BATTERY ELECTRIC BUS
Familiarization
FOR TRANSIT TECHNICIANS
June 2020

BYD Build Your Dreams · ENC REV GROUP · GILLIG · GreenPower MOTOR COMPANY · NEW FLYER · NOVABUS · PROTERRA

TRANSPORTATION LEARNING CENTER

BATTERY ELECTRIC BUS FAMILIARIZATION

Session 1
BEB Overview

June 2020

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Battery Electric Bus Familiarization
Session 1
BEB Overview

Welcome

- Who we are.
- Why this course.
- How we got here.

John Schiavone
Program Director
johnjschiavone@cs.com

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Welcome to BEB Familiarization course and thanks for attending.

John Schiavone, Program Director, Transportation Learning Center
johnjschiavone@cs.com

Transportation Learning Center’s Mission: Advance frontline worker training on joint labor-management basis

As BEB procurements grow, so does need for increased skills. Familiarization Course Intended for those with no or limited BEB Experience.

Asked OEMs to participate and response was positive – all OEMs volunteered for this course.

BEB Familiarization Course Overview: 3 Sessions

1. BEB Technology Overview
2. High-Voltage Safety Considerations
3. Battery Charging Technologies

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Course being delivered in three sessions:

1. General Technology Overview (today’s session)
2. High-Voltage Safety Considerations
   Planning now underway, Date TBD
3. Various Approaches to Battery Charging
   Date TBD

Future sessions will address ways to enhance electrical/electronic training

Today's Presenters

PROTERRA

NEW FLYER

GILLIG

1. Fundamentals of BEB Technology
2. PM & Diagnostics
3. Battery Management & Cooling

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Today's Presenters

1. James Hall, Proterra
   - BEB General Overview
2. BEM PM Considerations
   - David Warren, New Flyer
3. Battery Management and Cooling
   - Kevin Hardesty, Gillig

Other BEB OEMs will Participate in Subsequent Sessions

Nova, BYD & Eldorado will participate in Session #2 High-Voltage Safety

Learning Outcomes

1. Identify major BEB components.
2. Compare BEB technology to other bus types.
3. Describe principles of operation of BEB.
4. List PM & diagnostic requirements for BEB.
5. Describe battery management and cooling system on BEB.

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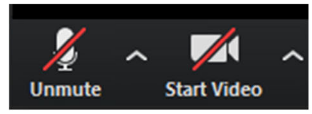
Upon Completion of today's BEB Overview Session, learners will be able to:

1. Identify the major components found on a BEB
2. Compare BEB technology to hybrid, fuel cell, and ICE propulsion buses
3. Describe BEB principles of operation
4. Identify the generic BEB PM requirements
5. Describe the battery management system and cooling

During Today’s Presentation

- Attendees are muted and video turned off.



- Attendees send questions via Zoom Q&A.
- Session will be recorded and available on www.TransitTraining.net.

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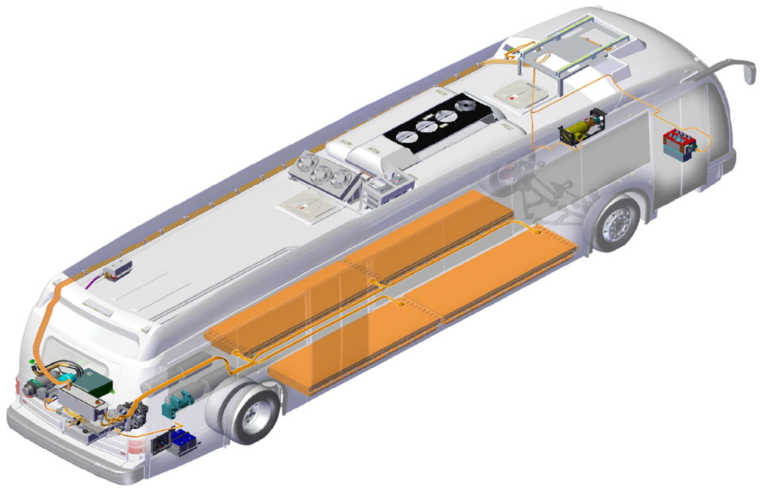
All Attendees will be muted & web cams turned off .

Type in Questions Using the “Q&A” in the Zoom Webinar controls.

John Schiavone moderates all questions.
Session will be recorded – download from Transportation Learning Center websites:
www.TrainsitTraining.net

Download will include audio, slides and presenter’s written notes



Fundamentals Of BATTERY ELECTRIC BUSES

BEB Major Components

June 2020

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Presenter and Topics

- Component Identification
- Similarities and Differences
- Principles of Operation

James Hall
Manager of Training
jhall@proterra.com

PROTERRA

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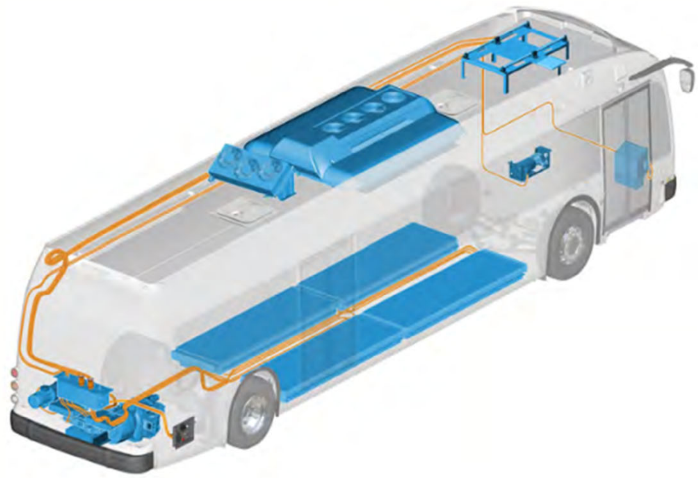
James Hall, Proterra
I will cover three topics in my presentation:

1. Component Identification – here I will Identify the major components found on a BEB
2. Similarities and Differences – I will give an overview of how BEB technology compares to hybrid, fuel cell, and ICE propulsion buses by pointing our some similarities and differences
3. Finally, I will describe the principles of operation of the BEB

What is a BEB?

- **B**attery **E**lectric **B**us.
- Driven by at least one electric motor.
- On-board high voltage batteries provide energy.
- Similar with other bus designs.
- Benefits environment.



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What is a BEB? By now you know that BEB refers to a Battery Electric Bus. A BEB is an electric bus that is driven by one (1) or more electric motor(s) that utilize the energy from on-board HV batteries.

- High-voltage (HV) is defined as any voltage above 50V
- The most common voltages to run a typical BEB are between 400V and 800V

Most components, including the axles, suspension, brakes, and steering are the same as, or similar to, other bus designs.

The BEB design is a technological response to the need to reduce greenhouse gas emissions, utilize renewable energy, increase fuel economy, and offer quiet operation.

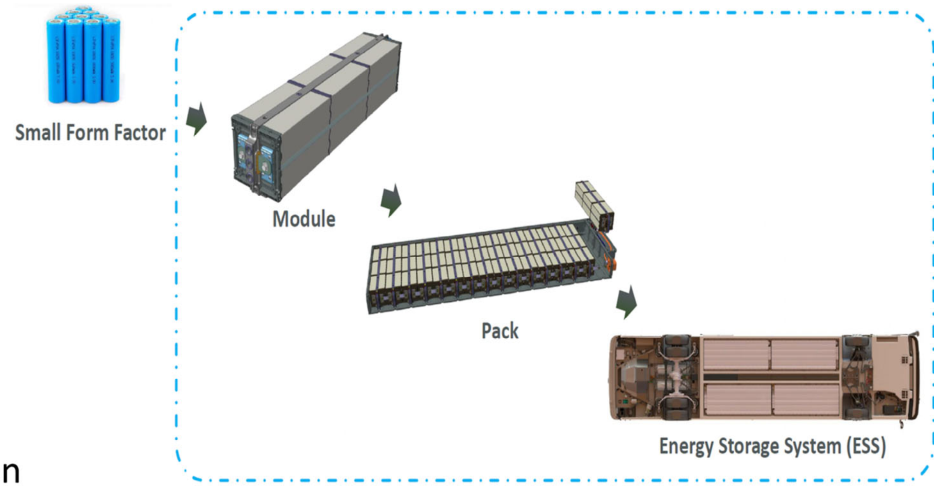
Acronyms

- **ABS** – Anti-lock Braking System
- **AC** – Alternating Current
- **BEB** – Battery Electric Bus
- **BMS** – Battery Management System
- **CAN** – Controller Area Network
- **DC** – Direct Current
- **ECU** – Electronic Control Unit
- **EMI** – Electromagnetic Interference
- **ESS** – Energy Storage System
- **HV** – High Voltage
- **HVIL** – High Voltage Interlock Loop
- **HVJB** – High Voltage Junction Box
- **IGBT** – Insulated Gate Bipolar Transistor
- **LOTO** – Lock-out Tag-out
- **LV** – Low Voltage
- **MSD** – Manual Service Disconnect
- **MUX** – Multiplex
- **TM** – Traction Motor

Presenter: Throughout my presentation, you may see these acronyms.

Energy Storage System (ESS)

- High-voltage (HV) batteries.
- Each HV battery pack consists of modules and cells.
- ESS equivalent to on-board fuel.
- Various locations on bus.



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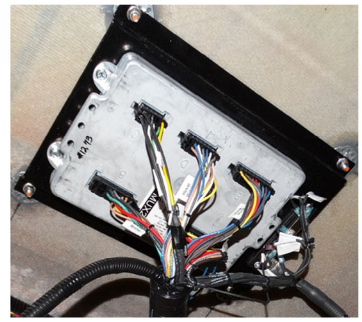
- The Energy Storage System (ESS) is comprised of the high-voltage batteries that power the bus and various controllers.
- Cells comprise modules within the HV battery pack. Multiple battery packs are connected to create strings.
- The ESS is the equivalent of on-board fuel (diesel, hydrogen, etc.).
- Located in various locations on the bus; under-floor, side panels, rear, or roof-top.

Electronic Controllers

- Various controllers are used throughout the bus.
- Used to monitor and control the HV and LV power.
- Ensures the safe operation of all subsystems on the bus.



- Various controllers are used throughout the bus.
- Used to monitor and control the HV and LV power.
- Ensures the safe operation of all subsystems on the bus.
- Examples may include:
    - Vehicle Controller
    - BMS
    - ABS ECU
    - HVAC Controller

High Voltage Cables

- Transports HV energy to HV components.
- Covered with orange insulation or looming.
- Separated from LV cables to prevent EMI.

- HV cables are used to carry the HV energy from the ESS to various HV components on the bus.
- HV Cables will always be covered in orange insulation or looming.
- HV cables are separated from LV cables to prevent EMI (electromagnetic interference)

High-Voltage Junction Box (HVJB)

- HV Distribution Box.
- Safely distributes HV from ESS to HV components.
- Contains fuses, contactors, voltage sensors, current sensors, allowing for complete control of HV energy.
- Access requires special PPE and training.

