PSA AGV
Battery Management System (BMS)

Functional Specifications
&
External CAN Communications Protocol

Version Number: 1.1

25-Jan-19

Version Control

Ver	Date	Author	Changes
1.0	15/10/18	Tham YK	
1.1	25/01/19	Chew JQ	Section 4.1: Added Cooling System Bypass Request Section 5.1: Removed “Cooling System Fault Alarm”. Section 5.2: Amend resolution for battery capacity from 1 kWh to 2 kWh.

Table 1: Version Control History

Contents

Appendices

Abbreviations

ADS	PSA AGV Deployment System
AGV	Automated Guided Vehicle
AGV Contractor	PSA nominated AGV Contractor (“Main Contractor”)
BMS	Battery Management System
BMC	BMS Master Controller
BSC	BMS String Controller
BMCU	Battery Module Control Unit
DoD	Depth of Discharge
FAT	Factory Acceptance Test
HV	High-Voltage
NS	Navigation System
SAT	Site Acceptance Test
SOC	Battery State-of-Charge
SOH	Battery State-of-Health
VS	Vehicle System

1. Introduction

The purpose of this document is to specify a standardised, external CAN communication data interface and protocol between Battery Management System (BMS) and PSA AGV. All BMS must comply strictly with this data interface to integrate with PSA AGV. This common data interface shall support both vehicle power management and battery charging management.

2. Battery System Design & Specifications

2.1 General Specifications

Key Designs:

- Support up to 16 multi-battery strings operations. Preferred three or more battery strings.
- Auto degradation in battery performance under localised string fault condition without total power lost
- Built-in cooling system. Water-cooled is preferred.
- Battery modules shall be front accessible for ease of maintenance

The lithium batteries shall meet the following minimum specifications:

a.	Operating Voltage Range	450 – 750 Vdc
b.	Min Battery Capacity @ Start State	156 KWh
c.	Min Operating Battery Capacity @ EOL	120kWh (DoD)
d.	Peak Power Output	320KW for less than 30s per instance
e.	Continuous Charging Power & Max Current	450KW, 750A (<20 mins for 120 kWh)
f.	Working Ambient Temperature	20 – 40°C
g.	Working Humidity	90% Condensing
h.	Useful Life-span	Minimum 8 Years
i.	External Dimension	2.50m (L) x 2.95m (W) x 0.97m (H)
j.	Total Weight	Not exceeding 5 Tons

The expected operating duty cycle of the Battery System is given in Appendix 1.

2.2 Battery Management System (BMS)

The BMS is an integral unit of the battery pack. It comprises the Battery Master Controller (BMC), Battery String Controllers (BSCs) and Battery Module Control Units (BMCUs). Each battery string is managed by BSC while the battery module is managed by BMCU. The BMC, BSC and BMCU communicates via their internal CAN communication buses.

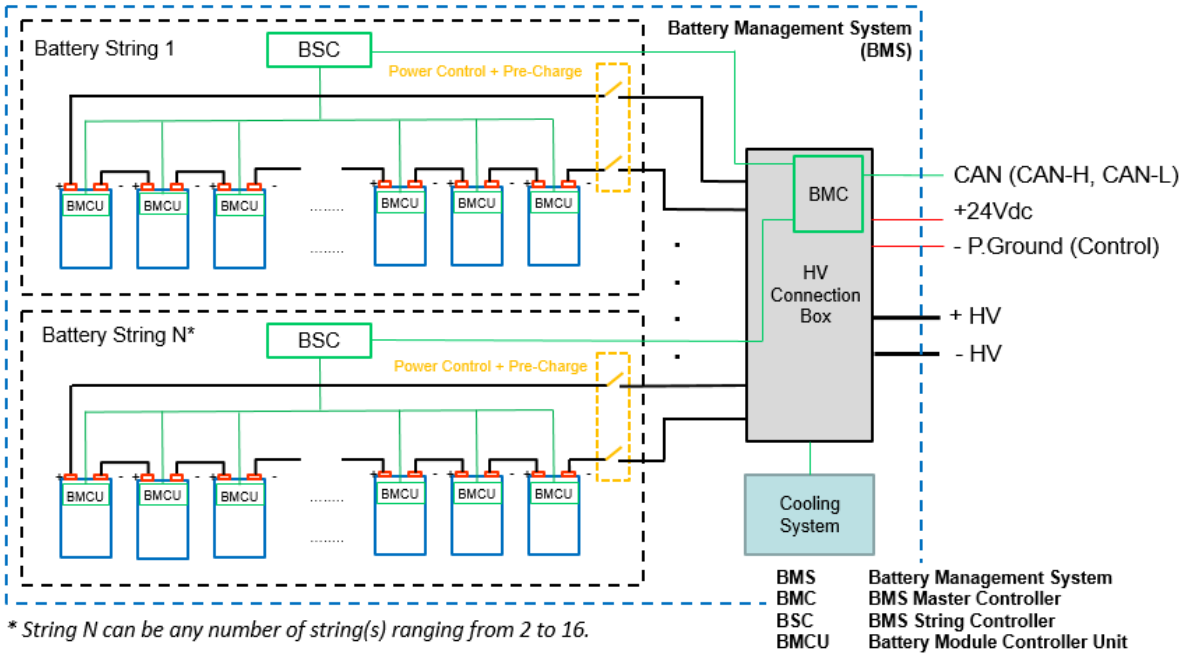


Figure 1. Battery & Communications Architecture Diagram

The BMS shall monitor and control the health of individual battery cells, modules, strings and pack, and report active faults upon activation. It shall provide the following management and protection functions for the battery pack:

a. Management of the battery charging and discharging operations
b. Continuous monitoring on the health status of battery cells, modules, strings and pack
c. Built-in intelligent cell level balancing
d. Battery capacity calculation – State-of-Health (SOH)
e. State-of-Charge (SOC) calculation
f. Cumulative battery energy counter
g. Management of the battery cooling system
h. Monitoring of HV system insulation
i. Diagnostic – Maintain historical status and fault logs of the battery system, battery modules and cell status

Pre-charging during power up and power supply connection are managed by the Battery String Controller (BSC) at battery string level.

2.3 Active Mode Operation

The BMS interacts with the Vehicle System (VS) via a CAN bus communications link. The VS can control the system's working mode by sending commands to the BMS.

2.3.1 Operational Mode

The battery system has 3 different operating modes:

- **Standby Mode**: The main relay is disconnected. 24Vdc supply is turned on and the battery system boots up and is ready to operate.
- **Charge Mode**: The main relays are closed. BMS is actively monitoring the batteries while being bulk charged. The VS can control the charging process with set-point information provided by the BMS.
- **Discharge Mode**: The main relays are closed. BMS is actively monitoring the batteries' condition.

