GILLIG

HIGH VOLTAGE SAFETY TRAINING FOR BATTERY ELECTRIC BUS

Class Objective

After completion of the GILLIG Battery Electric Bus Safety and Familiarization program, each mechanic will be familiar with the system component identification, location and operation. We will also cover electrical accessory systems and their operation. Safety precautions and troubleshooting will also be discussed.

Class SOP's

- Break times
- Lunch time
- End of class
- Questions are encouraged
- Handouts are provided, but please take notes!

SAFETY

- Practice general safety procedures.
- Always wear safety glasses and proper PPE equipment.
- Use high voltage test equipment properly.
- Use care when working with high voltage components.
- Care should be used dealing with electricity, as shocks can occur.
- High voltage safety will be covered in detail later in the class.

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HV Safety Training Note

To safely work on the Gillig Battery Electric Bus technicians must be both **Authorized** and **Qualified** to perform said work.

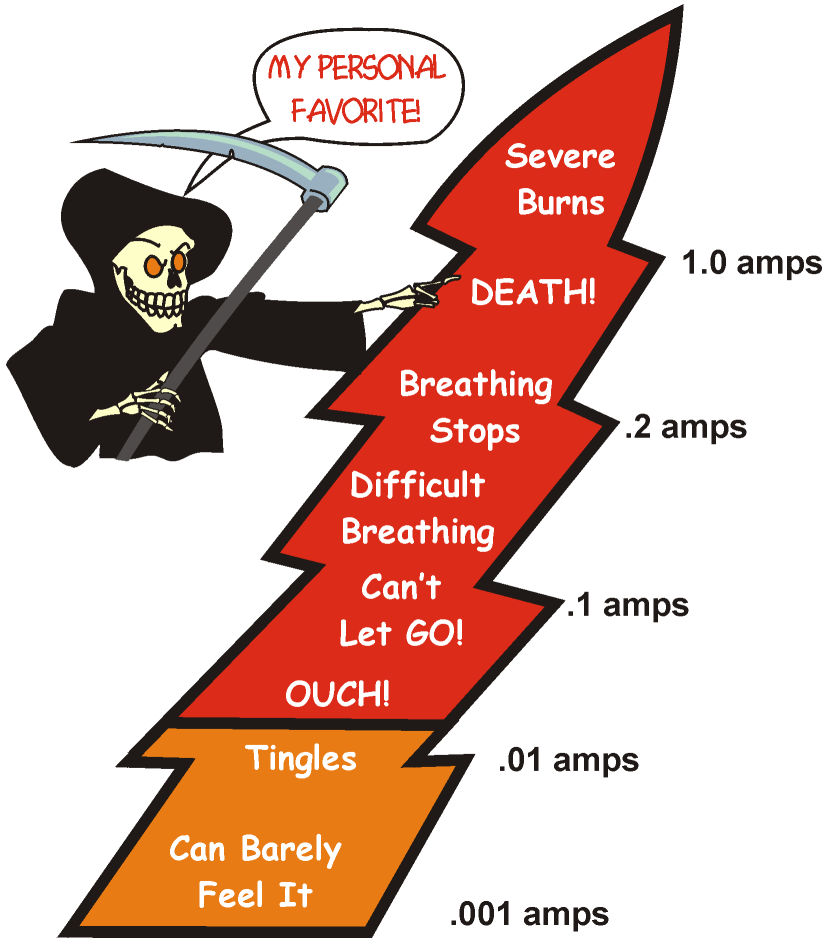
Upon completion of Gillig BEB training the technician will be **Trained** in the Gillig safety procedures for the lock out/tag out of both the Low Voltage and High Voltage electrical systems.

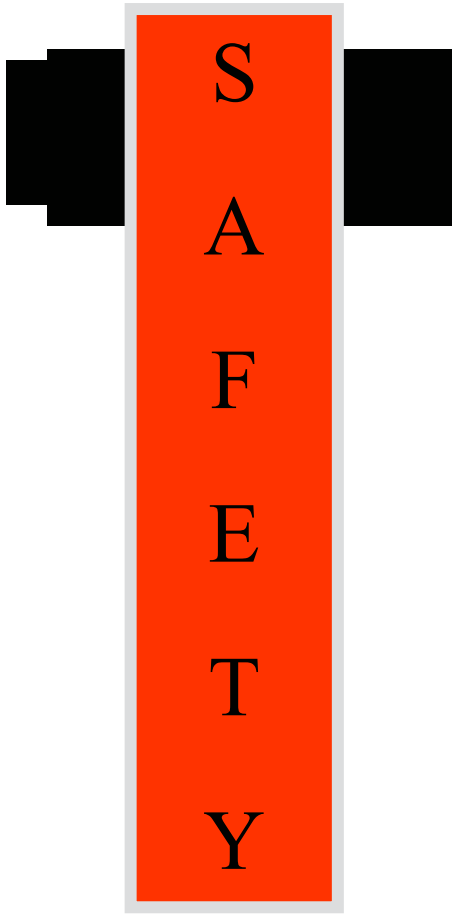
For the technician to be **Authorized** and Q**ualified** to perform the work requires training from the technician's employer.

This training includes training in NFPA 70e, Arc flash and Fall protection.

Please receive this training prior to working on the HV electrical system of the BEB

Safety


MY PERSONAL FAVORITE!
Severe Burns
1.0 amps
DEATH!
Breathing Stops
.2 amps
Difficult Breathing
Can't Let GO!
.1 amps
OUCH!
Tingles
.01 amps
Can Barely Feel It
.001 amps


S
A
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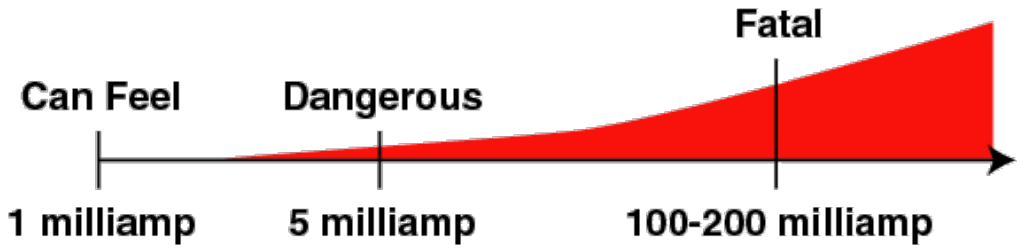
Ebus High Voltage

- Amount of Current Passing Through Bodies Varies
  - Body resistance varies from 1000 to 500,000 ohms
  - Resistance lowers when skin is moist or damaged (cut, broken, burned)

- 5 Milliamps Under the Right Conditions Can Be Dangerous
  - 100-200 milliamps can be fatal
  - Ebus can operate up to 750 volts and 350 amps



High Voltage Electric Vehicle Safety

- This is a fully electric vehicle which operates at or above 700 volts DC.
  - Therefore, **ONLY** trained and qualified personnel can service the internals of the components.
    - NFPA70E and this training are required in order to be authorized to service this electric vehicle
    - Cummins Technical Training Department needs to be involved in all technician training prior to being allowed to work on the unit internal parts of the components
- Ensure proper lockout-tagout is performed on the vehicle during every service event
- The high voltage battery will not be serviceable in the field
  - If a battery failure is found, the entire high voltage battery pack will be replaced or it will be repaired by a factory Cummins technician
- PPE required
  - Class 0 Insulated gloves
    - Gloves should be replaced 6 months after manufactured date printed on the gloves
    - Leather glove protectors
  - Safety glasses
  - Long sleeve natural fiber clothing
  - Emergency Safety hook

NOTE: Check the integrity of gloves by inflating and rolling them up toward the fingers to see if they hold air. If they do not, throw the gloves away and buy new gloves. Also visually inspect the gloves by stretching it to make sure there are no cracks or tears. Ensure gloves are not expired.

In addition, a minimum of 2 individuals are required to be present while working on the EV system. One works on the system and the other observes and is prepared to respond in case of emergency.

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High Voltage & LOTO Safety Training for GILLIG's Battery Electric Bus

Before attempting any assembly or disassembly of the high voltage system components you must take the required supplementary classes listed below:

- Arc Flash
- Lockout/Tagout
- Fall Protection

Special tools will also be required to work on the high voltage system and these tools must "always" be used to ensure your safety.

Safety Labeling and Terminology

High voltage shock warning labeling

- Arc Flash
- Warning / Caution
- Dangerous / Deadly
- Reference existing electric bus user's manual for labels.

Definitions

- Kissling LV Automatic Disconnect – Low Voltage Automatic Disconnect – the new version of the “Knife” switch.
- BEBDT – Battery Electric Bus Drive Train
- BMS – Battery Management System
- ESS – Energy Storage System
- EVSE – Electric Vehicle Supply Equipment – the infrastructure side charger
- LOTO – Lockout/Tagout
- LV – Low Voltage (less than 50 V AC or DC, or typically 12/24V DC)
- HV – High Voltage (greater than 50 V AC or DC)
- HV AC – High Voltage Alternating Current (not to be confused with HVAC – Heating, Ventilation, and Air Conditioning)
- HV DC – High Voltage Direct Current
- HVIL – Hazardous or High Voltage Interlock Loop
- MSD – Manual Service Disconnect
- SCM – System Control Module
- VAC – Volts Alternating Current
- VDC – Volts Direct Current
- HVJB – High Voltage Junction Box
- MPIL—Measurement Port Interlock Loop

Relevant Standards

- NFPA National Fire Protection Agency Part 70E (National Electric Code)
  - Article 480 – Storage Batteries
  - Article 490 – Equipment, over 600V, Nominal
  - Article 625 – Electric Vehicle Charging Systems

- SAE J2910_2014 – Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety
- OSHA CFR 1910.147 Lockout/Tagout – The Control of Hazardous Energy
- Cal-OSHA Title 8 Regulations

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Emergency Shutdown Procedure

In an emergency, first responders can perform a rapid high voltage shutdown by either turning the HV Disconnect to OFF or the LV disconnect to OFF. The HV disconnect is the preferred Emergency Shutdown Switch, as it provides the highest levels of safety and redundancy. Nevertheless, the LV disconnect can safely be used as an Emergency Shutdown Switch.

Be aware that using the HV Disconnect may result in high voltage system fault codes and errors. You may be required to clear these codes and errors before resuming normal vehicle operation.

CAUTION: Follow the regular LOTO procedures when not an emergency.

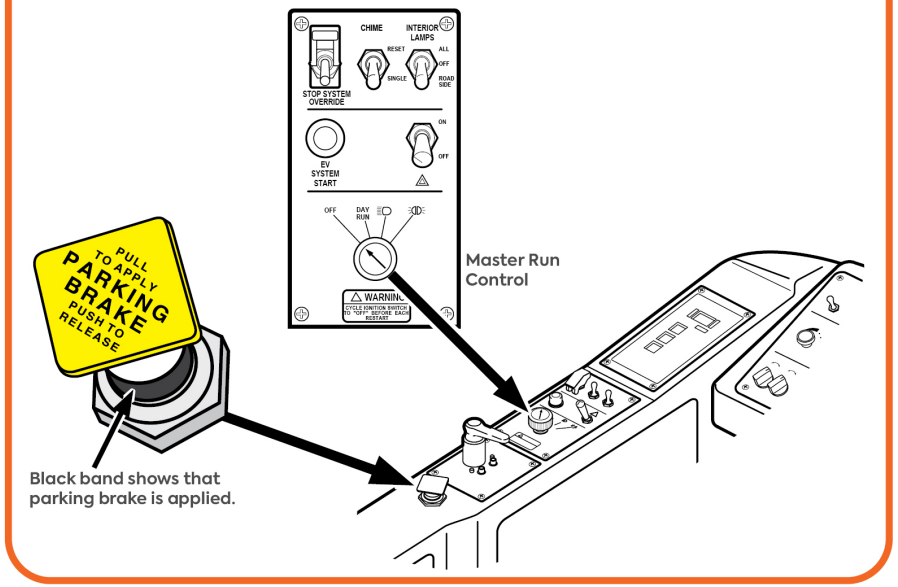
EMERGENCY MANUAL SHUTDOWN

FOR GILLIG BATTERY ELECTRIC BUS

1

Set the parking brake and then **turn the master run control to "OFF" position.**

NOTE: Proceed to Step 2 even if Step 1 cannot be completed.

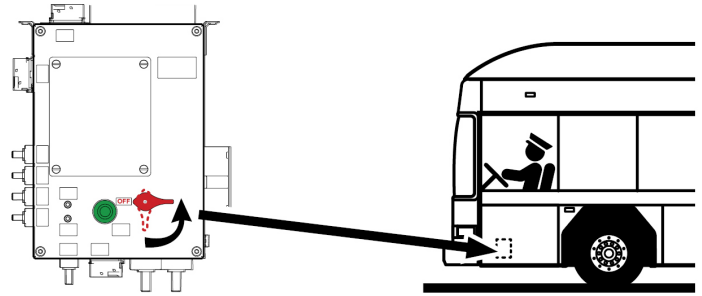


2A OR 2B

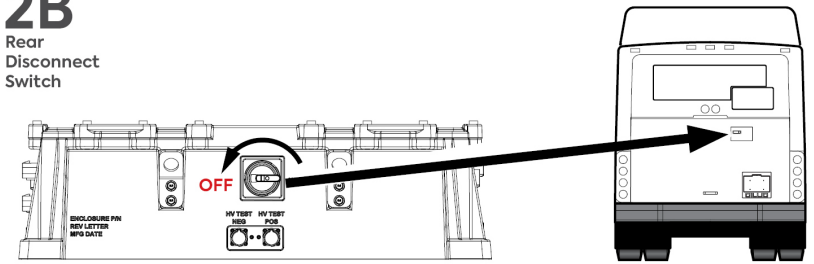
Rotate **front disconnect switch** to **"OFF"** position **(Front of Bus)**

Rotate **rear disconnect switch** to **"OFF"** position **(Rear of Bus)**

2A
Front Disconnect Switch



2B
Rear Disconnect Switch



3

Inform emergency personnel of the onboard high-voltage components

(See the reverse side of this card)

4

Wait ten minutes after shutdown before accessing high-voltage components

(This is a mandatory safety discharge period)

System Manufacturer: **Cummins**
Model: **BES CM 2450 EV101B**
Emergency Call: **1.800.CUMMINS (1.800.286.6467)**

81-EMERG-ELE3

PRECAUTIONS
FOR GILLIG BATTERY ELECTRIC BUS

BATTERY WARNING

- Lithium ion batteries contain flammable liquid electrolyte that may vent, ignite, and produce sparks when subjected to temperatures higher than **150°C (302°F)** when damaged.
- Do **NOT** step on top of batteries
- Burning cells can ignite other batteries in close proximity.
- The interaction of water or water vapor and exposed lithium hexfluorophosphate (Li PF6) may result in the generation of hydrogen and hydrogen fluoride (HF) gas.
- Contact with battery electrolyte may be irritating to skin, eyes, and mucous membranes.
- Fire will produce irritating, corrosive, and/or toxic gases.
- Fumes may cause dizziness or suffocation.

FIRE WARNING

In case of fire:

- Wear a positive pressure self-contained breathing apparatus (SCBA); structural firefighting clothing is required.
- Extinguish fires using an **ABC extinguisher**
- Do **NOT** use a Class D extinguisher.

PROTECTIVE EQUIPMENT

If working near high-voltage cabling or components, use **1,000 VDC, Class 00** electrical gloves, rubber-soled shoes, and make sure you and the environment are perfectly dry.

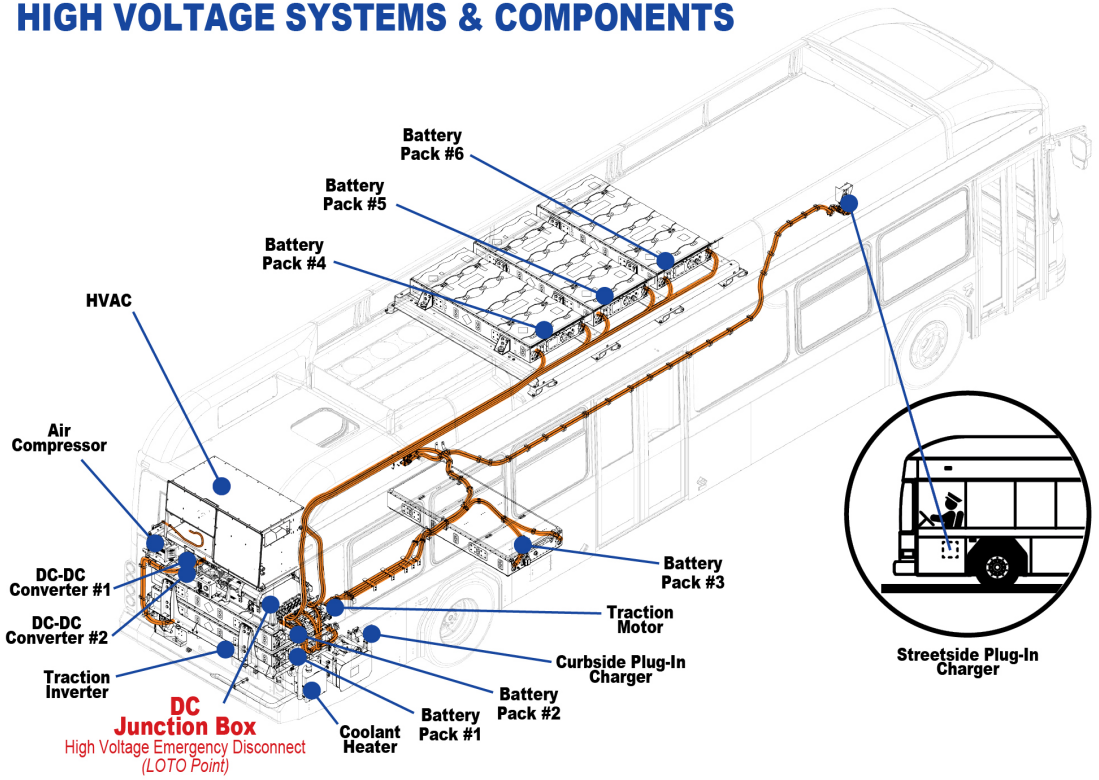
HIGH-VOLTAGE WARNING

Operating voltage of the Cummins electric drive system is **750 VOLTS!** HVIL (high-voltage interlock loop) systems protect all circuits and components, but it is still possible to receive a fatal electric shock from the high-voltage system.

Avoid cutting and handling orange high-voltage cables and components, as this could result in severe injury or death!

See the reverse of this card for system shutdown information.

HIGH VOLTAGE SYSTEMS & COMPONENTS



System Manufacturer: **Cummins**
Model: **BES CM 2450 EV101B**
Emergency Call: **1.800.CUMMINS (1.800.286.6467)**

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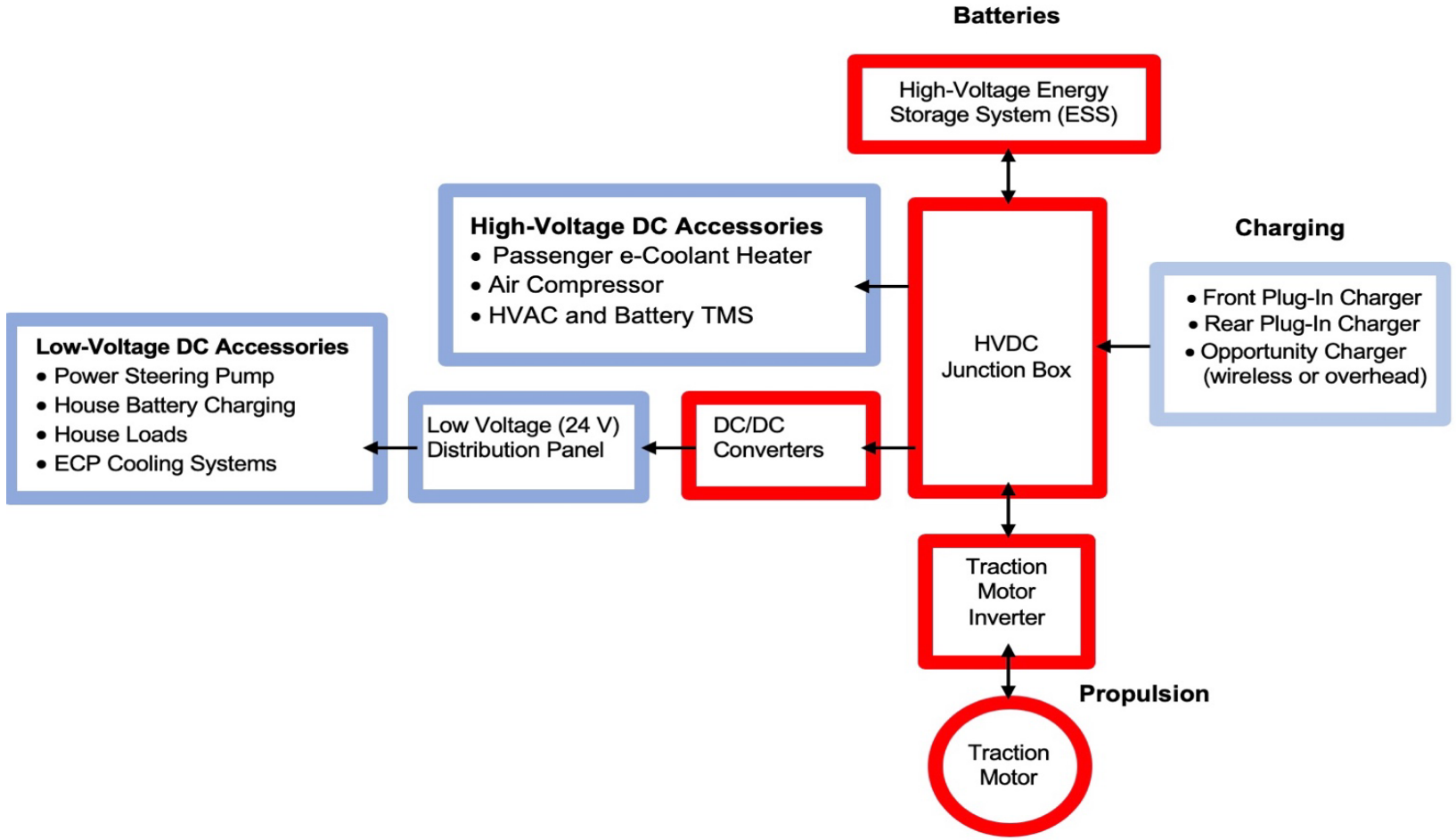
GILLIG's Battery Electric Bus High Voltage & Accessories Architecture

Description of the high voltage components and system design

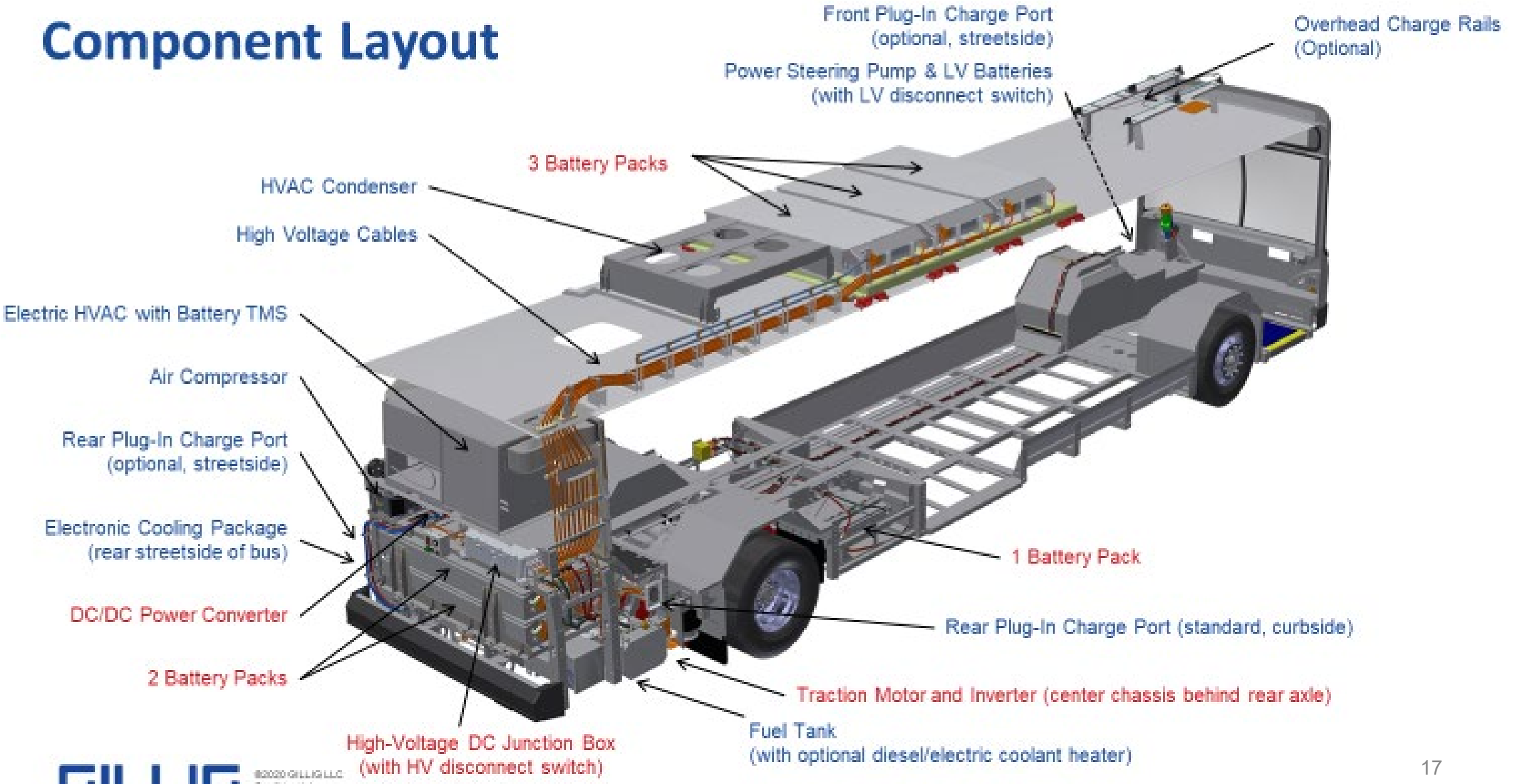
Red components are supplied by Cummins.

Blue components are supplied by GILLIG.

The Cummins Electric Powertrain operates at up to 750 VDC.

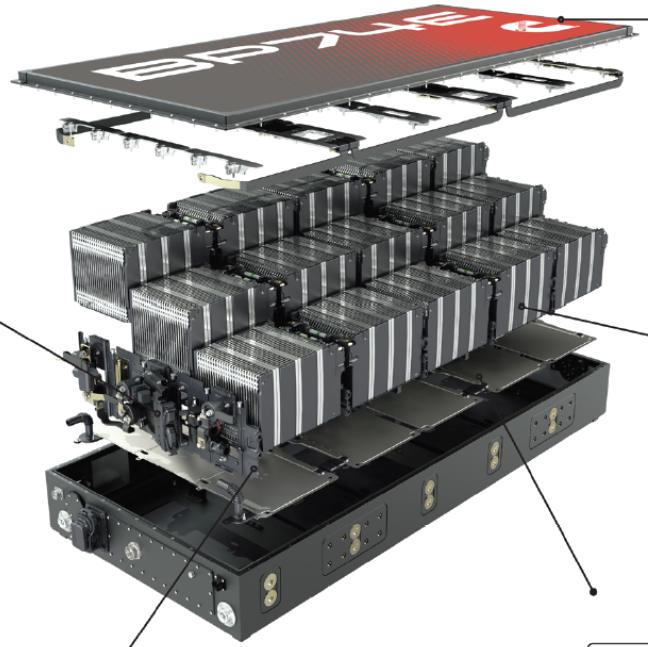


Component Layout



Component Overview

High Voltage Battery Pack



Lightweight Enclosure

Cummins' super light weight case uses composite materials to maximise energy density and increase durability.

Proprietary BMS

Cummins' proprietary BMS is the brains of the pack. It ensures safety by continuously monitoring and controlling key parameters, as and when required.

Flexible Modules

Flexible, energy dense modules make it easy to scale battery packs against specific vehicle applications.

Temperature Control

The battery thermal management system targets 68°F +/- 6°F to maintain isothermal performance of the battery.

Cross-flow Cooling

Using a modular, cross flow approach to liquid cooling, cells can be maintained at an optimum temperature range during vehicle operation to help prolong the life of the battery.

Nominal voltage	650 V
Battery chemistry (electrolyte)	Lithium ion
Cooling	Water and Ethylene glycol (50:50)
Capacity	74 kWh

High Voltage Battery Information

- Pack contains 360 individual cells
- Controllers

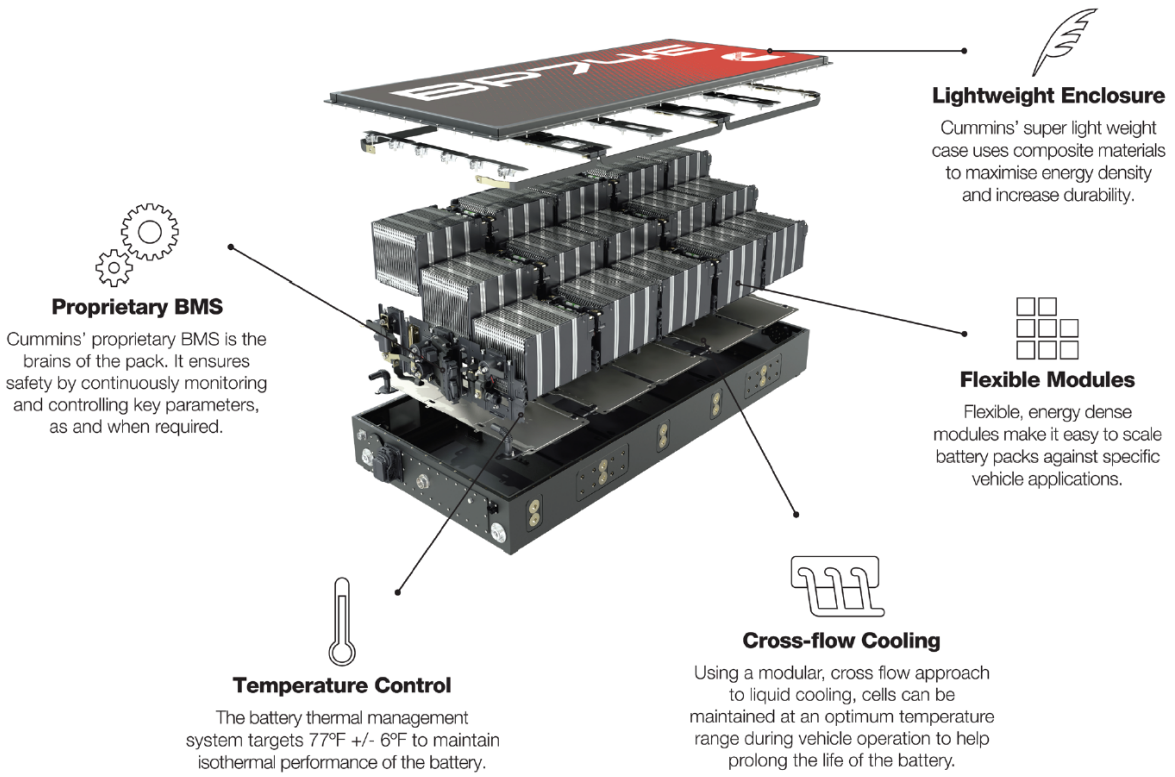
There are 16 controllers in each battery pack

15 battery module units (BMU's)

1 pack management unit (PMU)

- Then a supervisory controller that controls all battery packs that is called the Battery Management Controller (BMC)
- These controllers need 24 volts (power, ground, and ignition) to operate

Any voltage much lower than 24 volts may cause a controller to not wake up



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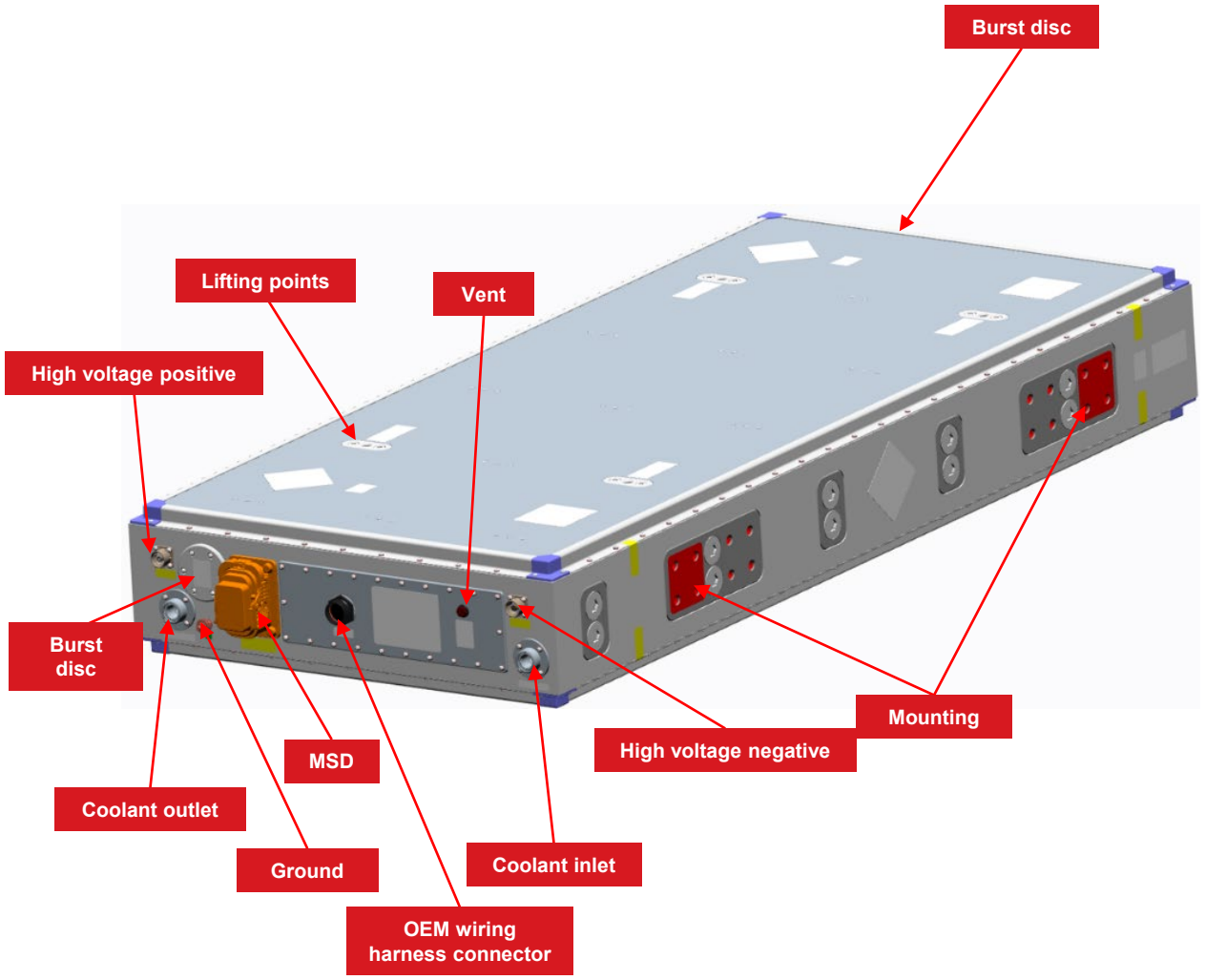
Lithium-Ion Battery (ESS)

- The Lithium-Ion Battery is the power source for the Battery Electric Bus Drive Train (BEBDT) on the e-Bus
- Nickel Manganese Cobalt is the specific subtype of Lithium-Ion battery used.
- These batteries output very high voltages (600-750 VDC) and are therefore potentially very dangerous if not properly handled.
- Usable capacity of the battery is approximately 80% of rated capacity.
- The battery packs are liquid cooled by the BTMS. The liquid cooling system is also used in cold conditions to warm the batteries up for use.