- May also be referred to as the HV Distribution Box.
- The HVJB is used to safely distribute the HV from the ESS to various HV components.
- Contains Fuses, Contactors, Voltage Sensors, and Current Sensors, allowing for complete control of HV energy.
- Access requires special PPE and training.

Contactors

- Electrical switching device.
- LV power (12/24V) controls HV switching function of the contactor.
- HV equivalent of LV relays and switches.
- Contains special provisions for arc-control.

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- A contactor is an electrically-controlled switch used for switching electrical power in a circuit.
- On BEBs, LV power (12/24V) is used to control the HV switching function of the contactor.
- Considered the HV equivalent of LV relays and switches.
- Contains special provisions for arc-control not found in typical relays and switches.

Inverters

- Changes DC voltage to 3-phase AC.
- AC voltage supplied to electric motor to generate movement.
- Multiple inverters that perform different tasks.

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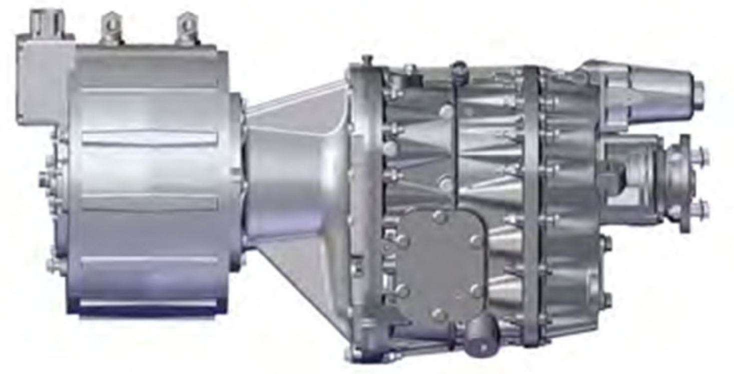
- Inverters are used to change the DC voltage stored in the HV batteries, to 3-phase AC.
- The AC voltage is supplied to an electric motor to generate movement.
- BEBs will have multiple inverters to perform different tasks.

Traction Motor

- Uses AC voltage from an inverter for torque to turn wheels.
- Replaces traditional diesel engine.
- BEBs may have up to 3 traction motors.
- Design varies.



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- The Traction Motor uses AC voltage from an Inverter to generate torque to turn the wheels.
- Replaces the traditional diesel engine.
- Current BEB designs may have up to 3 Traction Motors.
- Many different variations. Some may be direct-drive, others may use a transmission.

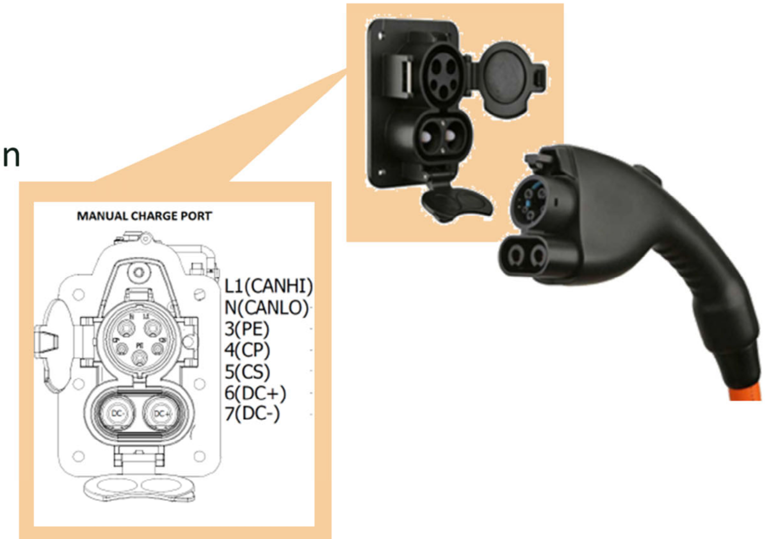
DC-DC Converters

- Change **HV** DC to **LV** DC.
- Replace alternator.
- Charge LV batteries, and supply LV power when the HV system is enabled.
- Number of converters depend on the LV load.

- DC-DC converter(s) are used to change HV DC to LV DC.
- The DC-DC converter(s) replace the need for an alternator.
- These converters charge the LV batteries, and supply LV power when the HV system is enabled.
- BEBs may have multiple converters, depending on the LV load.

Manual Charge Port

- Connects depot charging equipment BEB.
- Facilitates CAN communication between vehicle charge controller and charging equipment.
- SAE J1772 CCS Type-1.
- 150kW maximum power



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- Used to connect the depot charging equipment to the bus.
- Allows for CAN communication between the vehicle charge controller and the charging equipment.
- Utilizes SAE J1772 CCS Type-1 standard configuration.
    - Maximum power is 150kW

Overhead Charging

- Two pantograph options:
  - Roof-mounted (bus-up)
  - Inverted (bus-down)
- Both on-route and depot charging options.
- Roof-mounted allows option to install more powerful chargers for a faster charge time.
- SAE standard J3105

Roof-mounted pantograph

Inverted pantograph

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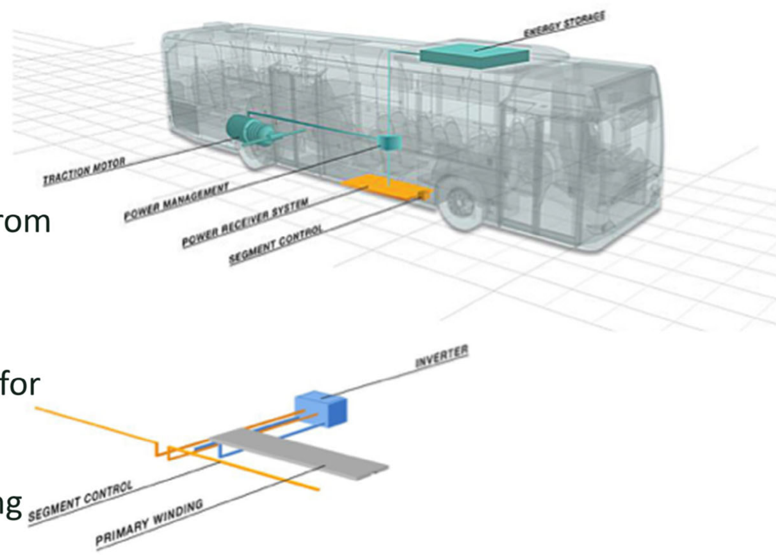
- 2 options currently available: roof-mounted pantograph (bus-up), and inverted pantograph (bus-down)
- Allows for both on-route and depot charging options.
- Roof-mounted overhead charging options allow for the option to install more powerful chargers for a faster charge time.
- Both options utilize SAE standard J3105

Inductive Charging

- Emerging technology.
- On-route and depot charging options.
- Electromagnetic field generated from road surface windings.
- Bus receiver system turns electromagnetic field into energy for ESS charging.
- Similar technology used in charging cell phones.



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https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0060.pdf
FTA Research: Review and Evaluation of Wireless Power Transfer (WPT) for Electric Transit Applications – FTA Report No. 0060

- Currently an emerging technology that is continuing to be refined.
- Allows for both on-route and depot charging options.
- Windings built into the road surface generate an electromagnetic field.
- A receiver system under the floor of the bus turns the electromagnetic field into energy that can be supplied to charge the ESS.
- Similar to the inductive charging technology used to charge most modern cell phones.
- Not common in current transit applications.

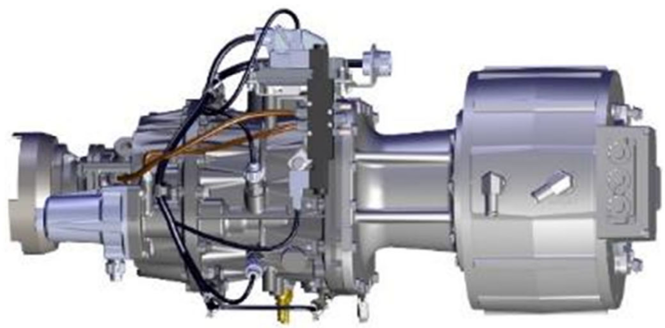
How BEB Systems Differ

Powertrain – power supplied by ESS.

High-voltage batteries - ESS replaces on-board fuel.

Overhead charging and/or depot charging - Charging system components unique to industry.

Battery management system (BMS) – Manages control of HV batteries, including enabling/disabling packs, cooling, and fault management.



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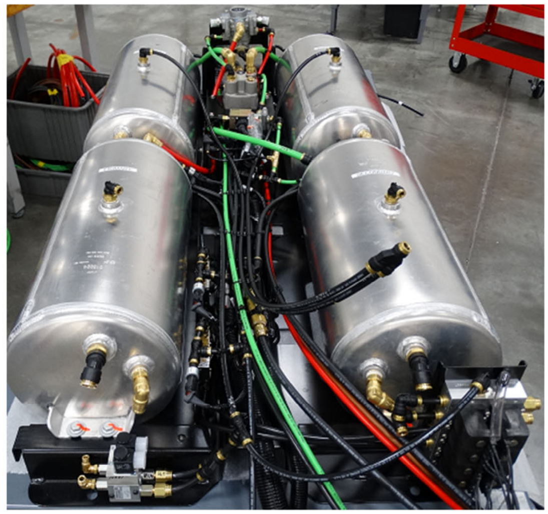
- POWERTRAIN - The powertrain uses power from the ESS to move the bus through an Inverter and Traction Motor.
- HIGH-VOLTAGE BATTERIES - The high-voltage batteries (ESS) replace the on-board fuel.
- OVERHEAD CHARGING AND/OR DEPOT CHARGING - The Charging System components are unique to the industry.
- BATTERY MANAGEMENT SYSTEM - The BMS manages the control of the HV batteries, including enabling/disabling packs, cooling, and fault management.