The conditions for mode change are listed in the diagram below:

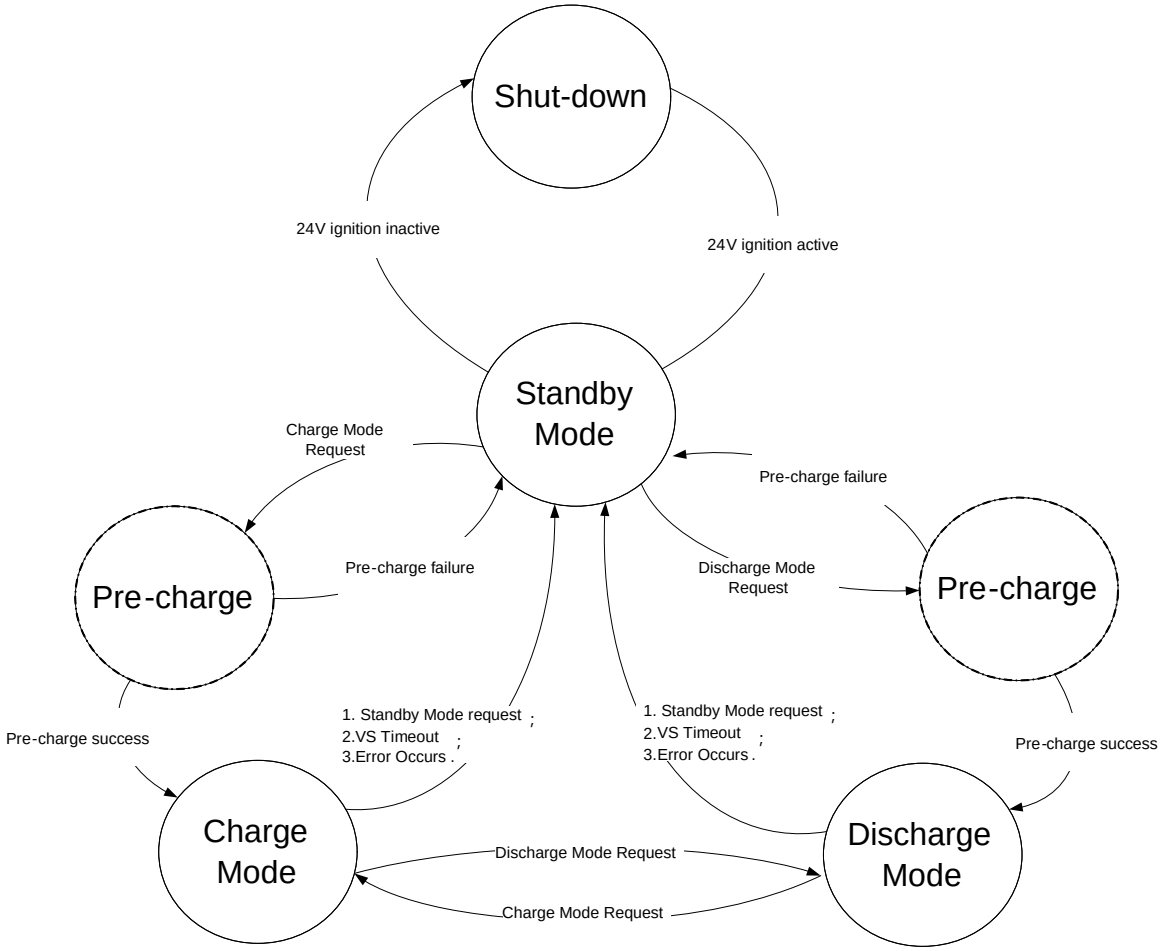


Figure 2.1 VS Active Mode State Machine

The time taken for transition between each mode is given in the diagram below. As the pre-charge timeout is set as 5 secs, VS shall allow about 6 secs for mode transition.

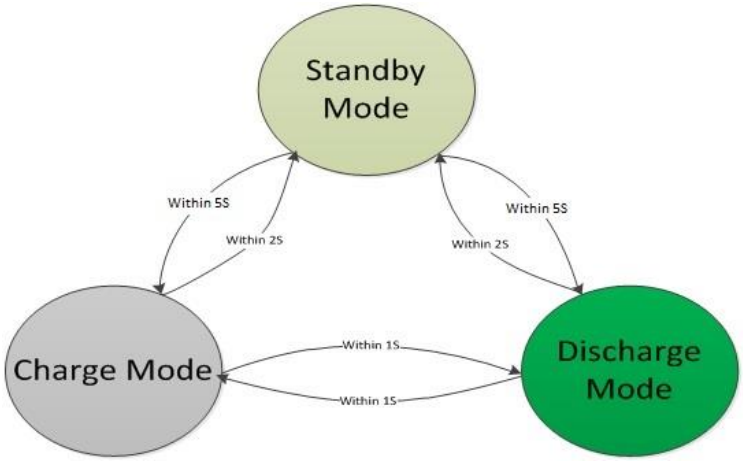


Figure 2.2 Transitions between Operating Modes

2.3.2 Battery System Status

When BMS is powered up, it goes through an initialization process. BMS will not communicate with VS until the self-inspection process is complete. The maximum duration for self-inspection is **12s**.

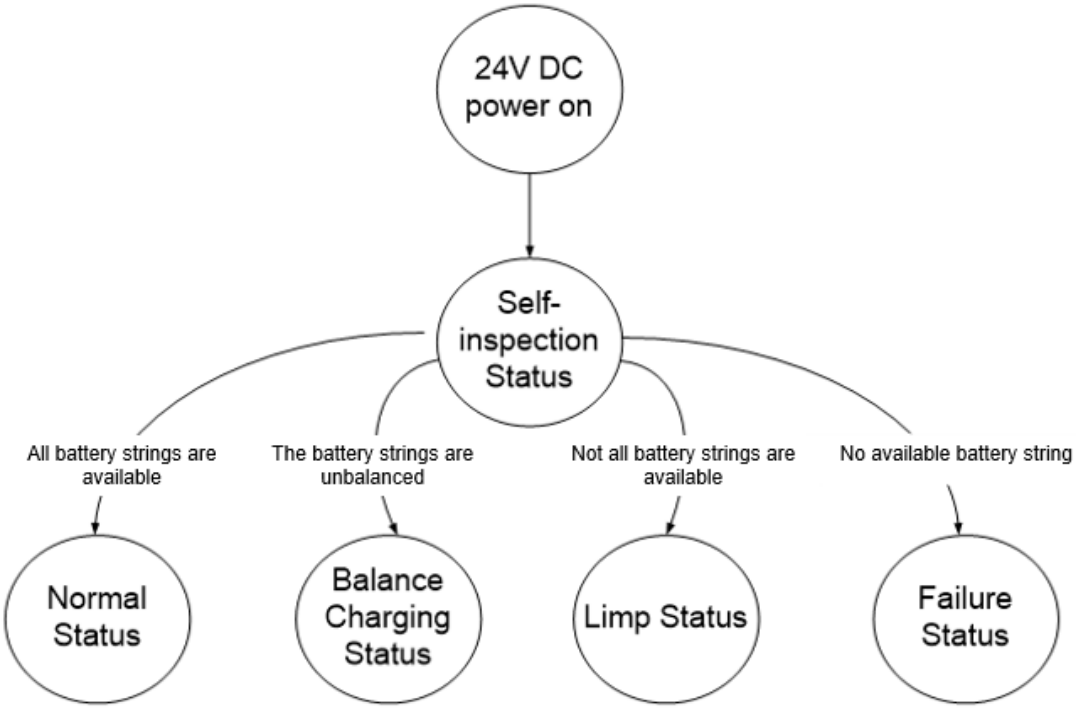


Figure 2.3 Battery Initialisation & Self-Inspection Process

After self-inspection is completed, the battery system will go into one of the following states:

A. Normal Status

All battery strings are operational.

B. Balance Charging Status

The battery system enters **<Balance Charging>** status when the difference between the highest battery string voltage and the lowest battery string voltage is greater than the allowable threshold value (say, >15V). To restore **<Normal>** status, there is a need to balance the voltages across the battery strings through charging operations.

Note: A battery system in **<Balance Charging>** status will go into **<Limp>** status when the mode is switched from **[Standby]** to **[Charge] or [Discharge]**.

Standby Mode → Discharge Mode

If VS sends **[Discharge]** mode request when BMS is in **<Balance Charging>** status, BMS will close the main relays of the battery strings that are within allowable voltage range (say, 15V) from the **highest** voltage string (including the highest voltage string). The battery system will then enter **<Limp>** status as the number of operational strings is less than the designed N strings.