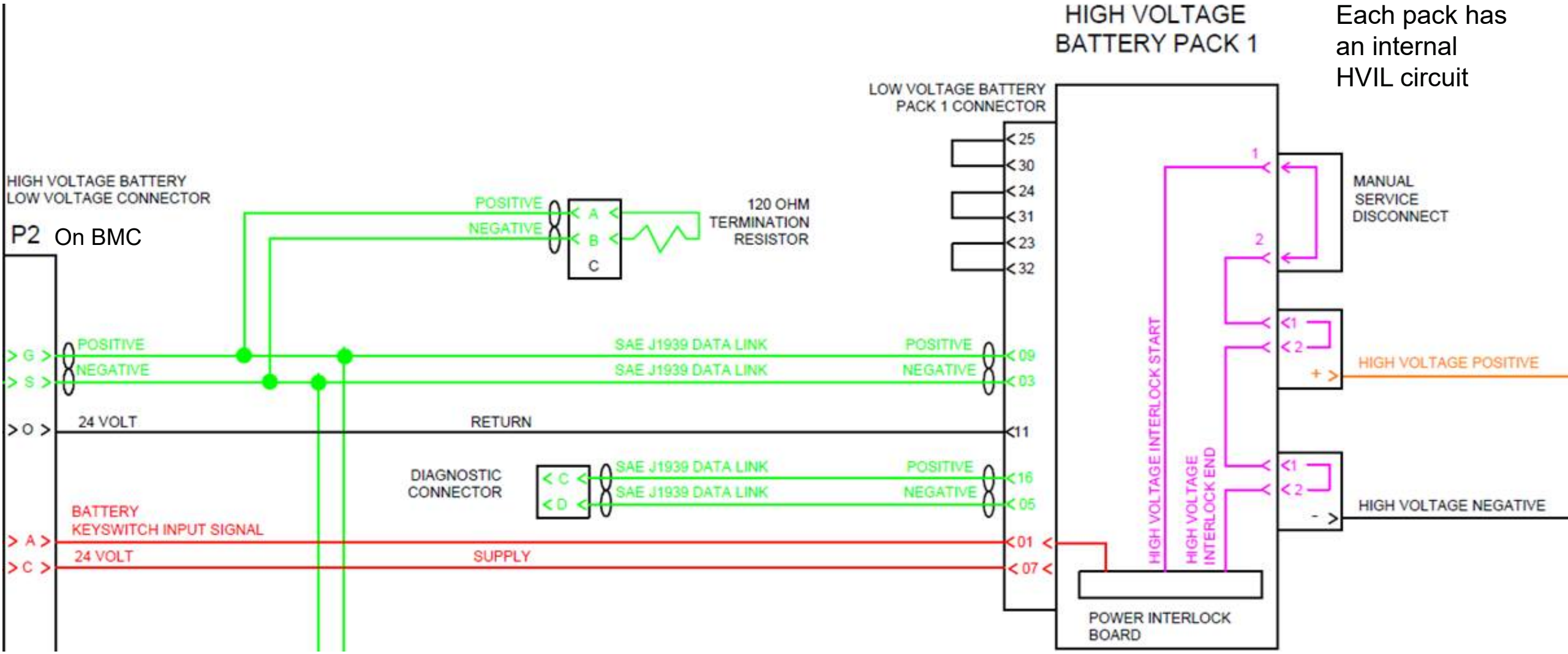
High Voltage Battery Pack (ESS)



Description:

- Location: On the roof, rear of the bus, and in front of the rear axle
- Multiple HV battery packs on the bus
- Weight: 536 kg [1181.68 lb.]/ea
- The High voltage battery stores chemical energy which is used to power all devices.
- Serviceable parts
  - MSD
- Service tools
  - Battery lifting tool

Battery Pack Pin Out



Each pack has an internal HVIL circuit

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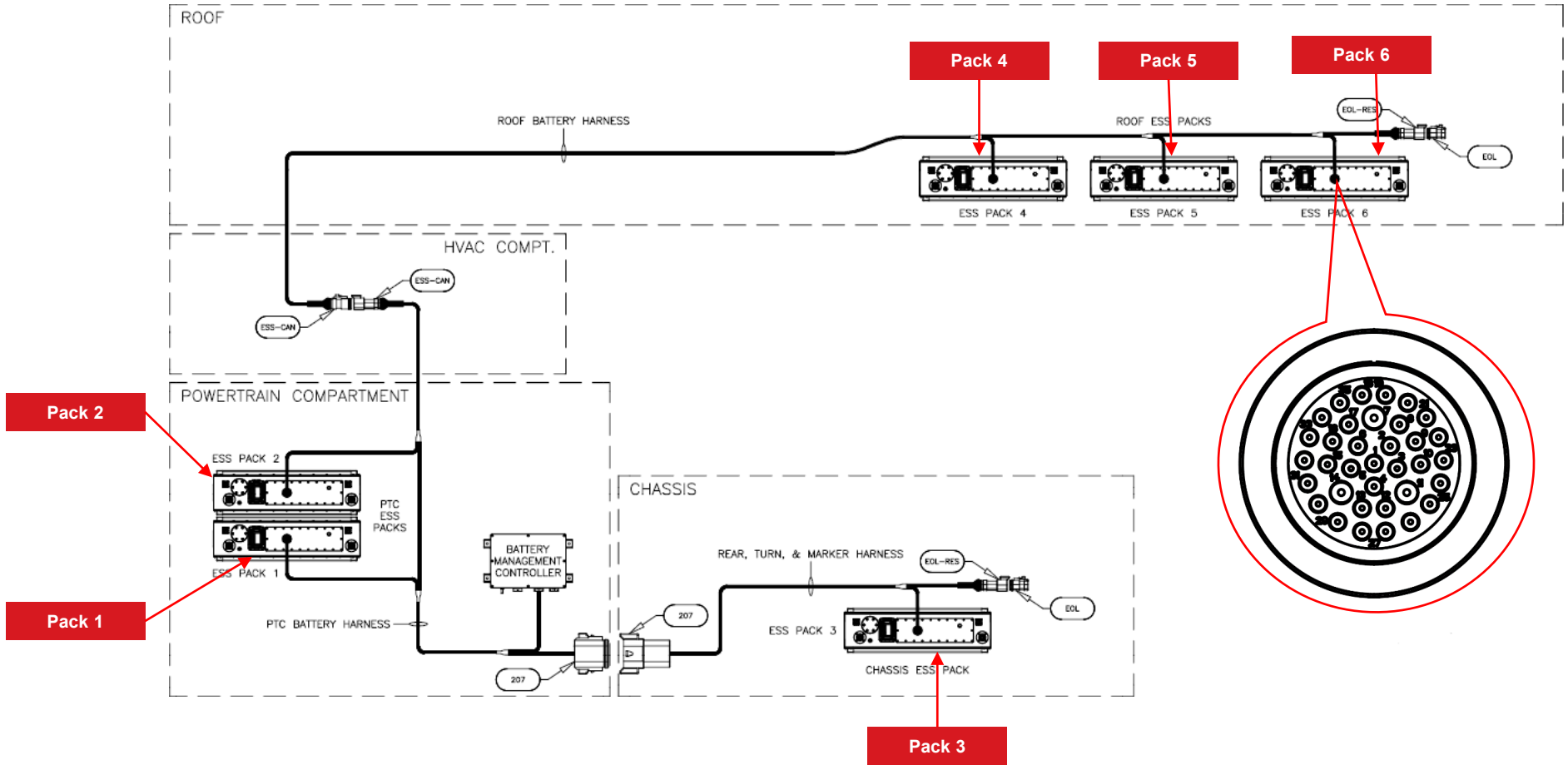
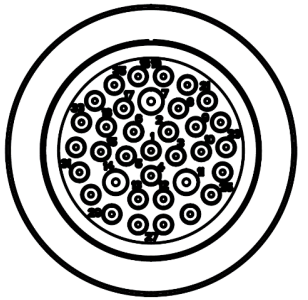
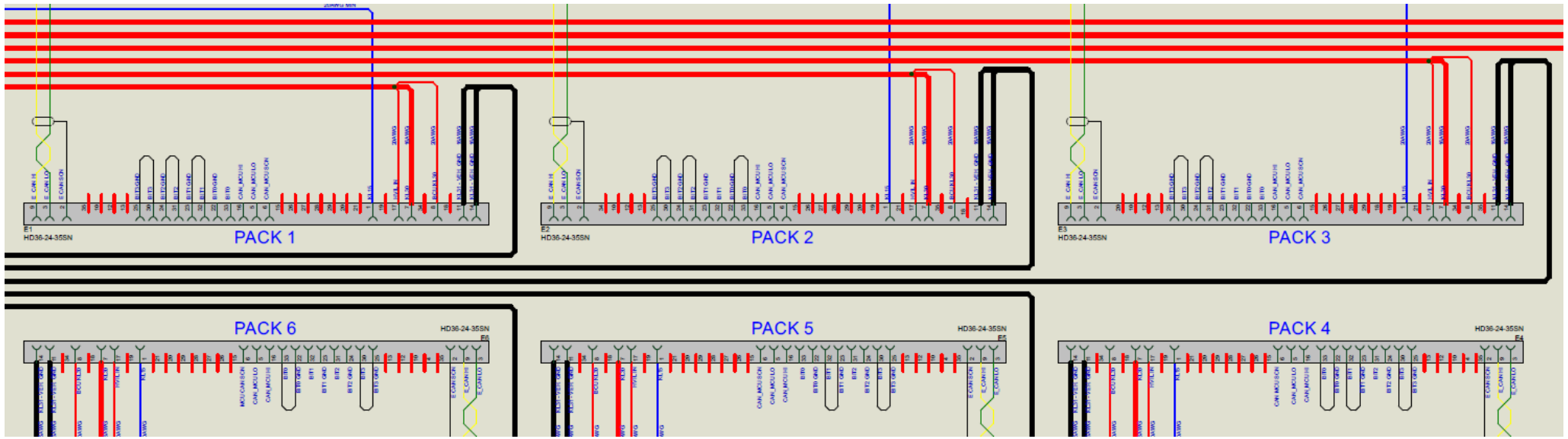
High Voltage Battery Packs CAN



High Voltage Battery Pack ID



Battery Pack (ESS) Pack ID Adress Configuration



PACK 1			PACK 2			PACK 3			PACK 4			PACK 5			PACK 6		
33		22	33		22	33		22	33		22	33		22	33		22
32		23	32		23	32		23	32		23	32		23	32		23
31		24	31		24	31		24	31		24	31		24	31		24
30		25	30		25	30		25	30		25	30		25	30		25

High Voltage Battery Pack

High voltage battery location identification

- Each high voltage battery has a unique serial number which is used for identification
- All packs are the same part number
- Each pack has 16 controllers
- Each Battery connector is keyed differently
  - Pins on the harness connector are shorted together for location identification
- PMU will read the serial number of each battery pack and send these S/Ns via CAN to the Cummins Private CAN network
- BMC identifies battery location by the keyed connectors on the battery
- Electronic service tool needed for recalibration

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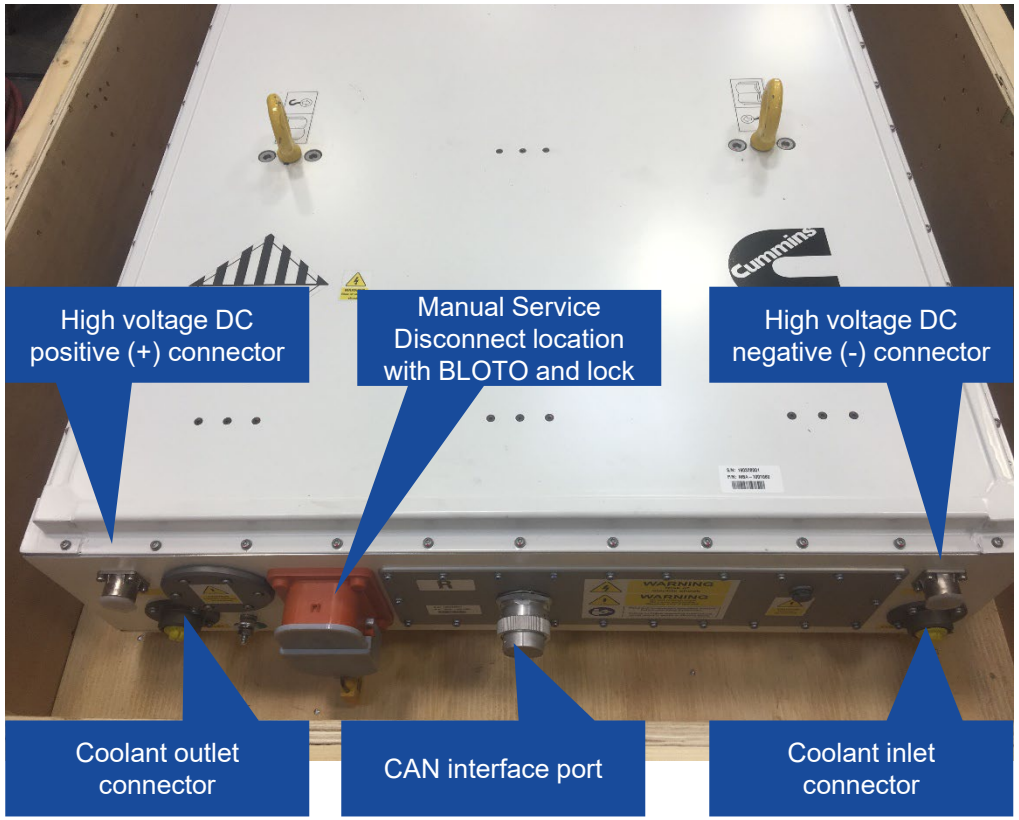
Lithium Ion Battery Handing Procedure

Battery High Voltage Safety Design

There are two contactors inside each ESS battery pack, one for the positive high voltage output and one for the negative high voltage output. Both of these contactors must turn on for high voltage to be available outside the battery pack.

The picture identifies these connectors as they should all be avoided when handling the batteries unless you are doing an assembly or disassembly operations that requires that you to be exposed to them.



Lithium Ion Battery Handing Procedure

<u>Do not step on battery</u> or place tools on top of the battery at any time.

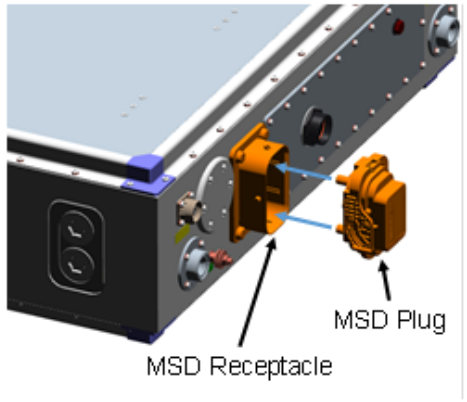
Lithium Ion Battery Handing Procedure

Battery Storage:

The following guidelines have been provided by Cummins (battery manufacturer), **for full battery handling details, refer the Cummins BP74E Lithium, Ion Cell Safety Data Sheet:**

- ✓ Do not crush, puncture, incinerate, immerse in water or heat over 125 degrees F.
- ✓ Do not attempt to remove the battery casing.
- ✓ This battery contains flammable electrolyte. Incorrect use may cause heat generation or electrolyte leakage.
- ✓ **Evacuate area if smoke or fire is present, IMMEDIATELY REPORT IT**
- ✓ Store in a cool, dry place. Store at room temperature for best results. Keep away from heat, sparks and flames. Keep below 60 degree C. Keep above -30 degree C. Charge between – 30 degree C and 45 degree C. Use only approved charging equipment. Do not disassemble cell. Do not puncture, crush or dispose of in fire.
- ✓ Do not open crate unless doing incoming inspection or battery installation on bus chassis or roof

Manual Service Disconnect (MSD)



Description:

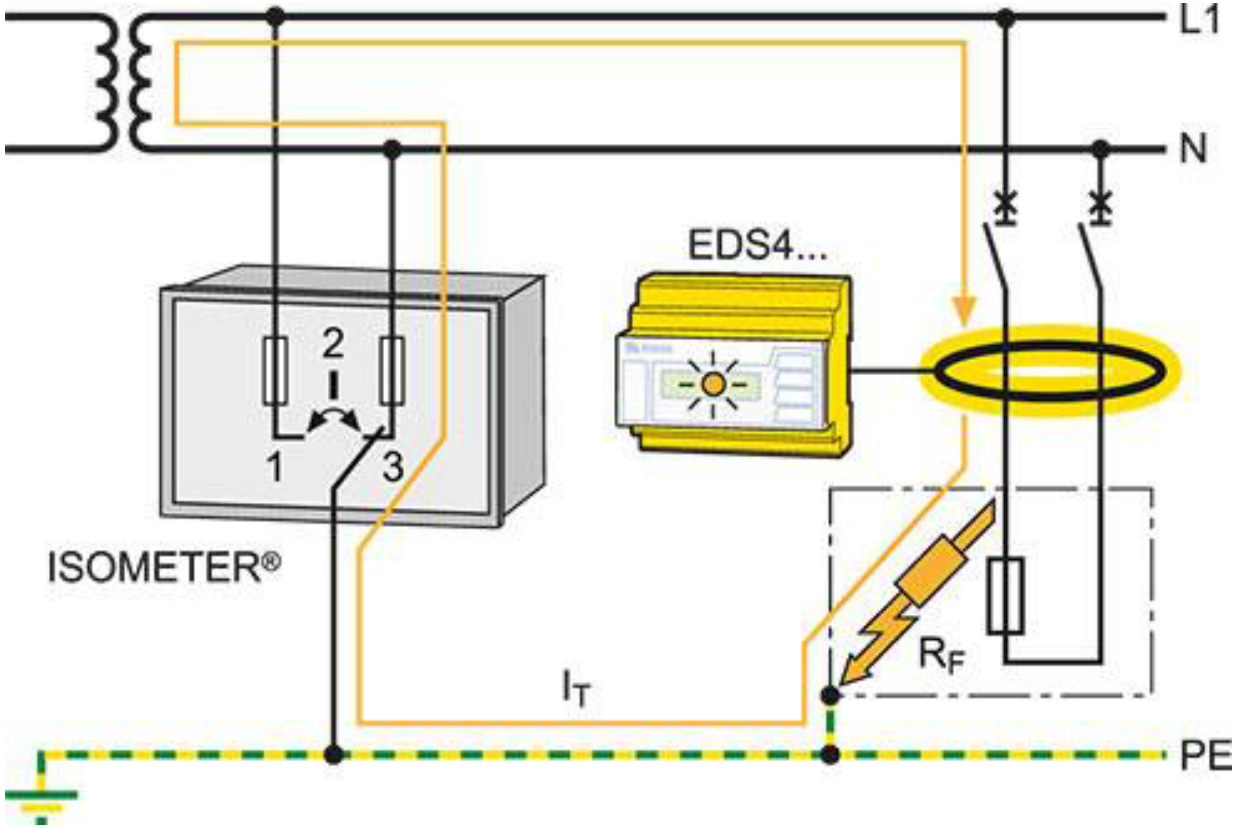
- Location: On the High voltage battery pack
- The MSD provides a safe, reliable solution to manually disconnect the HV battery system
- Large terminals of the MSD breaks the connection between the contactor and the HV ESS positive cable connection
- Small terminals are part of internal ESS HVIL
- MSD Lockout tool (bloto) should be used to lockout the MSD receptacle
- Before removing the MSD, make sure low voltage is shut-off and locked out.
- To remove the MSD, use the following:
  - Hold down the MSD lever to release the receptacle locking feature
  - Rotate the MSD lever back by 90
  - Disconnect the MSD from the receptacle pins
  - Remove the MSD and store in a safe place

What Is High Voltage Isolation Safety

- Essential for high voltage safety
- Two isometers are inside the ESS battery
- One detects potential between high voltage (positive and negative) cables/components and ground when contactors close.
  Second Isometer detects battery isolation faults internally when contactors are open
- Any potential triggers a fault which then ESS opens contactors.
- If isolation fault is triggered, a “high voltage exposure” on the dash display will be illuminated

Voltage Isolation Diagnostics

- Monitored by the BMS, Isolation faults are triggered at system level.
- If isolation falls below 500 Ohms/V, the “high voltage exposure” light will be illuminated, and the drive system will be disabled and high voltage will be disconnected once the vehicle is brought to a stop.
- In addition, the high voltage system will be de-energized and discharged to less than 60 VDC within 2 minutes of an event which disconnects a high voltage connection.
- Refer to troubleshooting tree for proper troubleshooting procedures



Bus Doors Interlocks

Function Of Proximity Sensors:

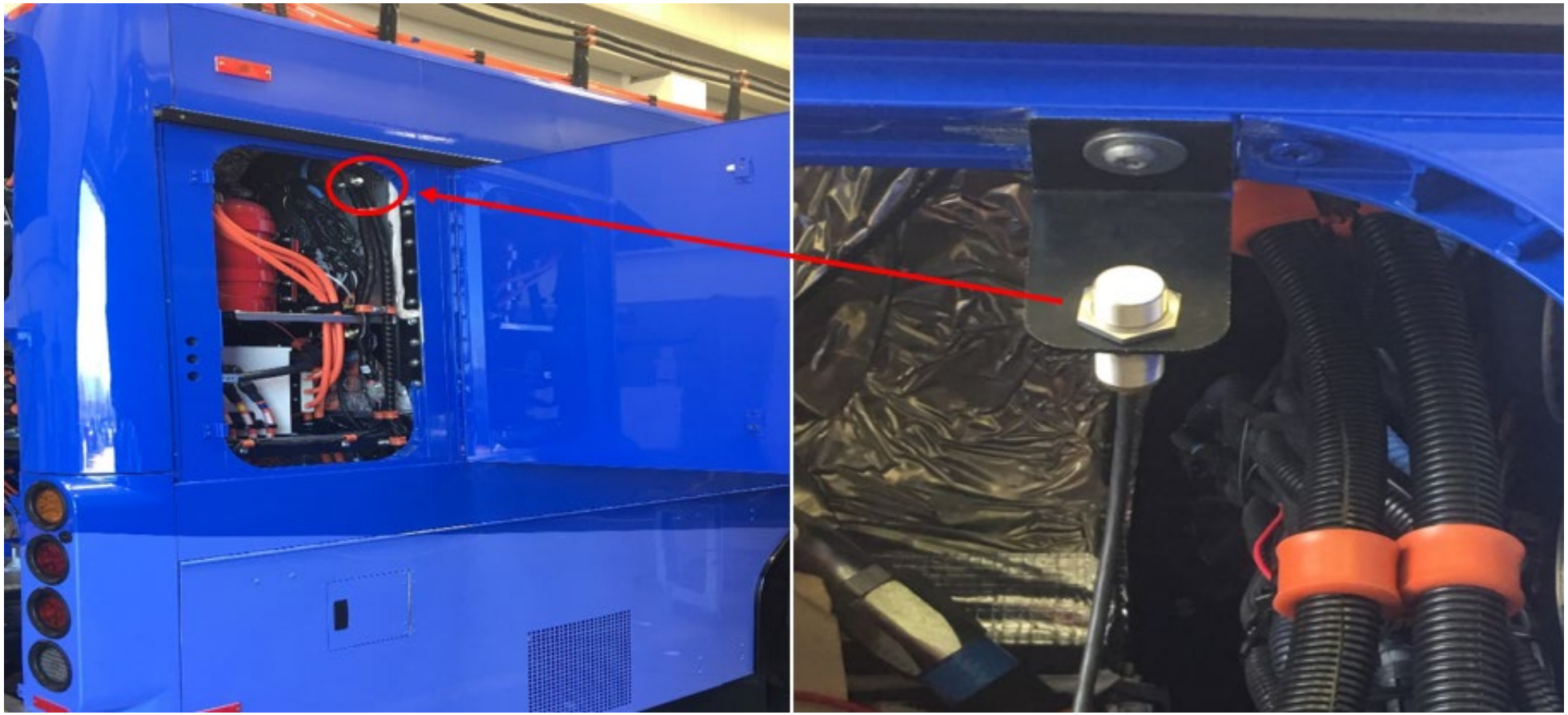
If interlocks (4 Switches) are broken (door opened) then the bus propulsion is disabled. A proximity sensor is synonymous with “safety interlock switch”

Interlocks are not operational when the bus is in **“Rear Run”** or **“Maintenance”** Mode. This allows properly trained service specialists to perform maintenance safely.

On initialization the high voltage contactors inside the ESS Battery Packs will not close when an interlock is tripped, disabling the high voltage out of the ESS and into the High Voltage junction box.

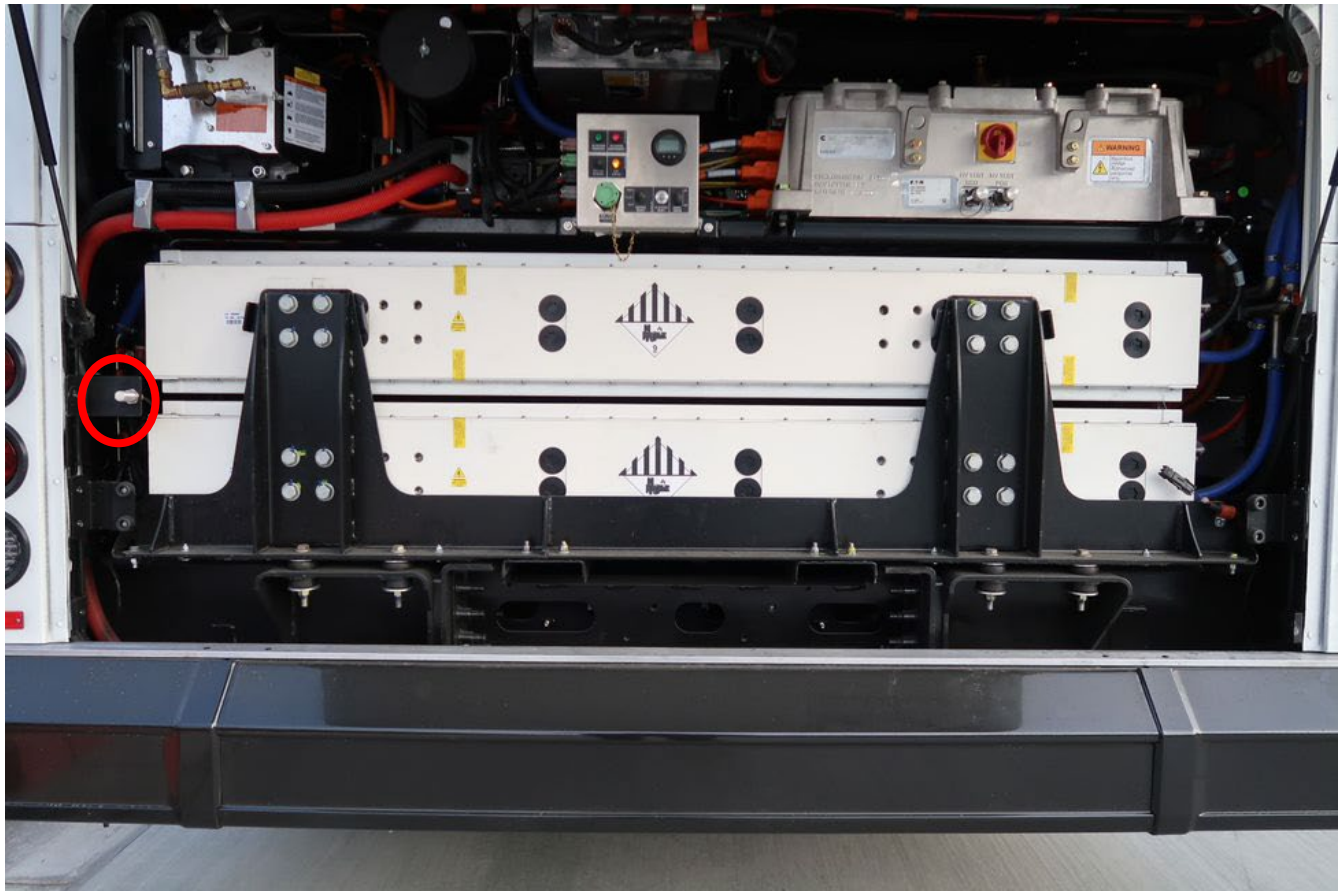
Interlocks also ensure that all exterior doors are closed and secured before bus propulsion begins.

Bus Doors Interlocks

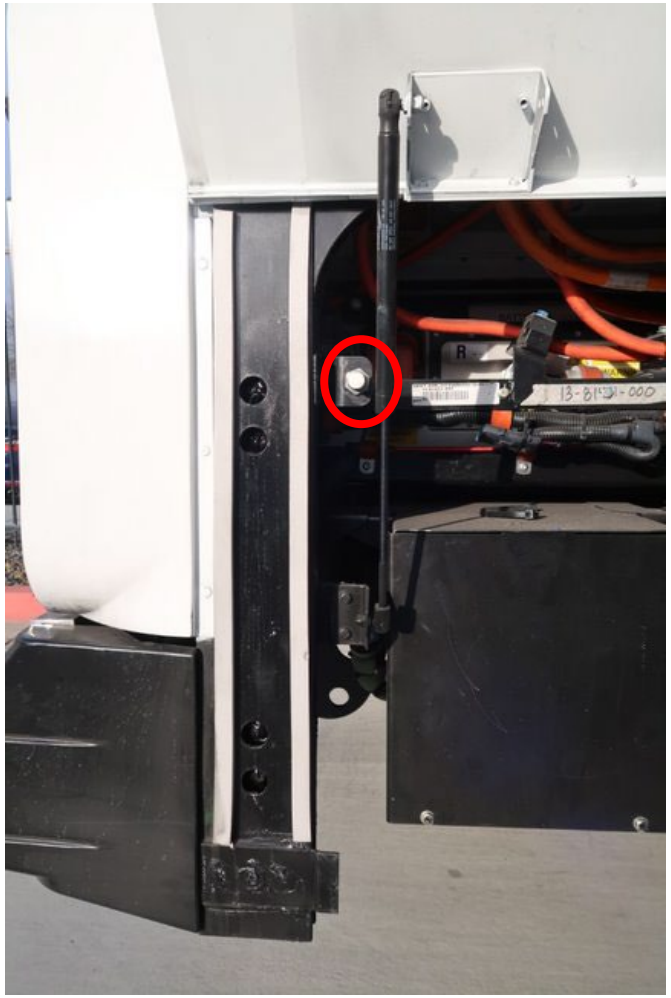


Streetside: HVAC Access Door

Bus Doors Interlocks (Continued)

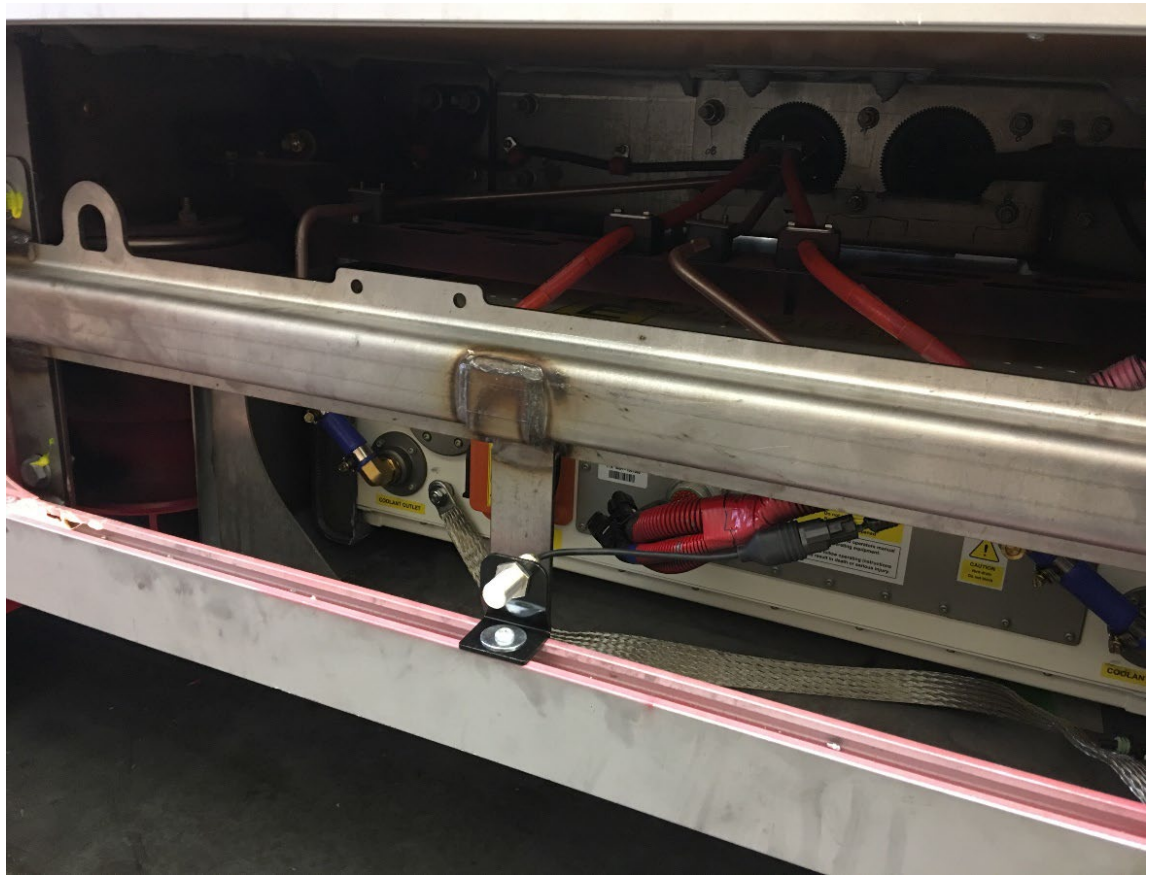


Rear: Powertrain Compartment Door



Curbside: Power Train Compartment Door

Bus Doors Interlocks (Continued)



Curbside: Chassis Battery Access Body Panel Interlock Location

Curbside Body Panel For Chassis Battery Access Interlock:

The interlock for the chassis battery on the curbside is located just forward of the rear wheel access door.