How BEB Systems are Similar to Traditional Bus – part 1

- Air Systems
- Power steering
- Axles
- Low-voltage system
- Grounding
- Multiplex (mux)
- Cooling system



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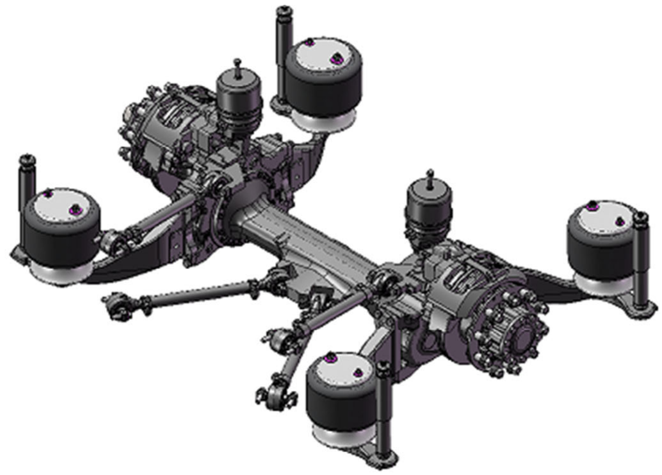
- AIR SYSTEM – Standard pneumatic components, electrically-driven
- POWER STEERING – Standard components, electrically-driven
- AXLES – Standard design, different gearing
- LOW-VOLTAGE SYSTEM - 12/24V systems are similar to other low-voltage systems used in transit vehicles. A DC-DC converter is used in place of an alternator
- GROUNDING- Grounding of the LV system is similar to previous designs. Some buses have composite bodies, requiring grounding of the LV system through large-gauge wires and buss bars.
- MULTIPLEX (MUX) - MUX and I/O systems are similar, with more software control and less ladder-logic
- COOLING SYSTEM – Most cooling systems utilize 50/50 ethylene-glycol mixes. BEB’s utilize electronic coolant pumps and have up to 3 separate loops,

How BEB Systems are Similar to Traditional Bus – part 2

- Suspension
- Brakes
- Controller Area Network (CAN)
- Doors
- ADA equipment



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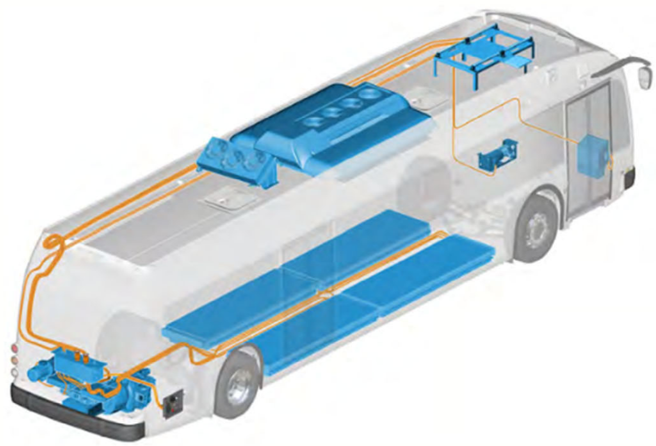
- SUSPENSION - The front and rear suspension systems are nearly identical to current designs
- BRAKES – Pneumatic brake systems are the same disc or drum assemblies currently on the axles
- CAN (Controller Area Network) - The CAN principles operate the same as in previous designs.
- DOORS - Front and rear doors are transit-standard pneumatic or electric units.
- ADA EQUIPMENT - The ADA ramps and securements are industry standard.

Theory of Operation

- Power generated from the engine transferred to axle then the wheels through torque converter
- Uses energy stored in the ESS to power a traction motor which is connected directly to the drive axle.
- When ESS depletes charge, it is recharged through dedicated charging system that is connected to the local power grid.



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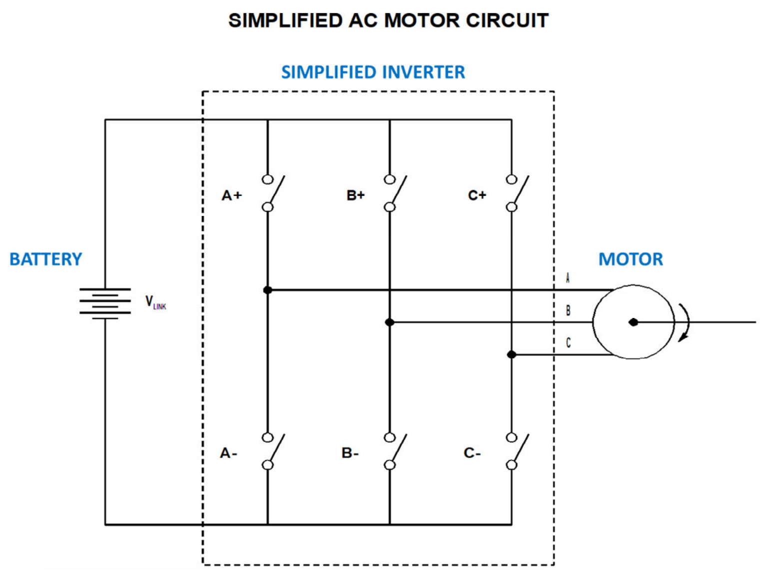
- In a typical diesel bus, power generated from the engine is transferred to the axle and then the wheels through the torque converter.
  - Compressors and pumps are driven by the accessory belt.
- BEBs use the energy stored in the ESS to power a traction motor which is connected directly to the drive axle.
  - In any instance where a subsystem was driven by an accessory belt on a diesel bus, an appropriately sized electric motor is used to drive the accessory.
- When the ESS has depleted its charge, it is recharged through a dedicated charging system that is connected to the local power grid.

Inverters

- Battery, Simplified Inverter and Traction Motor.
- IGBTs as switches.
- 3-phase inverter switches HV DC energy on/off to create an AC signal.



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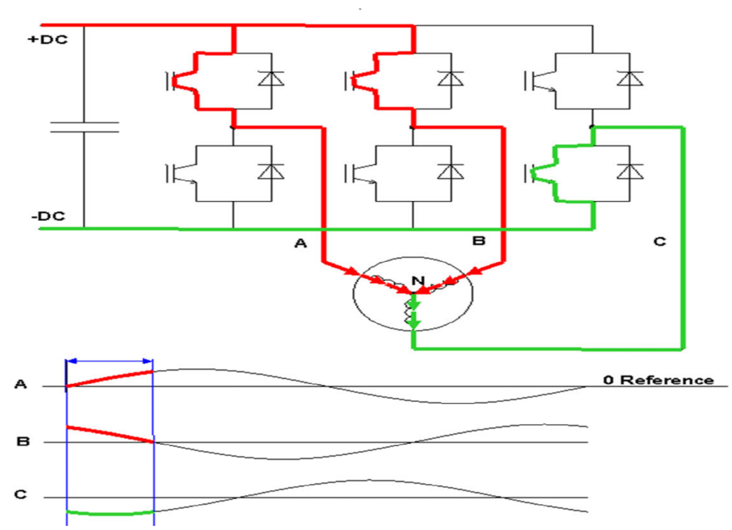
In this example, we have a battery, simplified inverter, and traction motor.

The IGBTs in the inverter can be represented as switches.

The 3-phase inverter switches HV DC energy on/off to create an AC signal.

Inverters

- Rotor turned when power is suppled to coils which generating 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.



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- In order to turn the rotor inside the traction motor, power is supplied to the coils to generate a magnetic field in each.
- To continue the rotation of the rotor, the pattern alternates
- The positive and negative IGBTs of each phase must not be switched on at the same time, or it will cause a direct short condition.

Supplemental Notes

- If the positive A and B-phase IGBT is turned ON, a circuit is established from the supply positive through the A and B phase motor stator winding to the motor neutral. To complete a circuit, negative C-phase IGBT must be turned ON. With the positive A and B phase IGBT on and negative C-phase IGBT were turned on, a current path is established through the AC windings of the motor. In this case, the current flow is from the A and B winding to the C winding.
- If the positive A-phase IGBT is turned ON, a circuit is established from the supply positive through the A-phase motor stator winding to the motor neutral. To complete a circuit, either the negative B-phase or negative C-phase IGBT must be turned ON. With the positive A-phase IGBT on, if the negative C-phase IGBT were turned on, a current path is established through the AC windings of the motor. In this case, the current flow is from the A winding to the B and C winding.
- If the positive A and C-phase IGBT is turned ON, a circuit is established from the supply positive through the A and C phase motor stator winding to the motor neutral. To complete a circuit, negative B-phase IGBT must be turned ON. With the positive A and C phase IGBT on and negative B-phase IGBT were turned on, a current path is established through the AC windings of the motor. In this case, the current flow is from the A and C winding to the B winding.
- If the negative A and B phase IGBT is turned on and the positive C-phase IGBT were turned on, a current path is established in the opposite direction through the AC winding of the motor. Depending on which positive IGBT and which negative IGBT is turned on at the same time, it will control what windings will be energized and in what direction the current flows (which controls direction of rotation of the traction motors).
- If the positive B and C phase IGBT is turned ON, a circuit is established from the supply positive through

the B and C-phase motor stator winding to the motor neutral. To complete a circuit, the negative A-phase IGBT must be turned ON. With the positive B and C phase IGBT on, the negative A-phase IGBT were turned on, a current path is established through the AC windings of the motor. In this case, the current flow is from the B and C winding to the A winding.

- If the negative A and C phase IGBT is turned on and the positive B phase IGBT were turned on, a current path is established in the opposite direction through the AC winding of the motor. Depending on which positive IGBT and which negative IGBT is turned on at the same time, it will control what windings will be energized and in what direction the current flows (which controls direction of rotation of the traction motors).
- If the positive A and B phase IGBT is turned ON, a circuit is established from the supply positive through the A and B-phase motor stator winding to the motor neutral. To complete a circuit, the negative C-phase IGBT must be turned ON. With the positive A and B phase IGBT on, the negative C-phase IGBT were turned on, a current path is established through the AC windings of the motor. In this case, the current flow is from the A and B winding to the C winding.
- If the negative A and C phase IGBT is turned on and the positive B phase IGBT were turned on, a current path is established in the opposite direction through the AC winding of the motor. Depending on which positive IGBT and which negative IGBT is turned on at the same time, it will control what windings will be energized and in what direction the current flows (which controls direction of rotation of the traction motors).
- The current flow through each motor winding is separated by 120 degrees. This being the case, more than one upper (positive) IGBT and one lower (negative) IGBT will be conducting at any given moment. The reference point for each individual motor winding voltage (and current) is the motor neutral connection N. If a vertical straight line is drawn down through each of the phases at any point, you can see which upper phase IGBT and which lower phase IGBT are conducting at the same time.

Traction Motors

- **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 this lesson.

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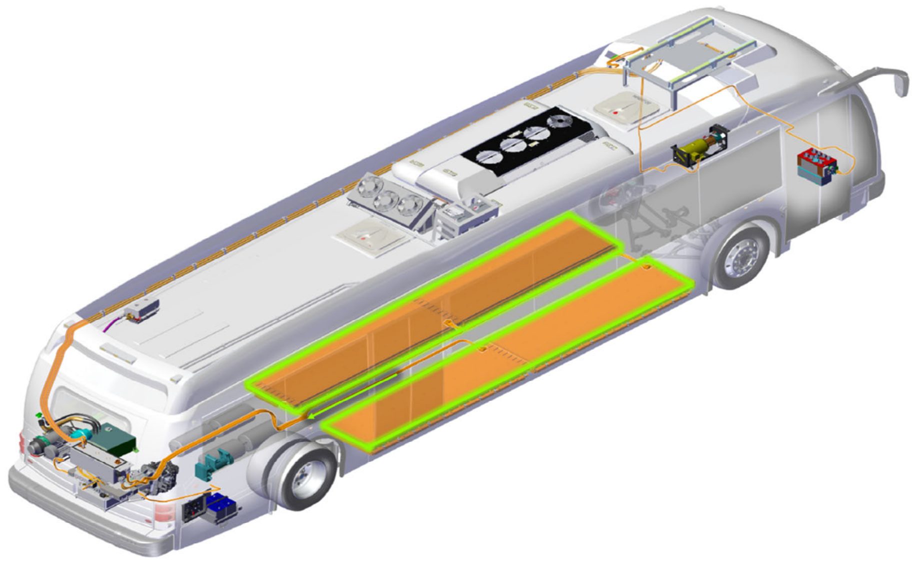
- An AC motor works by applying alternating current to stator windings, which produce a rotating magnetic field in the rotor.
- The rotor will start to follow the stator due to magnetic attraction.
- The rotor turns at a slower speed than the alternating magnetic field of the stator, referred to as slip.
- No slip means no current, which means no torque.
- Cooling is essential for proper operation and will be covered later in this lesson.