Standby Mode → Charge Mode

If VS sends **[Charge]** mode request when BMS is in **<Balance Charging>** status, BMS will close the main relays of the battery strings that are within allowable voltage range (say, 15V) from the **lowest** voltage string (including the lowest voltage string). The battery system will then enter **<Limp>** status as the number of operational strings is less than the designed N strings. Charging will be carried out for the connected battery strings only.

C. Limp Status

If the number of the operational battery strings is less than the designed N strings, the battery system will enter **<Limp>** status.

D. Fault Status

When there is no operational battery string, the battery system will go into **[Standby]** mode with **[Fault]** status.

2.3.3 Battery Discharging Mode Workflow

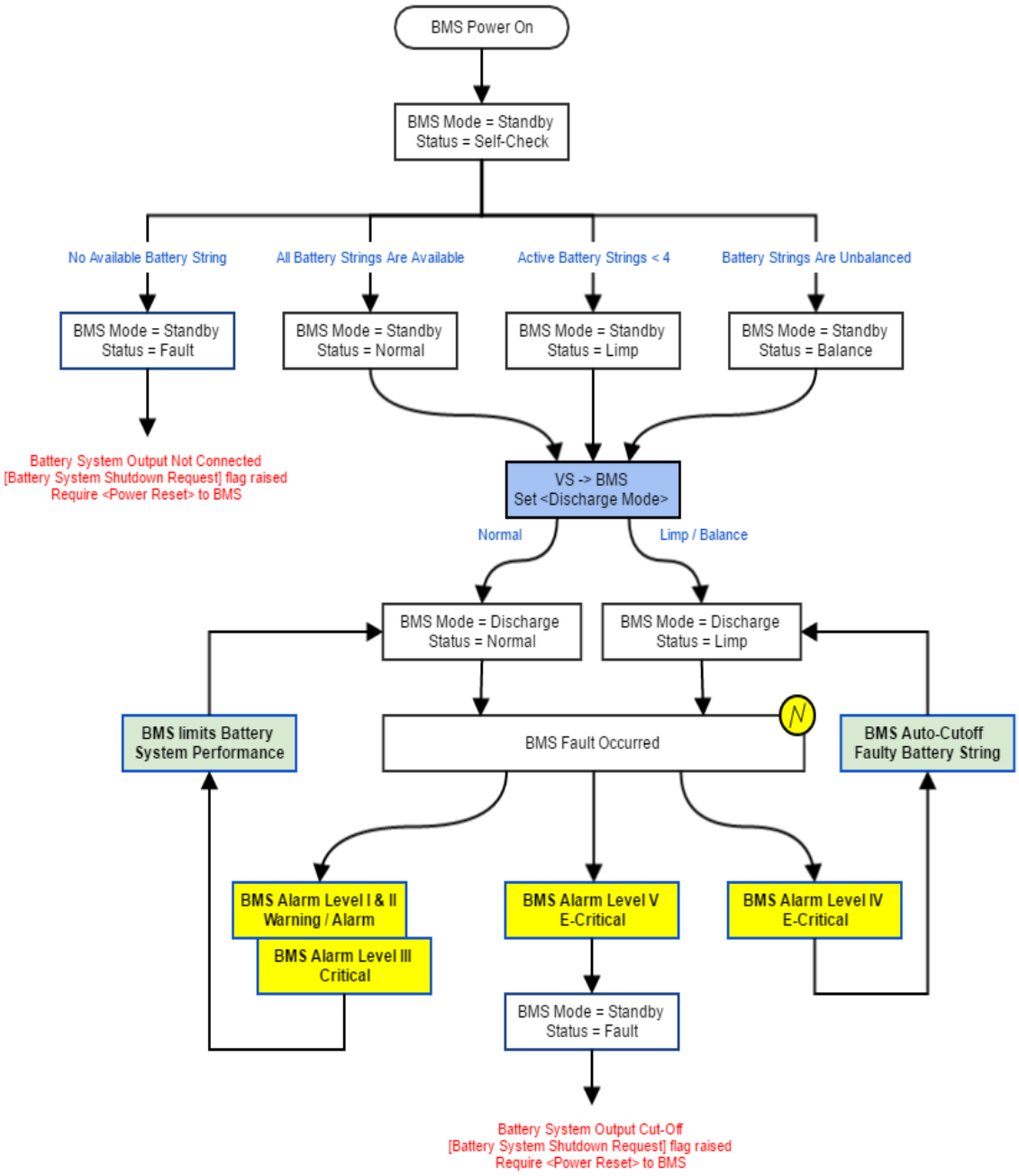


Figure 2.4 Battery Discharging Mode Workflow Diagram

2.3.4 Battery Charging Mode Workflow

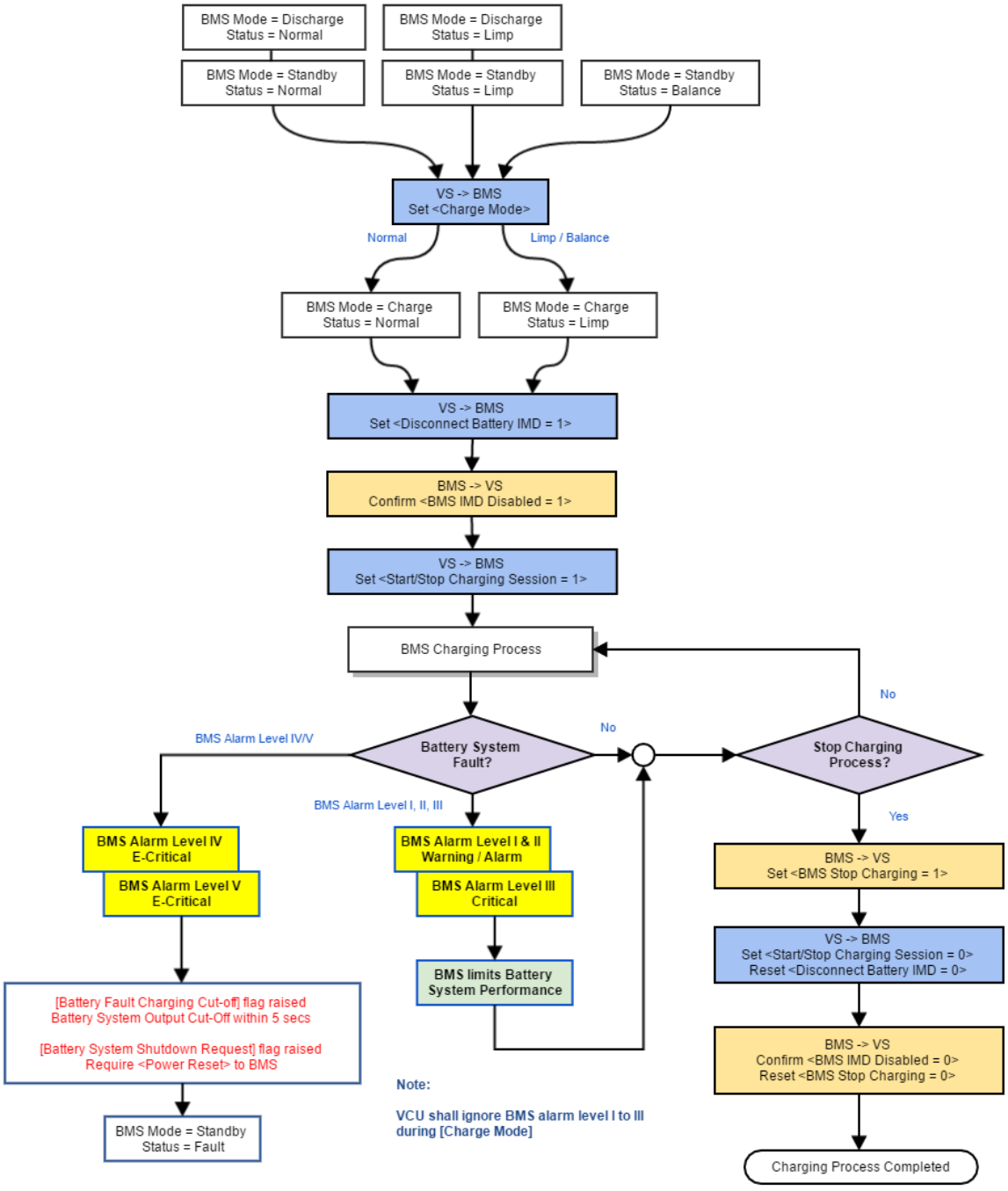
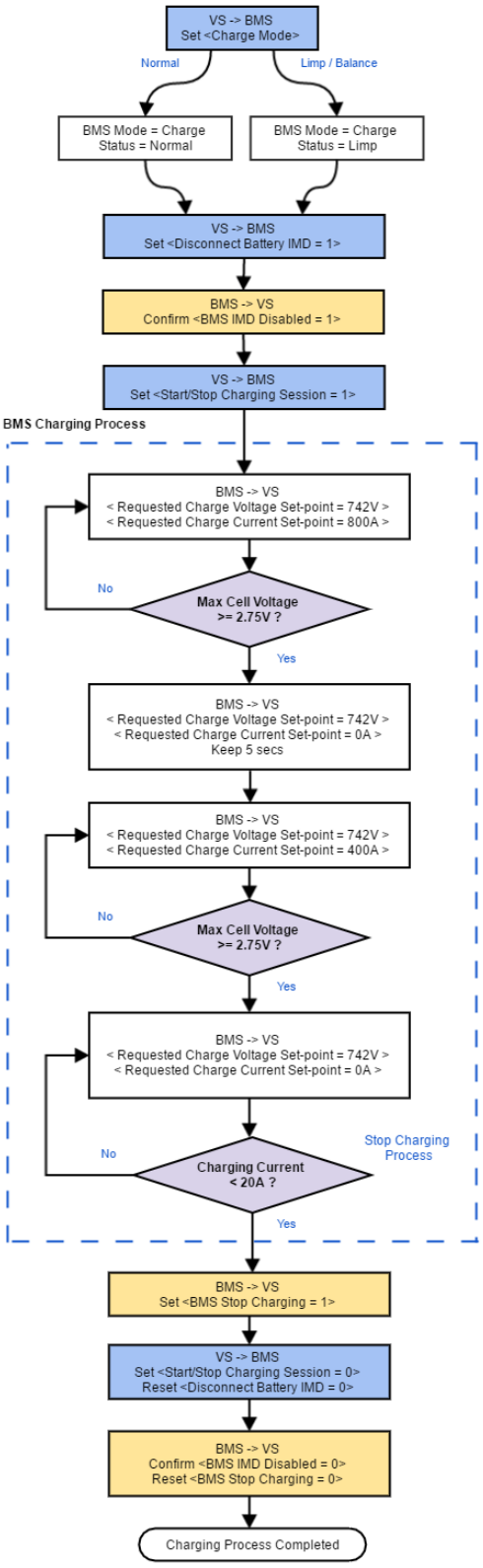


Figure 2.5 Battery Charging Mode Workflow Diagram

2.3.4.1 Battery Charging Process when Battery Status is Normal



Note:
The BMS Charging Process will differ for different battery solutions and chemistry. Vendors shall propose the respective charging strategies suitable for their proposed battery systems.

Figure 2.6 Battery Charging Normal State-Flow Diagram

2.3.4.2 Battery Charging Process when Battery is in <Balance Charging> Status

Note:

1. The battery charging process when battery is in <Balance Charging> status may differ for different vendor's solutions. Vendors shall propose their respective charging strategies suitable for their proposed battery solutions.
2. See section 2.3.2(B) for the battery connection process when battery is in <Balance Charging> status.

If VS sends **[Charge]** mode request when BMS is in **<Balance Charging>** status, BMS will manage the charging process by charging sequentially from strings with the lowest voltage to the higher voltage ones while maintaining at least one battery string connected at all times. This is necessary to provide non-interrupted power supply to VS/AGV.

For illustrative purposes, we assume that the battery system has Strings A, B, C, D in order of lowest to highest voltage. BMS will manage the charging process as follows:

1. BMS closes the main relays of the battery strings (Strings A-B) that are within allowable voltage range (say, 15V) of the lowest voltage string
2. Strings A-B are charged up to the voltage level of the next lowest string, say, String C.
3. The requested charging current is reduced momentarily to zero and the main relay of String C is activated. The connected strings are charged up to the voltage level of the next lowest string, say, String D.
4. The process repeats until all strings are at the same voltage level.

2.3.5 Battery System Alarm Levels During Standby/Discharge Mode

