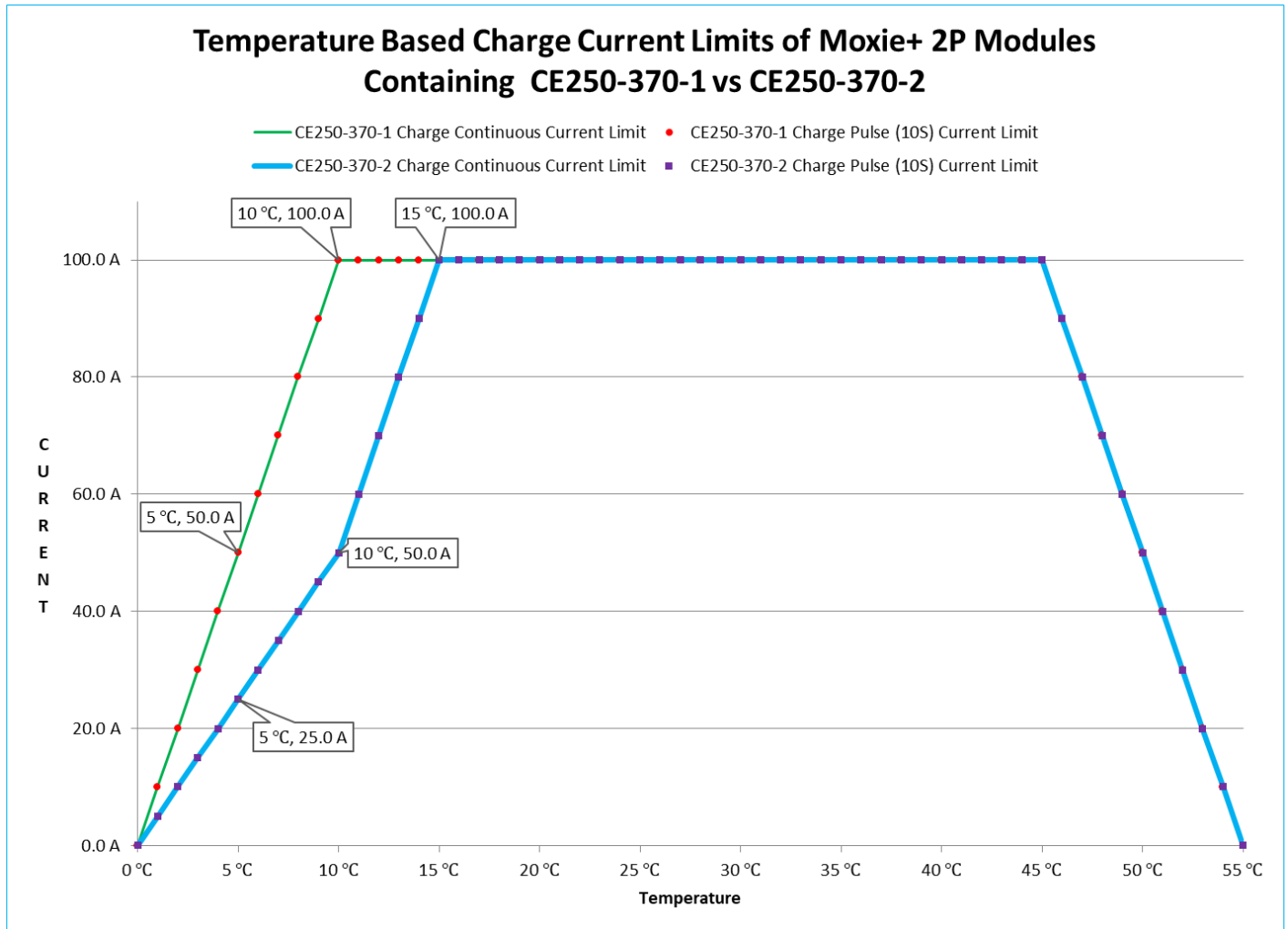
Figure 20: Temperature Based Charge Current Limits of Moxie+ 2P Modules Containing CE250-370-1 vs CE250-370-2

Revision Record

Revision Level	Revision Date	Author	Change Description and Section(s) affected by the change
01	12-09-2021	W. Rinaldi R Fildes	Initial Release

Table 18: Revision Record

10. End of Document Marker

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