Supplemental Notes

- The stator windings of an AC induction motor are distributed around the stator at 120-degree intervals. When three phase AC voltages are applied to the stator windings, a rotating magnetic field is produced.
- In this example, we are using a rotor of an induction motor consisting of a copper squirrel cage imbedded within iron laminates. Only the iron laminates are shown in this animation. As the magnetic field rotates, magnetic lines of force cut across the copper bars of the squirrel cage rotor which induces a current to flow in the rotor bars. This current flowing in the rotor bars produces a magnetic field.
- The magnetic field produced by the currents in the squirrel cage rotor bars reacts with the rotating magnetic field to make the rotor rotate in the same direction. The speed at which the rotor rotates is determined by the speed at which the magnetic field rotates which is a function of the frequency of the three phase AC voltage.
- Due to the load on the motor, the rotor does not quite keep up with the the rotating magnetic field of the stator. It falls behind or “slips” as the field rotates. In this animation, for every time the magnetic field rotates, the rotor only makes three fourths of a turn. The slip has been greatly exaggerated to enable visualization of this concept. In a real induction motor the slips is only a few percent.

Powerflow

- Controller performs initial safety checks.
- Contactors in HV batteries are closed.
- Power then supplied to HV system.



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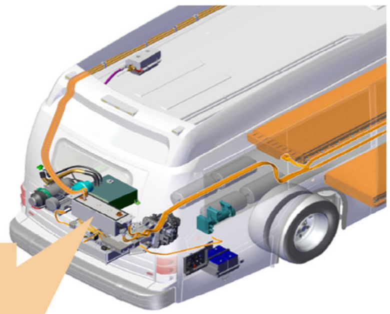
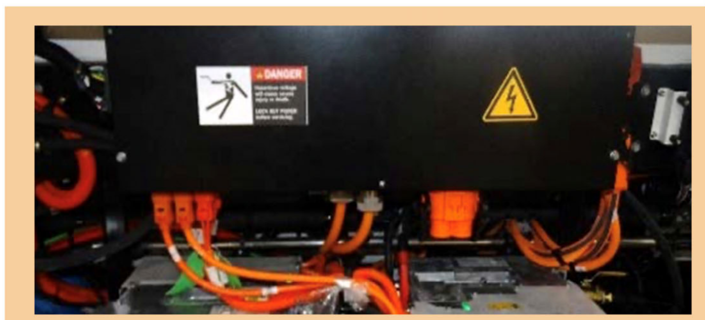
After initial safety checks performed by the controller(s), the contactors inside the HV batteries are commanded closed to supply power to the HV system.

Powerflow

- ESS sends power to HVJB for distribution to HV subsystems.
- HVJB contains fuses, contactors, and sensors.
- First point of HV energy after the batteries.

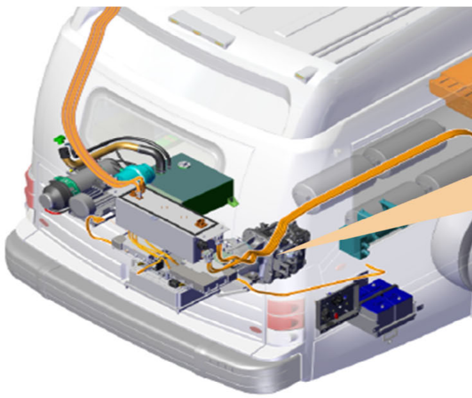


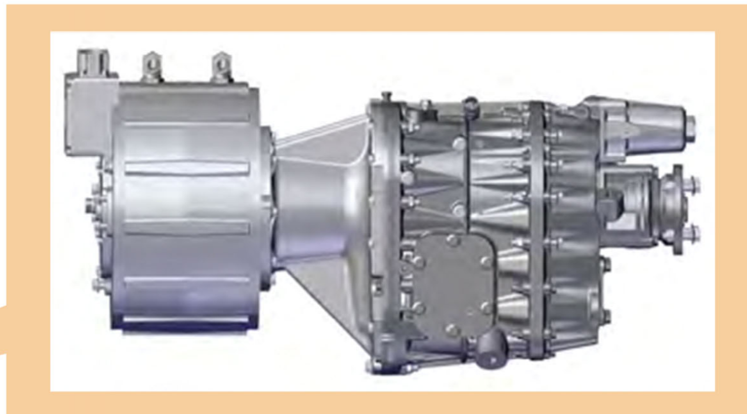


- The HV power from the ESS is sent, first, to the HVJB, for distribution amongst the HV subsystems.
- The HVJB contains fuses, contactors, and sensors.
- First point of HV energy after the batteries.

Powerflow

- HVJB supplies power to TM and inverter to provide acceleration to move the bus.





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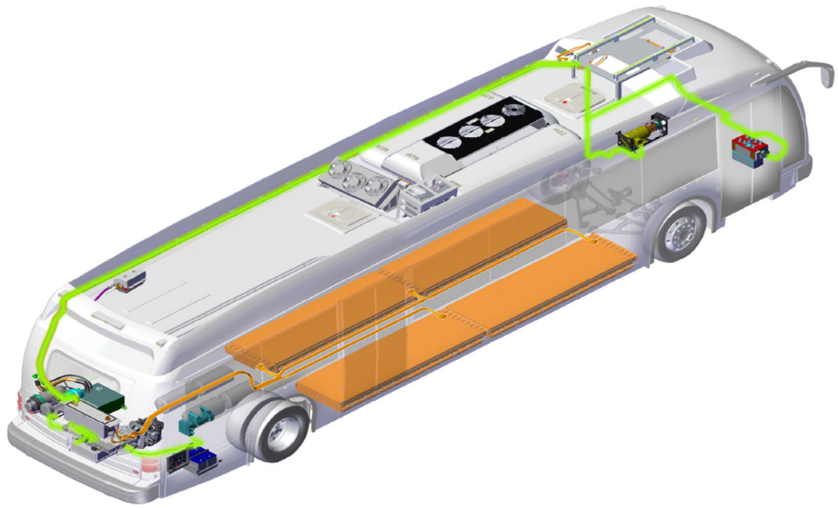
- HV power is supplied to the TM and Inverter from the HVJB to provide acceleration to move the bus.

Powerflow

- HVJB also distributes HV power to the various HV subsystems, such as:
  - Power Steering
  - HVAC
  - Air Compressor
  - BMS Heater/Chiller

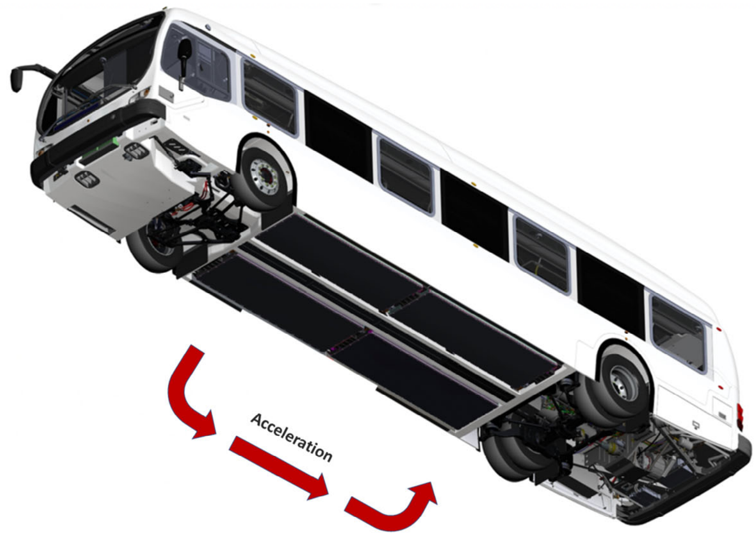


- The HVJB also distributes HV power to the various HV subsystems.

- Examples may include:
  - Power Steering
  - HVAC
  - Air Compressor
  - BMS Heater/Chiller

Acceleration

- During normal driving conditions, HV batteries provide energy to the traction motor which supplies torque effort to turn the wheels on the drive axle.



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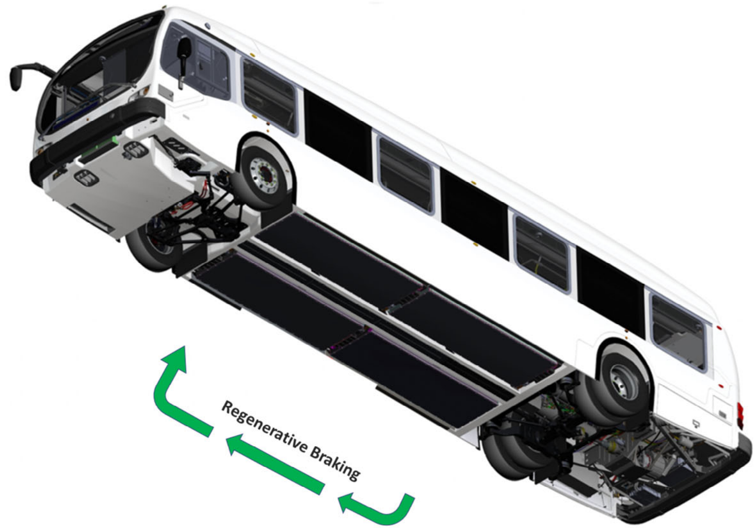
During normal driving conditions, the high-voltage batteries provide energy to the traction motor which supplies torque effort to turn the wheels on the drive axle.

Regenerative Braking

- Energy flow reversed such as when coasting to a stop.
- TM becomes generator.
- Deceleration similar to tradition retarder.
- Stops when operator reapplies accelerator.



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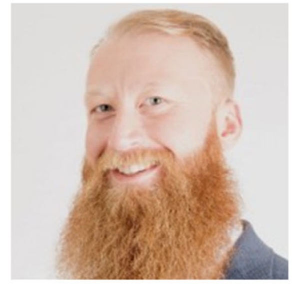
- During regenerative braking, such as coasting to a stop, the flow of energy is reversed.
- The traction motor then becomes a generator, where the motion of the wheels on the drive axle turns the transmission and traction motor, charging the high-voltage batteries.
- Regenerative braking undergoes a deceleration similar to that of a traditional retarder.
- This concept is also used in hybrid buses.
- Regenerative braking will stop as soon as the operator reapplies the accelerator.