BMS alarms are categorized into 5 levels, each requiring different action as detailed in the table below. The mapping to PSA AGV alarm levels are also indicated in the same table for ease of reference.

BMS Alarm Level	Description of Alarm Action	PSA AGV Alarm Level
I	Alarm without action	Warning
II	Max. Regenerative / discharge current allowed decrease to 80% *Note: This degradation in battery performance should not have practical impact to the AGV dynamic performance.*	Warning
III	Max. Regenerative / discharge current allowed decrease to 50% *Note: AGV Fault Bypass (Battery System Critical) is required at AGV end to allow continued operations at degraded speed.*	Critical
IV	Max. Regenerative / discharge current allowed decrease to 0. BMS shall auto cut-off faulty battery string and then enters into Limp mode. The max regenerative/discharge current limit are then redefined based on the numbers of connected battery strings. *Note: AGV Fault Bypass (Battery System E-Critical) at AGV end is required to restore operation in Limp mode at degraded speed.*	E-Critical
V	Max. Regenerative / discharge current allowed decrease to 0. As this is a severe system level fault, BMS will automatically cut-off battery system. If it is operational at the time of fault, BMS will automatically cut-off its output after 5 secs to protect the battery system. Regardless of its operating mode, BMS will transit to **[STANDBY]** mode with **[FAULT]** status.	E-Critical

Table 2-1: Battery System Alarm Levels During Standby/Discharge Mode

2.3.6 Battery System Alarm Levels During Charge Mode

During Charge Mode, BMS will continue to monitor, report and update its operating parameters such as maximum discharge / regenerative current permitted of the battery system according to its alarm level.

VS shall not respond to reported BMS alarm level I to III during Charge Mode, as it is expected some of the internal battery operating parameters such as cell voltage and module temperature may exceed its normal limits.

BMS shall immediately stop charging operation when battery system reaches alarm level IV (PSA alarm level = E-Critical).

- VS shall **ignore** BMS Alarm Level I to III during Charge Mode only.

BMS Alarm Level	Description of Alarm Action	PSA AGV Alarm Level
I	Alarm without action	Warning
II	Alarm without action	Warning
III	Alarm without action	Critical
IV	Max. Charging Current decrease to 0. BMS shall raise the following fault alerts: – **[Battery Fault Charging Cut-Off]** – [General Battery Malfunction / Battery Temperature Inhibit Charging] – [Battery System Shutdown Request]	E-Critical
V	Same as IV	E-Critical

Table 2-2: Battery System Alarm Levels During Charge Mode

3. Message Summary between VS and BMS

The interface between VS and BMS operates with the following CAN Bus specifications:

- CAN 2.0B
- 250kbps
- 29-bit identifiers
- Multi-byte data are encoded using **little-endian byte ordering**. Signed values are encoded using **two's-complement** representation.