High Voltage Junction Box

Description:

- The HVJB connects all positive and negative sides of all batteries into one positive and one negative DC output source
- The junction box is a Cummins supplied component
- High Voltage measurement after lockout-tagout will be taken on the high voltage junction box
- High Voltage Test Ports include MPIL circuits
- Service tools
  - Multimeter (1000 volt)
  - High Voltage PPE

High Voltage Junction Box HV Emergency Disconnect Switch

- High Voltage Disconnect Switch (Quarter turn and LOTO lockable)

- The HVJB is located at the rear of the vehicle. This switch has two functions – 1) as an easily accessible, rear bus mounted high voltage emergency shut off switch and 2) as an additional LOTO switch for the high voltage system downstream to the HV junction box which includes;

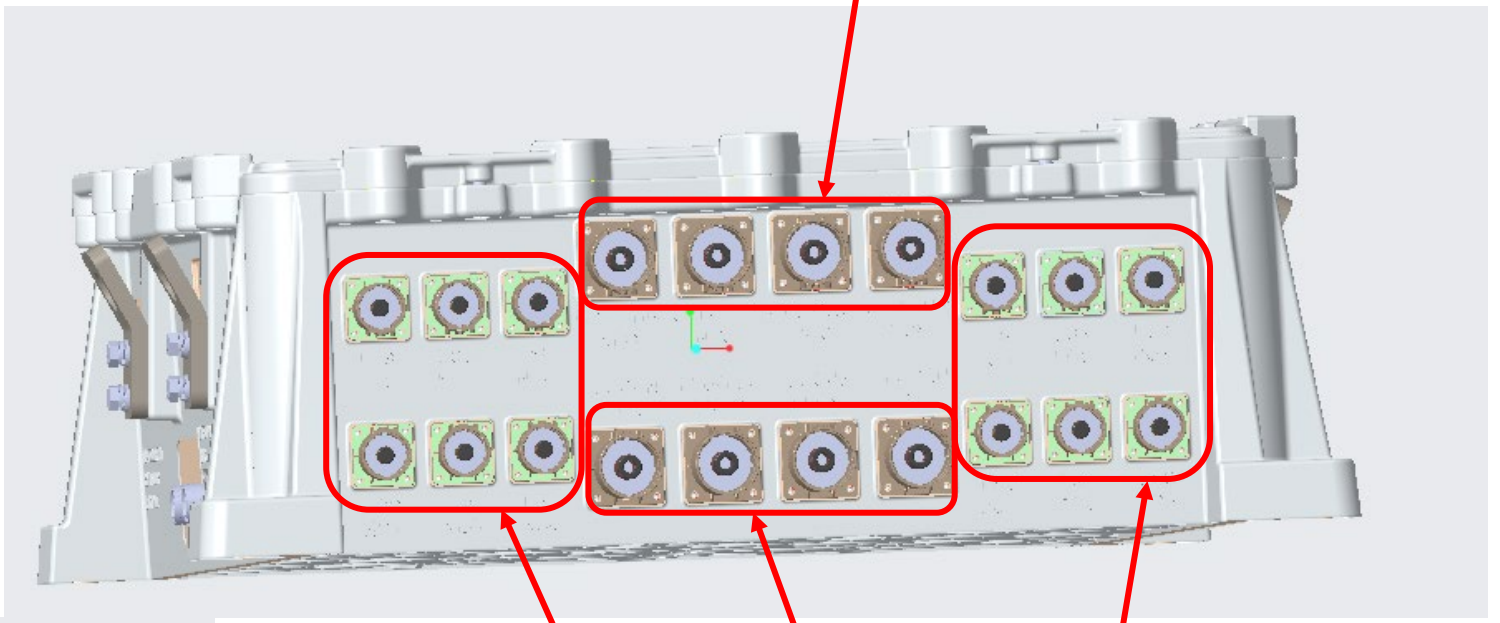
    - ✓ HVDC Junction Box, including front and rear DC plug-in chargers
    - ✓ Motor Inverter and Motor
    - ✓ Accessory Inverter and downstream components (HVAC, and Air Compressor)
    - ✓ DC/DC Converter
    - ✓ Coolant Heater

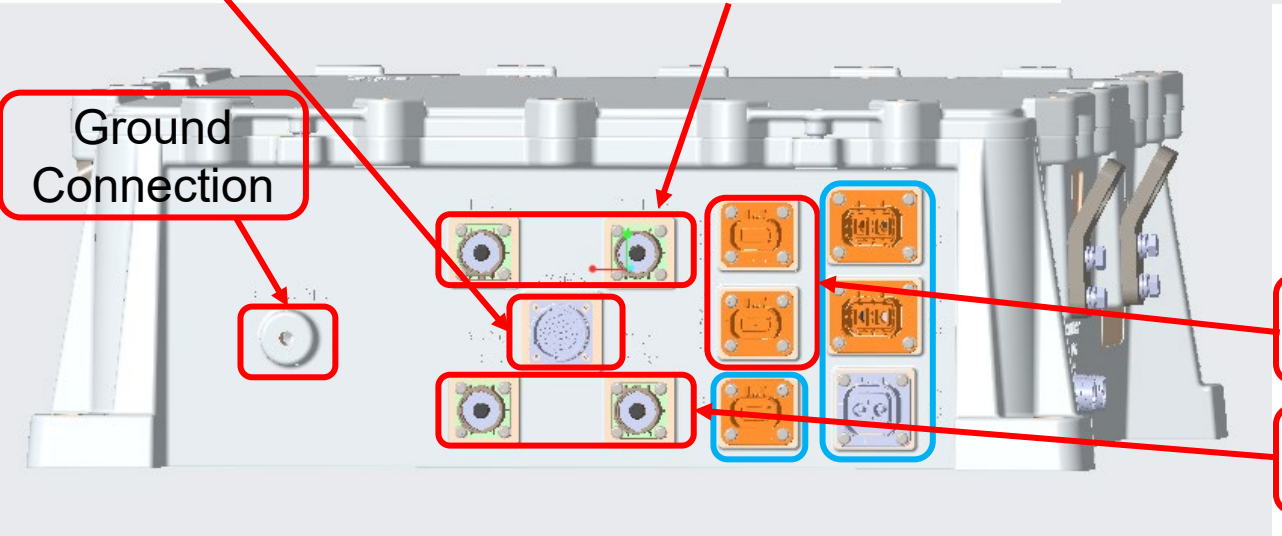
- Benefits of this disconnect switch: When combined with the high voltage measurement test ports, it allows the operator to safely work on the bulk of the high voltage system.

Location of the HVJB Junction Box HV Emergency Disconnect Switch

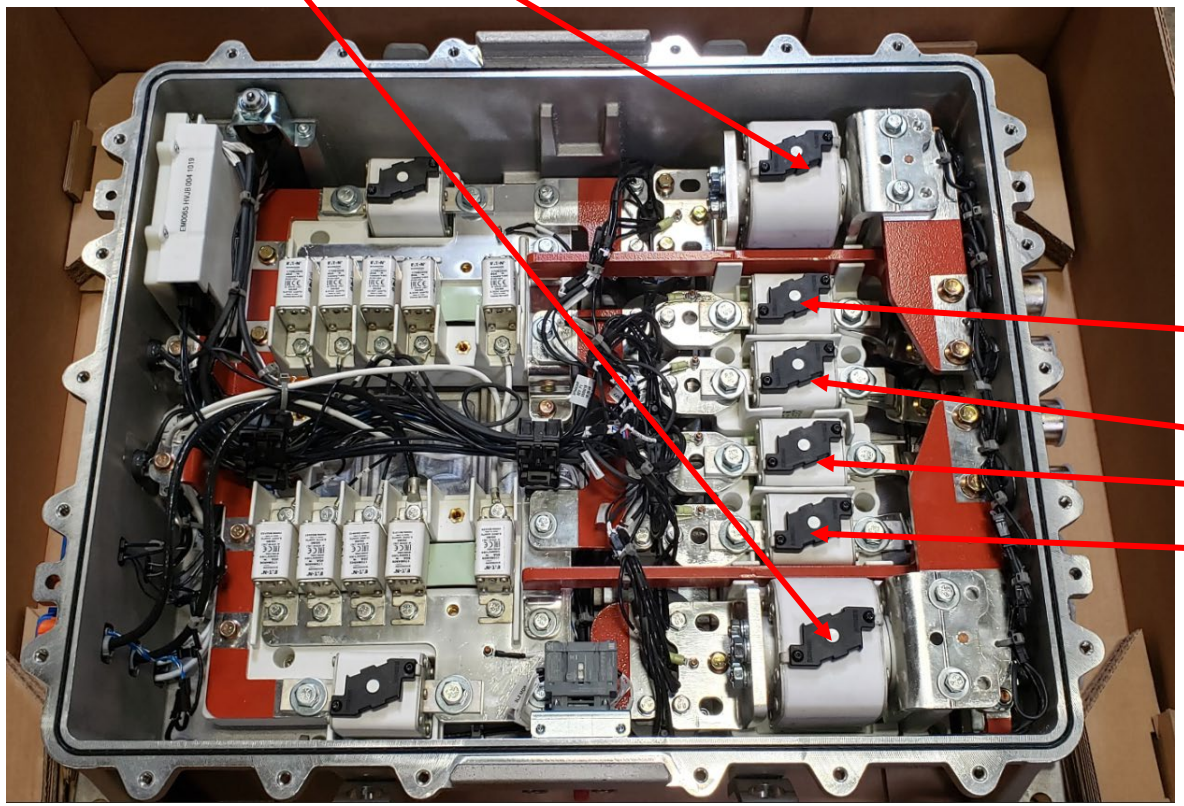
High Voltage DC Junction Box

- All Connections are labeled on the junction box.
- Connections in blue circles are AUX Connections





High Voltage DC Junction Box

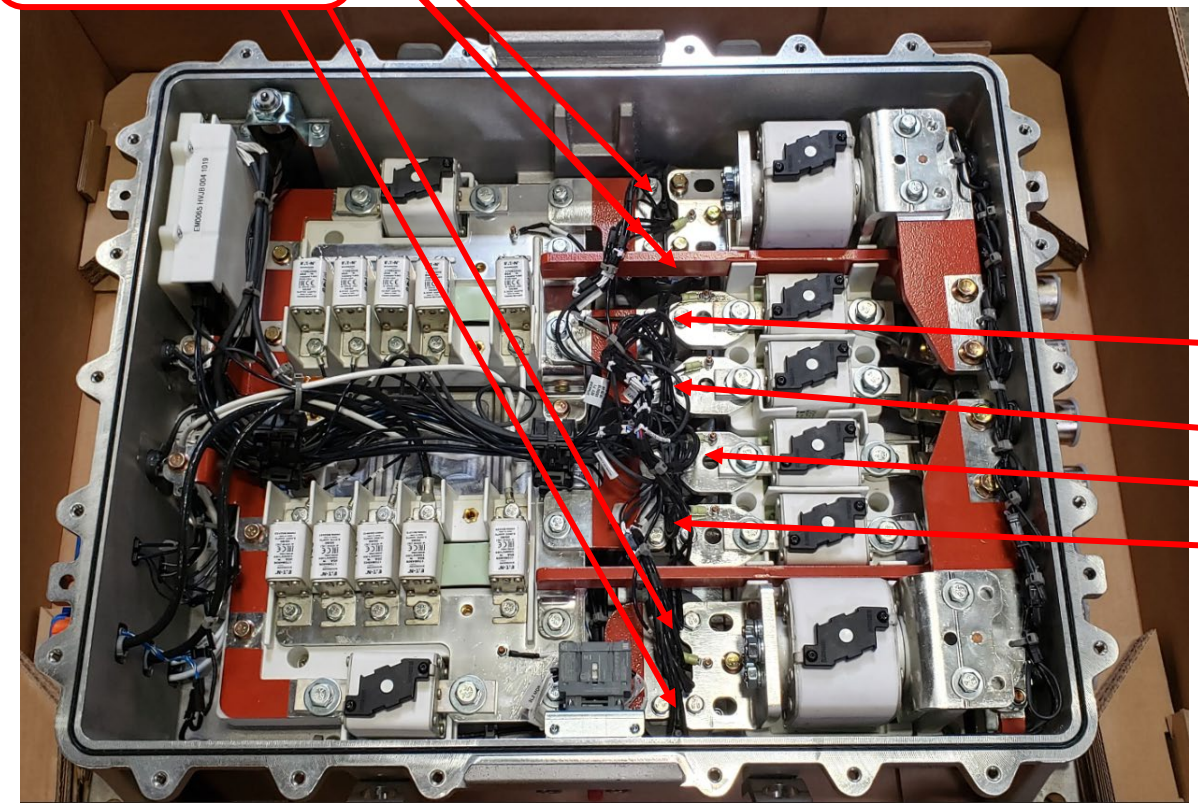


Serviceable Parts By Cummins Only At This Time

- Voltage Sensor Assembly
- Fuses
  - Many Different sizes. Make sure to replace with same size.
- Charge Contactors

NOTE: Only Cummins Factory Trained Technicians should service the HVJB

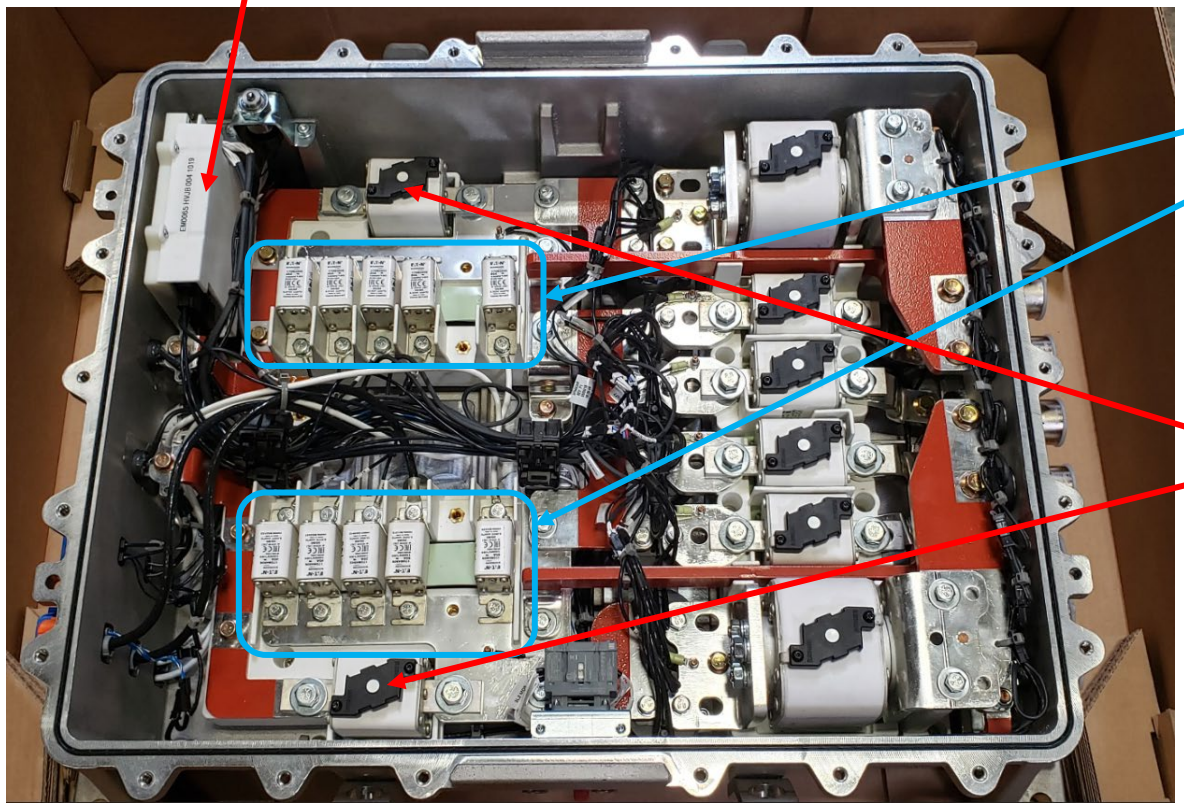
High Voltage DC Junction Box



Serviceable Parts By Cummins Only

- Voltage Sensor Assembly
- Fuses
  - Many Different sizes. Make sure to replace with same size.
- Charge Contactors

High Voltage DC Junction Box



Serviceable Parts By Cummins Only

- Voltage Sensor Assembly
- Fuses
  - Many Different sizes. Make sure to replace with same size.
- Charge Contactors

High Voltage Junction Box Fuses

Opportunity Fuses
- 2000 amp

Plug in Charge Fuses
- 800 amp

Traction Inverter Fuses
- 800 amp

DC/AC Fuses
- 400 amp

DC/DC Fuses
- 40 amp

AUX Fuses
- 20 amp
- 40 amp
- 80 amp
- 100 amp

NOTE: Make sure when replacing AUX fuses that the same size of fuse is installed that was removed. AUX fuse sizes will depend on OEM.

Location of the High Voltage Junction Box HV Emergency Disconnect Switch (Continued)

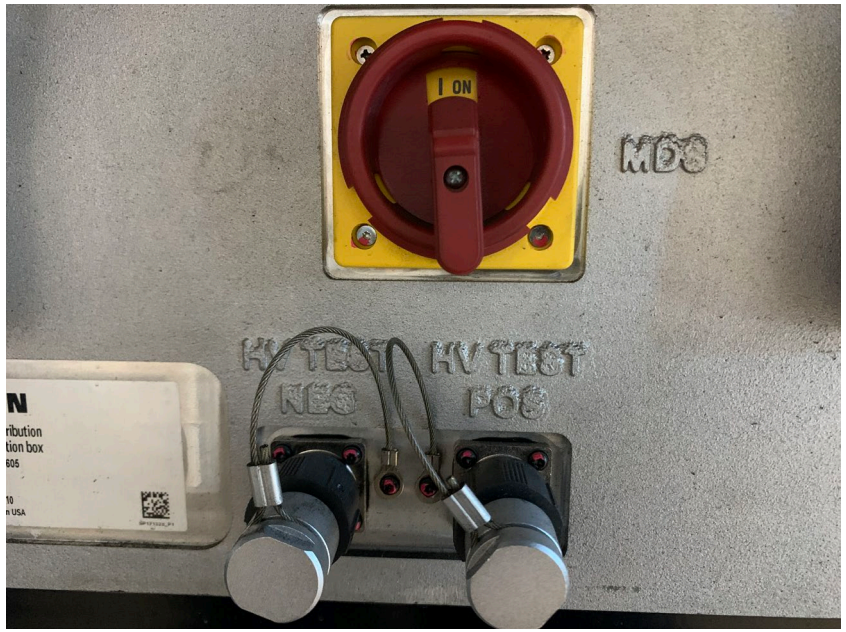
When to use: The switch should be used during an emergency. However, it should be expected that fault codes may be set during the emergency stop process.

The switch should also be used as part of GILLIG's normal LOTO procedure for the high voltage system on the bus, after the automatic low-voltage disconnect has been locked out at the front street side of the bus.

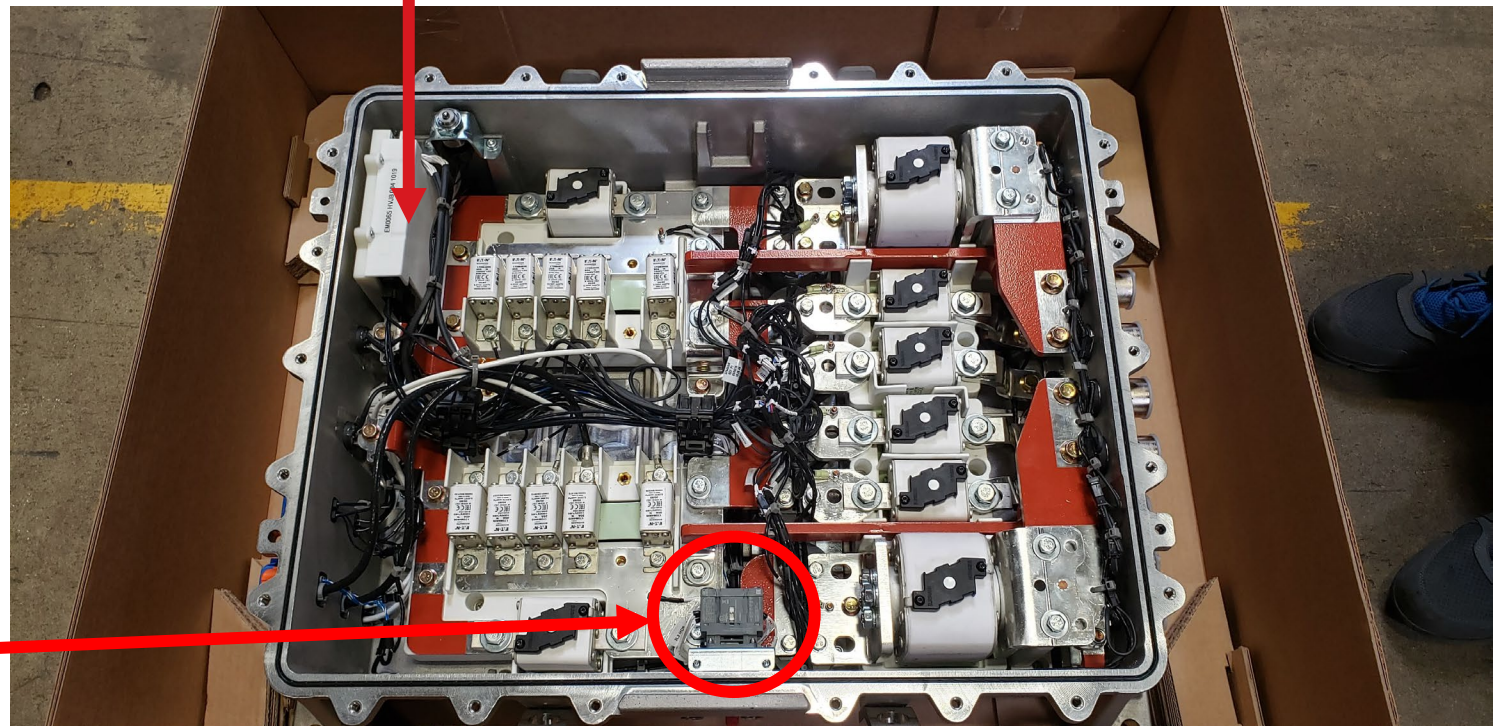
When not to use: The HV Junction Box Emergency Disconnect switch should not be used in the standard process of turning off the bus. It is only intended for emergencies or part of the LOTO as indicated above.

HVJB High Voltage Box Measurement Ports

- HVJB Measurement ports are used to confirm the shut down of the high voltage system.
- This confirmation utilizes a LOTO procedure using a meter test to validate the system is deenergized.
- The measurement ports also include an interlock loop. When the caps are removed the interlock, the loop is broken, and high voltage will not initialize or shutdown if activated.
- This circuit is referred to as MPIL (measurement port interlock loop)
- The measurement ports are not wired directly to high voltage bus bars
- The voltage sensor provides the voltage to the ports via two small wires (HV+ and HV-)

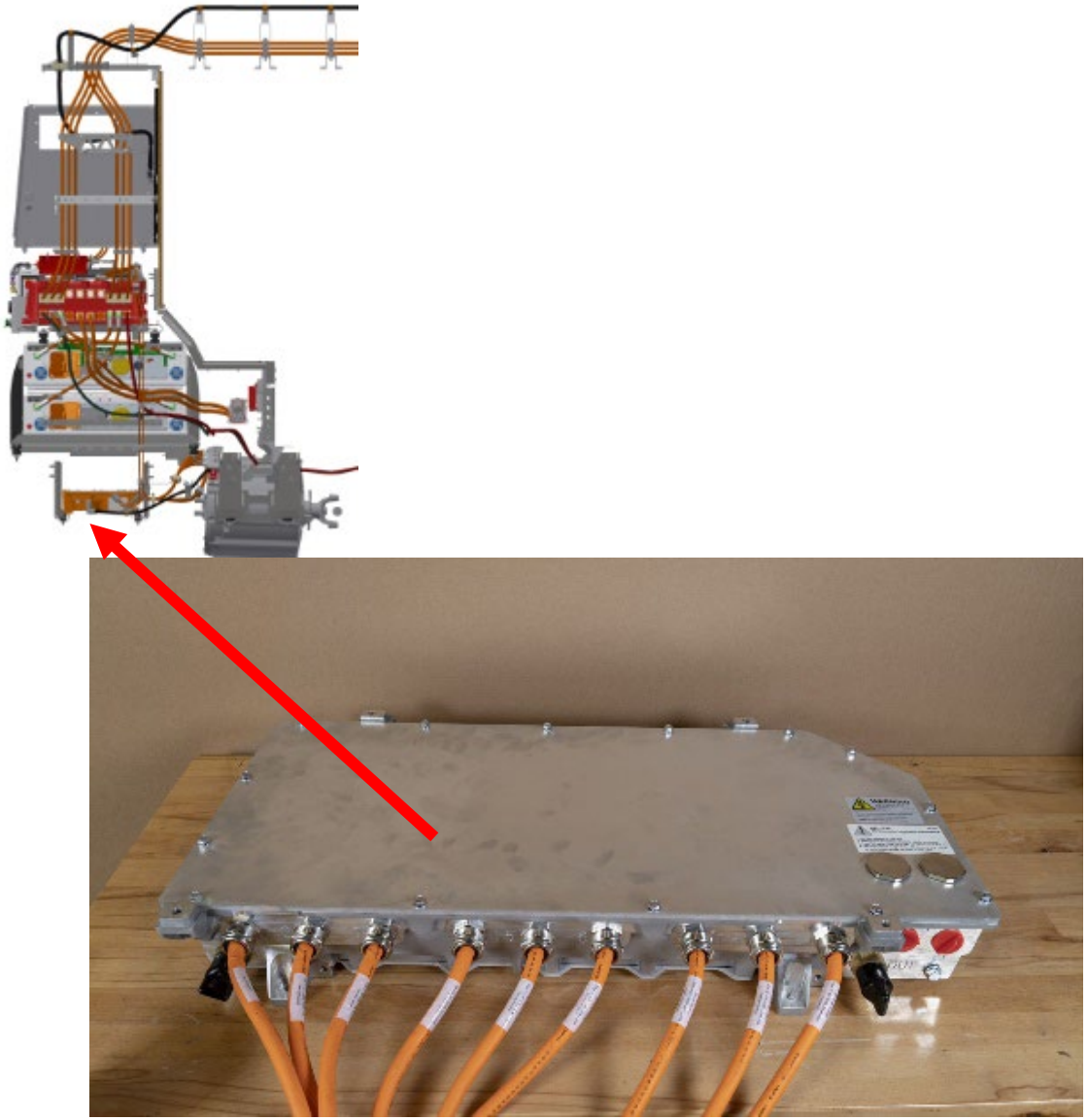


Voltage Sensor



MPIL Port

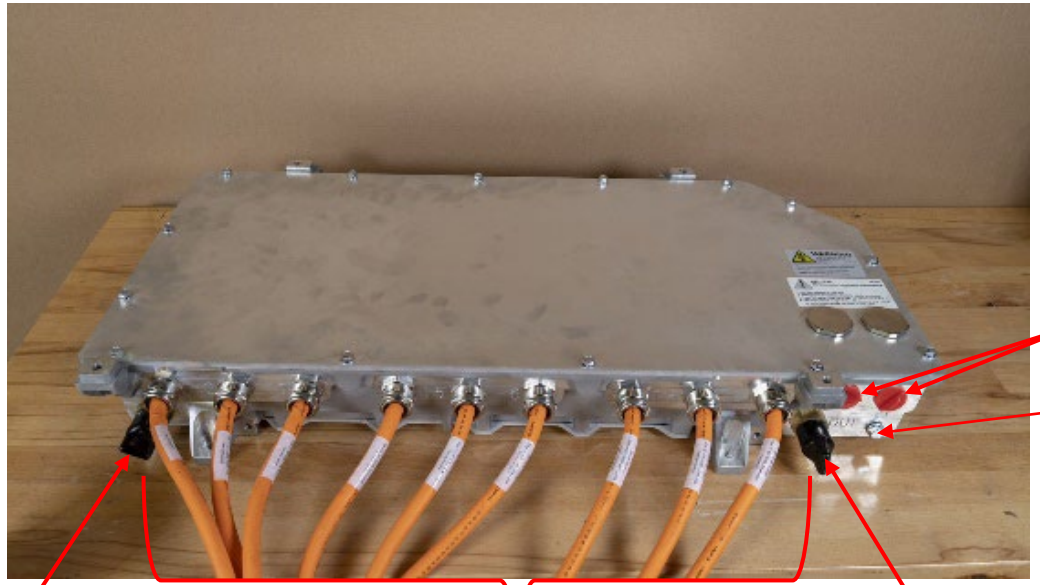
Propulsion Inverter



Description:

- Location: Rear of the bus underneath the rear HV battery packs.
- Weight: 36 Kg [78 lb.]
- Propulsion inverter regulates the AC power provided to the propulsion motor to meet driver commands for vehicle propulsion.
- The inverter receives high voltage DC power and produces 9-phase AC power output. The inverter also receives 9-phase AC power during regenerative braking by the traction motor and rectifies back to DC power for battery storage
- Serviceable parts
  - Coolant ports
- Service tool
  - Floor jack

Propulsion Inverter



DC power - in

Ground

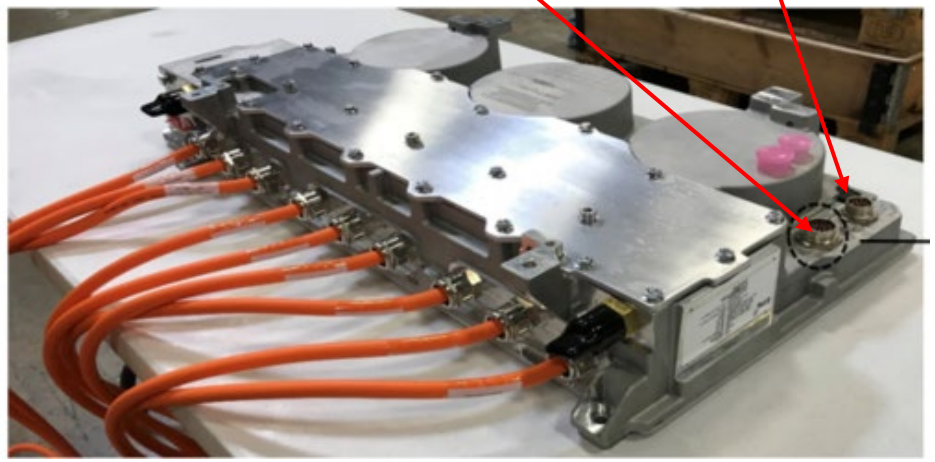
Coolant in/out

9-phase AC cable

Coolant in/out

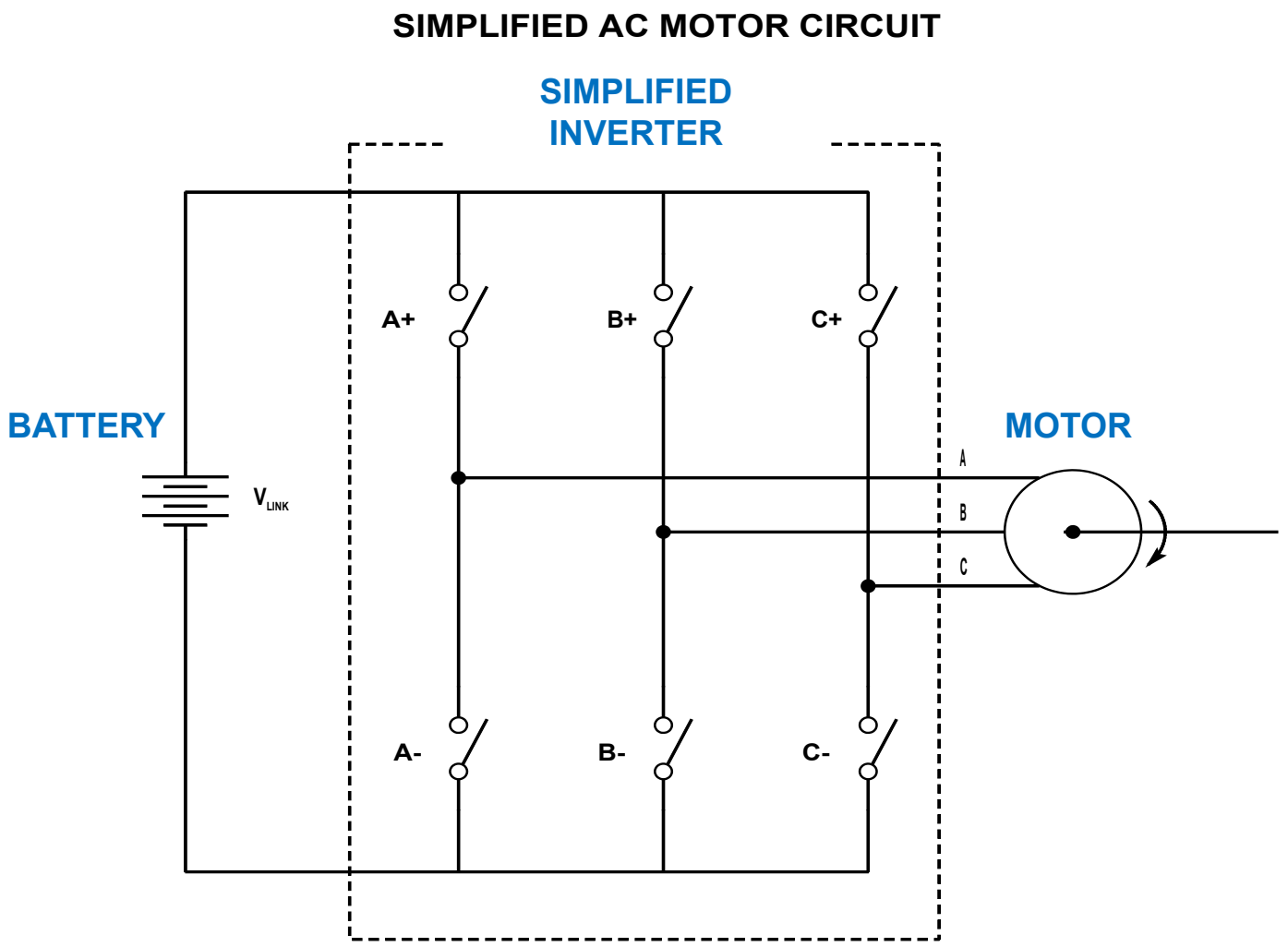
OEM wiring harness connection

Resolver harness to propulsion motor connection

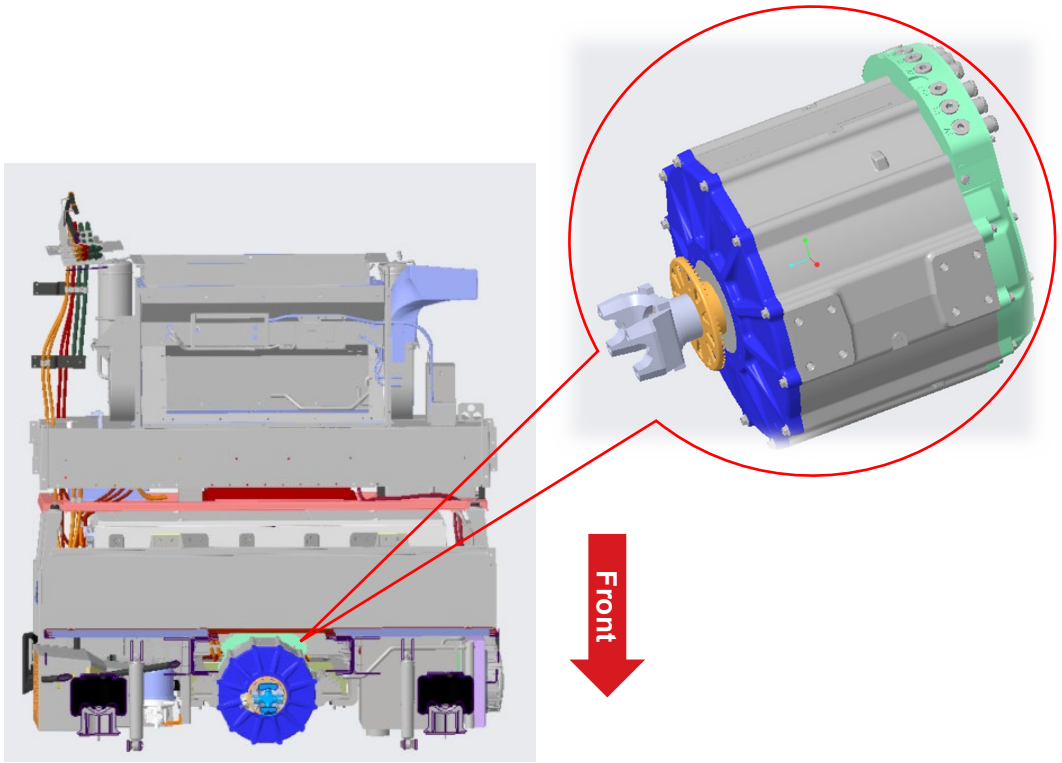


Propulsion Invertor

- Battery, Simplified Inverter and Traction Motor.
- IGBTs as switches.
- 3-phase inverter switches HV DC energy on/off to create an AC signal.
- Cummins uses a 9 phase invertor (3-3 phase invertors in one housing)