Questions and Answers



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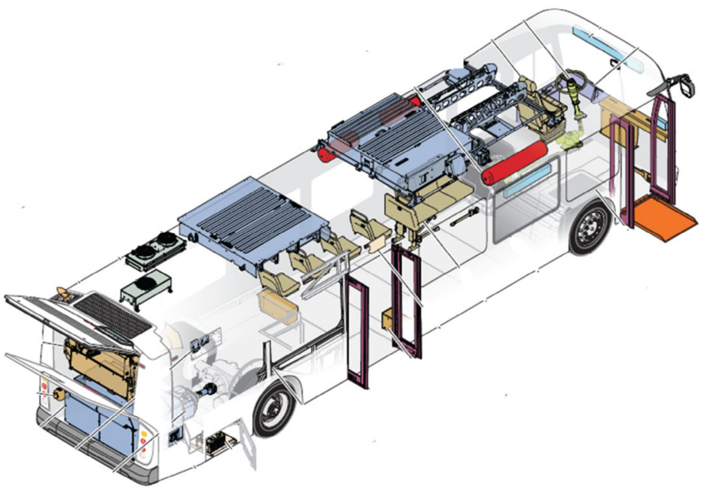

Fundamentals Of BATTERY ELECTRIC BUSES

BEB Preventive Maintenance and Diagnostics

June 2020

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Presenter and Topics

- Safety and Precautions
- BEB Preventive Maintenance
- Diagnostic Tools
- Data Logging

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David Warren, New Flyer
I will cover four areas of BEB Preventive Maintenance in my presentation:

1. Emphasis of safety precautions while inspecting and troubleshooting
2. Familiarization with BEB Preventative Maintenance Items (Many inspections)
3. Use of Diagnostic Tools for Troubleshooting
4. Finally, I will describe Data Logging

High Voltage Safety

- Components operate at dangerous voltage levels.
- Failure to follow HV instructions can be severe.
- Consult OEM manuals.
- Only trained persons should work on HV components.

- The electric vehicles are equipped with electrical equipment components which operate at dangerous voltage levels. Only appropriately qualified personnel may work on this equipment or in its vicinity.
- Failure to observe High Voltage instructions can result in severe bodily injury and material damage.
- Refer to specific OEM service manuals and training for additional information and equipment needed.
- Only trained personnel shall supervise and perform High Voltage system testing, checkout and troubleshooting.

High Voltage Preventive Maintenance

- Based on average vehicle use and typical conditions.
- Customer should determine maintenance intervals.
- Transit agency responsible for scheduled maintenance.

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- The maintenance intervals indicated in this presentation are based upon average vehicle use and typical operating conditions. Unusual vehicle operating conditions, such as geographic environmental conditions, will require service at more frequent intervals.
- It is the customer's responsibility based upon experience with localized environmental conditions and local regulations to determine if more frequent intervals are required.
- The transit authority is responsible for the performance of all scheduled maintenance to maintain the vehicle warranty.

ICE Tasks Not Applicable to BEBs

	Component	Preventative Maintenance Item	Description	Maintenance Interval (Miles unless noted by time)	Applicability to Battery-Electric Bus
1	Alternator	Bearings	Replacement	2-Years	Not required
2	Engine	Air Filter	Restriction Inspection	3,000	Not required
3	Engine	Fluid and Filter	Drain and Refill	6,000	Not required
4	Engine	Primary Fuel Filter	Replacement	6,000	Not required
5	Engine	Secondary Fuel Filter	Replacement	15,000	Not required
6	Engine	Turbocharger	Inspection	30,000	Not required
7	Engine	Vibration Damper	Inspection	30,000	Not required
8	Engine	Spark Plugs	Inspection / Replacement	45,000	Not required
9	Engine	Ignitiion Coil	Inspection and Test	45,000	Not required
10	Engine	Valves	Adjust	60,000	Not required
11	Engine	Oil-Water Seperator	Filter	2-Years	Not required
12	Engine	CNG Tank Vent Caps	Inspection	6-Months	Not required
13	Engine	Oil-Water Seperator	Inspection	6-Months	Not required
14	Engine	Air Filter	Replacement	As needed	Not required
15	Engine	Fluid	Check dipstick level	Daily	Not required
16	Engine	Crankcase Breather Tube	Inspect	Daily	Not required
17	Engine	CNG Fuel Filter	Drain and Inspection	Daily	Not required
18	Engine	Muffler	Inspection	Daily	Not required
19	Engine	Air Intake Piping	Inspection	Daily	Not required
20	Engine	Gas Leak Detectors	Inspection	Monthly	Not required
21	Engine	CNG Fuel Tanks	Inspection	Yearly	Not required
22	Transmission	Various conditions	Inspect Breather, Mounting , bolts, oil leaks	6,000	Not required
23	Transmission	Fluid	Drain and Refill	75,000	Not required
24	Transmission	Filter	Change	75,000	Not required
25	Transmission	Fluid	Check dipstick level	Daily	Not required

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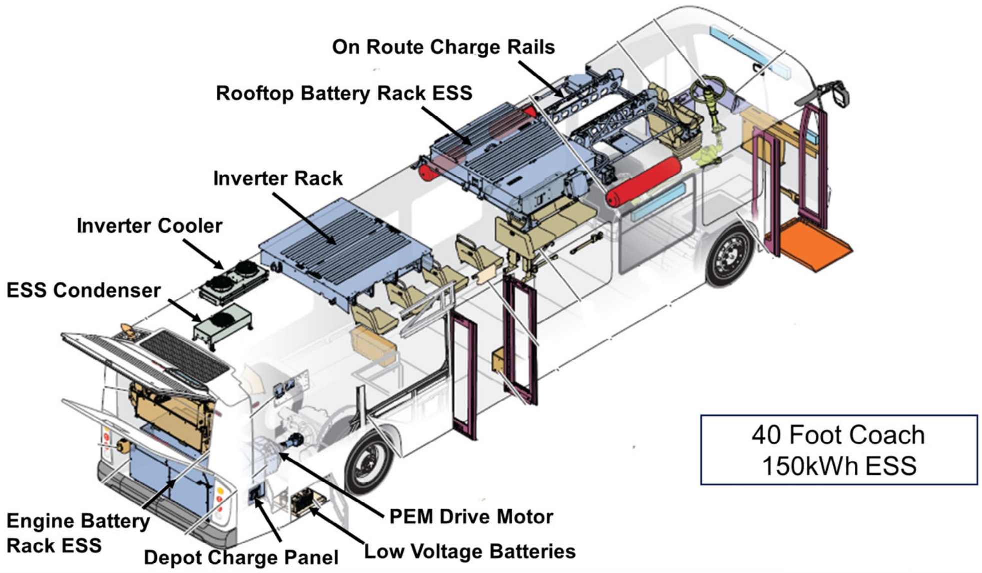
After presenter discusses ICE tasks not applicable to BEBs.

Major Components



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Location of components and and nomenclature vary by OEM.

PM Schedule

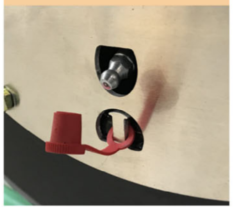
- Run-in
- Weekly
- Monthly
- Quarterly
- Semi-annual
- Annual

Initial PM (motor run-in)
Weekly PM – just include major bullets (HVAC test) and move more detailed slide to appendix
Monthly PM - same, use major bullets (battery pack cell voltage test, battery charging and balance, etc and move more detailed slide to appendix
Quarterly PM – same as above
Six-Month PM – same as above
Annual PM – same as above

Motor Run-in

- Lubricate bearings after first 1,000 miles (1,500 km).
- Grease traction motor fittings.

Drive End



Non Drive End

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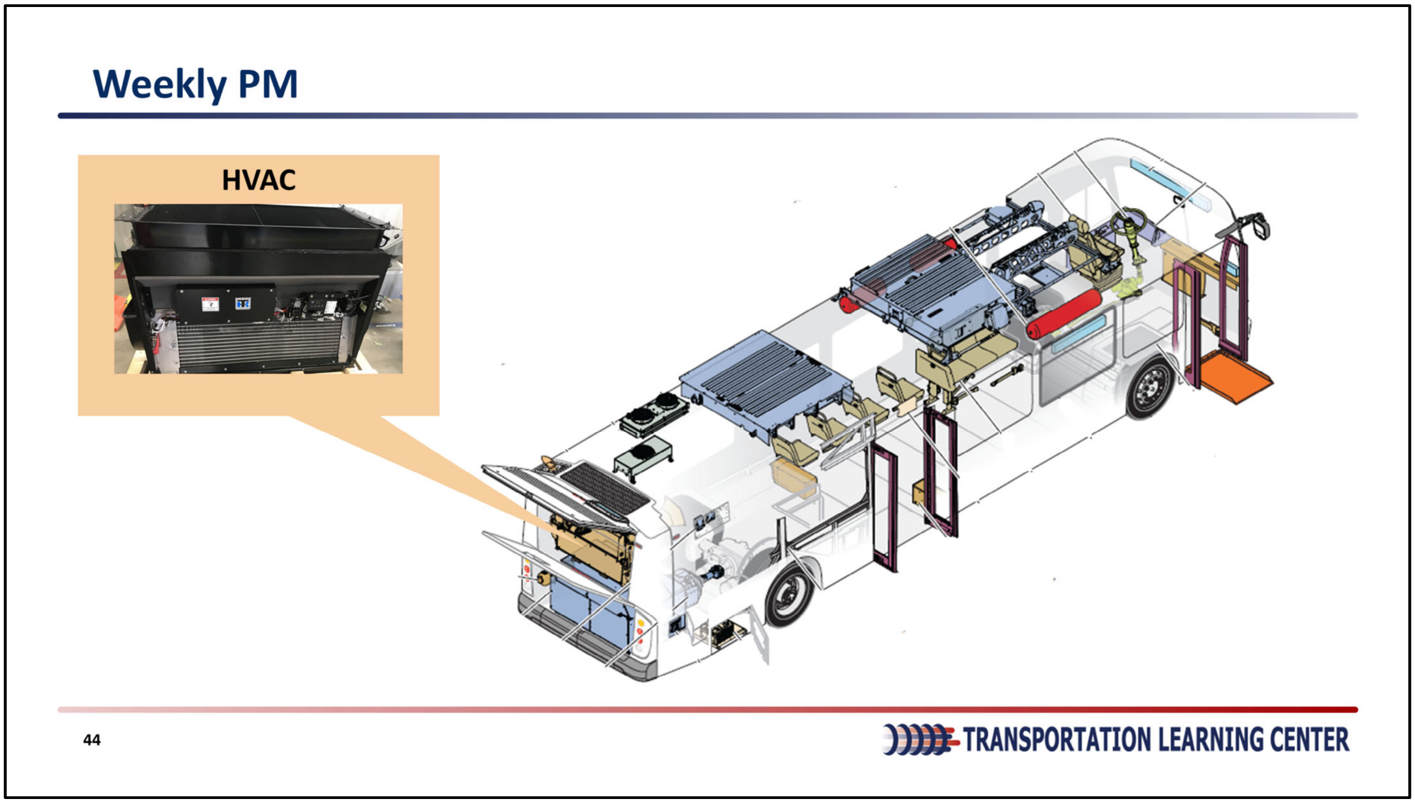
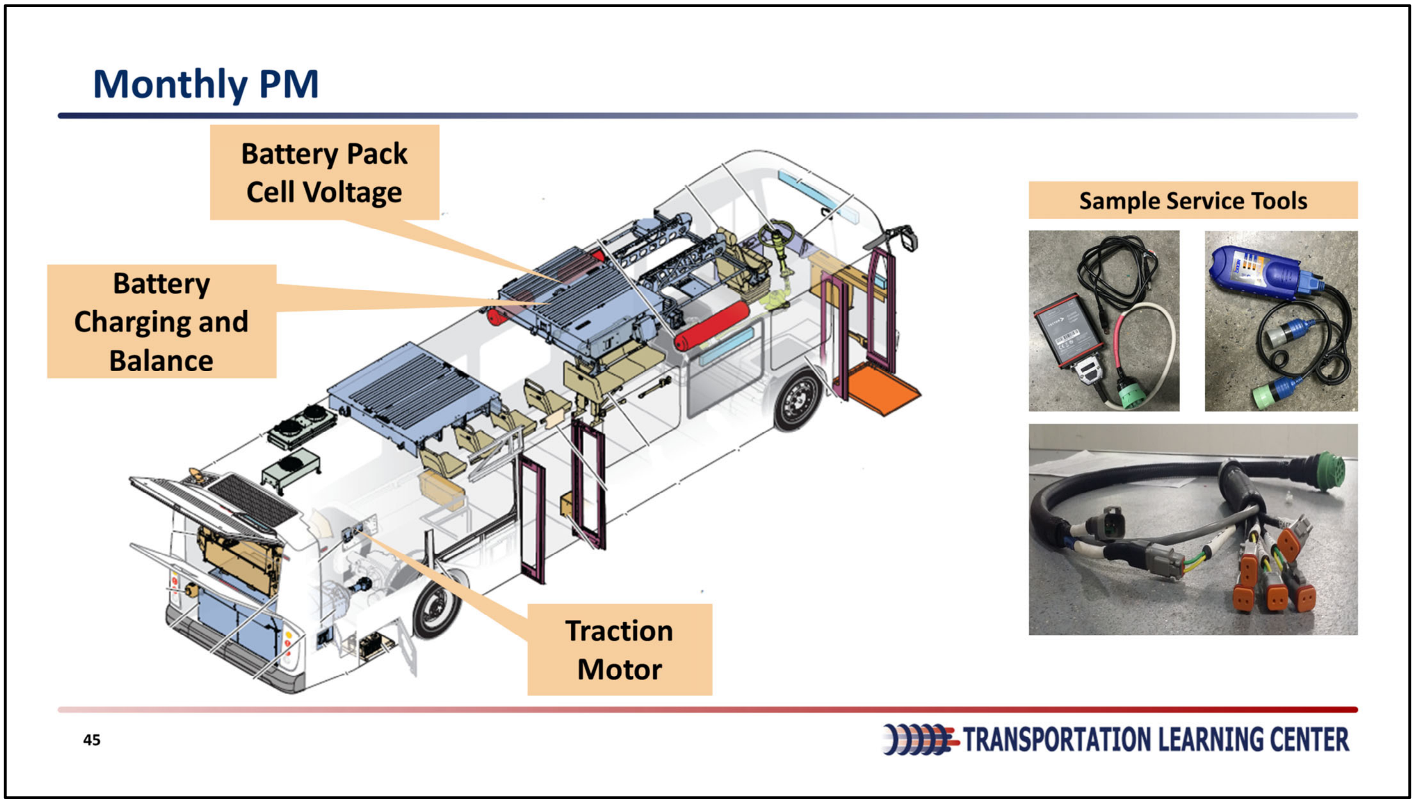
Motor Run-in