The following summarizes the main characteristics of the control and status messaging flow between VS and BMS.

Message	CAN ID	DLC	Period	Timeout
VS-to-BMS Control Message				
VS_BMS_CMD_MESSAGE	0x18FF4027	8	200 ms	2s
BMS-to-VS Status Message				
BMS_VS_FAULT_MESSAGE	0x18FFC0EF	8	200 ms	2s
BMS_VS_BATT_DATA_MESSAGE_1	0x18FFC1EF	8	500 ms	5s
BMS_VS_BATT_DATA_MESSAGE_2	0x18FFC2EF	8	500 ms	5s
BMS_VS_STATUS_MESSAGE_1	0x18FFC3EF	8	500 ms	5s
BMS_VS_STATUS_MESSAGE_2	0x18FFC4EF	8	500 ms	5s
BMS_VS_STATUS_MESSAGE_3	0x18FFC5EF	8	500 ms	5s
BMS_VS_CHARGER_SETPOINT_1	0x18FFC6EF	8	500 ms	5s
BMS_VS_CHARGER_SETPOINT_2	0x18FFC7EF	8	200 ms	2s

Table 3-1: Message Summary Between VS & BMS

1. VS shall continuously check for message timeout from BMS. In case of timeout from any of the BMS message, VS shall activate E-Critical alert which will stop the physical AGV and cutoff the drive system.

2. In case of BMS losses communication with VS, BMS will set maximum regenerative / discharge current allowed to 0. BMS will cut off battery system relay when DC current < 50A or after a maximum 5s timeout if current remains above 50A.

4. VS to BMS Command

The following command is used by VS to control the operation of the Battery system.

4.1 VS_BMS_CMD_ Message

CAN ID	0x18FF4027				
DLC:	8		Frequency	200 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0	UINT8	BMS Mode Request 1 = Standby Mode 2 = Charge Mode 4 = Discharge Mode	-	-	
1	UINT1 [Bit 0]	Disconnect Battery IMD	1	[0, 1]	1 = Disconnect IMD 0 = Connect IMD
	UINT1 [Bit 1]	Start/Stop Charging Session	1	[0, 1]	1 = Start charging 0 = Stop charging (1 → 0)
	UINT1 [Bit 2]	Bypass Cooling System Request	1	[0, 1]	1 = Bypass Active 0 = Bypass Inactive
	UINT6 [Bit 3-7]	Reserved			
2	UINT8	Heart-beat flag (Toggling 1 and 0)	1	[0, 1]	If flag is unchanged for 2s, BMS will report External CAN network communication fault
3-7	UINT8	Reserved	-	-	

Table 4-1: VS_BMS_CMD_MESSAGE

(1) BMS shall always listen to the **[BMS Mode Request]** from VS. Only exception occurs when battery system is in **[FAULT]** status where BMS mode is forced to **[Standby].**

(2) For transition from **[Charge]** or **[Discharge]** mode to **[Standby]** mode, VS shall ensure that the vehicle is stationary and is drawing minimum current from the batteries.

(3) In case **[Standby]** mode request is received from VS, BMS will cut off battery system output relay immediately, regardless of the magnitude of the current flow.

(4) VS shall disable the insulation monitoring device (IMD) before starting the charging session. In case if IMD was not disabled, BMS will not respond to the [Start Charging] session. The charging current set-point will be maintained at 0, and there will not be any alert send.

(5) In case of a cooling system fault resulting in battery low insulation alarm, user may bypass the battery cooling system via VS to allow the battery system to start up. Upon receiving a bypass request for the battery cooling system, BMS shall cut-off both positive and negative supply line to totally isolate the battery cooling system.

5. BMS to VS Commands

The following BMS to VS CAN commands are required by the VS to capture, interrogate, monitor and to manage the operation of the battery system.

5.1 BMS_VS_FAULT_MESSAGE

CAN ID	0x18FFC0EF				
DLC	8		Frequency	200 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0	UINT1 [Bit 0] UINT1 [Bit 1] UINT1 [Bit 2] UINT1 [Bit 3] UINT4 [Bit 4-7]	Cell Voltage Imbalance Warning Temperature Imbalance Warning Low Insulation Warning Cooling System Fault Warning Reserved	--	--	**BMS Alarm Level 1 Warning** 0 = In-active 1 = Active
1	UINT1 [Bit 0] UINT1 [Bit 1] UINT1 [Bit 2] UINT1 [Bit 3] UINT1 [Bit 4] UINT3 [Bit 5-7]	Cell Under-Voltage Level 1 Cell Over-Voltage Level 1 Over Temperature Level 1 Discharge Over-Current Critical Charge Over-Current Critical Reserved	--	--	**BMS Alarm Level 2 Warning** Battery pack limited to operate at 80% rating.
2	UINT1 [Bit 0] UINT1 [Bit 1] UINT6 [Bit 2-7]	Reserved Insulation Measurement Device Fault Reserved	--	--	**BMS Alarm Level 1** Warning.
3	UINT1 [Bit 0] UINT1 [Bit 1] UINT1 [Bit 2] UINT1 [Bit 3] UINT1 [Bit 4] UINT1 [Bit 5] UINT3 [Bit 6-7]	Cell Under-Voltage Level 2 Cell Over-Voltage Level 2 Over Temperature Level 2 Battery System Over Voltage Fault Battery System Under Voltage Fault Cooling System Fault Critical Reserved	--	--	**BMS Alarm Level 3 Critical** Battery pack limited to operate at 50% rating. Bypass needed at VS to limit AGV driving speed to 2 m/s.
4	UINT1 [Bit 0] UINT1 [Bit 1] UINT1 [Bit 2] UINT1 [Bit 3] UINT1 [Bit 4] UINT1 [Bit 5] UINT1 [Bit 6] UINT1 [Bit 7]	Cell Under-Voltage Level 3 Cell Over-Voltage Level 3 Over Temperature Level 3 Internal CAN Network Communication Fault Middle CAN Network Communication Fault Electrical Circuit Breaker fault Battery String Relay Adhesion fault Cooling System Fault E-Critical	--	--	**BMS Alarm Level 4 E-Critical** Bypass needed at VS to allow battery operation in limp mode. Speed limit to 2 m/s at VS.
5	UINT1 [Bit 0] UINT1 [Bit 1] UINT1 [Bit 2] UINT1 [Bit 3] UINT1 [Bit 4] UINT3 [Bit 5-7]	Ultra-High Temperature Fault External CAN Network Communication Fault Low Insulation Fault Pre-charge Failure Battery System Relay Adhesion fault Reserved	--	--	**BMS Alarm Level 5 E-Critical** Cannot be bypassed. BMS mode is forced to [Standby]. Battery in [FAULT] status.

CAN ID	0x18FFC0EF				
DLC	8		Frequency	200 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
6	UINT1 [Bit 0] UINT1 [Bit 1] UINT1 [Bit 2] UINT1 [Bit 3] UINT1 [Bit 4] UINT3 [Bit 5-7]	Battery SOC Low Alarm Battery SOC Too Low Critical Battery SOC Too Low Cut-off Battery System in Limp State Battery System Shutdown Request Reserved	-- -- --	-- -- --	SOC low flag used to trigger final warning for battery charging Flag raised when battery is in limp state. Flag raised when BMS is in [FAULT] status. Battery outputs are cut-off. Re-power BMS is necessary to recover battery system operation.
7	UINT8	Reserved	--	--	

Table 5-1: BMS_VS_FAULT_MESSAGE

(1) BMS_VS_FAULT_MESSAGE will only indicate fault alarms for **connected** battery strings. Faults relating to battery strings that are disconnected shall not be reported but reflected as "**Battery System in Limp State**".