Propulsion Motor



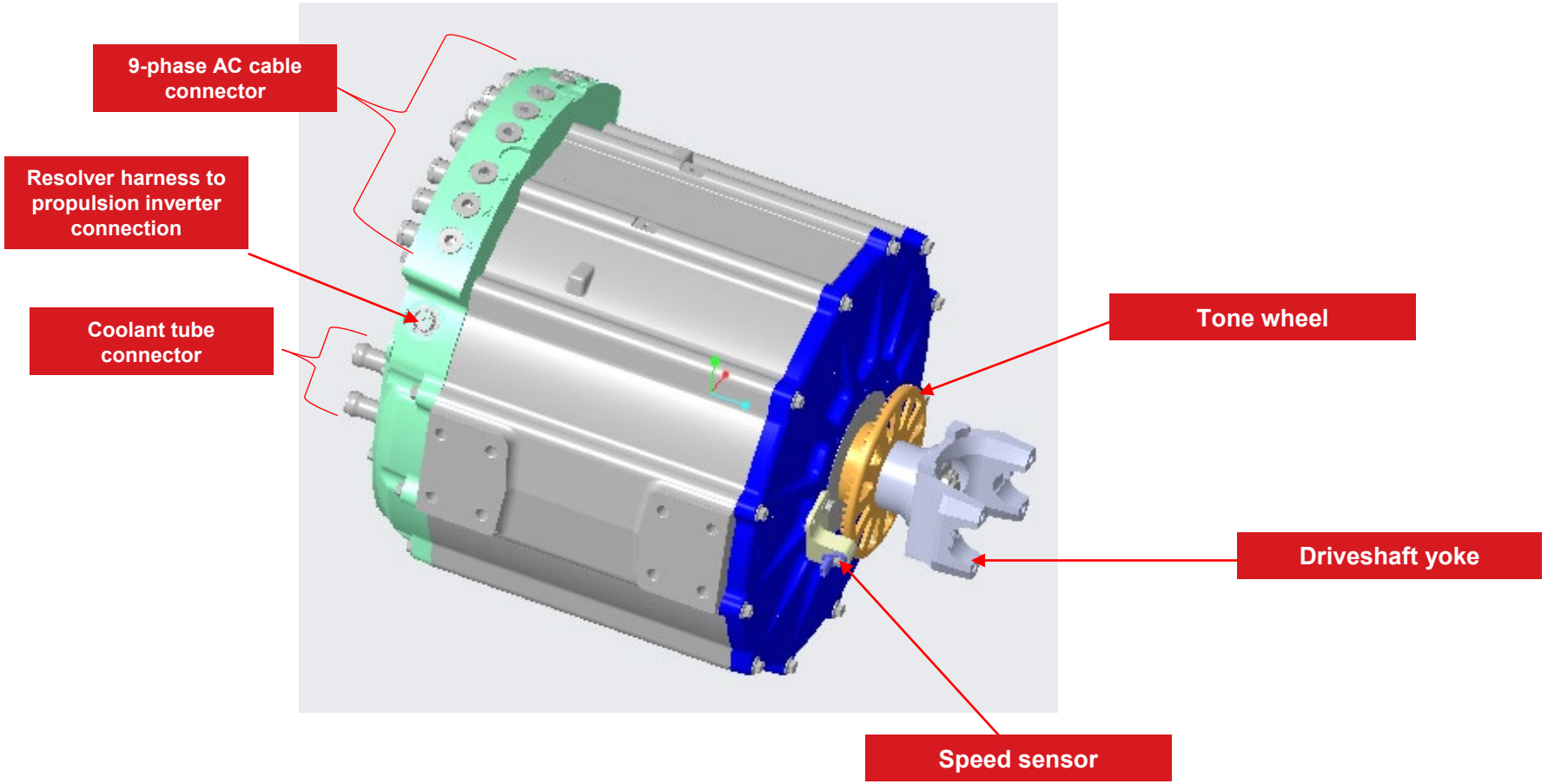
Description:

- Location: Under the bus-rear end.
- Weight: 363 kg [800 lb.]
- The propulsion motor is used for the conversion of electrical energy to mechanical energy and vice versa (regenerative braking).
- The propulsion motor receives high voltage 9-phase AC power and produces mechanical torque at its output shaft.
- Serviceable parts:
  - Speed sensor
  - Driveshaft yoke
  - Tone wheel
- Service tool:
  - Propulsion motor cradle

Propulsion Motor

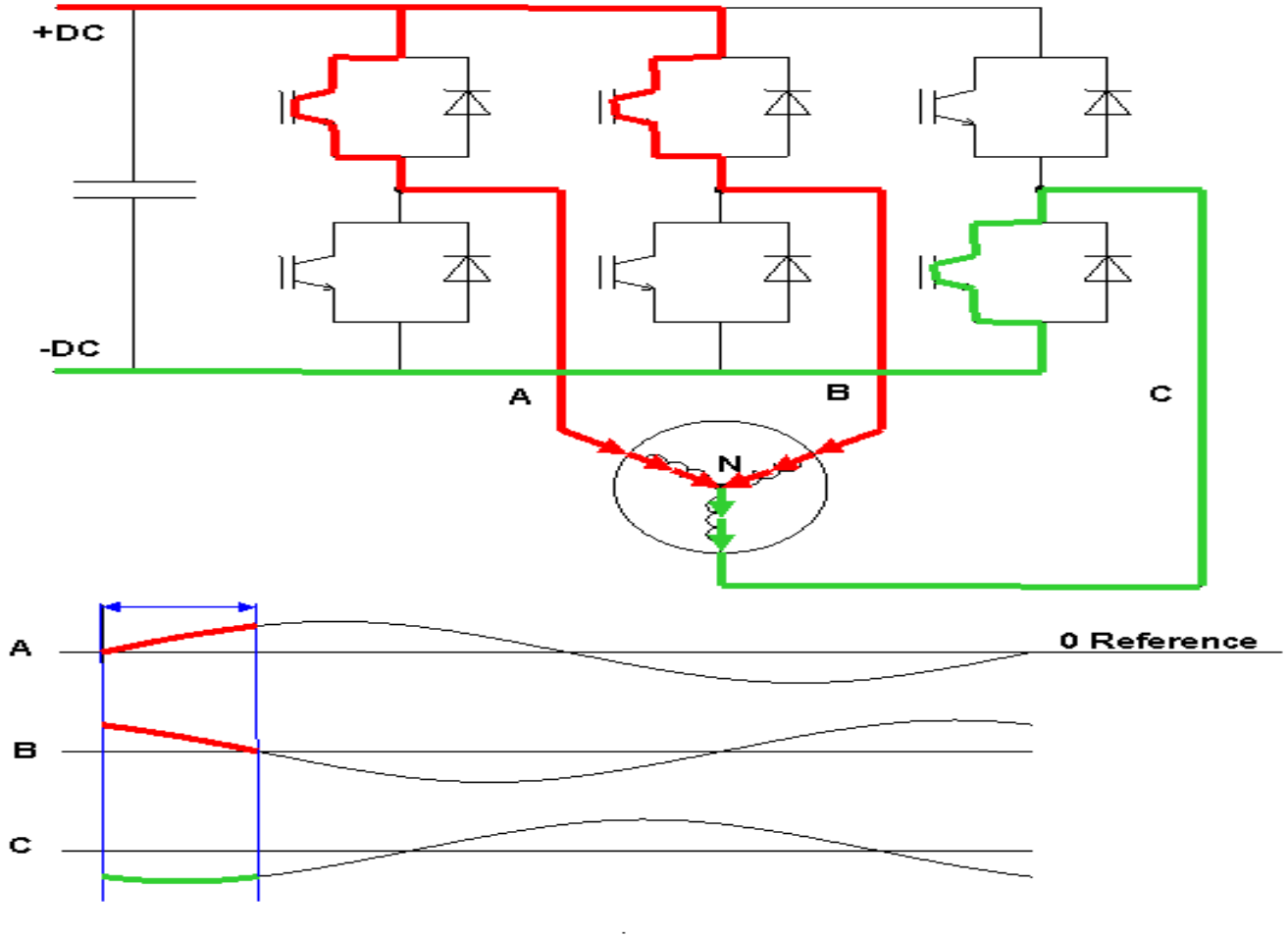
The traction motor provides 3,500 N-m (2581 lb-ft) of torque for up to 30 seconds with a continuous output of 2,060 N-m.

Power output is 350 kW (469 hp) for up to 30 seconds, with a continuous output of 195 kW.
Operating range is 0 to 3,400 rpm.



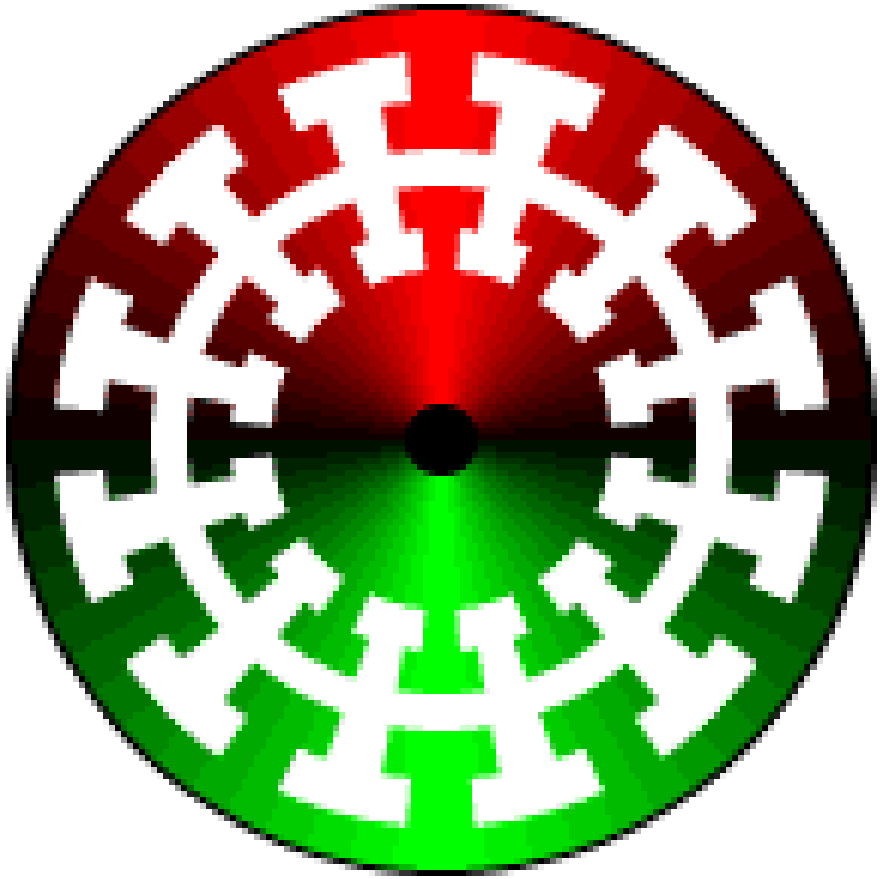
Traction Motor

- Rotor turned when power is suppled to coils which generates magnetic field in each.
- Pattern alternates to continue rotation of the rotor.
- Each phase of positive and negative IGBTs must not be switched on at the same time.



Traction Motor

- **Alternating current** applied to stator windings to produce rotating magnetic field in the rotor.
- **Magnetic attraction** makes rotor to follow stator.
- **Slip**: When rotor turns at slower speed than the alternating magnetic field of the stator.
- No slip means no current, which means no torque.
- **Cooling** essential for proper operation and will be covered later in the class.



GILLIG

Propulsion Motor Maintenance

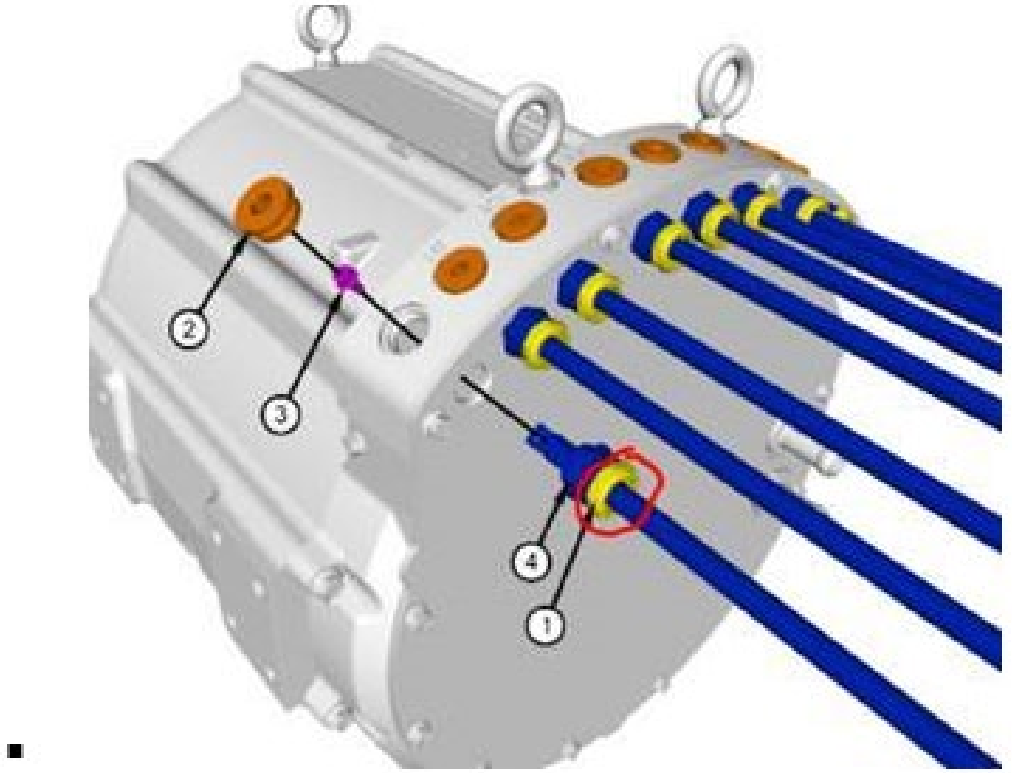
Daily Checks

- Check SOC of HV batteries
- Check coolant level of electronics cooling package
- Check coolant level of battery thermal management system

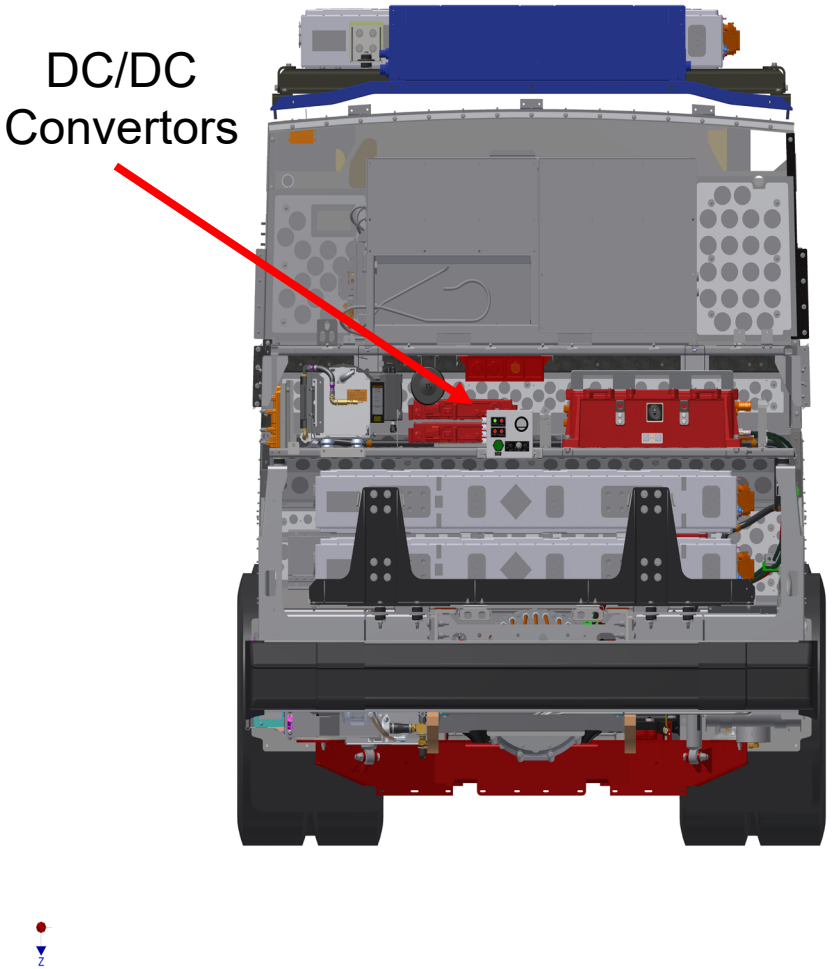
Routine Maintenance

- Check propulsion motor mounting bolts are still torqued once a year- 165 Nm

- Check high voltage cable compression fitting (yellow in picture below) on propulsion motor once a year- 12 Nm



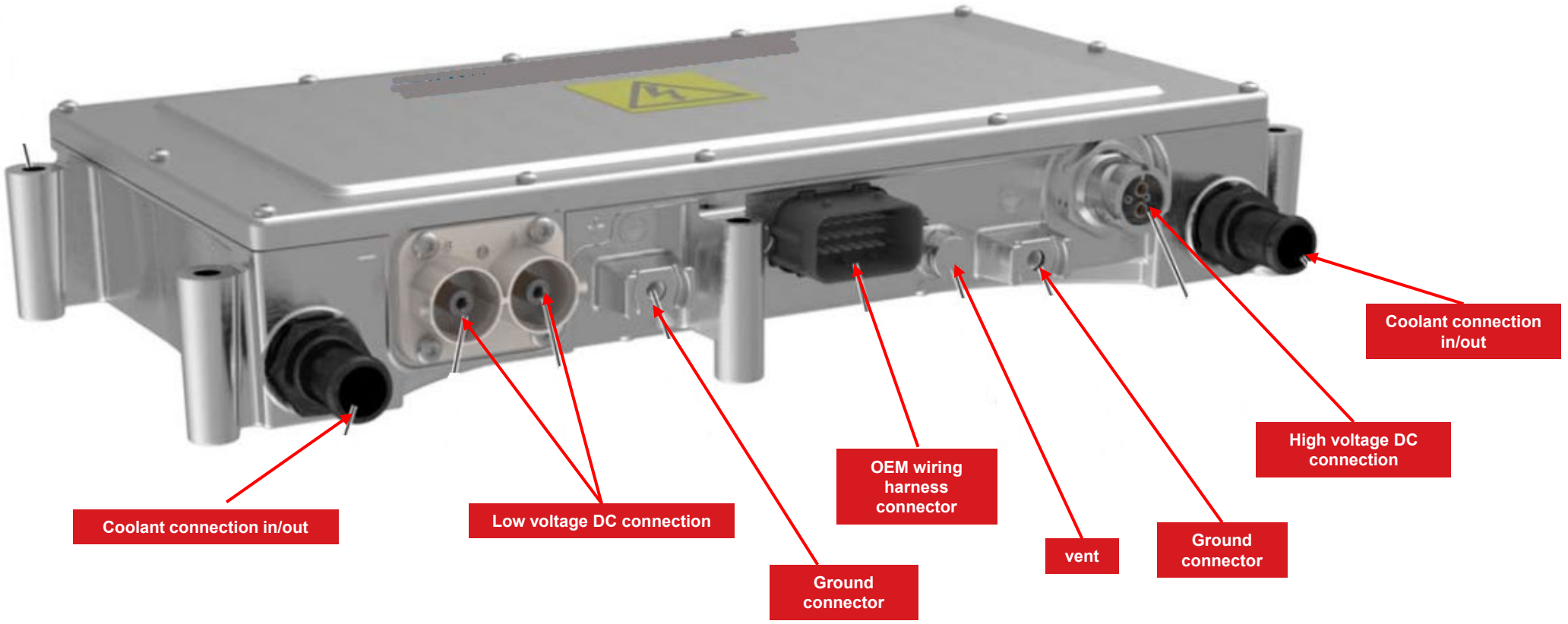
DC/DC Converters



Description:

- Location: On the rear left side of the bus beside the Air compressor
- There are 2 DC/DC converters on the electric vehicle. A maximum of 3 DC/DC could be on the electric vehicle
- Weight: 10.3 kg [23 lb.]/ea
- DC/DC Converter modifies or steps down DC voltage. It is used where conventional belt driven alternators are not present.
- The DC/DC converter receives high voltage DC power and produces a regulated low voltage DC power output (750 VDC to 24 VDC).
- Max output
  - Current: 270 amps at 28.5 volts each
  - Power: 7.5 kW each
- Gillig runs battery sense wires (Pos/Neg) from the convertors to the Kissling switch 10a fuse 16. These wires tell the convertor LV battery voltage so the convertor can control charge rate.
- Cummins will control the voltage/current output based on HV potential
- Serviceable parts:
  - Coolant ports

DC/DC Converters



System Control Module (SCM)

Description:

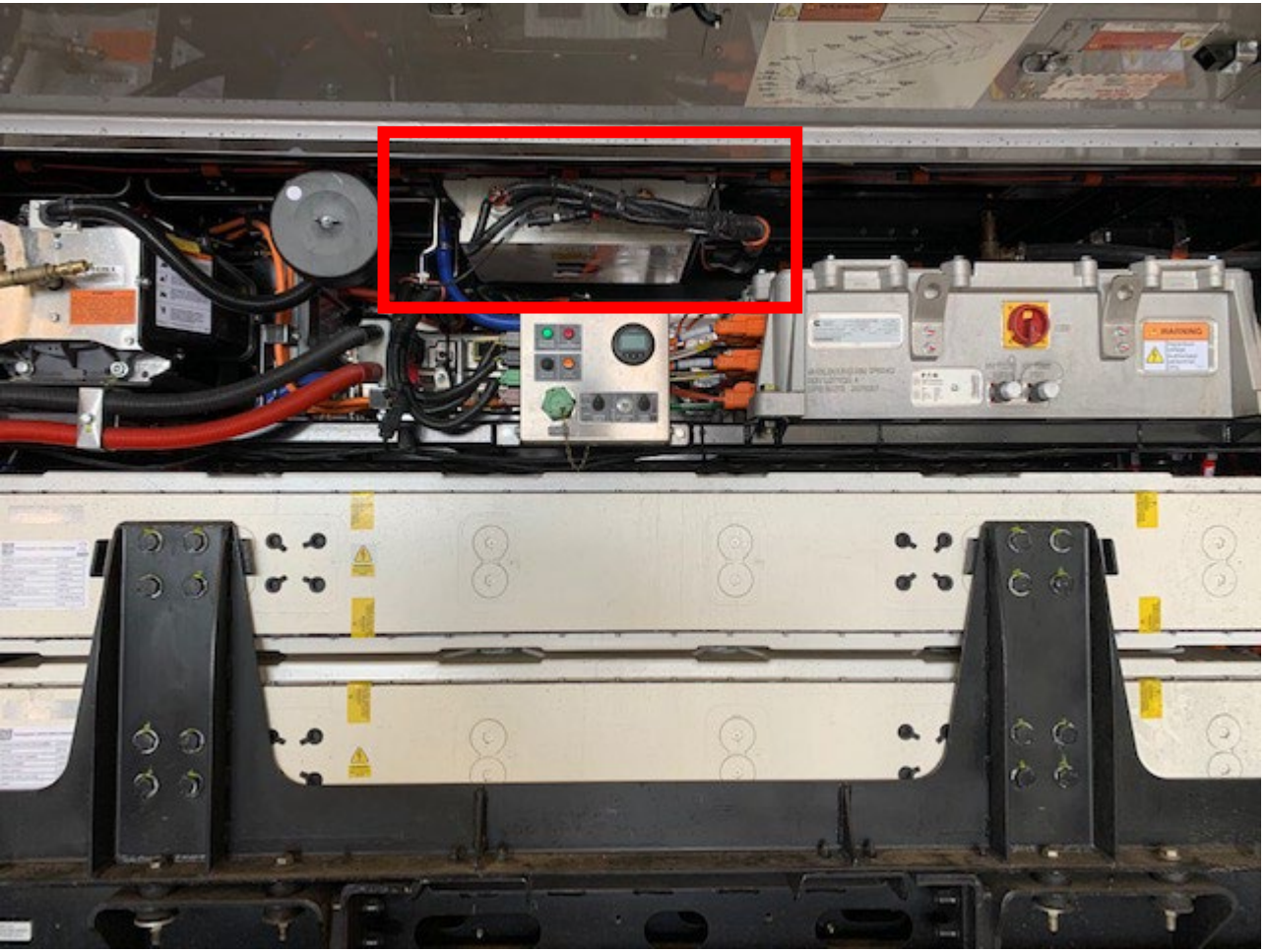
- Location: Rear left side of the bus
- The (SCM) system control module controls the entire system.
- Gillig will activate Gateway output G1-O013 High voltage shutdown to the SCM to initialize high voltage.
- Serviceable parts
  - No serviceable parts

Charge Controller Unit

Description:

- Location: On the rear and front sides of the vehicle close to the charging receptacles
- Weight: 1.5kg [3.3 lb.]/ea
- One per charging receptacle
- Interface between EVSE (electric vehicle supply equipment) and SCM
- Controls plug lock, measures receptacle temperature sensors, monitor for EVSE connection to charging receptacle
- Serviceable parts
  - No serviceable parts

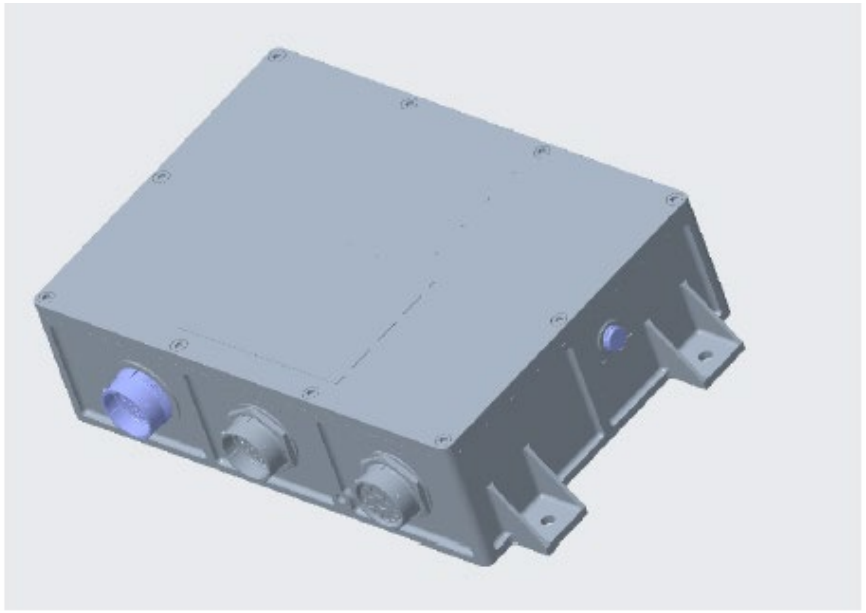
Battery Management Controller (BMC)

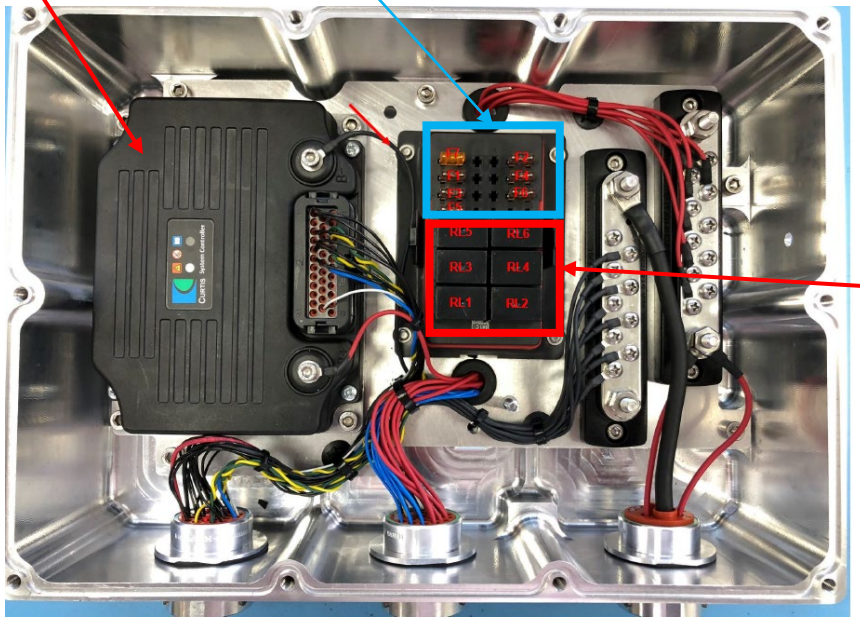


Description:

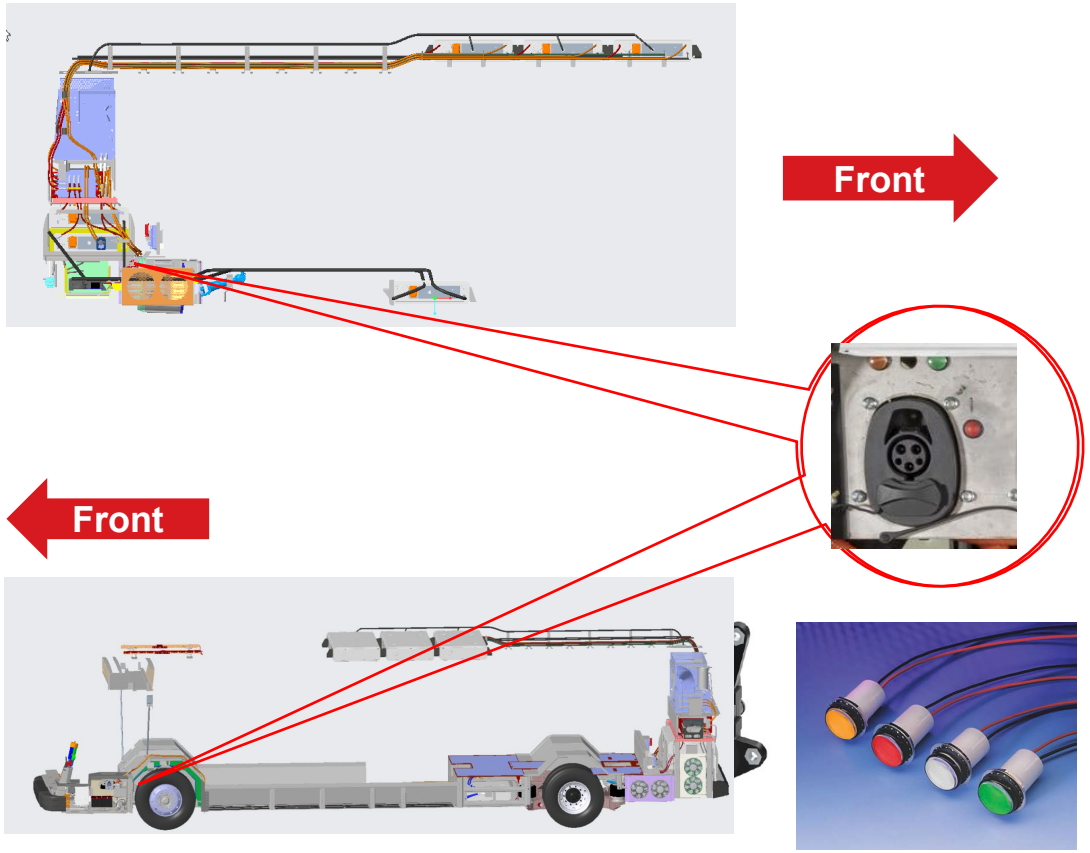
- Location: Upper center of the PTC compartment. Mounted on the AC bulkhead plate
- In charge of the Cummins private ESS CAN
- Weight: 5 kg [11 lb.]
- The BMC controls the battery system. It is the brains of all 6 battery packs
- Serviceable parts
  - Fuses
  - Relays
  - Control Board

Battery Management Controller (BMC)





Charging Receptacle

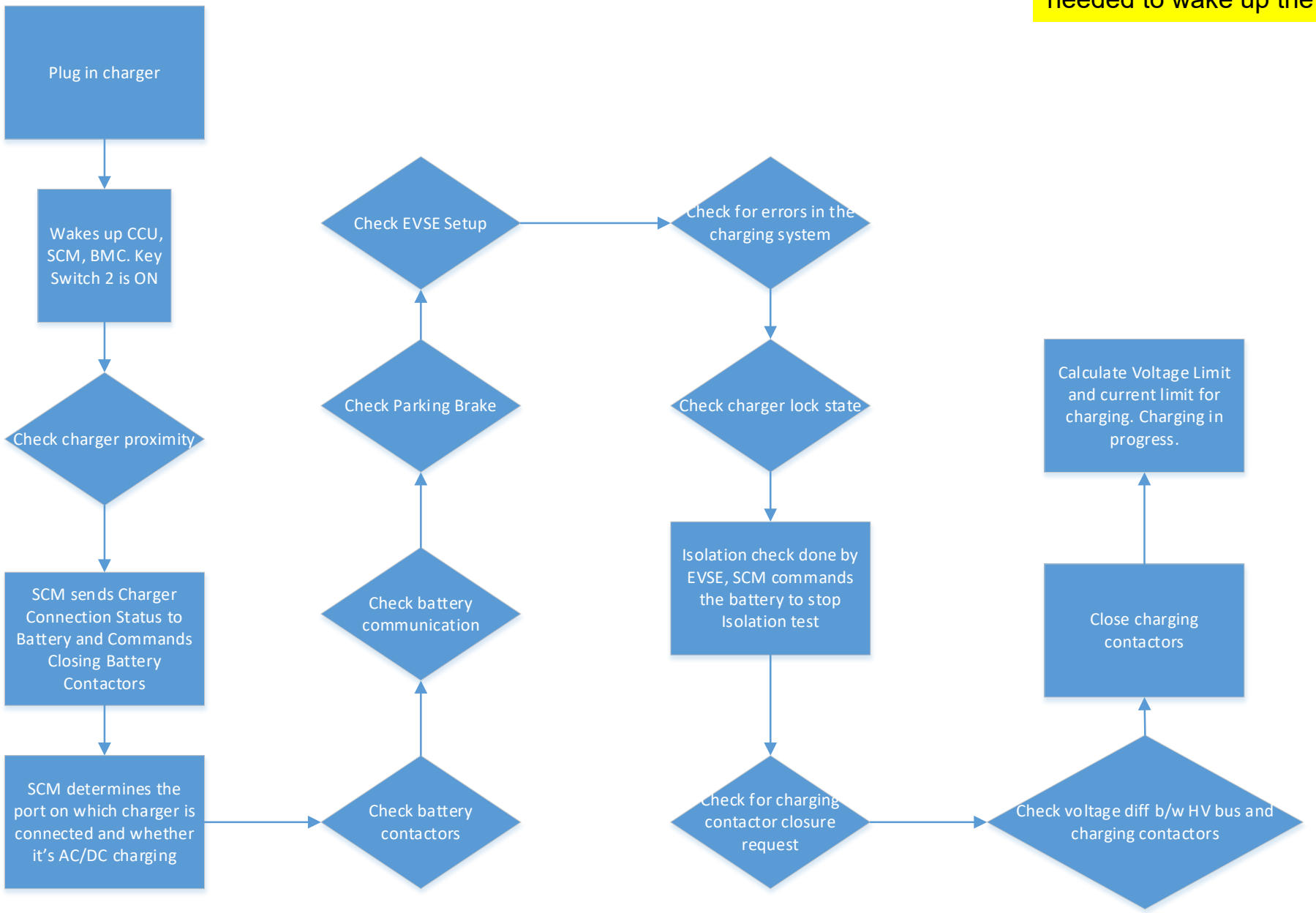


Description:

- Location: 3 charging receptacles - Rear curbside of the bus, rear street side of the bus and front street side of the bus
- Type 1 CCS
- EVSE Connection status indicator
  - Yellow/Orange – provides direct feedback to the user after connecting an EVSE that a valid EVSE connection has been detected by the SCM/CCU
- Charging status indicator
  - No light – Charger not connected
  - Green flashing light - charging
  - Solid green light – Fully charged (100% SOC)

DC Charging State Flow

The SOC of the LV battery has to be greater than 14 volts. This voltage is needed to wake up the SCM.