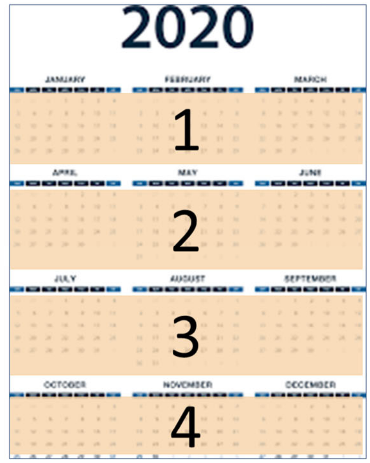
Location of components and and nomenclature vary by OEM.



- Battery Pack Cell Voltage
- Battery Charging and Balance
- Traction Motor

Quarterly PM – Part 1

- ESS Battery Chiller
- High Voltage Cable Inspection
- LV (25 VDC) Electrical Wiring
- Rear Battery Strings inspection
- Roof Top Battery Strings Inspection
- DC-DC Converter Inspection
- Roof Top Electronics Enclosure



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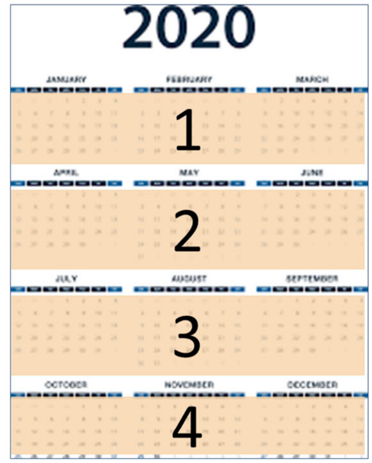
- ESS Battery Chiller
- High Voltage Cable Inspection
- LV (25 VDC) Electrical Wiring
- Rear Battery Strings inspection
- Roof Top Battery Strings Inspection
- DC-DC Converter Inspection
- Roof Top Electronics Enclosure
- Traction Motor Inverter Inspection
- ESS Battery Cooler Condenser Inspection
- HV Accessory Cable Inspection
- Power Steering
- Air compressor
- Charging Cable Receptacle

Quarterly PM – Part 2

- Traction Motor Inverter Inspection
- ESS Battery Cooler Condenser Inspection
- HV Accessory Cable Inspection
- Power Steering
- Air compressor
- Charging Cable Receptacle



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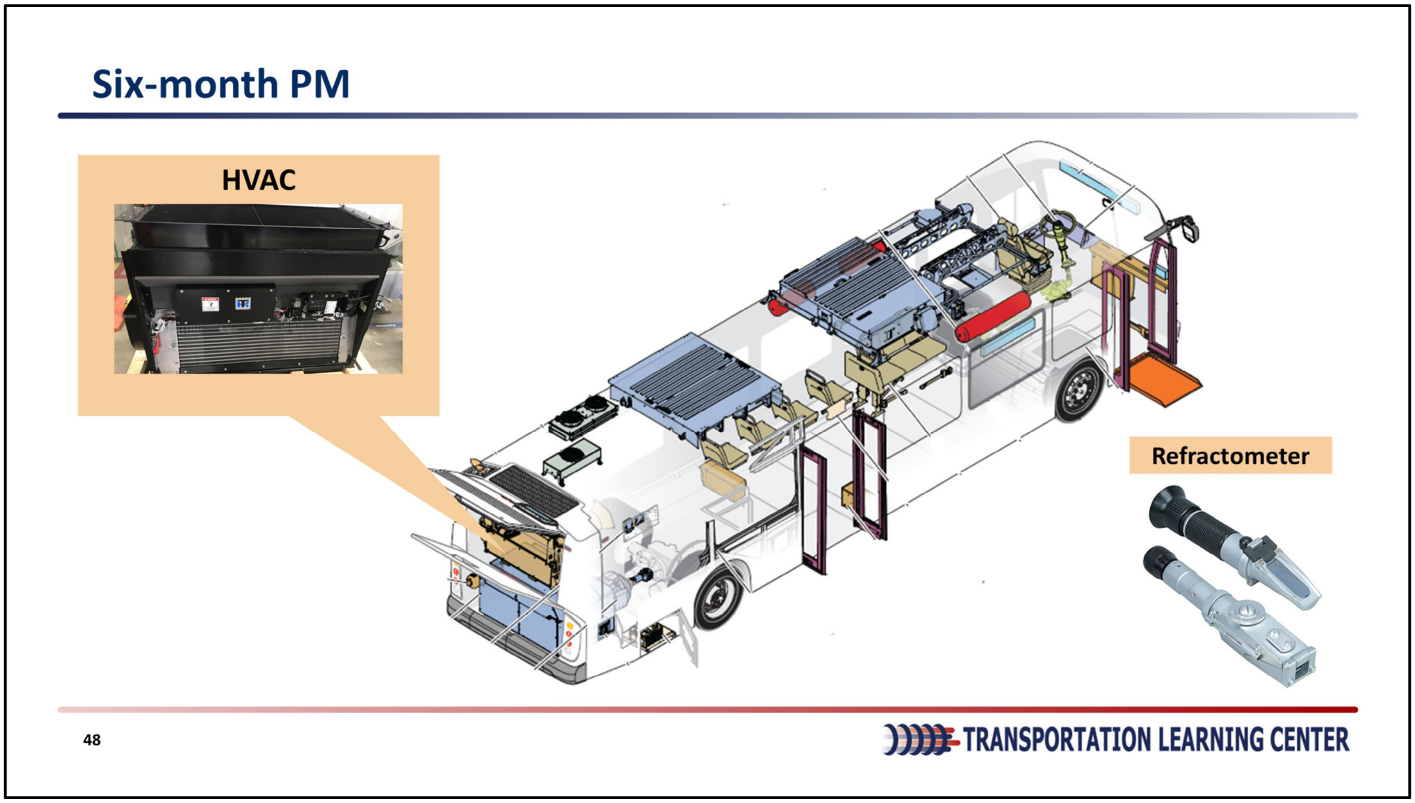
- Traction Motor Inverter Inspection
- ESS Battery Cooler Condenser Inspection
- HV Accessory Cable Inspection
- Power Steering
- Air compressor
- Charging Cable Receptacle



- HVAC System
- Coolant Fluid

Annual PM

- Low Voltage Distribution Box
- High Voltage Distribution Box
- Auxiliary Power Distribution Box
- Insulation Monitoring Device
- Battery Pack Inspection

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PM Schedule Overview

PM Item	Focus	Run-In	Weekly	Monthly	Quarterly	Semi-Annual	Annual
Traction Motor	Lube	x					
Electric HVAC	Cycle		x				
Battery Pack Cell Voltage	Measure			x			
Battery Charging and Balance	Measure			x			
Traction Motor	Inspect			x			
ESS Battery Chiller	Inspect				x		
High Voltage Cable Inspection	Inspect				x		
LV (25 VDC) Electrical Wiring	Inspect				x		
Rear Battery Strings inspection	Inspect				x		
Roof Top Battery Strings Inspection	Inspect				x		
DC-DC Converter Inspection	Inspect				x		
Roof Top Electronics Enclosure	Inspect				x		
Traction Motor Inverter Inspection	Inspect				x		
ESS Battery Cooler Condenser Inspection	Inspect				x		
HV Accessory Cable Inspection	Inspect				x		
Power Steering	Inspect				x		
Air compressor	Inspect				x		
Charging Cable Receptacle	Inspect				x		
HVAC System	Inspect					x	
Coolant Fluid	Inspect					x	
Low Voltage Distribution Box	Inspect						x
High Voltage Distribution Box	Inspect						x
Auxiliary Power Distribution Box	Inspect						x
Insulation Monitoring Device	Inspect						x
Battery Pack Inspection	Inspect						x

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PM Schedule Overview

Diagnostic Troubleshooting

- ✓ Powertrain Diagnostic Software
  - Requires OEM specific program & software
- ✓ Battery Diagnostic Software
  - Requires OEM specific program & software
- ✓ Typical Fault & Troubleshooting Approach
  - Confirm compliant, diagnose fault, apply Corrective Action
- ✓ Data Logging