(2) VS shall latch all BMS reported alarms in BMS_VS_FAULT_MESSAGE, as the triggering fault will not be reported when BMS automatically disconnect the faulty battery string and transit into **LIMP** mode.

(3) When BMS is in **[Standby]** mode with **[Fault]** status, it will raise [**Battery System Shutdown Request**] flag to VS. VS is required to re-cycle power to the BMS, as an attempt to restore the battery system operation. BMS will take at max 12 sec to self-initialize.

(4) VS shall use both [**Battery System Shutdown Request**] flag and BMS is in **[Standby]** mode with **[Fault]** status as a "catch-all" condition to indicate BMS in alert level V.

5.2 BMS_VS_BATT_DATA_MESSAGE_1

CAN ID	0x18FFC1EF				
DLC	8		Frequency	500 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0-1	UINT16	Battery Pack ID	--	[1, 65535]	Configurable in persistent memory
2	UINT8	Designed Battery Capacity	2 kWh	[0, 510]	
3	UINT8	Current Battery Capacity	2 kWh	[0, 510]	SOH x Battery Designed Capacity
4	UINT8	Battery Upper Charge Limit	0.5%	[0, 125]	Maximum battery SOC to stop charging process.
5	UINT8	Battery SOC Low Limit	0.5%	--	Used as a warning to trigger battery charging immediately.
6	UINT8	Battery SOC Too Low Limit	0.5%	--	
7	UINT8	Total Battery Strings	--	[1, 15]	Total nos. of battery banks (parallels)

Table 5-2: BMS_VS_BATT_DATA_MESSAGE_1

5.3 BMS_VS_BATT_DATA_MESSAGE_2

CAN ID	0x18FFC2EF				
DLC	8		Frequency	500 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0-3	UINT32	Cumulative Battery Energy Counter	1 kWh	--	Cumulative total energy stored into battery
4-5	UINT16	Cumulative Charging Counter	--	--	Cumulative number of charging counts
6	UINT8	BMS Software Version - Major Version No.	--	--	For Version 1.3, Major version=1
7	UINT8	BMS Software Version - Minor Version No.	--	--	Minor version=3

Table 5-3: BMS_VS_BATT_DATA_MESSAGE_2

5.4 BMS_VS_STATUS_MESSAGE_1

CAN ID	0x18FFC3EF				
DLC	8		Frequency	500 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0	UINT8	Battery System State of Charge(SOC)	0.50%	[0, 125]	
1	UINT8	Number of Strings Connected	--	[1, 15]	Current number of battery banks connected
2	UINT8	BMS Mode 1 = Standby Mode 2 = Charge Mode 4 = Discharge Mode	--	--	
3	UINT8	Battery System Status 1 = Self-Inspection 2 = Normal Status 4 = Balance Charging Status 8 = Limp Status 16 = Fault Status	--	--	Battery is in limp status when any of the active battery banks is disconnected.
4-5	UINT1 [Bit 0] UINT1 [Bit 1] UINT1 [Bit 2] UINT1 [Bit 3] ….. UINT1 [Bit 14] UINT1 [Bit 15]	String 1 Operation Status String 2 Operation Status String 3 Operation Status String 4 Operation Status ….. String 15 Operation Status String 16 Operation Status	--	--	0 = Disconnected 1= Connected
6	UINT8	Battery Insulation Resistance	8kOhm	[0, 2000]	
7	UINT8	Heart-beat flag (Toggling 1 and 0)	1	[0, 1]	

Table 5-4: BMS_VS_STATUS_MESSAGE_1

5.5 BMS_VS_STATUS_MESSAGE_2

CAN ID	0x18FFC4EF				
DLC	8		Frequency	500 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0-1	UINT16	Battery System Voltage	0.1V	[0, 1000]	
2-3	INT16	Battery System Current	0.1A	[-2000, 2000]	Positive = Discharging Negative = Charging
4-5	UINT16	Max Discharge Current permitted	0.1A	[0, 2000]	Computed based on the current battery configuration.
6-7	UINT16	Max Regenerative Current permitted	0.1A	[0, 2000]	Computed based on the current battery configuration.

Table 5-5: BMS_VS_STATUS_MESSAGE_2

5.6 BMS_VS_STATUS_MESSAGE_3

CAN ID	0x18FFC5EF				
DLC	8		Frequency	500 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0-1	UINT16	Current Maximum Cell Voltage	1 mV	[0, 65535]	
2-3	UINT16	Current Minimum Cell Voltage	1 mV	[0, 65535]	
4	INT8	Current Maximum Cell Temperature	1°C	[-128, 127]	
5	INT8	Current Minimum Cell Temperature	1°C	[-128, 127]	
6-7	UINT8	Reserved	--	--	

Table 5-6: BMS_VS_STATUS_MESSAGE_3

5.7 BMS_VS_CHARGER_SETPOINT_1

CAN ID	0x18FFC6EF				
DLC	8		Frequency	500 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0-1	UINT16	Maximum Charging Voltage Limit	0.1V	[0, 1000]	Limits used by DC charger to determine compatibility
2-3	UINT16	Maximum Charging Current Limit	0.1A	[0, 2000]	
4-7	UINT8	Reserved			

Table 5-7: BMS_VS_CHARGER_SETPOINT_1

5.8 BMS_VS_CHARGER_SETPOINT_2

CAN ID	0x18FFC7EF				
DLC	8		Frequency	200 ms	
Bytes	Data Type	Data Description	Resolution	Range Check	Remarks
0-1	UINT16	Charging Voltage Set-point	0.1V	[0, 1000]	BMS will always maintain charging voltage set-point as present battery voltage before receiving the **<Start Charging Session>** bit from VS.
2-3	UINT16	Charging Current Set-point	0.1A	[0, 2000]	BMS will always maintain charging current set-point as ZERO before receiving the **<Start Charging Session>** bit from VS.
4	UINT1 [Bit 0]	Battery Fault Charging Cut-Off	1	[0, 1]	Set if any battery fault occurred that should stop the charging process
	UINT1 [Bit 1]	General Battery Malfunction	1	[0, 1]	= FAILED_EVRESS Malfunction
	UINT1 [Bit 2]	Battery Temperature Inhibit Charging	1	[0, 1]	= FAILED_RESSTemperatureInhibit Battery too hot/cold to accept charge
	UINT5 [Bit 3..7]	Reserved			
5	UINT1 [Bit 0]	BMS IMD Disabled	1	[0, 1]	Set if insulation monitoring device is disabled
	UINT1 [Bit 1]	BMS Stop Charging	1	[0, 1]	Request from BMS to stop charging upon reaching Max SOC
	UINT6 [Bit 2..7]	Reserved			
6-7	UINT8	Reserved			

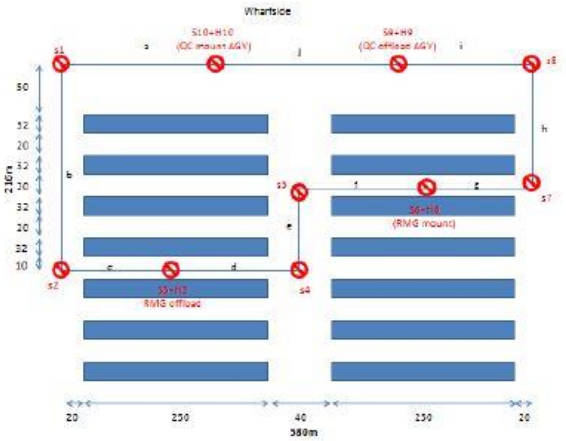
Table 5-8: BMS_VS_CHARGER_SETPOINT_2

Note: **VS shall be responsible to limit the final charging set-points based on the design limits of its charging circuit.**