Operator Guide

Charging

- There are 3 possible optional charging ports (1 front and 2 rear) on this electric vehicle.
  - Do **NOT** charge electric vehicle from both ports at the same time.
  - Only 1 of 3 can be active at any given time.
  - System only recognizes the first charging receptacle plugged in and only activate charging contactors on connected receptacle
- There are two methods for charging the HV battery
  - Grid charging
  - Regenerative charging

Grid charging

  - Direct current (DC) charger used
- Charging Lamps
  - No light – Charger not connected
  - Green flashing light - charging
  - Solid green light – Fully charged (100% SOC)

Safety Charging Systems

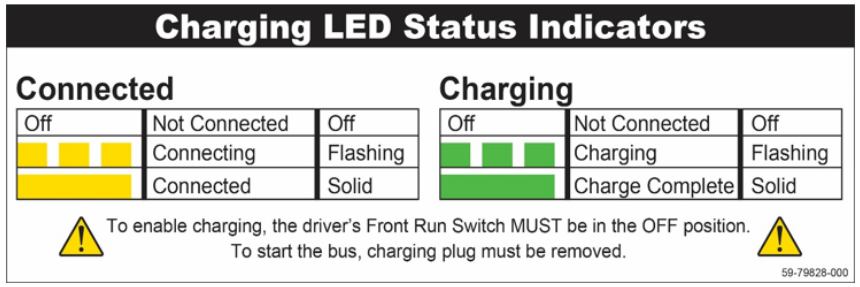
View of Rear Charging Port

Safety Charging Systems (Continued)

View of Front Charging Port

View of Front Charging Port Shown with Charging Ports Open

Safety Charging Systems (Continued)



Charging LED Status Indicator Label

Function Of Charging LED Status Indicators:

GILLIG's charging systems and charging station providers adhere to the CCS communication standard and use CCS-Type 1 or CCS-Combo 1 inlets and plugs.

The CCS protocol enforces strict handshaking between the charger and the bus to ensure that the charger only provides allowed voltages and currents that the vehicle requests.

The charger also enforces it's own limits for safety. Ground fault and isolation detection is employed to ensure that no unintended currents or voltages are present.

Charging will not occur if there is a fault. The charging safety systems are continuously in effect whenever a charger is plugged into the vehicle and powered up.

Operation

System Indicator Lights (Rear Run Box)

EV SYSTEM ENERGIZED: Indicates if HV contactors are closed and HV system is online.

EV MAINTENANCE: The HV system has detected a fault in the system and requires maintenance. Will flash until Dinex goes to sleep.

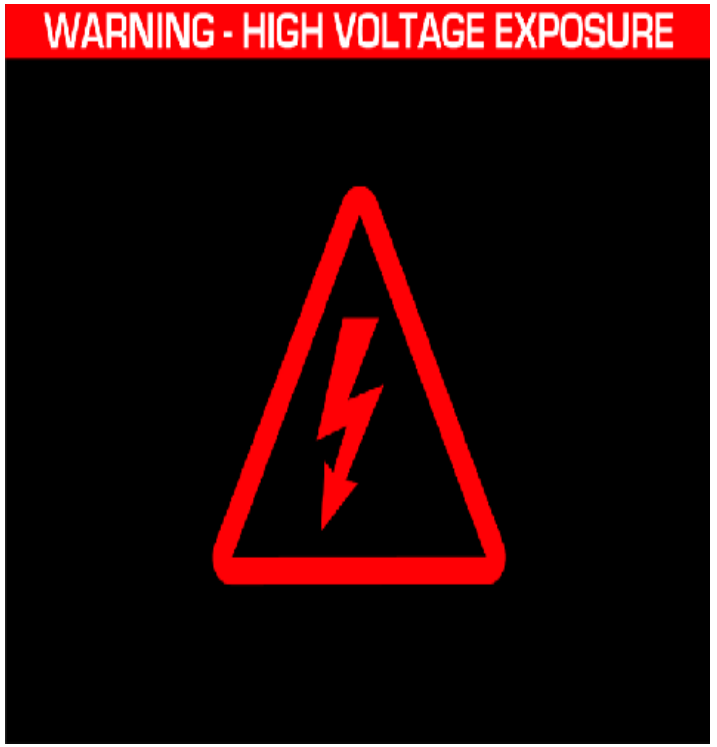
ECP STATUS: Indicates the status of the Modine ECP system efans. Indicator off is the normal status.

System Indicator Lights (MFD)

“Warning - High Voltage Exposure”

If the Cummins EV System senses a major fault, the red “EV Stop” Indicator will turn on. Once bus speed drops below 3 mph, “**Warning - High Voltage Exposure**” will fill the MFD screen. Once the bus stops, **propulsion will be disabled and** you will not be able to move the bus.

This warning may come on because a high-voltage contactor in the EV System has stuck shut, which could subject the chassis and body of the bus to the full 750 Volts DC potential of the EV Battery Packs (Isolation Fault). **If a person touches the bus and a ground, they could be electrocuted, possible fatally.**



System Indicator Lights (MFD)

ECP COOLANT LOW

The ECP Coolant (Low) indicator will turn on to warn you that the coolant for the Electronics Cooling Package is low.

ECP COOLANT TEMP

The ECP Coolant Temp indicator will turn on to warn you that the coolant for the Electronics Coolant package is overheated.

EV BATTERY COOLANT (LOW)

The EV Battery Coolant (Low) indicator will turn on to warn you that the coolant for the main high voltage EV battery packs is low

System Indicator Lights (MFD)

EV BATTERY COOLANT TEMP

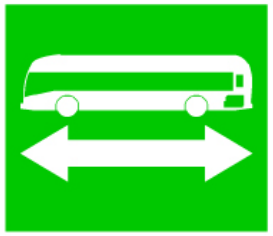
The EV Battery Coolant Temp indicator will turn on to warn you that the coolant for the for the main EV battery packs is overheated.

EV BATTERY FAULT

Lights when one or more of the six EV battery packs has been taken off-line because of an internal electrical problem.

EV PROPUSION ENABLED

This indicator means that the bus is ready to drive: the interlocks are disabled, the accelerator is enabled, and either “Drive” or “Reverse” is available.



System Indicator Lights (MFD)

EV WAIT TO START

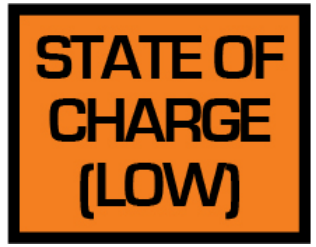
This indicator turns on when a EV System pre-starting sequence is underway. Wait until this indicator turns off before pressing the EV System Start button.

HVIL

The HVIL indicator will turn on if the High Voltage Interlock Loop has been broken.

STATE OF CHARGE (Low)

The State of Charge (Low) indicator lamp will alert you when the high voltage EV battery packs SOC has depleted to 10% or less.



System Indicator Lights (MFD)

EV READY

The “EV Ready” indicator flashes when connection is in process and turns on solid when High Voltage system is online.

EV STOP

The EV Stop indicator can turn on either Yellow or Red.

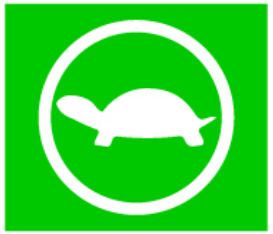
If the “EV Stop” indicator turns on **YELLOW**, along with a buzzer, it means an EV System problem has been detected and power may be restricted.

If the “EV Stop” indicator turns **RED,** along with a buzzer, the propulsion system will be disabled.

System Indicator Lights (MFD)

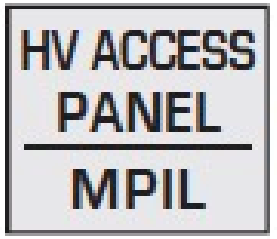
Vehicle Limited Performance Mode

If this indicator turns on, it means that the motor power requested cannot be provided due to battery temperature and/or SOC limits, and that performance may be reduced.

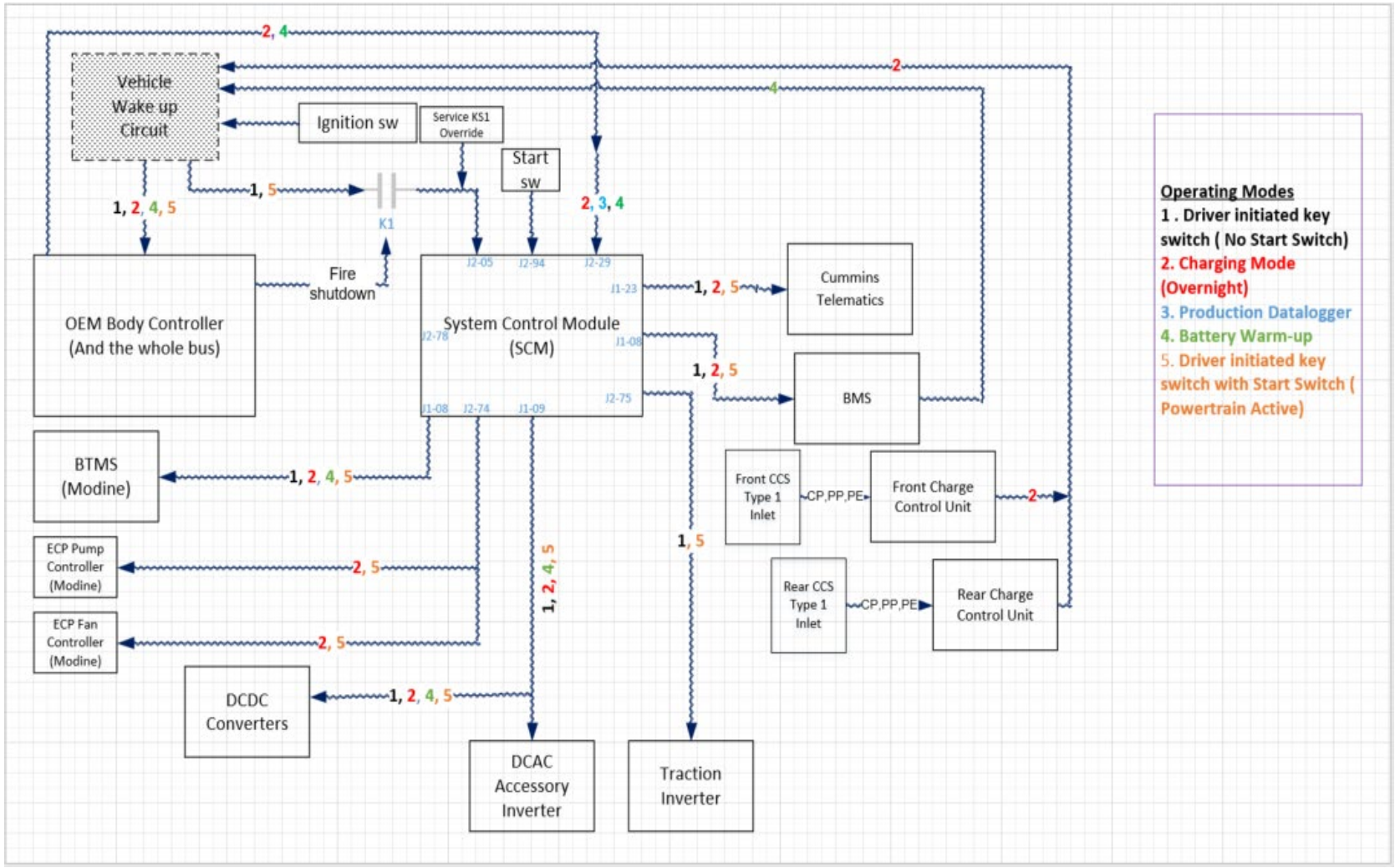


HV Access Panel

If this indicator turns on, it means that a high voltage access panel is open or an uncapped HV measurement port on the HVJB is uncapped. It can also indicate if the HV shut down switch is turned off. This indicator is a button. Press the indicator to view a full screen layout of the bus to determine what door or port is causing the issue

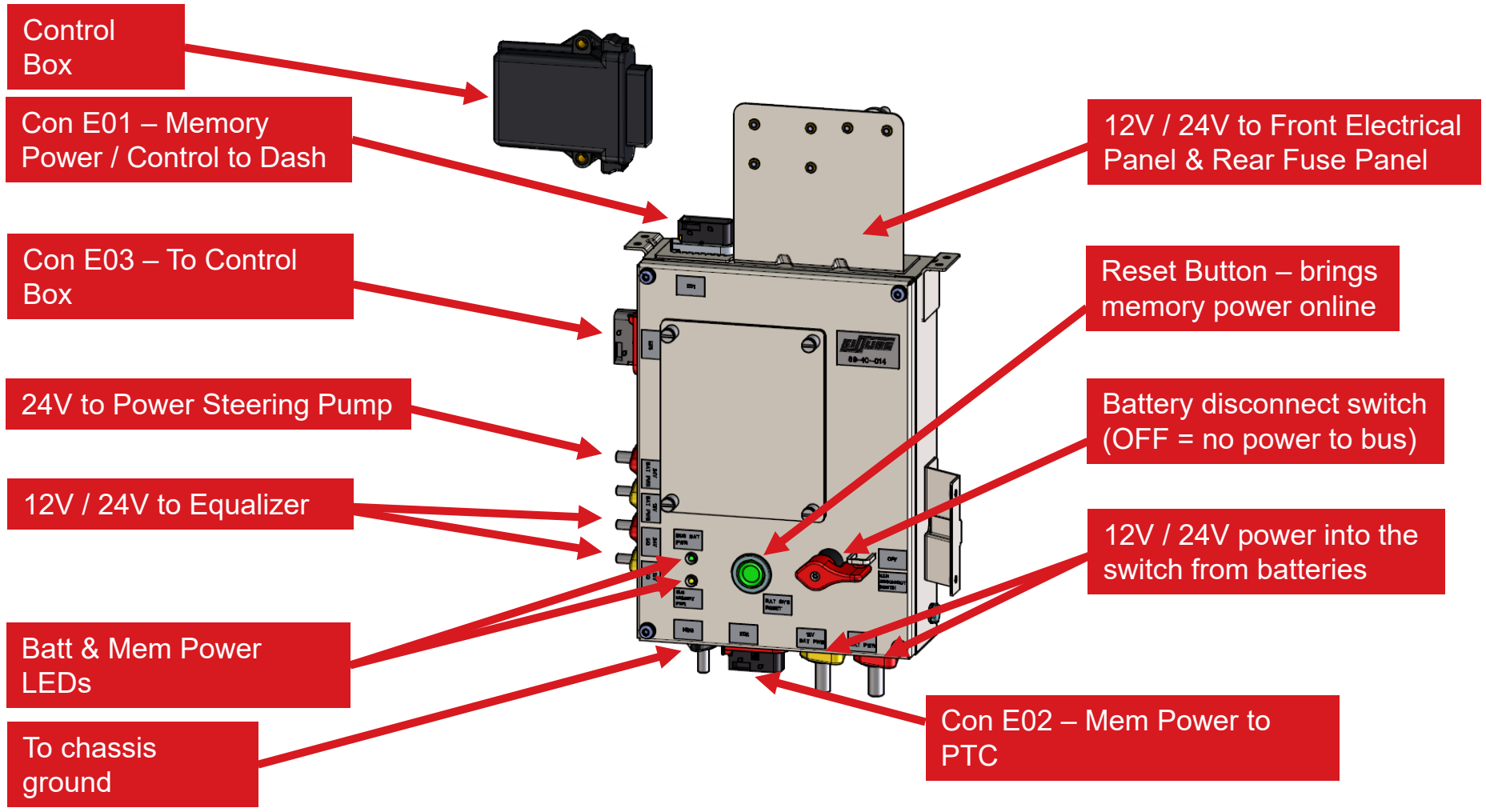


System Wake-up signal



Use GILLIG Schematics To Cover Wake Up Wiring

Power Distribution – Battery Saver / Disconnect Switch



Kissling Battery Saver – Functional Diagram

Relevant Circuits:

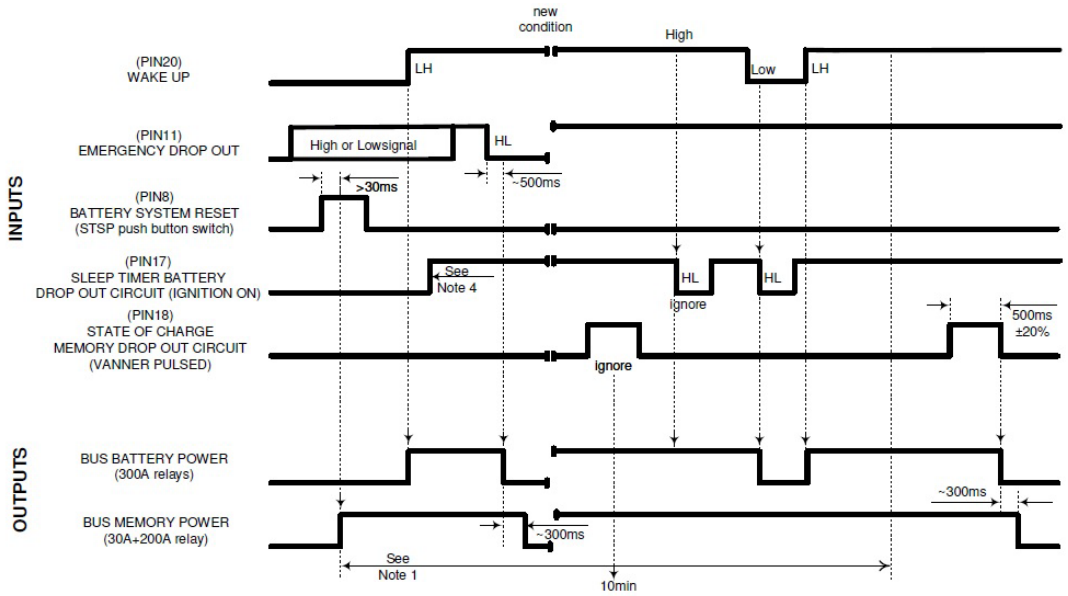
Pin 20 = IGNITION Circuit (keyswitch)
Pin 11 = BMS-BAT1A Circuit (Emergency Sw)
Pin 8 = BATT RESET Circuit (From STSP Sw)
Pin 17 = MASTER Circuit (From multiplex)
Pin 18 = LOW SOC DISC Circuit (From Vanner)

Reference Schematics:

13-76303R008 (Ignition Power Schematic)
13-76428R003 (Equalizer Schematic)
13-79756R000 (Kissling Control Box Schematic)

Power Levels:

Memory Power = SCM, BMS, Charge Controllers, dataloggers, fire detection & bell, keyswitch
Battery Power = power to front & rear electrical panels, rear fuse panel (see 13-71898R005)
Ignition Power = dedicated circuit breakers for devices that only need power with the key on



Note 1:
After pressing the STSP push button switch the impulses at pin 18 are ignored for 10 minutes.
Note 2:
When the manual disconnect switch is opened (checking voltage on pin 2 and pin 12 of the control box) and then closed the bi-stable relays are switched off (no power to the bus).
Note 3:
Pin 11 has priority over pin 20 and pin 8. The input signal from pin 20 is rising edge triggered (LH) and the input of pin 11 is falling edge triggered (HL). The other input pins are voltage-level-triggered.
Note 4:
If pin 20 has a rising edge and pin 17 do not follow after 10 seconds, we have following sequence (Battery off without pin 17): When pin 20 shows a falling edge turn off battery power after a time delay of 60 seconds.

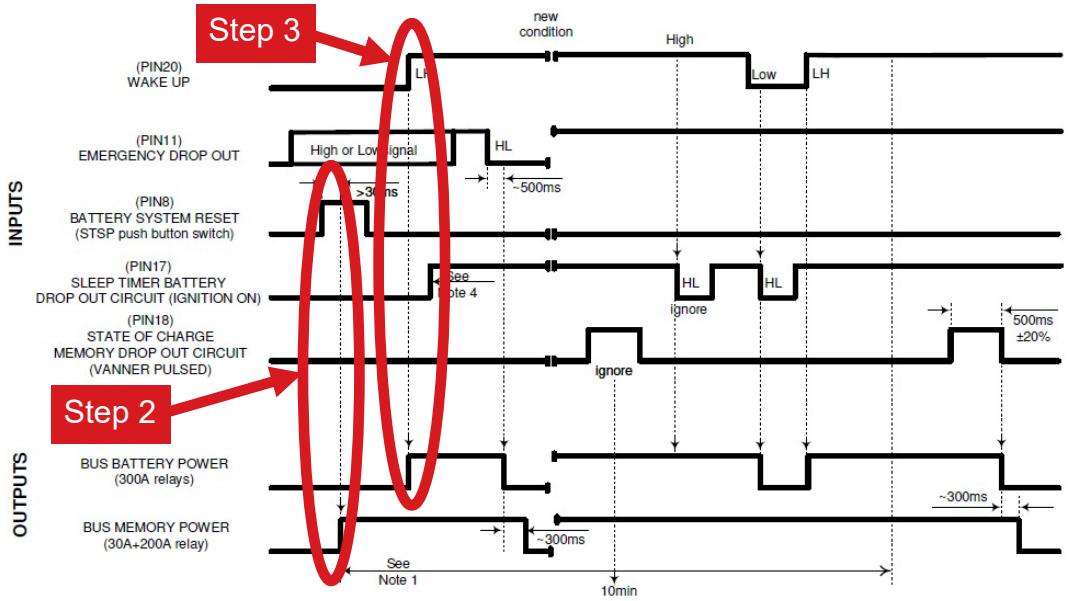
Kissling Battery Saver – Functional Diagram

Turning on the bus (typical process):

1. Turn battery saver main disconnect switch to the ON position. You may hear relays switching inside the box.

2. Press the green Bat Sys Reset push button until you hear the relays switch and the Bus Memory Pwr LED turn on. Memory power will be provided to critical powertrain system control modules, safety components, and the common of the key switches to allow for step 3 that follows.

3. Turn the front bus master run switch from OFF to Day Run and you will hear the relays coil and the Bus Bat Pwr LED turn on. Battery power will be provided to the distribution panels and the multiplex will start to power up the bus.



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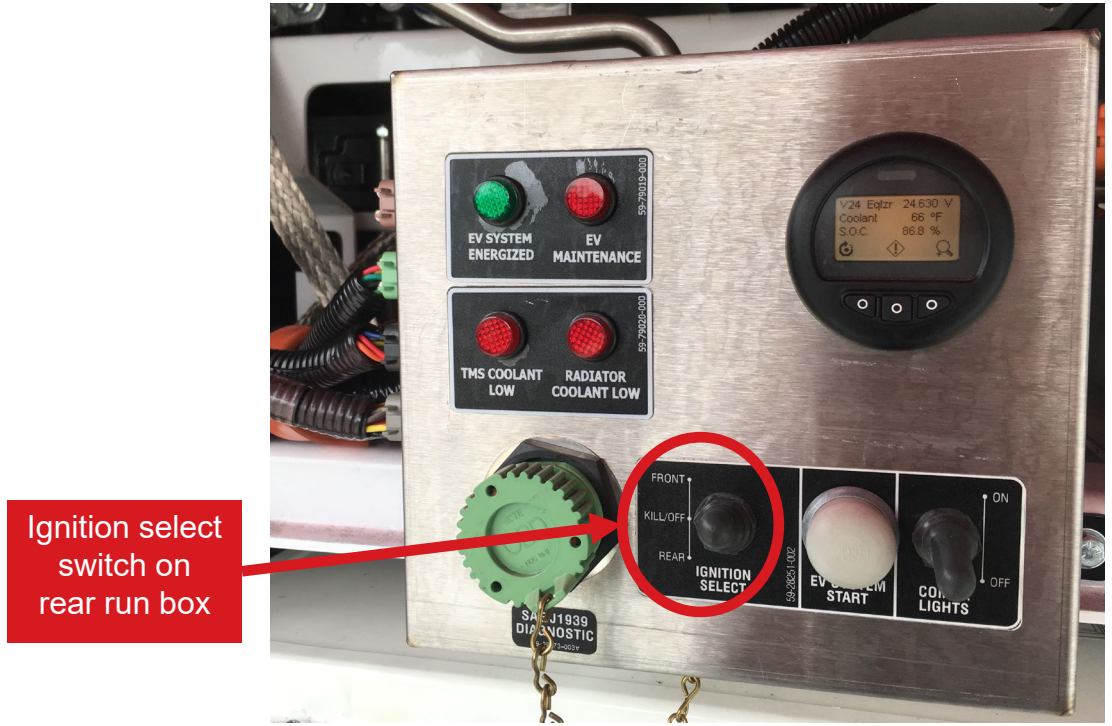
Kissling Battery Saver – Functional Diagram Continued

- Repeat steps 1 & 2 from the previous slide, but use the ignition select switch on the rear run box to select “rear ignition” and this will provide power to the powertrain, but disable propulsion and the driver’s controls at the front of the bus. This will also disable the rear door interlock switch to allow for servicing of components in the powertrain compartment.

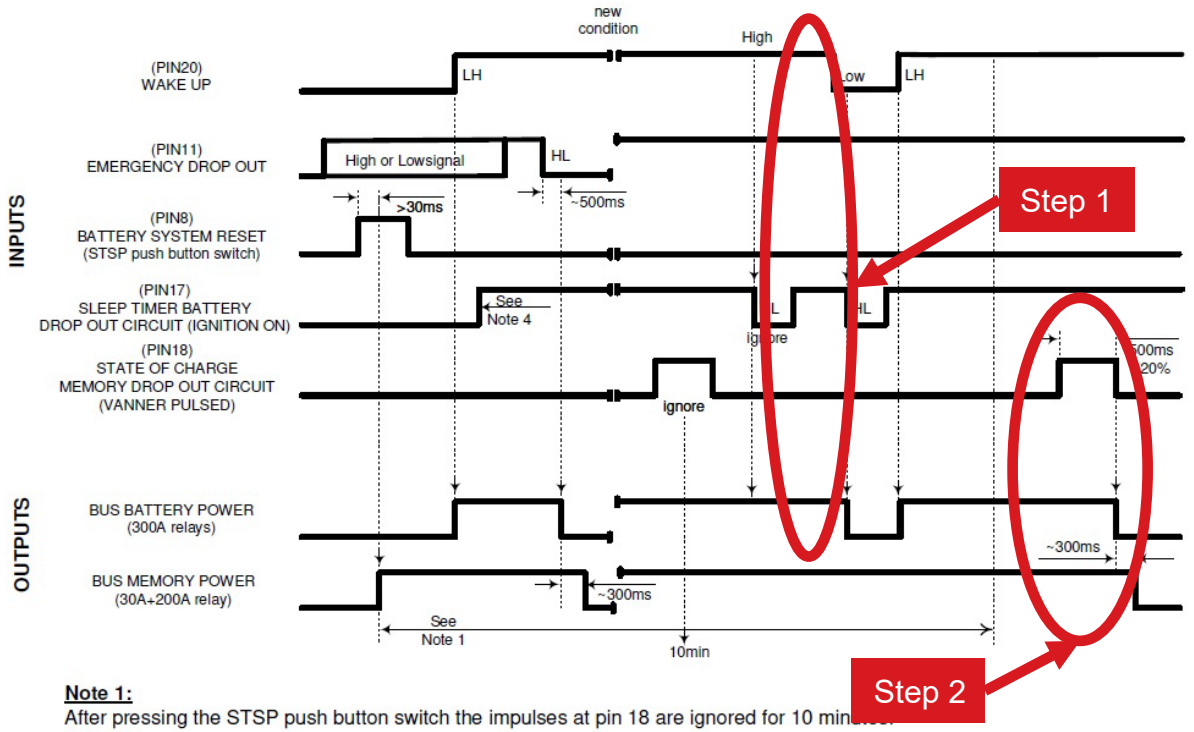


Kissling Battery Saver – Functional Diagram

Turning off the bus (typical process):

1. Turn the front bus master run switch from Day Run to OFF. The bus battery power will remain on until the multiplex sleep timer drops out. The sleep timer duration will vary by application and can be disabled at the MBC in the rear panel.

2. When the coach batteries have depleted beyond a pre-determined “low SOC” or “state of charge” threshold, the Vanner Equalizer will send a 24V pulse to the disconnect switch to drop out the memory power circuits. If battery power is still energized, then both battery and then memory power will be disconnected. This protects the batteries from deep cycling, extending battery life, and allows for a successful start up the next time the bus is needed for service.



Note 1:
After pressing the STSP push button switch the impulses at pin 18 are ignored for 10 min

Note 2:
When the manual disconnect switch is opened (checking voltage on pin 2 and pin 12 of the control box) and then closed the bi-stable relays are switched off (no power to the bus).

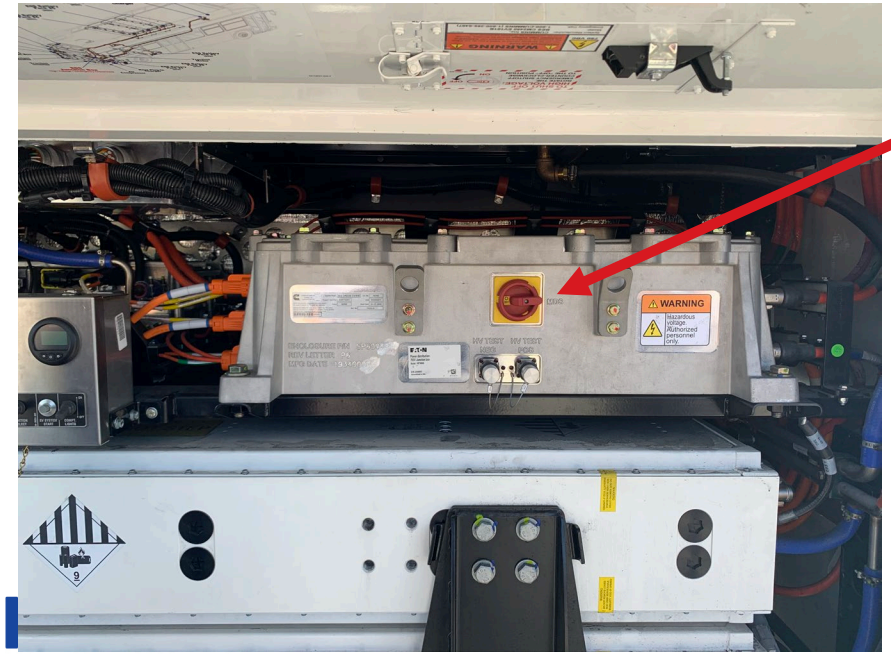
Note 3:
Pin 11 has priority over pin 20 and pin 8. The input signal from pin 20 is rising edge triggered (LH) and the input of pin 11 is falling edge triggered (HL). The other input pins are voltage-level-triggered.

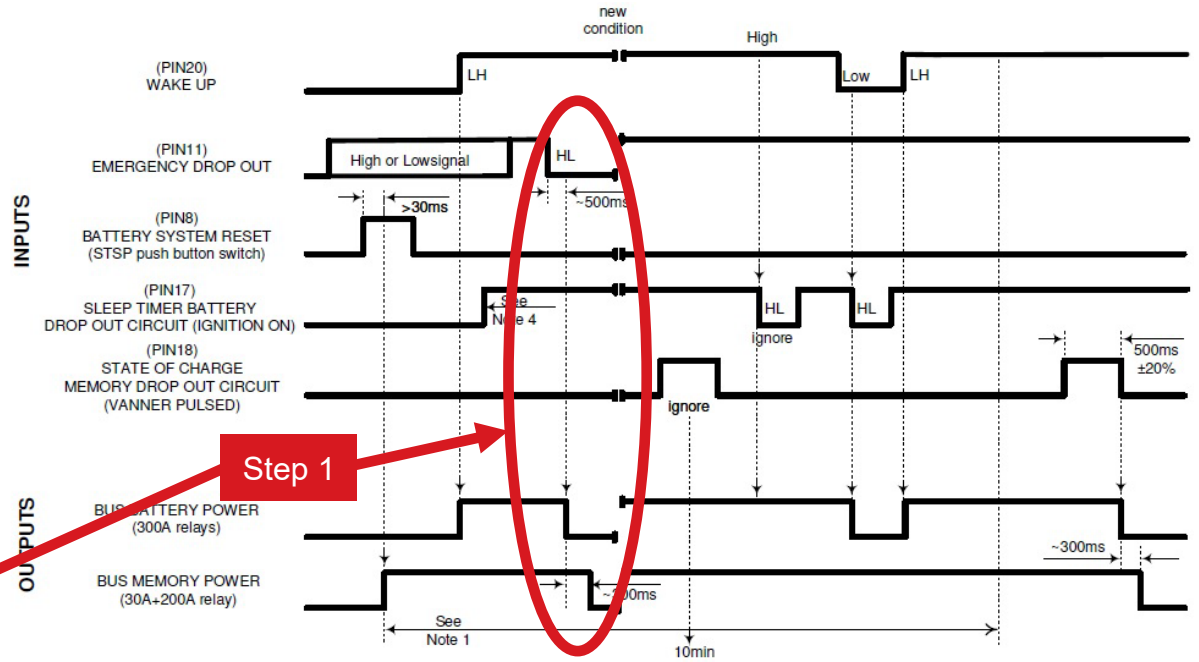
Note 4:
If pin 20 has a rising edge and pin 17 do not follow after 10 seconds, we have following sequence (Battery off without pin 17): When pin 20 shows a falling edge turn off battery power after a time delay of 60 seconds.

Kissling Battery Saver – Functional Diagram Continued

Turning off the bus (emergency process):

1. Turn the main “emergency” disconnect switch at the rear of the bus to the OFF position and the battery saver switch will first disconnect battery and then memory power. This switch is designed to only be used for emergency situations or to safely lock out the High Voltage system while allowing Low Voltage to be brought online.





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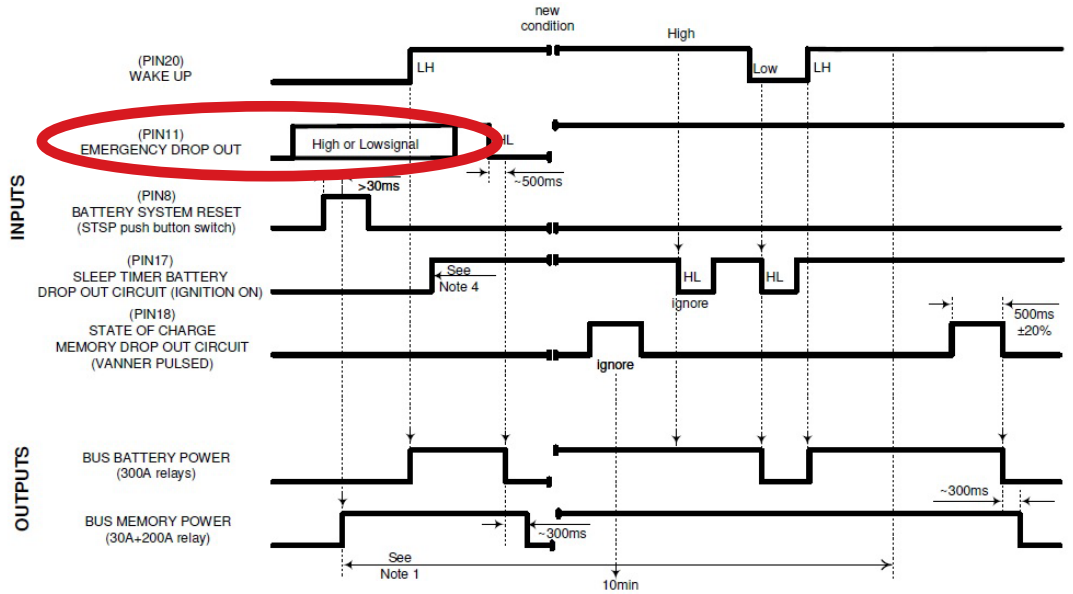
Kissling Battery Saver – Functional Diagram Continued

Turning off the bus (emergency process):

The battery saver switch only responds to a falling edge from the emergency disconnect. Therefore, it is possible to re-start the bus with the emergency switch at the rear of the bus locked out, preventing High Voltage exposure while allowing Low Voltage to be brought online to service the bus.