Diagnostic Troubleshooting

- Powertrain Dongle
- Laptop

Powertrain Dongle

Battery System Diagnostic Tool

Software works with

NEXIQ interface tool

Questions and Answers

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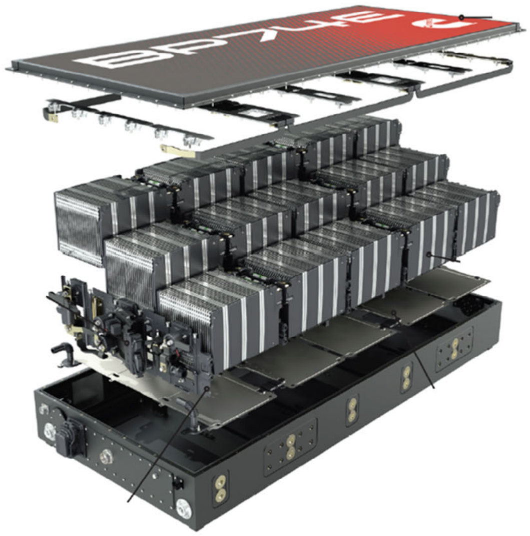

Fundamentals Of BATTERY ELECTRIC BUSES

Battery Management and Cooling

June 2020

Presenter and Topics

- ESS Construction
- ESS Connections and Wiring
- Battery ID and CAN Communication
- HV Battery Safety
- HV Battery Cooling

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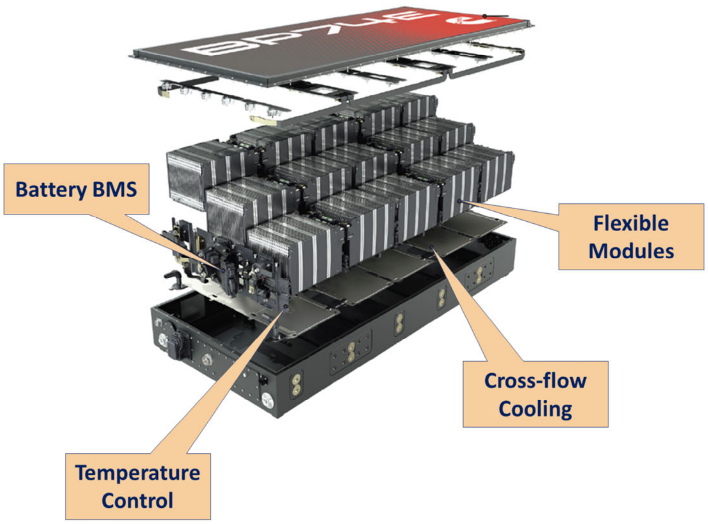
Kevin Hardesty, Field Service Trainer
I will cover five topics in my presentation:

1. ESS Construction
2. ESS Connections and Wiring
3. Battery ID and CAN Communication
4. HV Battery Safety
5. HV Battery Cooling

High Voltage Battery (ESS)



Sample Battery	
Nominal voltage	400-800 V
Battery chemistry (electrolyte)	Lithium ion
Cooling	Water and Ethylene glycol (50:50)
Capacity	74 kWh

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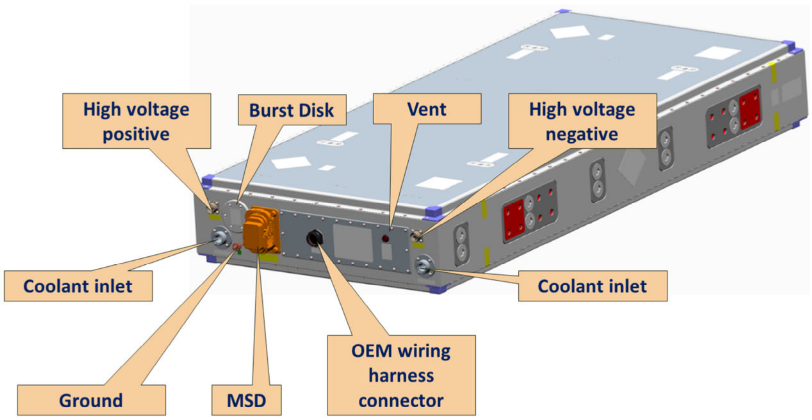
- Battery BMS – The BMS is the brains of the pack. It ensures safety by continuously monitoring and controlling key parameters, as and when required.
- Flexible Modules – Flexible, energy dense modules make it easy to scale battery packs against specific vehicle applications.
- Cross-flow Cooling – Using 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.
- Temperature Control – The battery thermal management system targets 77°F +/- 6°F to maintain isothermal performance of the battery.

High Voltage Battery (ESS) – Part 1



- Various locations by OEM
- Single or multiple packs
- Stores chemical energy to power HV devices
- Floating power and ground to battery only (no HV connection to vehicle chassis).

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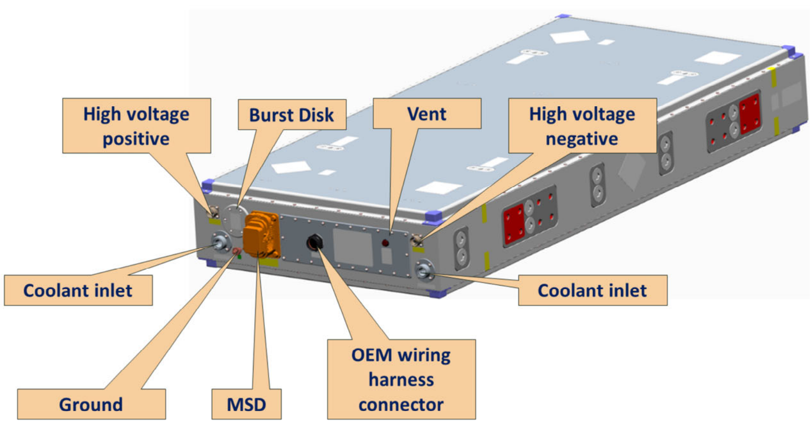
Description:

- Location: Multiple locations determined by the OEM.
- Could be single or multiple battery packs.
- The High voltage battery stores chemical energy which is used to power all HV/LV devices.
- Utilizes floating Power and Ground to Battery only.
- NOTE: Floating power and ground means no High Voltage connection to vehicle chassis.

High Voltage Battery (ESS) – Part 2



- HV connection positive
- HV connection negative
- OEM LV connection
- Coolant inlet
- Coolant outlet
- MSD
- Battery LOTO

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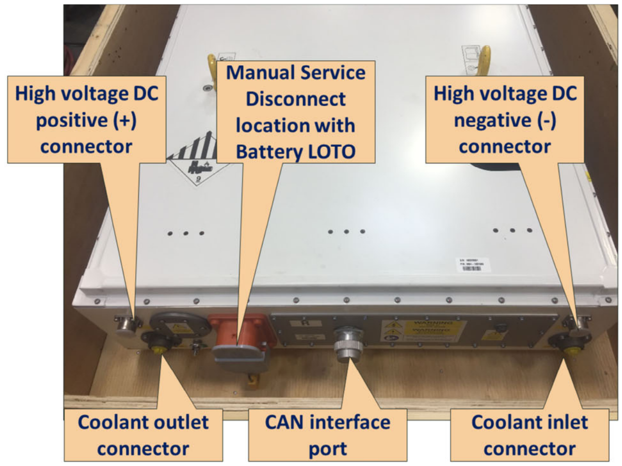
- High Voltage Connection Positive
- High Voltage Connection Negative
- OEM Low Voltage Connection (No Looming or routing with HV cables)
- Coolant Inlet
- Coolant Outlet
- Manual Service Disconnect (MSD)
- Battery Lock Out Tag Out

Handling HV Batteries

✓ Designed for safety

- Two +HV and -HV output contactors must turn on for HV to be available outside battery pack.
- Avoid HV connectors when handling batteries.



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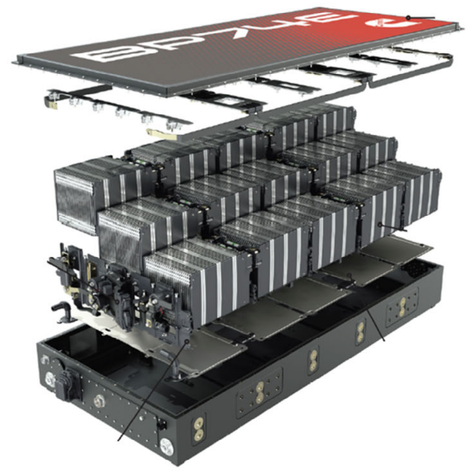
Battery High Voltage Safety Design

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 contactors must turn on for high voltage to be available outside the battery pack.

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

HV Battery Configuration

- Pack contains multiple cells producing approximately 2.0 volts per cell.
- Cells tied in series to achieve 400 to 800 volts.
- Each pack has multiple LV controllers.
- Controllers monitor down to cell level.
- One ESS controller communicates with BMC.
- Controllers operate at 12/24 volts.



Low voltage controls high voltage

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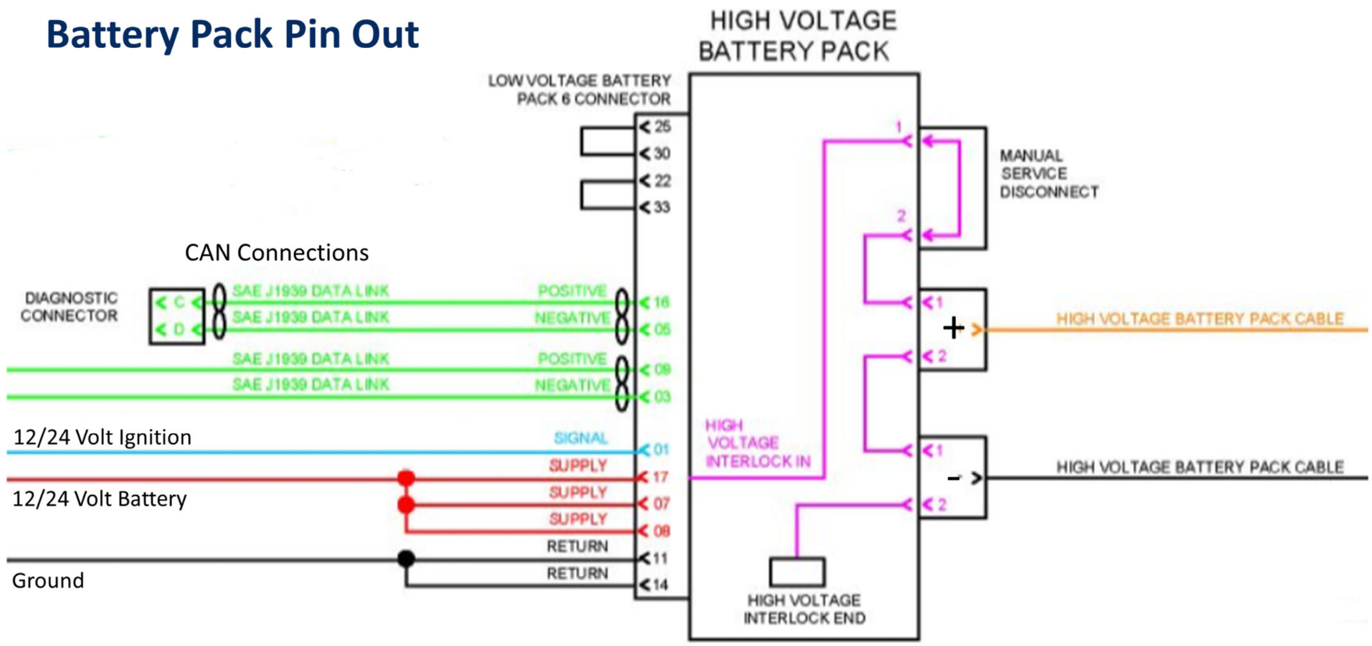
- Each pack contains multiple individual cells producing approximately 2.0 volts.
- The cells are then tied in series to achieve overall pack voltage of approximately 400 to 800 volts +/-.
- There are typically multiple low voltage controllers in each battery pack
    - Controllers monitor battery modules down to cell level.
    - A single ESS controller will communicate with the Battery Management Controller (BMC)
- The Battery Management Controller (BMC) will provide overall control of the battery system.
- These controllers need 12/24 volts (power, ground, and ignition) to operate
- Voltage lower than 12/24 volts may cause a controller to not wake up **[ADVANCE TO FOR IMPORTANT TEXT TO FLY IN]**
- Always remember “Low voltage controls high voltage”