Appendix 1 – Expected Operating Duty Cycle of Battery System

General Operating Duty Cycle of Battery System

Distance	Speed	Load Condition
200 m	0 m/s –> 5 m/s -> 0 m/s	Loaded
Stop 10 sec		
250 m	0 m/s –> 7 m/s -> 3 m/s	Loaded
250 m	3 m/s –> 5 m/s -> 0 m/s	Loaded
Stop 85 sec		
150 m	0 m/s –> 5 m/s -> 0 m/s	Empty
Stop 10 sec		
100 m	0 m/s –> 4 m/s -> 3 m/s	Empty
150 m	3 m/s –> 5 m/s -> 0 m/s	Empty
Stop 85 sec		
150 m	0 m/s –> 5 m/s -> 0 m/s	Loaded
Stop 10 sec		
150 m	0 m/s –> 5 m/s -> 3 m/s	Loaded
200 m	3 m/s –> 5 m/s -> 0 m/s	Loaded
Stop 20 sec		
200 m	0 m/s –> 5 m/s -> 0 m/s	Empty
Stop 20 sec		



Total Cycle Distance: 1.8 km, 24 x7, Continuous
Cycle Time: ~ 12 mins

Battery Energy Cycle for Nominal Load – 35 Tons

Peak Power Required During Acceleration — **320 KW for less than 30s per instance**
Average Energy Consumption per Trip — **7.5 KWh**

AGV Operation Cycle for 35T Load (Nominal Carrying Load)

Nominal Load: 35T

AGV Path	Distance (m)	Max speed (m/s)	Travelling Time Taken (s)			Total(s)	Average Power (KW)			Energy (KWh)		
			Accel Leg	Constant	Decel Leg		Accel Leg	Constant	Decel Leg	Accel Leg	Constant	Decel Leg
a	200	5.0	17.9	25.5	11.1	54.5	82.50	54.40	-46.50	0.45	0.43	-0.05
S1	Stop (10s)					10.0						
b	250	7.0	25.0	13.3	8.9	47.2	116.10	76.20	-92.90	0.9	0.40	-0.08
S2	Clear - 3 m/s											
c	250	5.0	7.1	35.1	11.1	53.4	132.00	54.40	-46.50	0.29	0.65	-0.05
H3	HStop (85s)					85.0						
d	150	5.0	17.9	11.9	11.1	40.9	82.50	54.40	-46.50	0.45	0.43	-0.05
S4	Stop (10s)					10.0						
e	100	4.0	14.3	12.3	2.2	28.8	66.00	43.50	-65.00	0.29	0.21	-0.01
S5	Clear - 3 m/s											
f	150	5.0	7.1	15.1	11.1	33.4	132.00	54.40	-46.50	0.29	0.31	-0.05
H6	HStop (85s)					85.0						
g	150	5.0	17.9	11.9	11.1	40.9	82.50	54.40	-46.50	0.45	0.26	-0.05
S7	Stop (10s)					10.0						
h	150	5.0	17.9	13.9	4.4	36.2	82.50	54.40	-74.30	0.45	0.29	-0.03
S8	Clear - 3 m/s											
i	200	5.0	7.1	25.1	11.1	43.4	132.00	54.40	-46.50	0.29	0.48	-0.05
H9	HStop (20s)					20.0						
j	200	5.0	17.9	21.9	11.1	50.9	40.30	24.60	-26.10	0.22	0.19	-0.03
H10	HStop (20s)					20.0						
Total	1800		150.0	182.7	93.3	669.6						

11.16 min per trip

35-Ton **Total KWh** **7.28**

Battery Energy Cycle for Empty AGV

AGV Operation Cycle for Empty

Load: Empty

AGV Path	Distance (m)	Max speed (m/s)	Travelling Time Taken (s)			Total(s)	Average Power (KW)			Energy (KWh)		
			Accel Leg	Constant	Decel Leg		Accel Leg	Constant	Decel Leg	Accel Leg	Constant	Decel Leg
a	200	5.0	17.9	25.5	11.1	54.5	40.20	24.40	-26.20	0.22	0.19	-0.03
S1	Stop (10s)					10.0						
b	250	7.0	25.0	13.3	8.9	47.2	56.70	34.20	-52.40	0.44	0.18	-0.05
S2	Clear - 3 m/s											
c	250	5.0	7.1	35.1	11.1	53.4	64.40	24.40	-26.20	0.14	0.29	-0.03
H3	HStop (85s)					85.0						
d	150	5.0	17.9	11.9	11.1	40.9	40.30	24.60	-26.10	0.22	0.12	-0.03
S4	Stop (10s)					10.0						
e	100	4.0	14.3	12.3	2.2	28.8	32.30	19.60	-36.50	0.14	0.10	-0.01
S5	Clear - 3 m/s											
f	150	5.0	7.1	15.1	11.1	33.4	64.50	24.60	-26.10	0.14	0.14	-0.03
H6	HStop (85s)					85.0						
g	150	5.0	17.9	11.9	11.1	40.9	40.20	24.40	-26.20	0.22	0.12	-0.03
S7	Stop (10s)					10.0						
h	150	5.0	17.9	13.9	4.4	36.2	40.20	24.40	-41.90	0.22	0.13	-0.02
S8	Clear - 3 m/s											
i	200	5.0	7.1	25.1	11.1	43.4	64.40	24.40	-26.20	0.14	0.22	-0.03
H9	HStop (20s)					20.0						
j	200	5.0	17.9	21.9	11.1	50.9	40.30	24.60	-26.10	0.22	0.19	-0.03
H10	HStop (20s)					20.0						
Total	1800		150.0	182.7	93.3	669.6						

11.16 min per trip

Empty Total KWh 3.49

Battery Energy Cycle for 60-Ton Loaded AGV

AGV Operation Cycle for 60T Load

Load: 60T

AGV Path	Distance (m)	Max speed (m/s)	Travelling Time Taken (s)			Total(s)	Average Power (KW)			Energy (KWh)		
			Accel Leg	Constant	Decel Leg		Accel Leg	Constant	Decel Leg	Accel Leg	Constant	Decel Leg
a	200	5.0	17.9	25.5	11.1	54.5	112.70	75.90	-60.90	0.62	0.60	-0.07
S1	Stop (10s)					10.0						
b	250	7.0	25.0	13.3	8.9	47.2	158.50	106.20	-121.90	1.22	0.55	-0.11
S2	Clear - 3 m/s											
c	250	5.0	7.1	35.1	11.1	53.4	180.20	75.90	-60.90	0.4	0.91	-0.07
H3	HStop (85s)					85.0						
d	150	5.0	17.9	11.9	11.1	40.9	112.70	75.90	-60.90	0.62	0.36	-0.07
S4	Stop (10s)					10.0						
e	100	4.0	14.3	12.3	2.2	28.8	90.10	60.70	-85.30	0.4	0.30	-0.02
S5	Clear - 3 m/s											
f	150	5.0	7.1	15.1	11.1	33.4	180.20	75.90	-60.90	0.4	0.91	-0.07
H6	HStop (85s)					85.0						
g	150	5.0	17.9	11.9	11.1	40.9	112.70	75.90	-60.90	0.62	0.36	-0.07
S7	Stop (10s)					10.0						
h	150	5.0	17.9	13.9	4.4	36.2	112.70	75.90	-97.50	0.62	0.41	-0.04
S8	Clear - 3 m/s											
i	200	5.0	7.1	25.1	11.1	43.4	180.20	75.90	-60.90	0.4	0.67	-0.07
H9	HStop (20s)					20.0						
j	200	5.0	17.9	21.9	11.1	50.9	40.30	24.60	-26.10	0.22	0.19	-0.03
H10	HStop (20s)					20.0						
Total	1800		150.0	182.7	93.3	669.6						