Pin 11 is only falling edge triggered.

Note 1:
After pressing the STSP push button switch the impulses at pin 18 are ignored for 10 minutes.
Note 2:
When the manual disconnect switch is opened (checking voltage on pin 2 and pin 12 of the control box) and then closed the bi-stable relays are switched off (no power to the bus).
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If pin 20 has a rising edge and pin 17 do not follow after 10 seconds, we have following sequence (Battery off without pin 17): When pin 20 shows a falling edge turn off battery power after a time delay of 60 seconds.

Regenerative Braking

- Regenerative braking is an energy recovery mechanism which slows the vehicle by applying a negative torque to the propulsion motor which inherently turns the propulsion motor into an electrical generator to charge the HV batteries.

Regenerative Braking

- **Operation**
  - Regen braking is activated when the driver gets to a lower percent of acceleration and increases up to zero accelerator pedal position. Vehicle slows down and energy is being recuperated.

- **Limitations**
  - Regenerative braking is dependent on the battery's state - the following will limit regen-braking
    - ➢ High battery temperatures
    - ➢ Low battery temperatures
    - ➢ High battery state of charge (> 90% SOC)

  - If Regen-braking is limited, the driver display will project a message stating "Regenerative braking is limited"

High Voltage Cables

750 VDC

WARNING

HAZARDOUS VOLTAGE

You will be severely injured or killed if you do not follow the procedure. Components marked with ***DANGER*** or ***WARNING High Voltage*** should be avoided. Service must be performed by qualified personnel only.

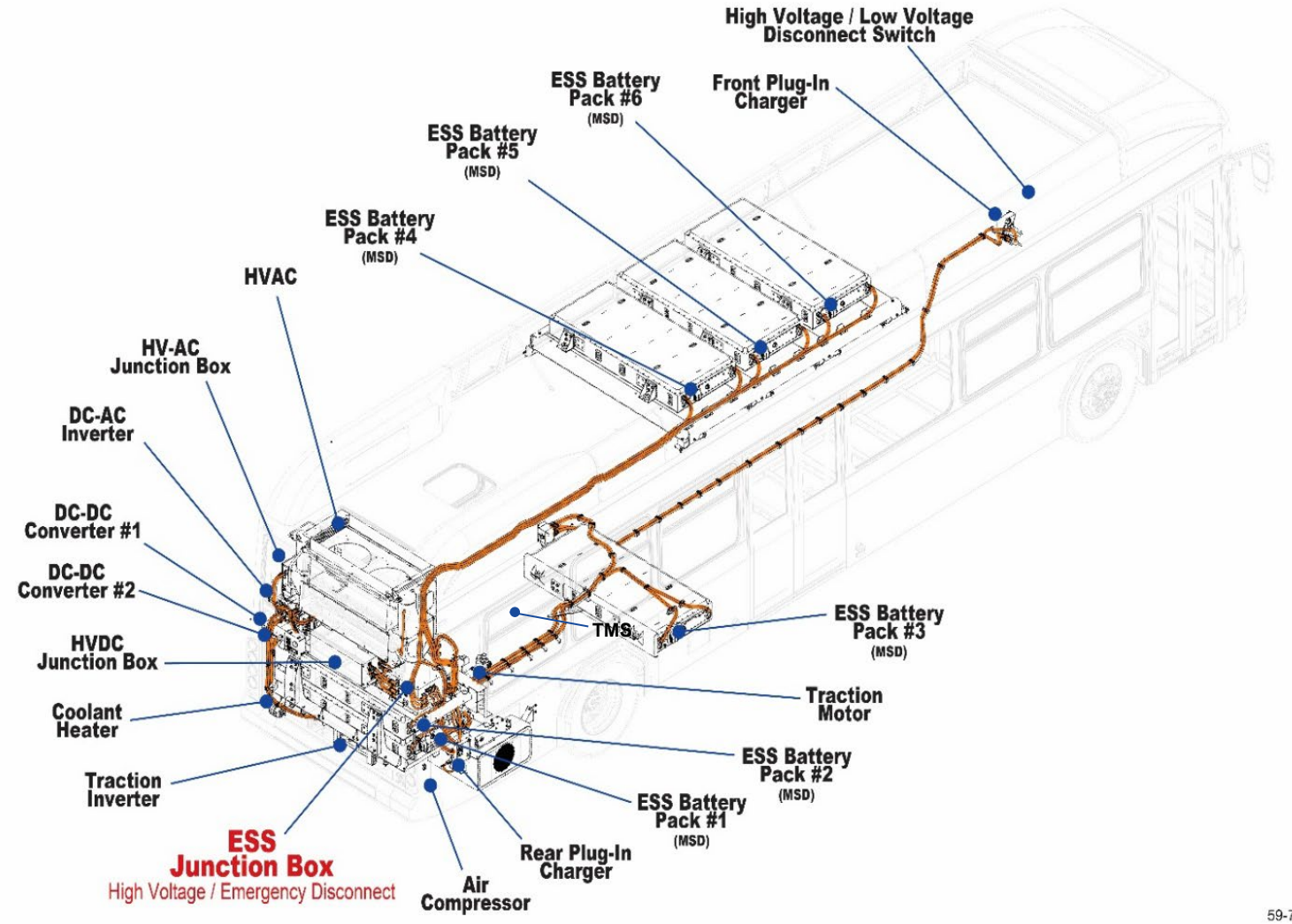
System Manufacturer: **CUMMINS Inc.**

Model: **BES CM2450 EV101B**

Emergency Call: **1-800-CUMMINS (1-800-286-6467)**

LEGEND

- High Voltage Cables are indicated by an **Orange highlight.**
- High Voltage Components are indicated by **Black lines.**



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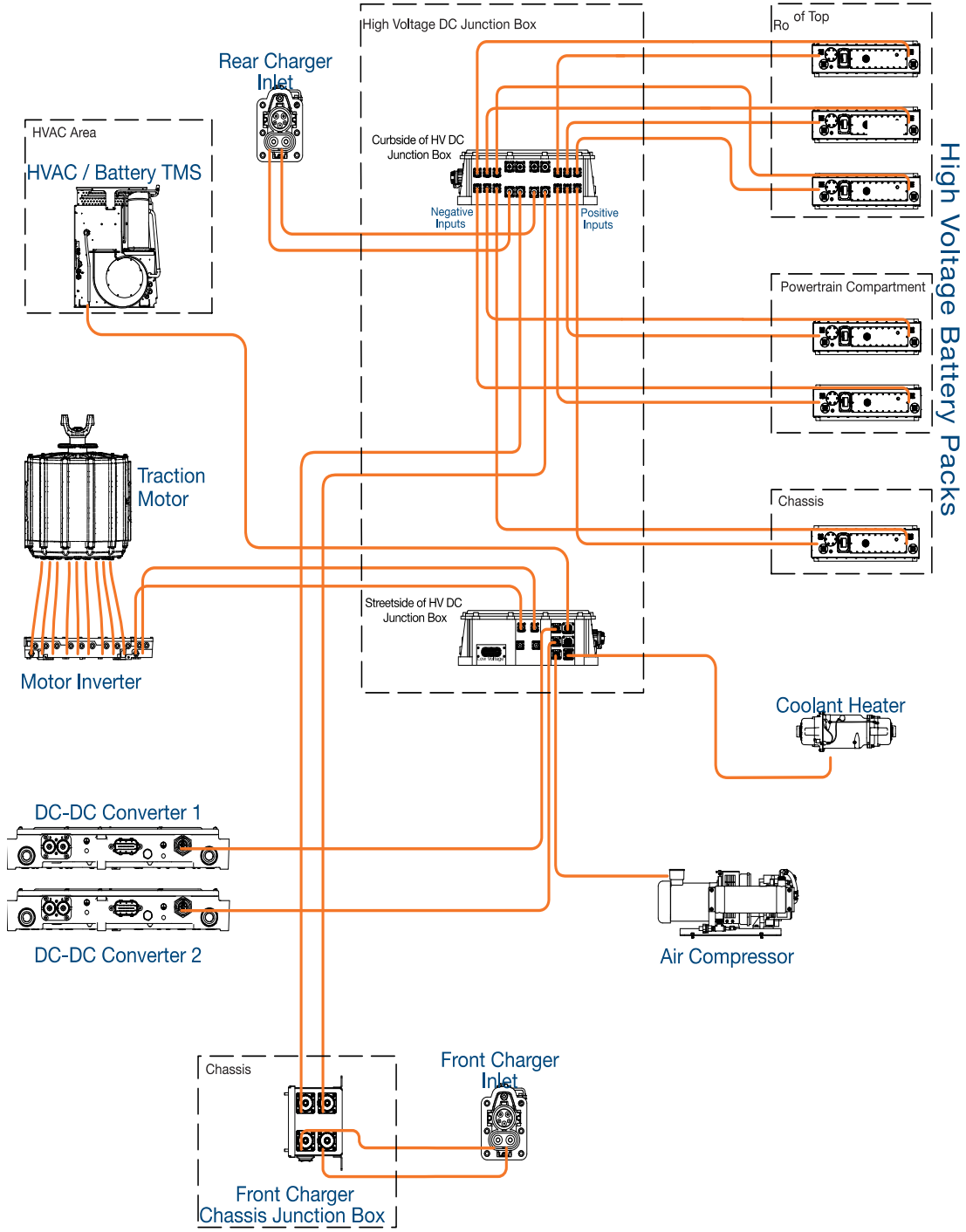
High Voltage Cables



High Voltage Cable Inspection

GILLIG LOW FLOOR

HIGH-VOLTAGE CABLE INSPECTION

High-voltage cables need to be inspected regularly, at least twice a year. Exposed or damaged high-voltage cables pose a hazardous condition.

NOTICE

GILLIG Battery Electric buses involved in a crash or fire, or which have been submersed in water, should be considered potentially hazardous until the high-voltage electrical system can be inspected by a qualified technician.

Inspection

Lockout/Tagout the low-voltage and high-voltage system before inspecting high-voltage cables. Allow **ten minutes** for EV system components to discharge electricity before inspection.

Inspect high-voltage cables for the following:

- Cuts, nicks, holes, crushed, pinched, kinked, or any damage or irregularities in the orange HV cables.
- Exposed high-voltage cable shielding, especially near connectors. If damage is found, the HV cable must be replaced to prevent moisture from entering HV cables and components
- Damage to the HV cable jackets. If damage is found, the HV cable must be replaced.

CAUTION

Moisture entry into high-voltage cables can cause system faults and inability to work properly.

Repairing High-Voltage Cables

Minor damage to high-voltage cables can be repaired with orange, self-bonding, high-voltage tape rated to 750 V minimum. Perform high-voltage insulation testing on repaired cables with an insulation meter to prevent loss of electrical properties.

Avoid the following when working with high-voltage cables:

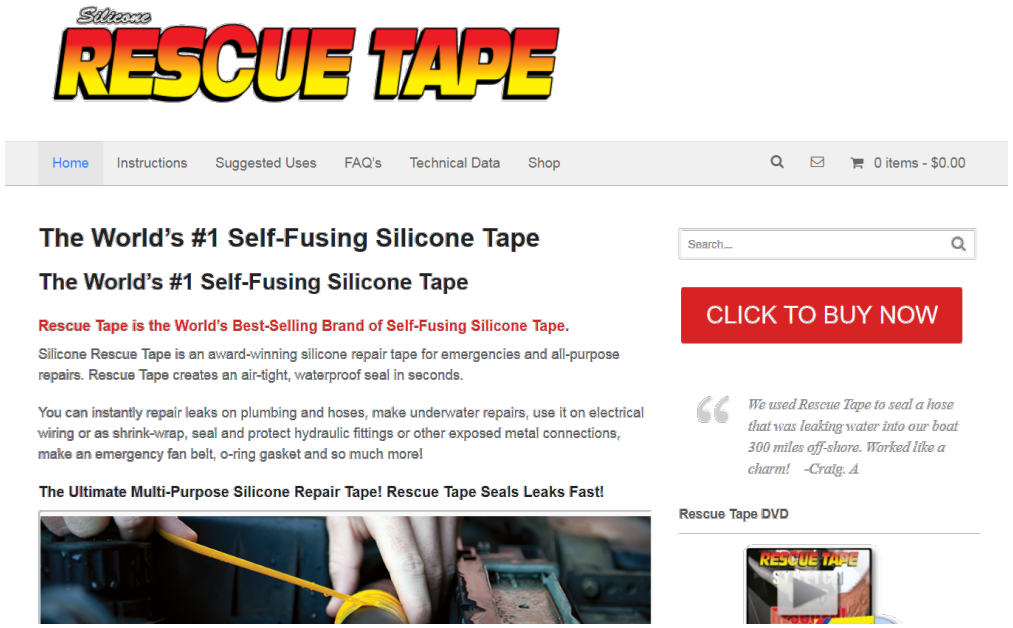
- Excessive cable "puckering" See Figure 4-23, and Figure 4-24.
- High-voltage cables rubbing against each other. Improper high-voltage cable clamping; pinching or damaging the cable jacket.
- Braided stainless steel ground straps rubbing other wiring or vehicle components. Ground straps must be free of any obstructions.

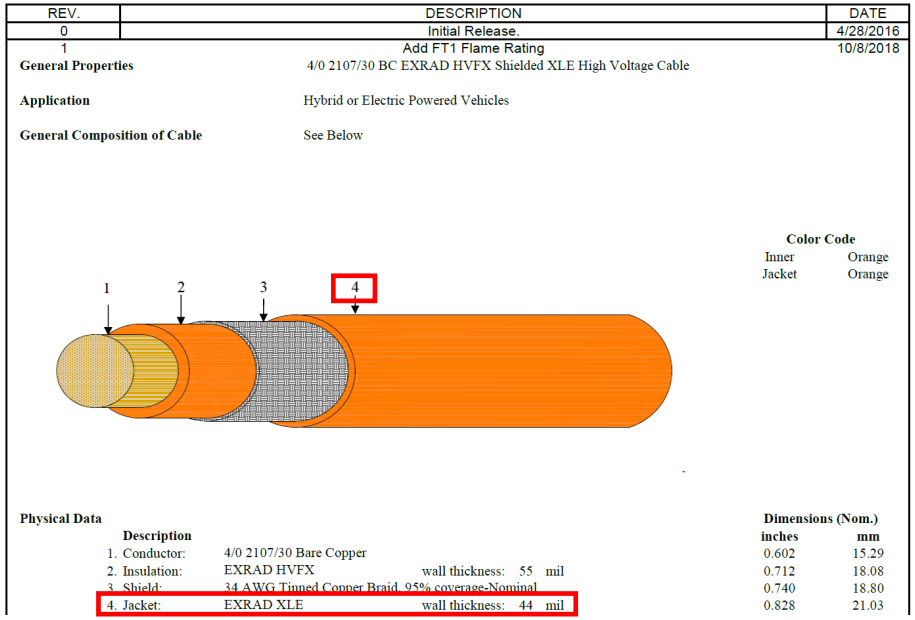
Figure 4-23, Acceptable Cable Puckering

Figure 4-24, Not Acceptable Cable Puckering

High Voltage Cable Repair

- ONLY for “minor” damage to jacket (outer layer)!
  - Minor nicks, cuts, abrasion, deformation to the jacket layer only
  - NOT for severe cuts or cable damage ← replace cables
  - Tape sample below





REV.	DESCRIPTION	DATE
0	Initial Release.	4/28/2016
1	Add FT1 Flame Rating	10/8/2018

General Properties 4/0 2107/30 BC EXRAD HVFX Shielded XLE High Voltage Cable

Application Hybrid or Electric Powered Vehicles

General Composition of Cable See Below

Color Code

Inner	Orange
Jacket	Orange

Physical Data

	Description		Dimensions (Nom.) inches	mm
1.	Conductor: 4/0 2107/30 Bare Copper		0.602	15.29
2.	Insulation: EXRAD HVFX	wall thickness: 55 mil	0.712	18.08
3.	Shield: 34 AWG Tinned Copper Braid, 95% coverage-Nominal		0.740	18.80
4.	Jacket: EXRAD XLE	wall thickness: 44 mil	0.828	21.03

Isolation Detection Review

- Essential for HV safety
- **Most severe faults in HV system will be caught by isolation detection**
  - **Coolant leak in high voltage packs**
  - **Severely damaged or cut high voltage cables**
  - **Damage to high voltage systems due to crash or impact**
- Performed inside Cummins ESS Battery Packs
  - Each pack can perform isolation detection, only one pack checks at a time
- Frequently measures resistance between
  - HV+ and chassis
  - HV- and chassis
- If resistance above 500 Ohms/volt, then no problem
- If resistance between 100 Ohms/volt and 500 Ohms/volt, then sets warning light and disables high voltage and propulsion when the vehicles comes to a stop.

Lockout-Tagout

GILLIG's Lockout/Tagout (LOTO) Program Policy

Procedures Involving More Than One Authorized Person

If more than one individual is required to Lockout/Tagout out equipment, each shall place their own personal lockout device on the energy isolating device(s). When an energy isolating device cannot accept multiple locks and tags, a multiple lock out HASP will be used.

In a group setting: If lock out is required, a single lock may be used to lock out the equipment with the lock's key being secured on one responsible person who will take ownership for everyone's personal safety. This key will be in their possession until the job task has been completed and all LOTO has been removed.

GILLIG's Lockout/Tagout (LOTO) Program Policy

Basic Rules for Using Lockout/Tagout Procedures

1. All equipment shall be locked out or tagged out to protect against accidental or inadvertent operation when such operation could cause injury to personnel.

2. Do not attempt to operate any switch, valve, or other energy isolating device when it is locked and tagged out.

3. Never try to repair or perform maintenance on any piece of equipment without locking and tagging it out ALL Energy Control Points (ECP's) first.

4. Do not touch or operate any piece of equipment unless trained and authorized to do so.

5. Do not touch anything that is locked out and tagged out unless you are responsible for working on it and are sure the energy has been disconnected.

GILLIG's Lockout/Tagout (LOTO) Program Policy

Removal of a Lockout Device

Only an authorized employee can remove their own lock and tag from any energy control points, to restore the operating functions to that particular piece of equipment but after they re-installed all guards and safety devices to it first.

However, should any authorized employee leave the facility before removing their lock and tag first, the safety manager is the ONLY authorized individual who may remove the authorized employee's lock and tag but only after all guards have been re-installed and the proper notification to that employee has been made first prior to the removal of the lock.

LOTO (Lockout / Tagout) Battery Electric Bus Procedures

High-Voltage LOTO Summary

	Type 1 HV LOTO	Type 2 HV LOTO
PPE and Tool Requirements (see pages 35–43 for details about when and how to use each of these items)	• Fluke 87 or Fluke 88 Industrial Multimeter or equivalent Cat III 1,000 Volt rated multimeter with alligator clips and probes (Figure 1-3). • Fluke 1587 Insulation Multimeter with narrow style tips (Figure 1-4). • 1,000-volt rated rubber gloves worn underneath leather protector gloves (Figure 1-5). • 8 LOTO locks with 1.5" shanks with LOTO tags for each lock. • 2 LOTO hasps. • 6 BLOTO battery locking device (GILLIG P/N 83-04679-000).	Same as Type 1
Summary of Procedures (see pages 35–43 for complete instructions)	• Step 1 Verify meter function. • Step 2 Verify test port function. • Step 3 Turn off high-voltage sources and verify high voltage is disconnected and the high-voltage system is de-energized. • Step 4 Verify meter function again. • Step 5 Install LOTO lock and tag on the HV Disconnect Switch.	Same as Type 1 + • Step 6 Removes battery pack MSDs and installs BLOTO (battery LOTO) lock and tag on the HV batteries.

Figure 1-3, Digital Multimeter

Figure 1-4, Insulation Multimeter

LOTO (Lockout / Tagout) Battery Electric Bus Procedures

WARNING

HV PPE is required until the HV LOTO has been completed. This PPE is listed below in the HV LOTO procedures.

Once the required type of LOTO is completed, the vehicle is safe for all approved repair or replacement procedures.

Step 0: Before starting LOTO

a. Park in a safe location.

b. Confirm no HV chargers (plug-in, pantograph, inductive) are connected to the vehicle.

c. Select neutral on the push-button shift selector and apply the parking brake.

d. Turn the Master Run Control to the OFF position.

e. Confirm the Main Disconnect Switch (12/24V) is in the "ON" position. Do not yet turn off the Main Disconnect Switch (12/24V).

f. Ensure that you have **1,000V rated HV rubber gloves** (see red tag on glove); the color of the gloves does not matter as long as they are tagged with this rating (Figure 1-5).

g. Ensure that the rubber gloves have not expired (labeled test date + 6 months = expiration date). Rubber gloves must be replaced every six months.

h. Ensure that you have a pair of leather gloves to wear over the rubber gloves.

i. **Glove Air Leak Inspection:** Grab the glove at the bottom and roll it tight until you see that the fingers are expanded and full of air. Put your ear close to each finger and squeeze the glove and listen for air leaks. If there are no air leaks, then the glove is safe to use.

Figure 1-5, HV Rated Gloves

LOTO (Lockout / Tagout) Battery Electric Bus Procedures

Step 1: Verify the Fluke 87/88 multimeter is functioning properly

a. Confirm both multimeters are in the "OFF" position.

b. Connect the Negative (Black) leads from each multimeter together using the alligator clips (Figure 1-6).

c. Connect the Positive (Red) leads from each multimeter together using the alligator clips.

d. Ensure the positive and negative probes do not contact each other.

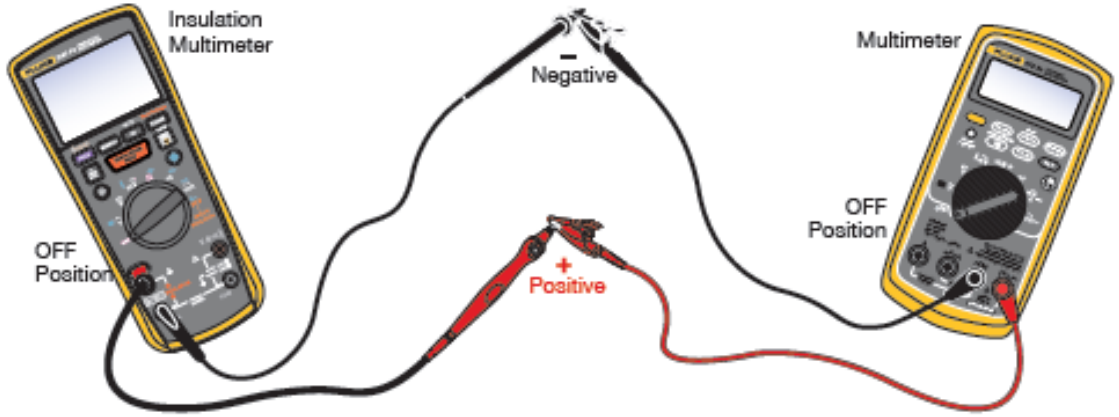


Figure 1-6, Leads Connected

e. Set the Fluke 87/88 multimeter to DC voltage setting and change the range to 1,000-volt.

f. Rotate the dial on the Fluke 1587 Insulation Multimeter setting clockwise to the last position: "50 volt to 1,000-volt INSULATION."

g. Press the "Range" button on the 1587 Insulation Multimeter until 1,000VDC is shown on the display as shown in Figure 1-7.

Figure 1-7, 1,000V Test

LOTO (Lockout / Tagout)
Battery Electric Bus Procedures

h. Press and hold the orange "Insulation Test" button until the voltage appears in the display window. Confirm both meters read the same voltage which should be close to 1,000 volts Figure 1-8).

i. This confirms the Fluke 87/88 meter is working correctly.

Figure 1-8, Verify Multimeter is Functioning Properly

LOTO (Lockout / Tagout) Battery Electric Bus Procedures

Step 2: Verify Test Port Function

Note: For this step, only use the **Fluke 87/88 Industrial Multimeter.**

a. Open the rear PTC door to gain access to the HV DC junction box (Figure 1-9).

b. On the HV DC junction box, unscrew the NEG and POS caps on the measurement ports.

c. Locate the "C" terminal ports on both the NEG and POS measurement ports (Figure 1-10).

d. One at a time, insert the black meter probe (NEG) into the NEG C port and then the red meter probe (POS) into the POS C port (Figure 1-10).

e. Make sure the probes can stay in the test ports by themselves.

f. Confirm the meter reading is less than 5VDC.

g. On the rear run box, move the Ignition Select switch from "Front" run to the "Rear" position.

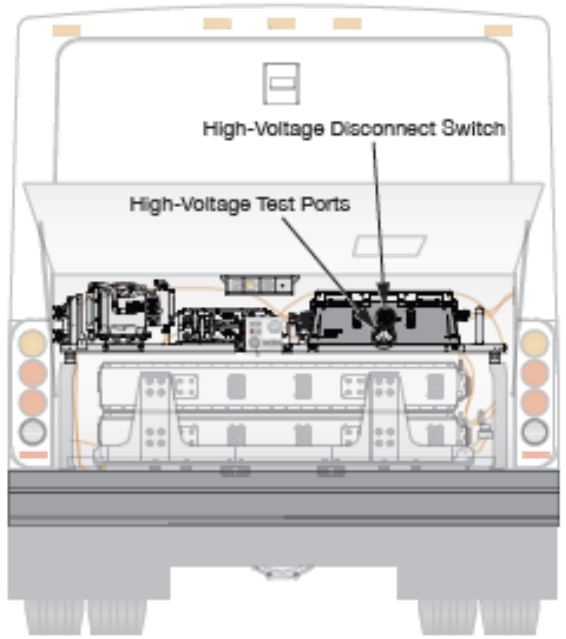


Figure 1-9, High-Voltage DC Junction Box Location

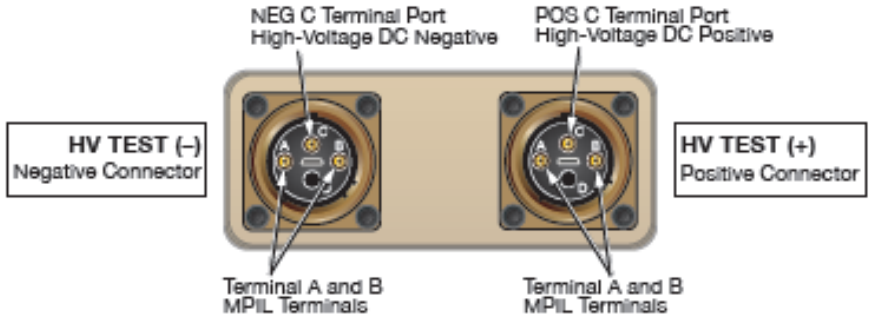


Figure 1-10, HV Test Ports on High-Voltage DC Junction Box

h. Wait 10 seconds.

i. Press the EV System Start button for 1 second.

j. Confirm the "EV System Energized" indicator turns on solid (this mean HV is online).

k. Confirm the meter reading is at least 600VDC.

l. Continue to leave the probes connected to the test ports and move to step 3.

GILLIG

LOTO (Lockout / Tagout) Battery Electric Bus Procedures

WARNING

If the meter reading is NOT at least 600VDC, STOP!

- **Move the Ignition Select switch to the KILL/OFF position and repeat steps 2.g through 2.k.**
- **If the meter reading is still not at least 600 VDC, DO NOT PROCEED!**
- **Identify the bus to prevent access and contact GILLIG or Cummins for instructions.**

DO NOT PROCEED if you failed to carry out any of these steps.

DO NOT PROCEED if any of the results does not match the expected result in the procedure.

Step 3: Turn Off High Voltage and Verification of High-Voltage System de-energization

Note: For this step, only use the **Fluke 87/88 Industrial Multimeter.**

a. On the rear run box, move the Ignition Select Switch from "REAR" to "KILL/OFF" position. This will shut down the bus.

b. On the meter, the voltage reading should drop to 5 Volts or less within 60 seconds.

c. Continue to watch the meter reading to make sure the voltage consistently stays below 5VDC.

d. On the HV DC Junction box, turn the Manual Disconnect Switch (MDS) to "OFF".

e. Confirm the voltage reading on the meter is still below 5VDC.

WARNING

If the meter reading is GREATER than 5 volts – STOP! DO NOT PROCEED!

- **Identify the bus to prevent access and contact GILLIG or Cummins for instructions.**

Step 4: Verify the Fluke 87/88 multimeter is functioning properly

a. Remove the meter probes from the measurement ports and repeat Step 1 to verify that the meter is still working as intended.

WARNING

If the meter is not working correctly, locate another meter, confirm function and recheck for 5 Volts or less on the measurement ports (repeat Steps 1 through 4).

If the meter reading is GREATER than 5 volts – STOP! DO NOT PROCEED!

- **Identify the bus to prevent access and contact GILLIG or Cummins for instructions.**

LOTO (Lockout / Tagout) Battery Electric Bus Procedures

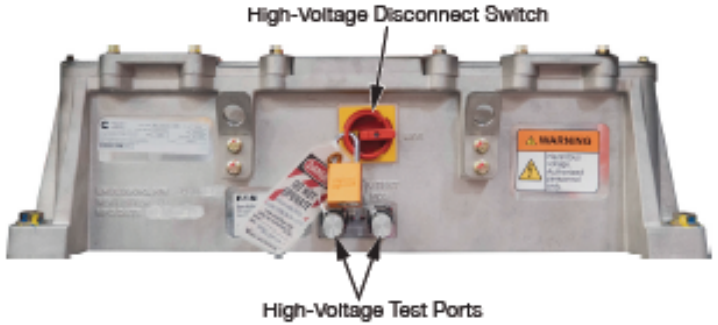


Figure 1-11, Locked and Tagged High-Voltage DC Junction Box

Step 5: Install LOTO Lock and LOTO Tag

a. Apply the LOTO lock to the HV Disconnect Switch (Figure 1-11) to lock the switch in the "OFF" position.

b. Apply the LOTO tag to the LOTO lock.

c. If required, to allow multiple LOTO locks, install a hasp when installing the LOTO lock

d. In the low-voltage battery compartment, turn the Main Disconnect Switch (12/24V) to the "OFF" position (Figure 1-12).

e. Install LOTO lock on the Main Disconnect Switch (12/24V) to lock it in the "OFF" position.

f. Apply the LOTO tag to the LOTO lock on the Main Disconnect Switch (12/24V).

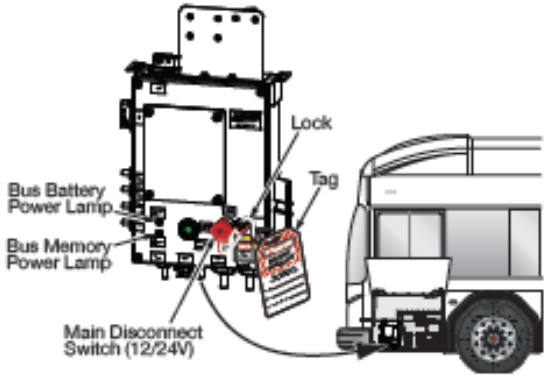


Figure 1-12, Locked and Tagged Main Disconnect Switch (12/24V)

This completes all the steps required for Type 1 HV LOTO.

NOTICE

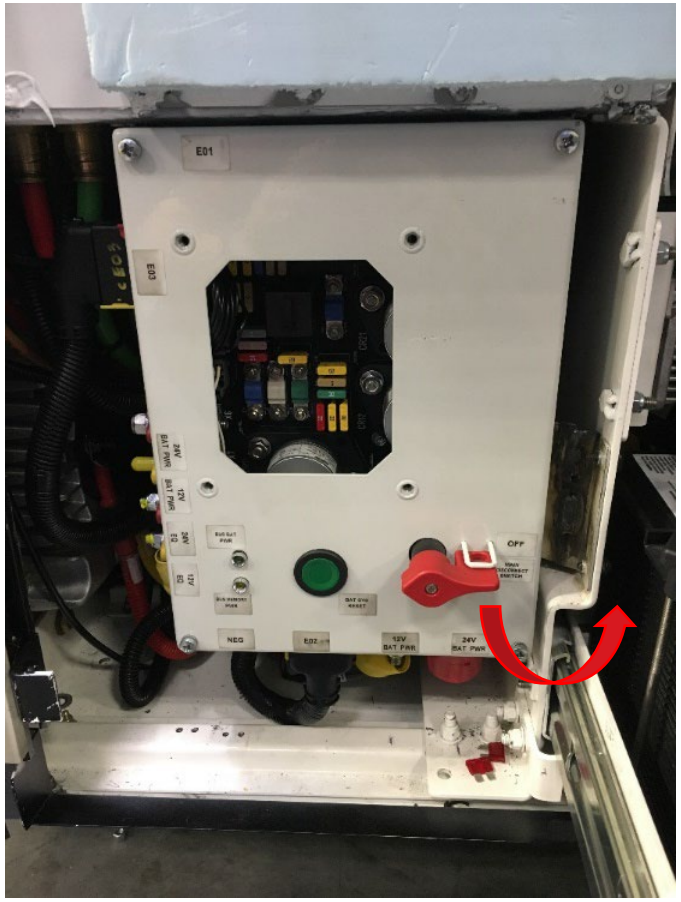
If Type 2 high-voltage battery LOTO is required, proceed to Step 6.

CAUTION

Never attempt to open, repair, or perform maintenance on the High-Voltage DC Junction Box. If a failure occurs, contact GILLIG or Cummins.

GILLIG

Main Service Disconnect (MSD)



Description

- Location: Driver's side
- Disconnects low voltage
- Rotate switch counterclockwise to disconnect low voltage
- Use a padlock to lockout LV disconnect switch during a service event

Manual Service Disconnect (MSD)

Description

- Location: On the High voltage battery pack
- The MSD provides a safe, reliable solution to manually disconnect the HV battery system
- MSD Lockout tool should be used to lockout the MSD receptacle
- Before removing the MSD, make sure low voltage is shut-off and locked out.
- Breaks HVIL
- To remove the MSD, use the following:
  - Hold down the MSD lever to release the receptacle locking feature
  - Rotate the MSD lever back by 90
  - Disconnect the MSD from the receptacle pins
  - Remove the MSD and store in a safe place

Cummins Battery Pack Hardware

Equipment shown, on the left is the

“Lockout / Tagout device and its referred

to as “BLOTO” and on the right is the MSD device.

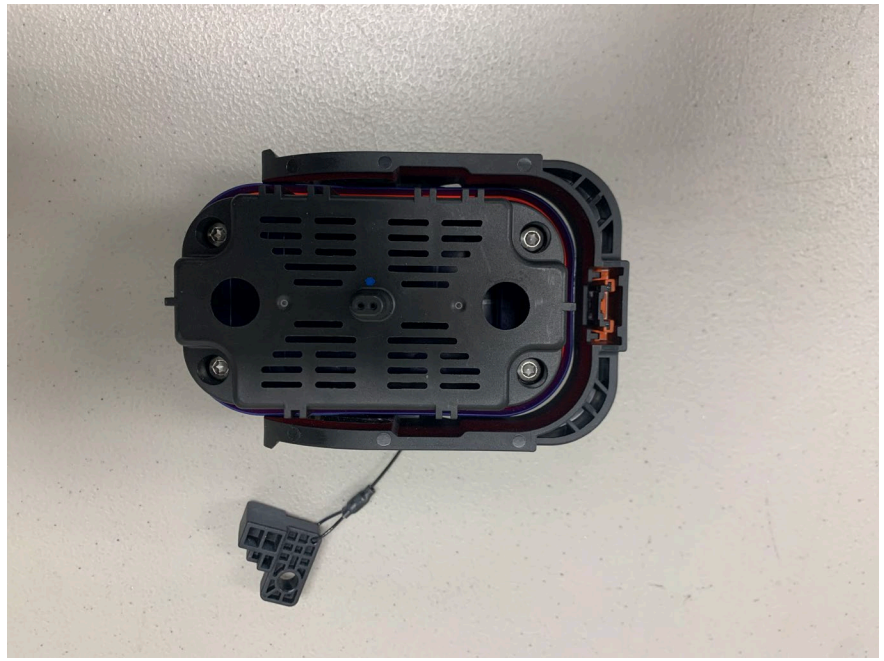
- The Manual Service Disconnect (MSD) is manually removeable and linked to the high voltage in the ESS batteries.
- When the MSD is disconnected there is no path for current to flow out of the ESS battery pack.
- The MSD has a latch that must been disengaged to remove the MSD
- The MSD is part of a high voltage interlock loop (HVIL). Taking out the MSD opens the HVIL thus disabling the high voltage
- The MSD should be removed from all ESS packs present on the vehicle only whenever maintenance needs to be performed on parts of the high voltage system

- **NOTE: The MSDs have a lifetime of 500 insertion/removal cycles**

Lithium Ion Battery BLOTO Procedure

Battery Lockout Tagout (BLOTO) Procedure

1. Place the BLOTO module and the padlock next to the battery.
2. Install the BLOTO module as shown in the pictures below.
3. Install padlock on BLOTO and provide key to the department’s supervisor.



LOTO (Lockout / Tagout) Battery Electric Bus Procedures

Testing – Follow the steps in order;

CAUTION: All ESS battery packs are connected in parallel. As a result, the MSDs for **ALL** ESS battery packs must be exchanged with the Cummins MSD LOTO Device (BLOTO) whenever any work is done on the high voltage system.

The entire high voltage system up to and including the cable side connections on the ESS battery packs is now in an electrically safe work condition.

Ebus Power up procedure:

- The first step is to install all of the MSDs from all 6 batteries (3 on roof, 2 in PTC, and one in chassis)
- Turn the High Voltage Junction box rotary switch to the on position
- Turn the Kissling red rotary switch to the on position, then press the green button that is to the left of the red on/off knob
- Turn the rear run Kill switch up to the front position
- Go inside the bus and turn the master run switch to the ‘on’ position
- Press the EV system start button on the dashboard
- Repeat the safety steps on probing HVJB junction ports and you should see HV 600-750 VDC

Potential Failure Modes

Symptoms: Unable to close contactors at key-on

Failure modes:

- High Voltage Interlock (HVIL) Failure Diagnostic
- ESS Isolation Diagnostic
- Datalink Diagnostics
- Low battery SOC
- Shifter Not in Neutral
- Communication Issue
- Rear Ignition Switch In Kill Position
- Emergency Disconnect Switch In OFF Position
- Engine Or Side Access Doors Open

What is High voltage interlock loop (HVIL)?

- The High Voltage Interlock Loop (HVIL) is a single circuit which is connected in series through every high voltage connection (Except ESS's) on the vehicle and through every lid switch
- /connection on a high voltage component.

- The HVIL system starts and ends inside the SCM (System Control Module). The SCM sends out a low voltage signal (12 Volt) on one wire of the HVIL loop and measures the voltage on the other wire.

- If any high voltage connection or lid to a high voltage component is removed, the HVIL loop will be broken, the SCM will measure an open circuit, and the high voltage contactors in the system will be opened, isolating all high voltage to the HV battery packs.

- HVIL within high voltage connections are typically, but not always, "last make/first break", meaning the HVIL loop will close after any high voltage connections are made and before any high voltage connections are opened, ensuring that the high voltage connections are never made or broken under current flow conditions.

HVIL Failure Diagnostic

- FC8173 : HVESS HVIL Status - Voltage Above Normal or Shorted to High Source.
- FC8174 : HVESS HVIL Status - Voltage Below Normal or Shorted to Low Source.
- FC8175 : HVESS HVIL Status - Condition Exists. HVIL_Open_Circuit_Error
- FC8176 : HVESS HVIL Status - Root Cause Not Known. HVIL_Shorted_High_Error

Refer to troubleshooting trees to diagnose the fault codes above.

High Voltage Interlock Loop (see 13-76976R001)

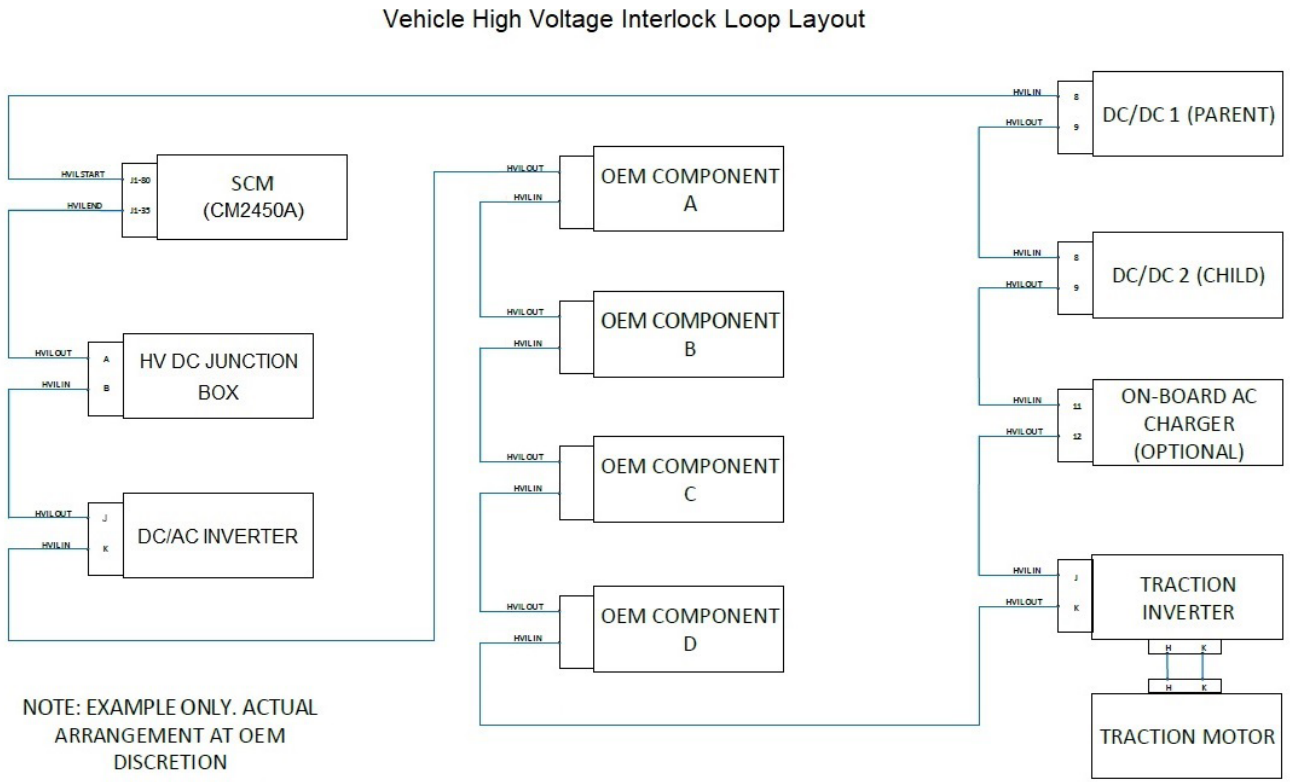
Cummins OEM Wiring Diagram:

- SCM outputs a 12V source from J1-80 which goes through a series circuit and is returned to J1-35.

Additional OEM Components:

- High Voltage Junction Box
- High Voltage Heater
- ThermoKing HVAC System
- Air Compressor
- Front Charger JB (PTC Area)
- Front Charger JB (Chassis Area)

- Refer to the HVIL Schematic for the bus



High Voltage Interlock Loop Continued

Driver Display:

There will be a message on the driver display (MFD) when the HVIL circuit is broken. The message “Warning – High Voltage Exposure” will appear along with a flashing lighting bolt and a HVIL indicator.

- This is driven by the “High Voltage Warning Lamp” status communicated via CAN from SCM.
- Commonly caused by an HVIL circuit break, but this is not the only root cause. Start by troubleshooting the HVIL circuit.

Summary of the High Voltage Interlock Loop

- The High Voltage Interlock Loop (**HVIL**) is a single circuit which passes in series through each high voltage connection on the vehicle.

- The HVIL system starts and ends inside the Cummins SCM (System Control Module). The Cummins SCM outputs a low voltage signal (12V) onto HVIL circuit and looks for the signal to be returned to the SCM after going through the loop.

- The HVIL is also connected to every top cover lid switch on all components in the HVIL loop.

- If any high voltage connection or lid to a high voltage component is removed, the HVIL loop will be broken, the Cummins SCM will measure an open circuit, and the high voltage contactors in the system will be opened, isolating all high voltage to the ESS battery packs.

- Impact on safety systems – The HVIL loop serves to ensure that the high voltage contactors within the ESS battery packs will be opened and high voltage will be contained within the ESS battery packs whenever someone tries to access high voltage

- The HVIL system is always active whenever the low voltage system is on. Removing power to the low voltage system will automatically ensure that the contactors within the ESS battery packs are open and there is no high voltage present outside the ESS battery packs.

Isolation Test with Megohmeter

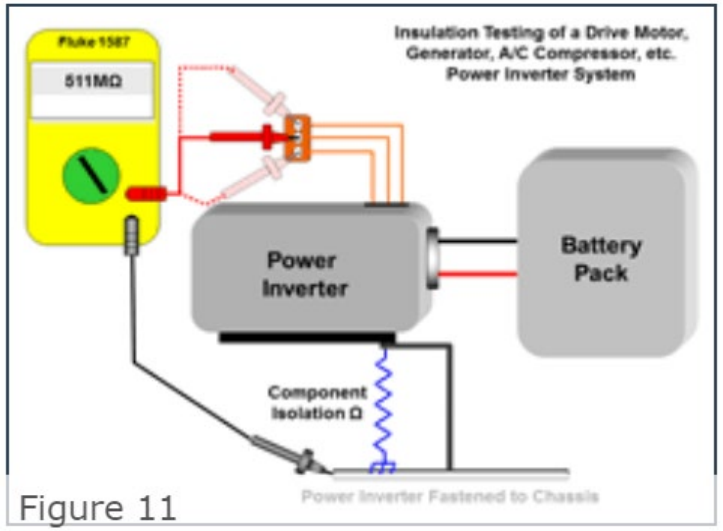


Figure 11

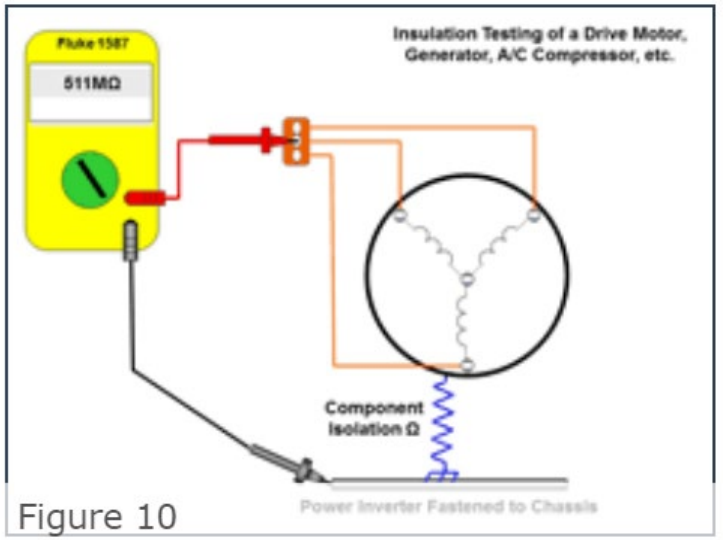
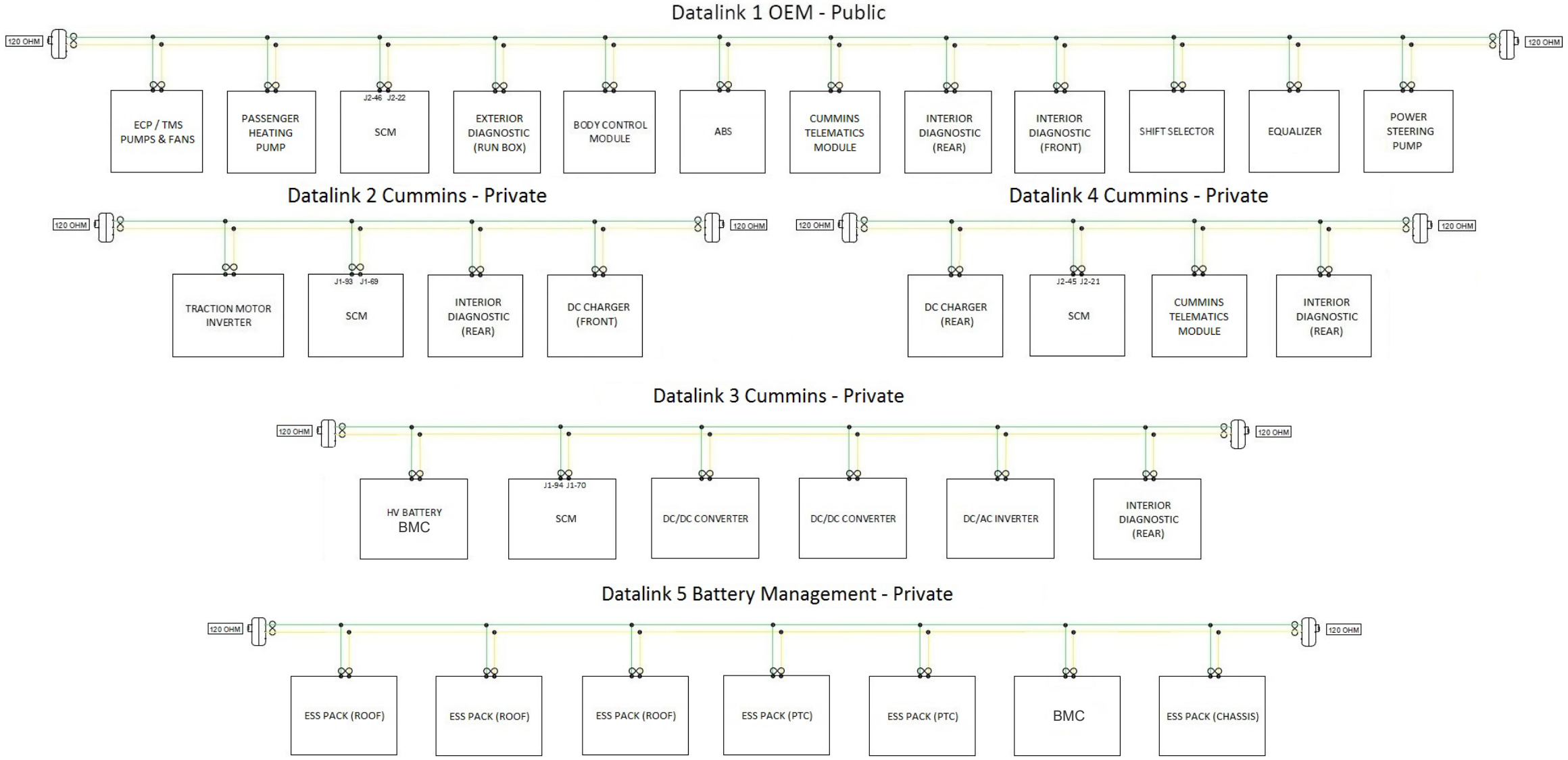


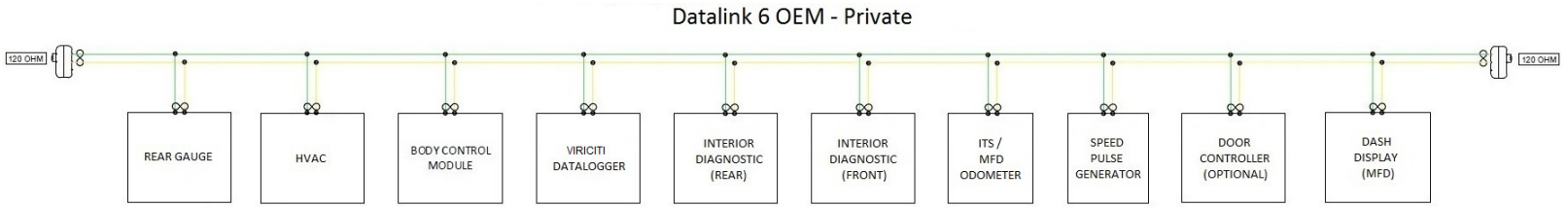
Figure 10

https://www.searchautoparts.com/motorage/electrical/hybrid-electric-vehicle-high-voltage-isolation-fault-systems?page=0,2

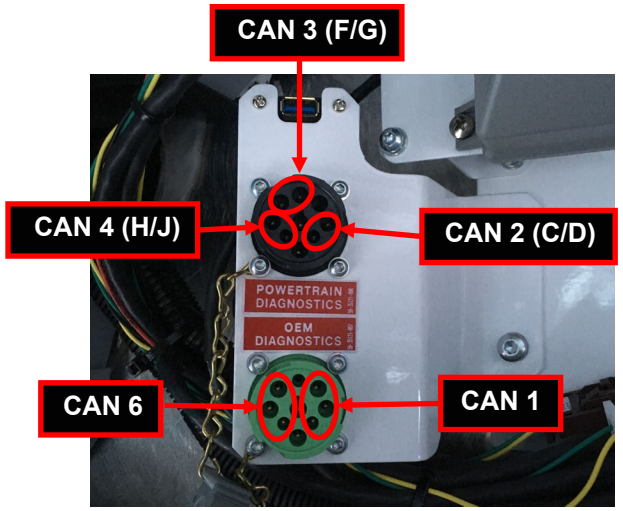
GILLIG E-bus CAN Architecture (see 13-76424R042)



GILLIG E-bus CAN Architecture (see 13-76424R042)



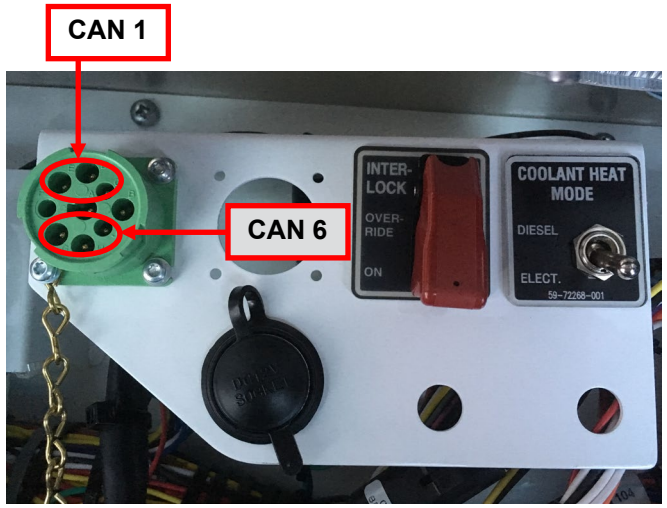
Service Diagnostic Connections:



Rear Electrical Panel

Color Code:
1 = Black
2 = Green
3 = Red
4 = White
5 = Blue
6 = Yellow

PIN	OEM	CMI
A	Ground	Ground
B	12V Battery	12V Battery
C	Can 1 Hi	Can 2 Hi
D	Can 1 Lo	Can 2 Lo
E	Can 1 Shield	NC
F	NC	Can 3 Hi
G	Can 6 Shield	Can 3 Lo
H	Can 6 Hi	Can 4 Hi
J	Can 6 Lo	Can 4 Lo



Front Electrical Panel

Maintenance Intervals

GILLIG LOW FLOOR

MAINTENANCE SCHEDULE

EV Drive System

Cooling fans - Check	Daily
Air tanks and reservoirs - Check	Daily
Coolant level - Check	Daily
ECP - Inspect for leaks, dirt, debris	Every 6,000 miles* (or every 450 hours)
ECP hoses and hose clamps - Check	Every 6,000 miles* (or every 450 hours)
Surge tank and pressure relief caps - Check	Every 6,000 miles* (or every 450 hours)
Mounting hardware - Check	Every 10,000 miles
BTMS Coolant filter - Replace	Every 18 months
Coolant - Test for replacement limits†	Every 150,000 miles (or every 3,000 hours)

* Maintenance to be performed based on number of hours accumulated. 14/15 mph reflects 1 hour.

† If coolant exceeds acceptable limits, flush the system and replace coolant.

GILLIG Accessory Components

GILLIG Accessory Components BTMS

- Battery charging and discharging generates heat.
- The HV battery system needs to be heated, cooled, and sub-cooled.
- Utilizes Liquid cooling.
- J1939 communicates to BTMS.
- Temperature controlled when vehicle awake and contactors are closed.
- Also functions during stationary charging.

Target Temp = 20 C / 68 F

Heating request ON: 8 C / 46.4 F

Heating request OFF: 10 C / 50 F

Cooling request ON: 20 C / 68 F

Cooling request OFF: 18 C / 64.4 F

GILLIG

GILLIG Accessory Components BTMS

- Battery Thermal Management System (BTMS)

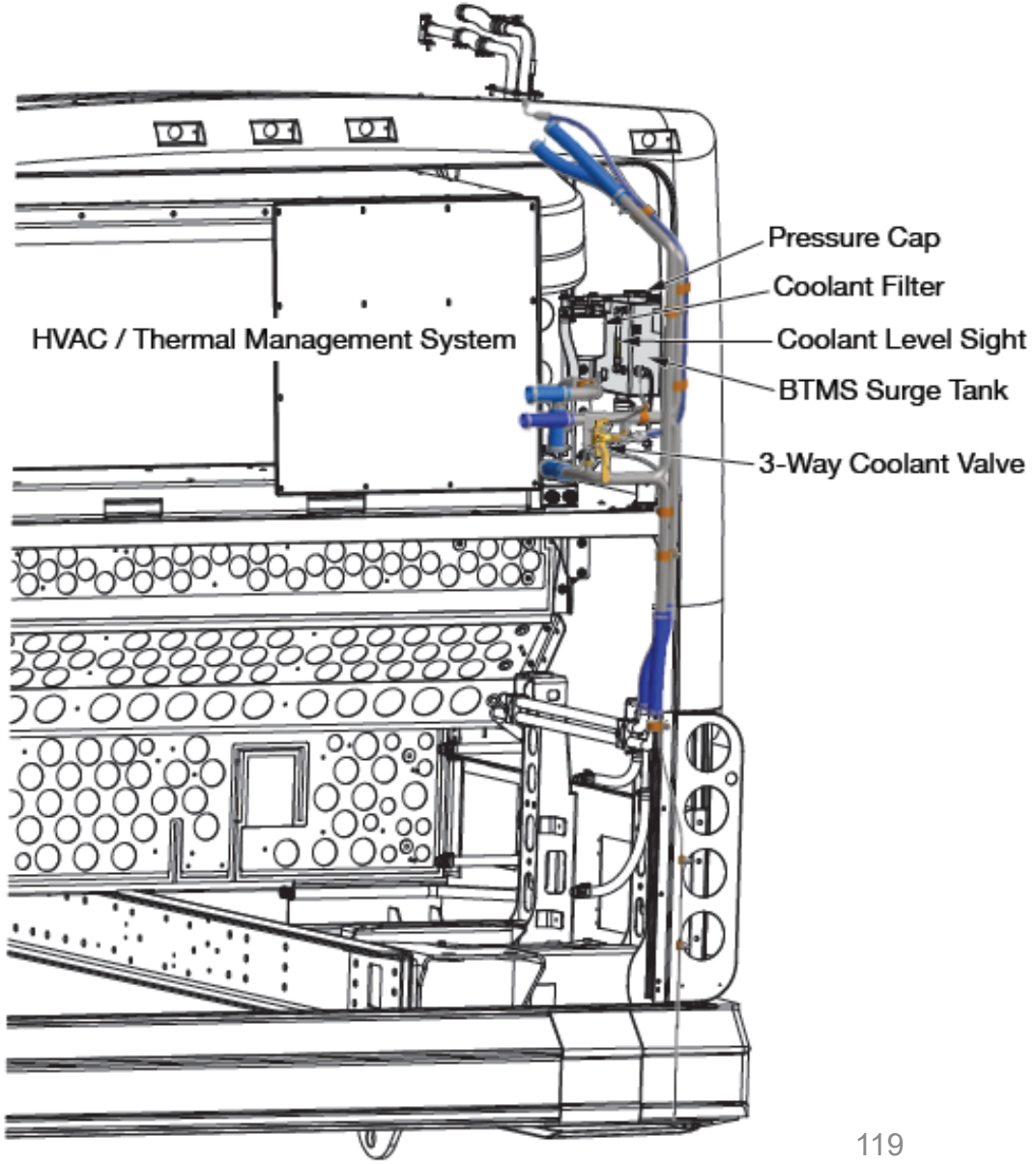
- Maintains battery cell temperature by circulating chilled or heated coolant through the packs
  - Standard 50/50 engine coolant (WEG)
  - Coolant temperature range is 50°- 70°F

- Two heat exchangers are integrated in the main HVAC unit to provide heating and cooling of the coolant for the high-voltage batteries.
  One heat exchanger uses refrigerant from the AC system to cool the battery coolant when cooling of the batteries is required.
  The second heat exchanger uses heated coolant from the main HVAC system to heat the battery coolant when heating of the batteries is required.

- Surge tank and coolant filter mounted above main unit

- HVDC compressor and coolant heater

- LVDC variable speed pump and fans

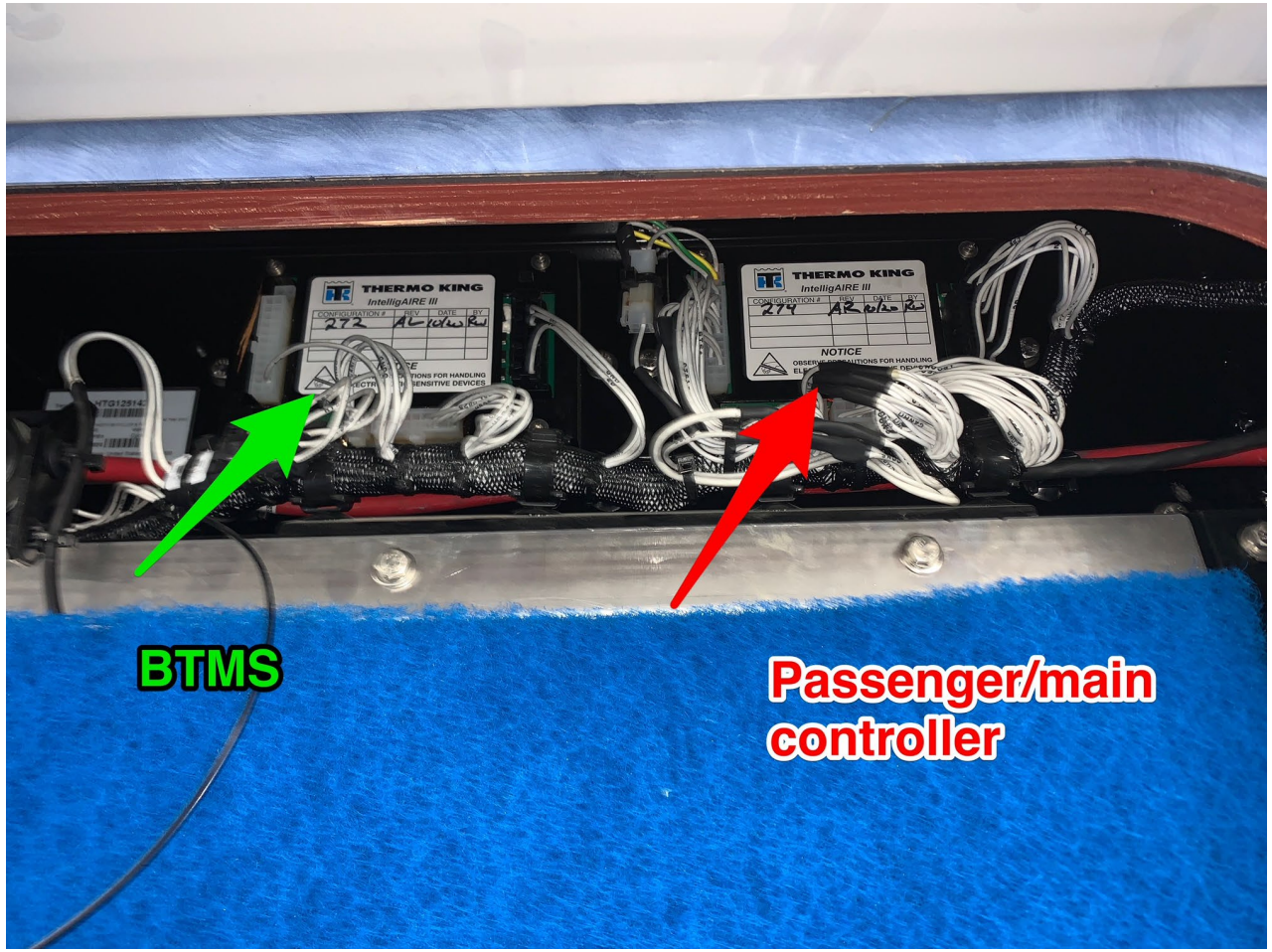


GILLIG Accessory Components BTMS Pump/Controller

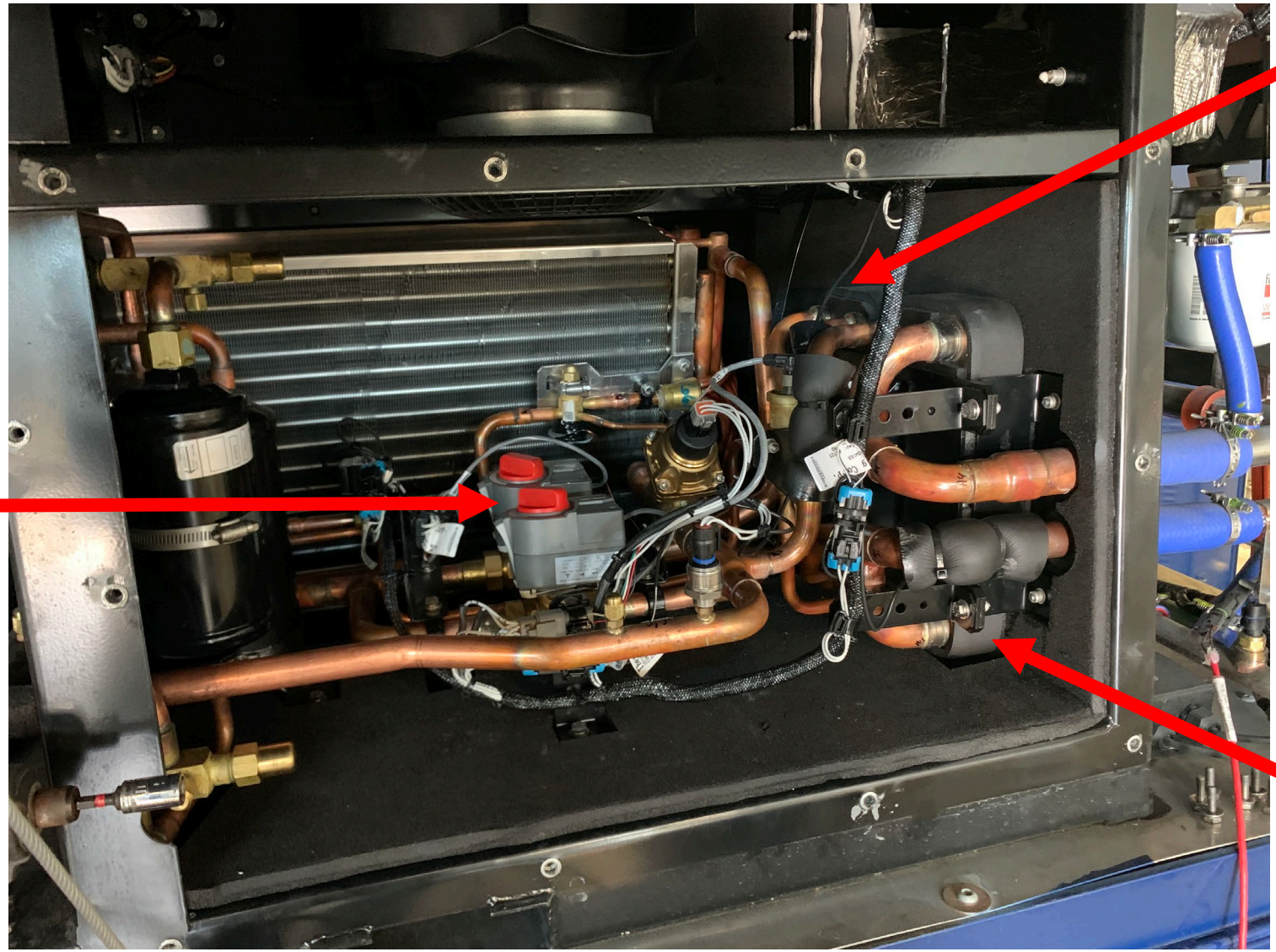
- Gillig uses a Gorman Rupp pump and controller.
- The BTMS pump and controller are the same parts as the HVAC pump and controller.
- When the controller is installed, the harness will set the controller address and make it location/system specific.
- The BTMS controller source address is ID 32.
- The controller will receive a speed signal from Gillig via CAN from the IO controls MBC.
- This CAN signal will set the speed of the pump to 450 watts.
- The speed is viewable using GRI pump software.
- If the controller loses CAN, the pump will default to 270 watts.
- The ignition wire (Con B pin 3) on the BTMS pump controller comes from the SCM or Battery Management Controller. It will be turned when a (ESS) battery cooling or battery heating request is being made by Cummins.

GILLIG Accessory Components BTMS

- Battery Thermal Management System controllers are located behind the Thermo King return air grill.
- Both controllers are the same part number but are programmed differently for their individual functions.
- The TK passenger/main controller is for bus HVAC functions
- The BTMS TK controller monitors the battery temps as transmitted by Cummins via J1939. Based on these temps the controller will open/close flow control valves for either heated coolant or refrigerant to the individual heat exchangers.
- Since the TK scroll compressor powered is inverted AC the duty cycle of the compressor is variable.
- During BTMS cooling operation, the compressor speed may be at full speed or down to slow enough speed that it may seem the compressor is off.



GILLIG Accessory Components BTMS



BTMS heating heat exchanger

Flow control valves

BTMS cooling heat exchanger

GILLIG Accessory Components BTMS

BTMS Maintenance

The battery thermal management system (BTMS) maintenance should be performed at the same intervals as the ECP. Replace the BTMS coolant filter (Figure 3-7, 3-11) according to *Chapter 2 Preventative Maintenance* schedule of this manual.