11.16 min per trip

60-Ton Total KWh 10.16

Appendix 2: Battery System Alarm Information Table (To be filled Up by Vendor)

No.	Item	Alarm Level	Alarm Threshold	Reset Value/ Reset Method	Alarm Trigger Filter Value (s)	Alarm Reset Filter Value (s)	Action	PSA Alarm Categorisation	PSA Bypass to be Defined
1	Cell Over-Voltage Level 1	II	> 0.00 V	< 0.00V	0s	0s	Max. Regenerative current allowed decrease to 80%	Warning	
2	Cell Over-Voltage Level 2	III	> 0.00 V	< 0.00V	0s	0s	Max. Regenerative current allowed decrease to 50%	Critical	Bypass Battery System Critical
3	Cell Over-Voltage Level 3	IV	> 0.00 V	Faulty battery string disconnected	0s	-	Max. Regenerative current allowed decrease to 0. BMS auto cut-off faulty battery string and then recover regenerative current.	E-Critical	Bypass Battery System to Limp Mode
4	Cell Under-Voltage Level 1	II	< 0.00V	> 0.00V	0s	0s	Max. discharge current allowed decrease to 80%	Warning	
5	Cell Under-Voltage Level 2	III	< 0.00V	> 0.00V	0s	0s	Max. discharge current allowed decrease to 50%	Critical	Bypass Battery System Critical
6	Cell Under-Voltage Level 3	IV	< 0.00V	Faulty battery string disconnected	0s	-	Max. discharge current allowed decrease to 0. BMS auto cut-off faulty battery string, and then recover discharge current.	E-Critical	Bypass Battery System to Limp Mode
7	Battery System Over Voltage Fault	III	Average cell voltage > 2.75V	< 0.00V	0s	0s	Max. Regenerative current allowed decrease to 50%	Critical	Bypass Battery System Critical
8	Battery System Under Voltage Fault	III	Average cell voltage < 1.80V	> 0.00V	0s	0s	Max. discharge current allowed decrease to 50%	Critical	Bypass Battery System Critical
9	Over Temperature Level 1	II	> 00℃	< 00℃	0s	0s	Max. Regenerative /discharge current allowed decrease to 80%	Warning	
10	Over Temperature Level 2	III	> 00℃	< 00℃	0s	0s	Max. Regenerative /discharge current allowed decrease to 50%	Critical	Bypass Battery System Critical
11	Over Temperature Level 3	IV	> 00℃	Faulty battery string disconnected	0s	-	Max. Regenerative /discharge current allowed decrease to 0. BMS auto cut-off faulty battery string and then recover regenerative/discharge current.	E-Critical	Bypass Battery System to Limp Mode
12	Ultra-High Temperature Fault	V	> 00℃	Re-power	0s	-	Max. Regenerative /discharge current allowed decrease to 0. Cut off battery system relay after 5s.	E-Critical	Set Battery System to Fault Status. Cannot be bypassed.
13	Cell Voltage Imbalance Warning	I	> 000mV	< 000mV	0s	0s	Alarm without action	Warning	
14	Temperature Imbalance Warning	I	> 00℃	< 00℃	0s	0s	Alarm without action	Warning	
15	Discharge Over-Current fault	II	Greater than 1.2 times of limited discharge current	Lower than this value	0s	0s	Max. discharge current allowed decrease to 80%	Warning	
16	Charge Over-Current fault	II	Greater than 1.2 times of limited regenerative current	Lower than this value	0s	0s	Max. Regenerative current allowed decrease to 80%	Warning	
17	Internal CAN Network Communication Fault	IV	Any frame loss	Faulty battery string disconnected	0s	-	Max. Regenerative /discharge current allowed decrease to 0. BMS auto cut-off faulty battery string and then recover regenerative/discharge current.	E-Critical	Bypass Battery System to Limp Mode

No.	Item	Alarm Level	Alarm Threshold	Reset Value/ Reset Method	Alarm Trigger Filter Value (s)	Alarm Reset Filter Value (s)	Action	PSA Alarm Categorisation	PSA Bypass to be Defined
18	Middle CAN Network Communication Fault	IV	Any frame loss	Faulty battery string disconnected	00s	-	Max. Regenerative /discharge current allowed decrease to 0. BMS auto cut-off faulty battery string and then recover regenerative/discharge current.	E-Critical	Bypass Battery System to Limp Mode
19	External CAN Network Communication Fault	V	Any frame loss	Re-power	2s	-	Max. Regenerative /discharge current allowed decrease to 0. If vehicle doesn't respond, BMS will cut off battery system relay when DC current < 50A. Otherwise, if there are alarm level IV, V, BMS will cut off relay right now.	E-Critical	Set Battery System to Fault Status. Cannot be bypassed.
20	Low Insulation Warning	I	< 000KΩ	> 000 KΩ	00s	00s	Alarm without action	Warning	
21	Low Insulation Fault	V	< 000KΩ	Re-power	00s		Max. Regenerative /discharge current allowed decrease to 0. Cut off relay after 5s.	E-Critical	Set Battery System to Fault Status. Cannot be bypassed.
22	Insulation Measurement Device (IMD) Fault	I	Loss comms with IMD				Alarm without action	Warning	
23	Pre-charge Failure	V	?	Re-power	-	-	Max. Regenerative /discharge current allowed decrease to 0. No powering on high voltage.	E-Critical	Set Battery System to Fault Status. Cannot be bypassed.
24	Electrical Circuit Breaker Fault	IV	?	Faulty battery string disconnected	-	-	Max. Regenerative /discharge current allowed decrease to 0 and BMS auto cut-off faulty battery string， then recover regenerative/discharge current.	E-Critical	Bypass Battery System to Limp Mode
25	Battery System Relay Adhesion fault	V	?	Re-power	-	-	Max. Regenerative /discharge current allowed decrease to 0. No powering on high voltage.	E-Critical	Set Battery System to Fault Status. Cannot be bypassed.
26	Battery String Relay Adhesion fault	IV	?	Faulty battery string disconnected	-	-	Max. Regenerative /discharge current allowed decrease to 0. BMS auto cut-off faulty battery string and then recover regenerative/discharge current.	E-Critical	Bypass Battery System to Limp Mode
27	Battery System in Limp State	IV	Not all strings are connected				Battery is in Limp Mode.	E-Critical	Bypass Battery System to Limp Mode
28	SOC Low Alarm	I	< 00%	> 00%	00s	0s	Alarm without action	Warning	
29	SOC Too Low Critical	II	< 00%	> 00%	00s	0s	Max. discharge current allowed decrease to 80%	Critical	Bypass Battery SOC Too Low
30	SOC Too Low Cut-off	III	< 00%	> 00%	00S	0s	Max. discharge current allowed decrease to 50%	Critical	Cannot be bypassed
31	Cooling System Fault Warning	I	To be classified according to different cooling system				Alarm without action	Warning	
32	Cooling System Fault Critical	III	To be classified according to different cooling system				Max. Regenerative /discharge current allowed decrease to 50%	Critical	Bypass Battery System Critical
33	Cooling System Fault E-Critical	V	To be classified according to different cooling system				Max. Regenerative /discharge current allowed decrease to 0%. Not Bypass-able.	E-Critical	Set Battery System to Fault Status. Cannot be bypassed.