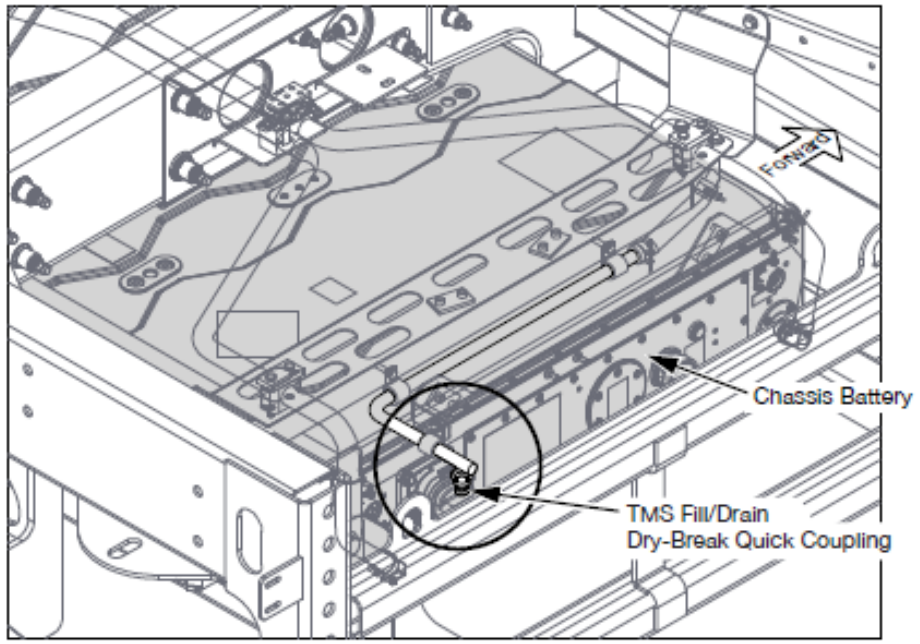


Figure 3-9, BTMS Fill/Drain Access on Curbside of Bus

BTMS Drain and Fill Procedure

BTMS Drain Procedure

1. Put the bus into rear run mode to open the battery coolant valves.
2. With the HV system shut down, turn the fill valve handle to the horizontal position (Figure 3-7).
3. Remove surge tank cap.
4. Connect the fill tank to the quick disconnect fitting (Figure 3-9) through the chassis battery access door.
5. Follow the FluidXchange operating instructions below to extract coolant.
6. Disconnect fill tank hose from quick disconnect fitting.
7. Turn the fill valve handle to the vertical position (Figure 3-7).
8. Reinstall surge tank cap.

GILLIG Accessory Components BTMS

BTMS Fill Procedure

Preferred for Initial Fill or After Significant Drainage (more than 3 gallons drained or more than 3 HV battery packs replaced)

1. Place a bucket underneath the rear curbside corner of the bus to catch excess coolant.
2. Put the bus into rear run mode to open the battery coolant valves. Do not turn on HV system.
3. Turn the fill valve handle to the horizontal position.
4. Connect the fill tank to the fitting at the chassis battery inlet (Figure 3-9).
5. Follow the FluidXchange operating instructions below to inject coolant. Do not exceed 10 psi while filling.
6. Continue to fill until coolant flows steadily from the rear corner vent line into the bucket. Sputtering flow indicates there is still air escaping.
7. Once coolant flows consistently out of the vent line, close the FluidXchange valve and disconnect the fill tank from the system.
8. Turn the fill valve handle to the vertical position.
9. Vent the surge tank until coolant is visible from the sight tube and at the cold full level. The pump will turn on at a low speed once the coolant level sensor detects coolant in the surge tank. The surge tank coolant level will slowly decrease as air from the rest of the system collects in the surge tank.
10. Continue to run the pump and vent the surge tank cap until a constant fluid level is achieved at the cold full level of the sight tube (Figure 3-7). If the cap no longer vents pressure and more coolant is required, remove the cap and add coolant directly into the surge tank.
11. Once the coolant level remains at the correct level, re-install the surge tank cap. The system is now full.

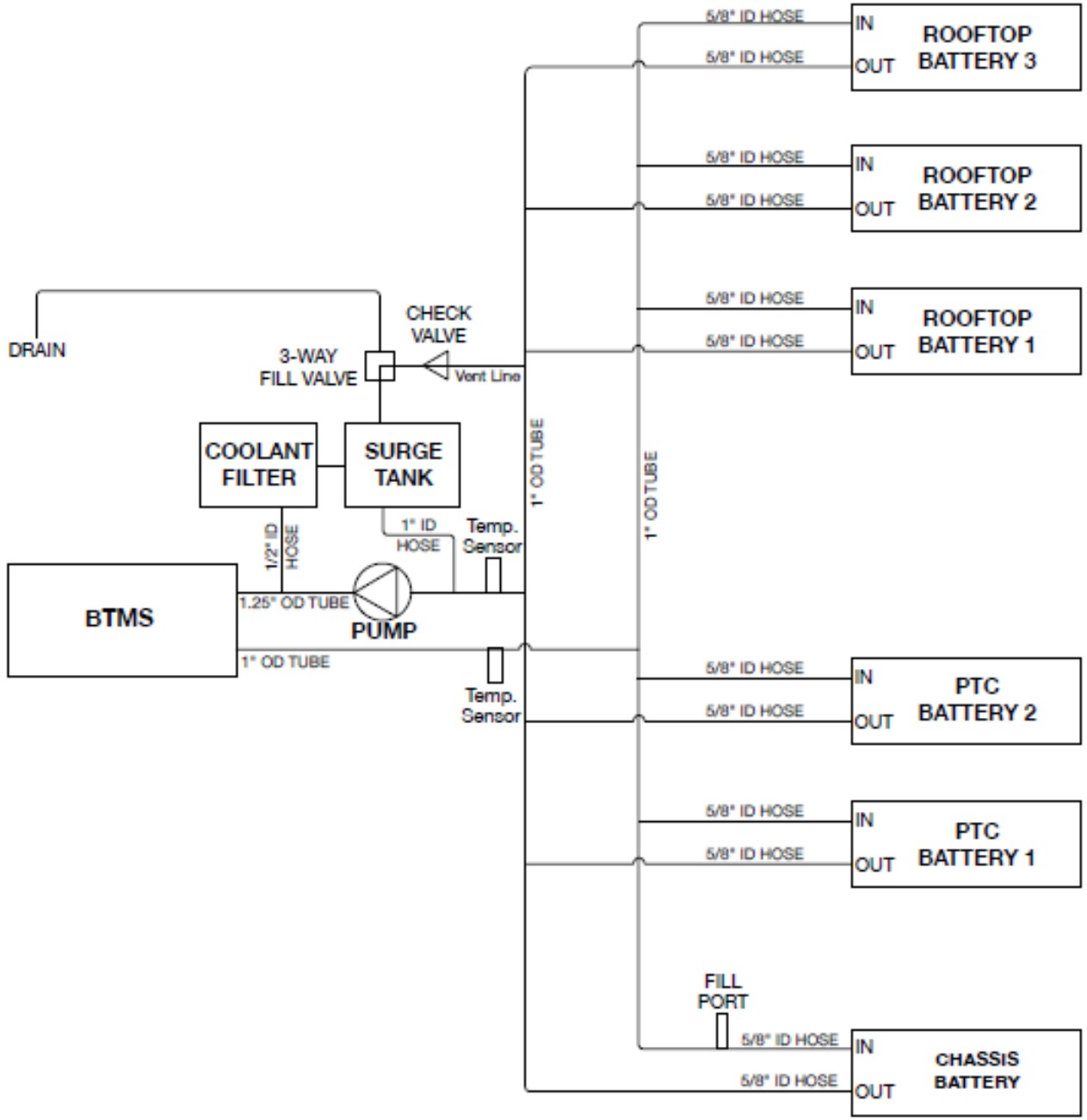
Alternative for Partially Empty System (fewer than 3 gallons drained or fewer than 4 HV battery packs replaced)

1. Fill the BTMS surge tank until coolant is visible from the sight tube and at the cold full level. Several "burps" may be required.
2. Start the BTMS coolant pump and open the battery pack internal coolant valves (place the bus in REAR RUN mode).
3. Run the pump and continue to fill the surge tank until a constant fluid level is achieved at the cold full level of the sight tube.
4. Once the coolant level remains at the correct level, re-install the surge tank cap and turn off the pump.

CAUTION

Do not run the pump dry. Running the pump dry will damage pump seals.

GILLIG Accessory Components BTMS



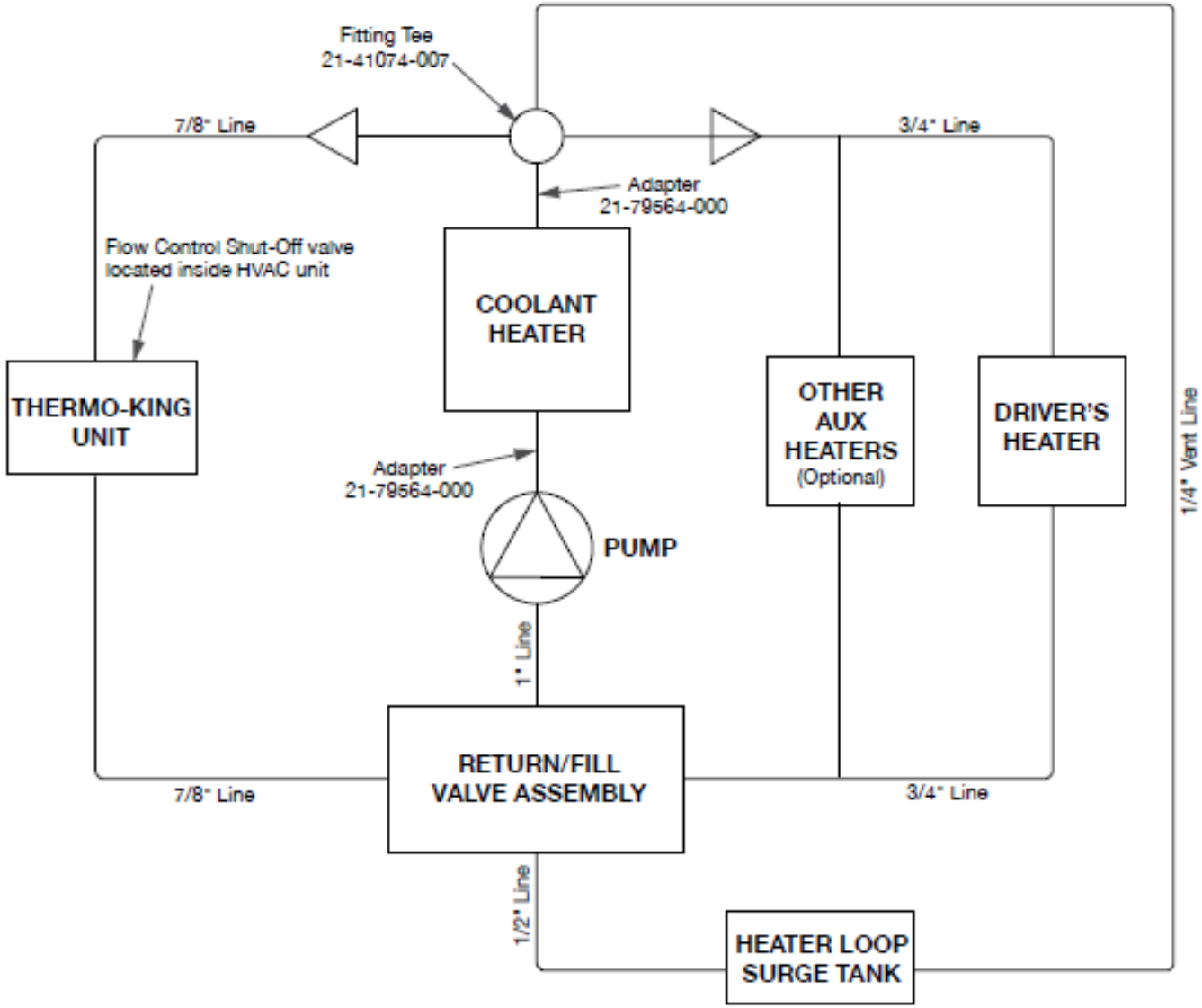
GILLIG Accessory Components Aux Coolant Heater

- Coolant heat
  - Same cabin heaters as diesel buses
  - Fill process is same as diesel buses
  - Standard 50/50 engine coolant

- Two versions: all-electric (warm climates) and dual mode (cold climates)

- All electric
  - Valeo Thermo DC
  - 700V DC heater
  - 20 kW (68,000 BTU/hr) capacity

- Dual mode
  - Electric + Diesel
  - Valeo Thermo H
  - Two heaters in one
    - Same all electric heater as Thermo DC
    - Diesel fired heater similar to Thermo S on diesel buses
      - 30 kW (102,000 BTU/hr) capacity
    - Both share one heat exchanger



GILLIG HVAC PUMP AND CONTROLLER

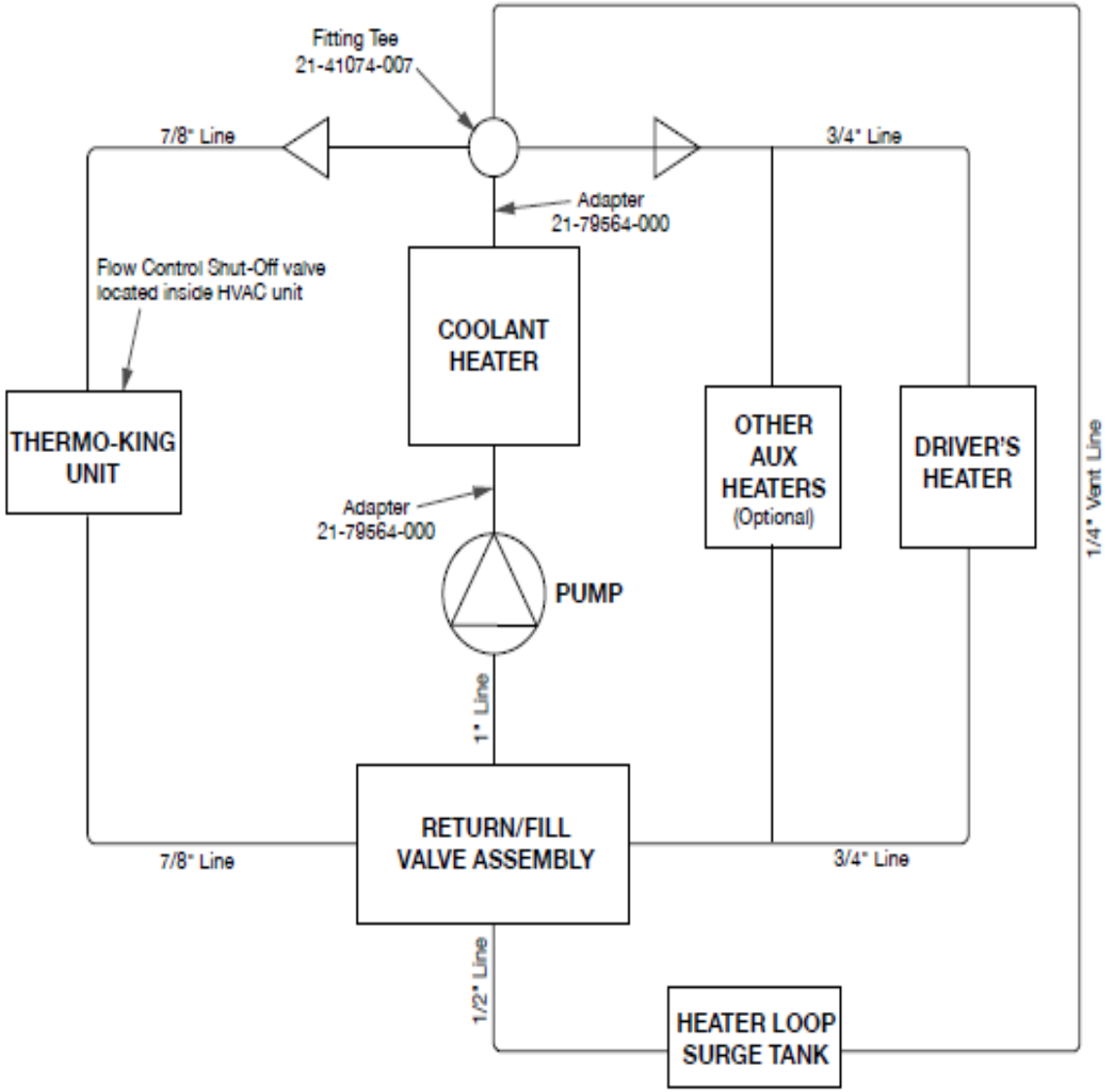
- HVAC pump controller is source address 57.
- The 24-volt ignition wire comes from rear PDM CB50 24-volt ignition. Loss of voltage on this wire will result in pump failing to run and loss of comms.
- The pump will run at three different speeds.

135 watts for circulation to TK only.

275 watts for circulation TK and passenger loop or passenger loop only.

400 watts during fill process.

- These requests are sent via gateway from IO controls as three separate digital outputs for speed. You should be able to use the G5 tablet/RTM and see if the logic is satisfied and messages are being sent. We also send the run request via gateway as a separate command.



GILLIG Accessory Components Air Compressor

- Electric Air Compressor (EAC)
- Powerex 700VDV Direct Drive Scroll Compressor
- Powerex convertor converts DC to 3 phase AC
- 100-120 psi operating range (down from 110-130 psi on diesel buses)
- Uses standard D2 governor.
- No ping tank, single AD-IP dryer
- Remote mounted air filter to draw in clean air
- Filter should be cleaned/replaced every 2500 hours

GILLIG Accessory Components Air Compressor

- Electric Air Compressor OS Bearing
- Lubricate every 10,000 hours
- Use only Powerex Grease and a hand powered grease gun
- Remove dust cap
- Rotate compressor till OS grease fitting is visible
- Pump hand power grease gun 4 times
- Replace dust cap

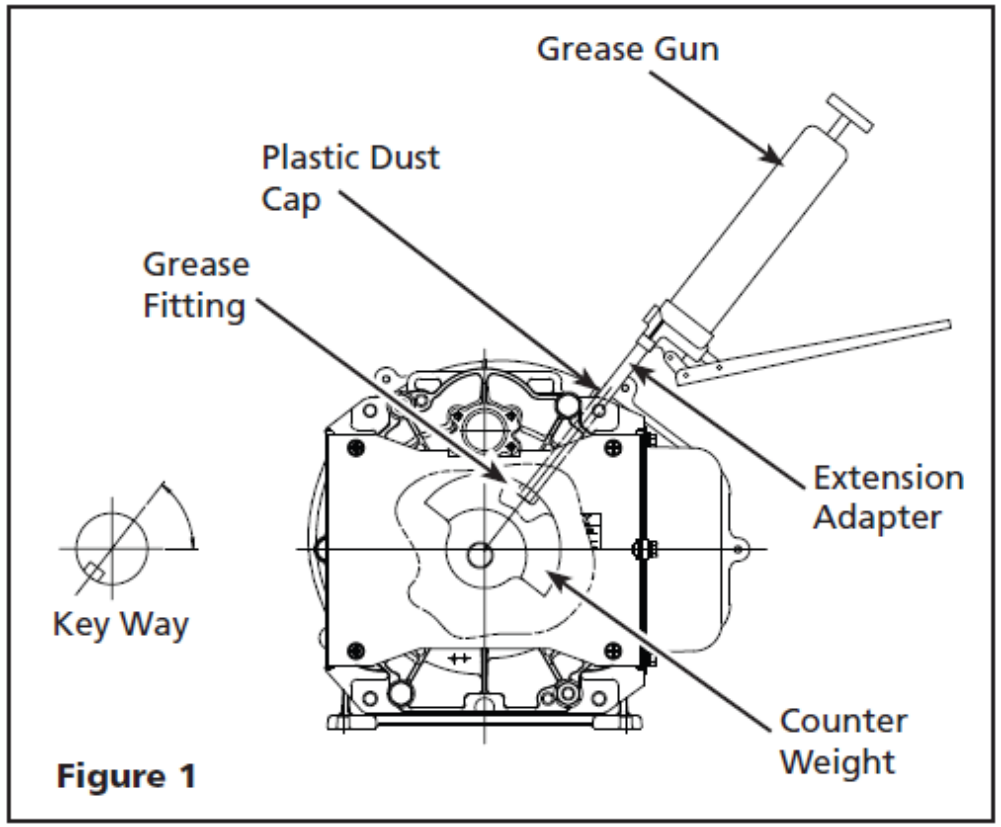
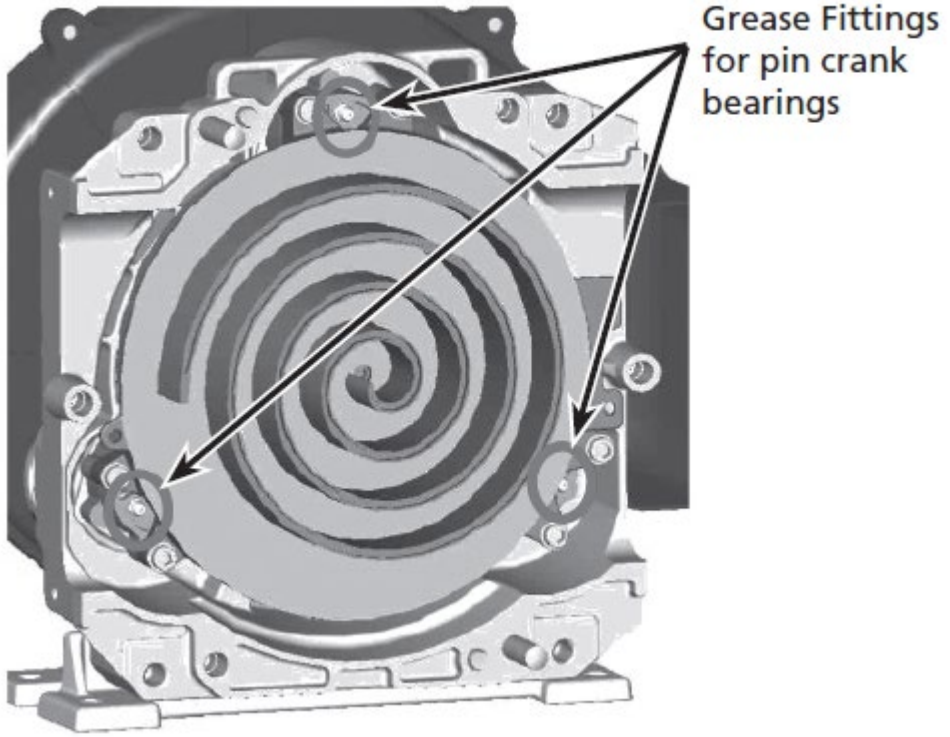


Figure 1

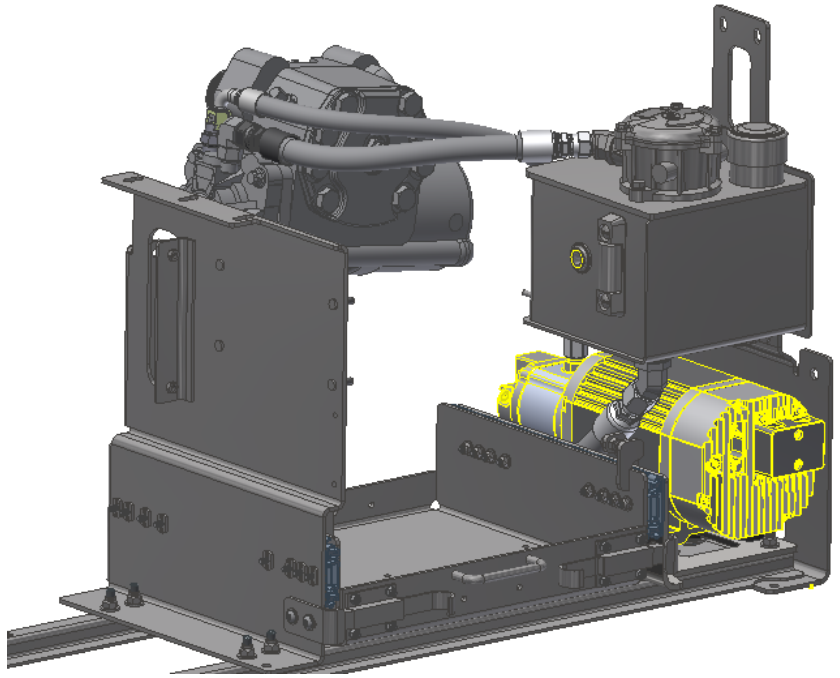
GILLIG Accessory Components Air Compressor

- Electric Air Compressor Pin Crank Bearings
- Lubricate every 10,000 hours
- Use only Powerex Grease and a hand powered grease gun
- Remove fan duct
- Remove nuts and bolts and then fixed scroll from air end
- Grease the three crank bearings with 4 pumps of a hand powered grease gun
- Replace fixed scroll and fan duct



GILLIG Accessory Components Power Steering

- Electro-Hydraulic Steering (EHS) system contained in LV battery box underneath driver
- Concentric 24V DC pump
- 5.1 qt reservoir with filter
- TAS85 steering gear
- 2 Group 31 batteries, not 4



GILLIG Accessory Components ECP

- Electronics Cooling Package (ECP)
- Cools the traction motor, traction motor inverter, HV to LV convertors and TK DC to AC invertor
- One radiator and one pump
  - Pump and fans all LVDC
- Radiator access through rear street side skirt panel
- Pump access through engine door or from underneath
- Surge tank access through street side access door
- Coolant temperature is 15° to 20°F above ambient
  - Standard 50/50 engine coolant

GILLIG Accessory Components ECP

ECP Radiator Drain and Fill Procedure

WARNING

Coolant is under pressure and extremely hot after the bus has been running. Wait until the coolant temperature is below 120°F before removing the pressure cap. Heated coolant spray or steam can cause personal injury.

ECP Drain Procedure

Preferred ECP Drain Procedure

1. Turn the ECP fill valve handle to point outboard.
2. Connect the fill tank to the quick disconnect fitting at the forward inboard edge of the ECP radiator
3. Remove surge tank cap.
4. Follow the FluidXchange operating instructions to extract coolant.
5. Disconnect fill tank hose from quick disconnect fitting.
6. Turn the ECP fill valve handle to point rearward.
7. Reinstall surge tank cap.

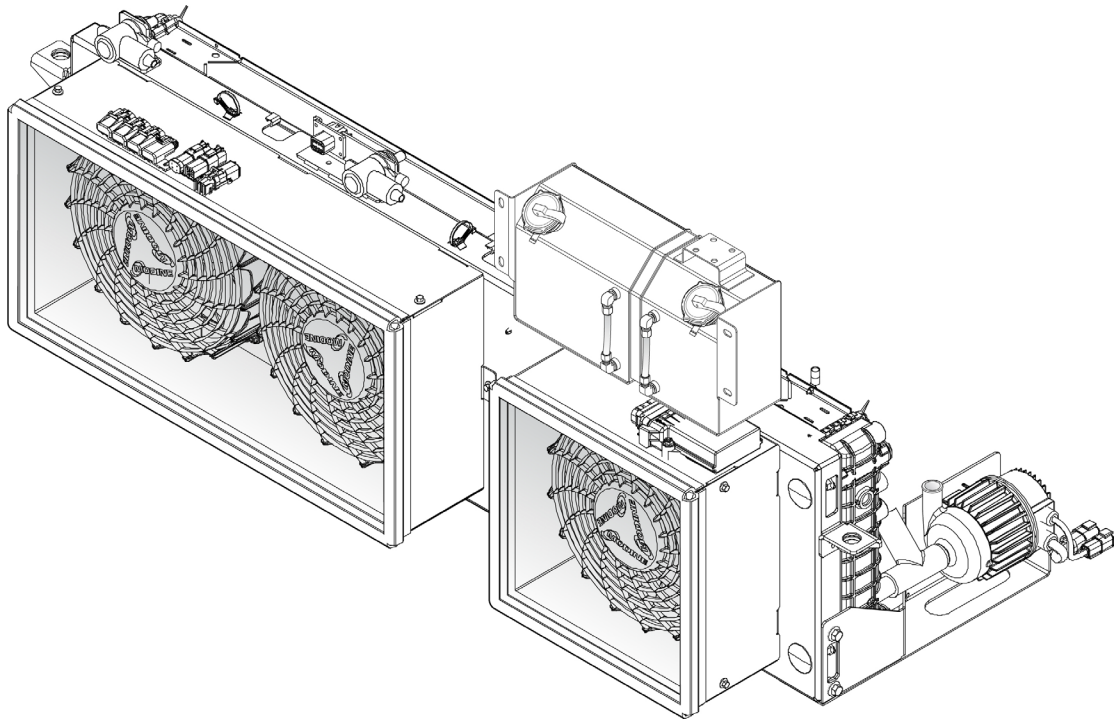
Alternative ECP Drain Procedure

1. Connect to the quick disconnect fitting at the forward inboard edge of the ECP radiator with the mating female quick disconnect fitting and a short hose. Direct the hose into a collection container suitable for coolant.
2. Remove surge tank cap
3. Allow coolant to drain out of the system until the flow stops.
4. Reinstall surge tank cap and remove hose from quick disconnect fitting.

ECP Fill Procedure

Preferred Initial Fill or After Significant Drainage (more than 1 gallon drained)

1. Place a bucket underneath the rear street side corner of the bus to catch excess coolant.
2. Turn the ECP fill valve handle to point outboard.
3. Connect the fill tank to the quick disconnect fitting at the forward inboard edge of the ECP radiator.
4. Follow the FluidXchange operating instructions below to inject coolant. Do not exceed 10 psi while filling.



GILLIG Accessory Components ECP

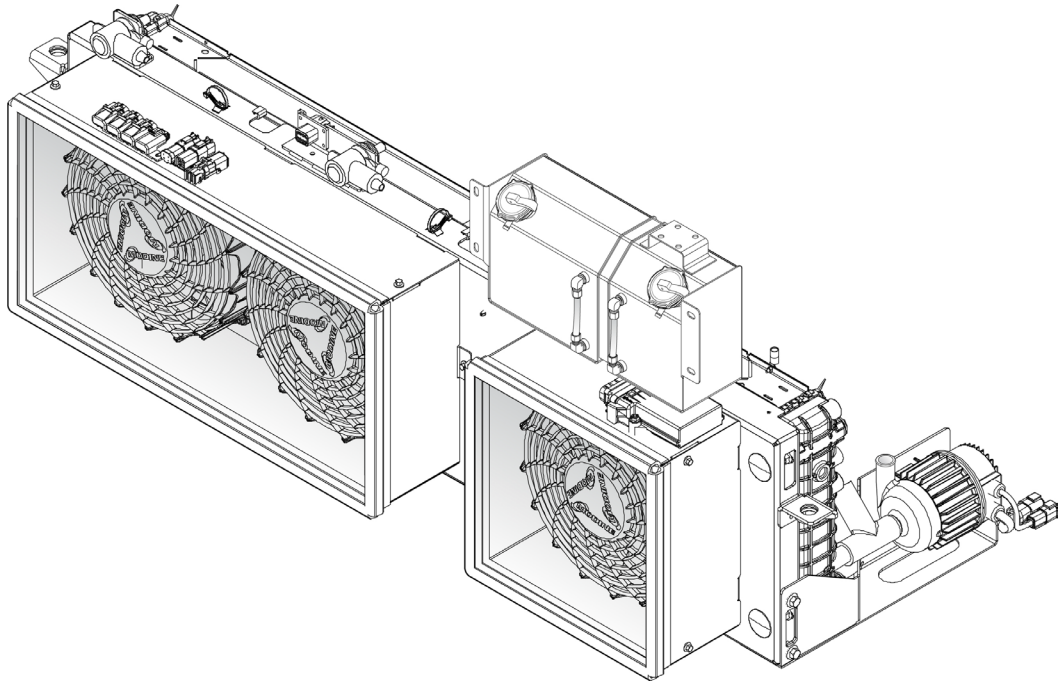
5. Vent the surge tank until coolant is visible from the sight tube and at the cold full level, then close the vent cap handle
6. Continue to fill until coolant flows steadily from the rear corner vent line into the bucket. Sputtering flow indicates there is still air escaping.
7. Once coolant flows consistently out of the vent line, close the FluidXchange valve and disconnect the fill tank from the system.
8. Allow the vent line to continue draining until the flow slows down, then turn the ECP fill valve handle to point rearward.
9. Vent the surge tank cap to relieve any remaining pressure.
10. Check the coolant level after the first drive of the bus and add coolant as necessary.

Alternative Fill for Partially Empty System (less than 1 gallon drained)

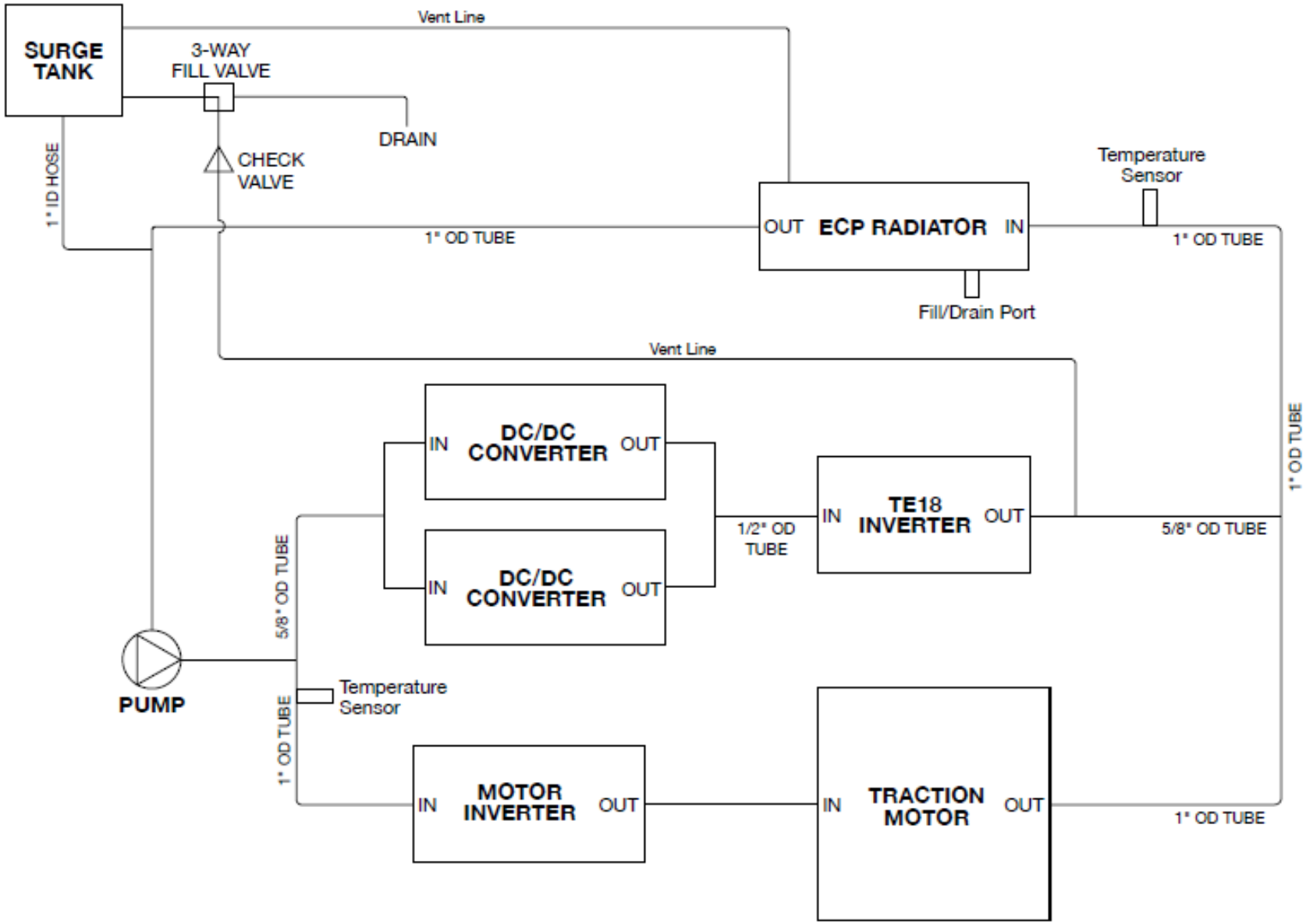
1. Fill the ECP surge tank until coolant is visible from the sight tube and at the cold full level. Several "burps" may be required.
2. Check the coolant level after the first drive of the bus and add coolant as necessary.

CAUTION

Do not run the pump dry. Running the pump dry will damage pump seals.



GILLIG Accessory Components ECP



Questions?