Battery Pack Pin Out



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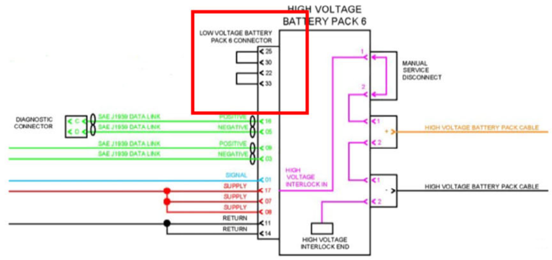
High Voltage ID

- Unique ID used by the BMC.
- Malfunction noted by ID.
- ESS ID system varies by OEM.
- LV battery connector keyed on each ESS
- Internal ESS controller reads serial number on each battery pack and sends to BMC via CAN.
- BMC identifies errors in relevant pack and supplies diagnostics.



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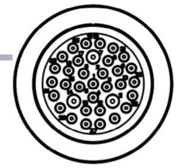
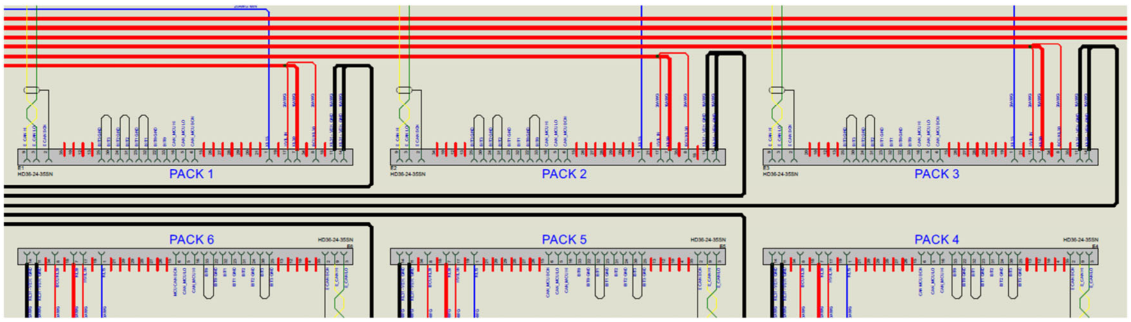
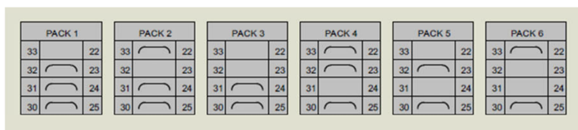
High voltage battery location identification

- Each high voltage battery has a unique number which is used for identification by the BMC
- This identification will allow the system to aid technicians in identifying what pack is malfunctioning
- Each OEM will use a different system to identify ESS ID’s
- One way is to Key the LV battery connector differently on each ESS.
- Pins on the low voltage harness connector are shorted together for location identification
- The internal ESS controller will read the serial number of each battery pack and send these S/Ns via CAN to the BMC
- The BMC will then identify what pack has errors and supply diagnostics for that malfunctioning pack

ESS Pack ID Address Configuration







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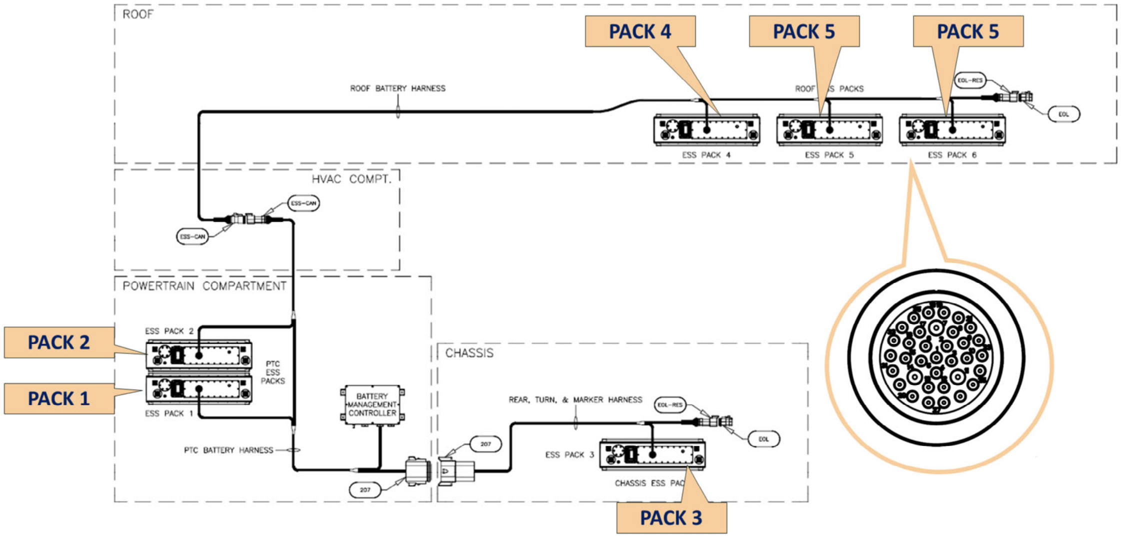
High Voltage Battery CAN



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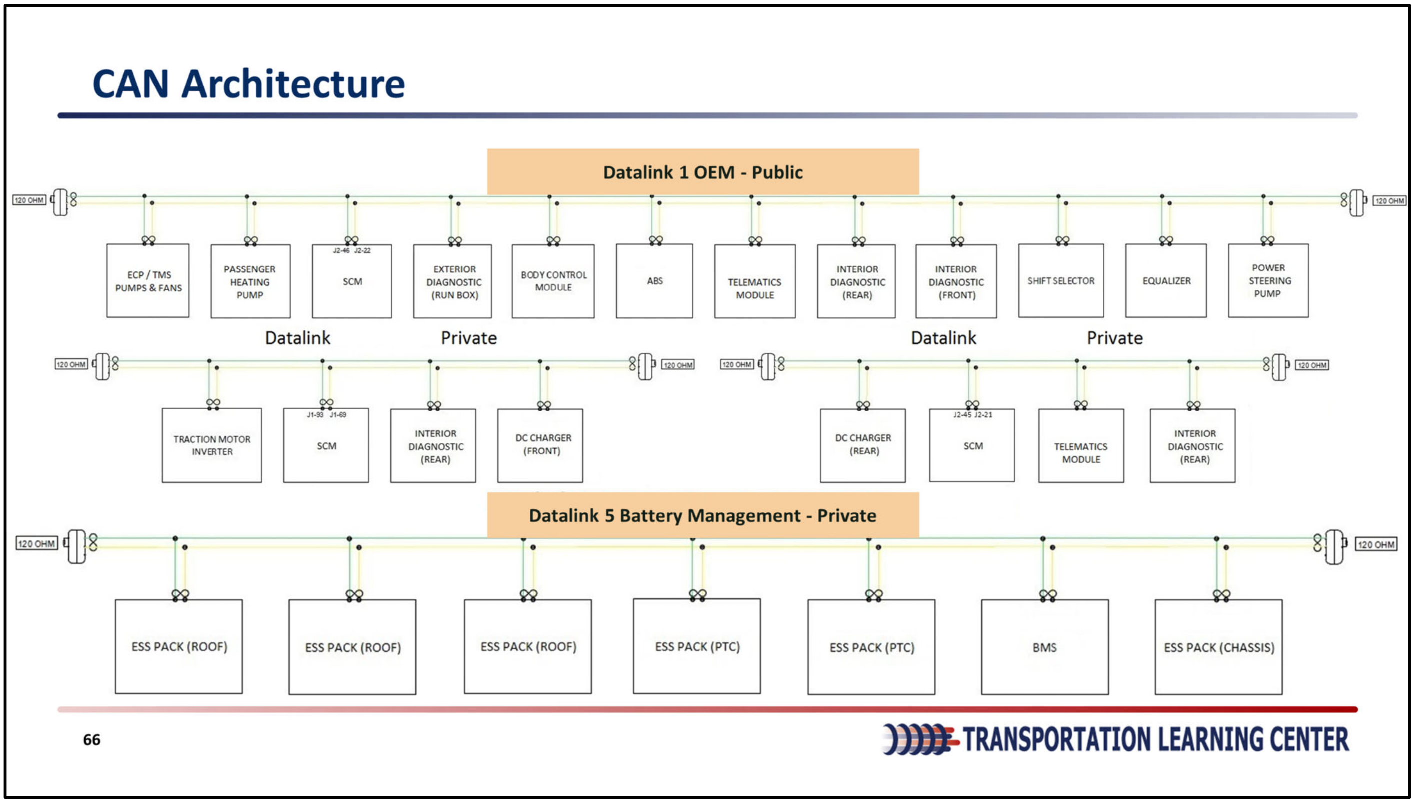
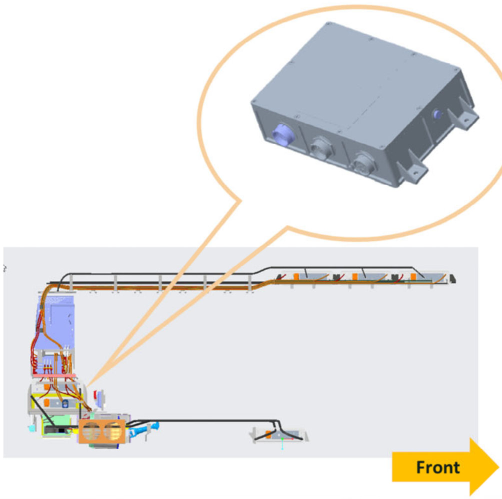


- A BEB bus will have multiple CAN networks.
- Some networks are shared with the end-user and some are deemed Private CAN's
- In this illustration the battery CAN network is Private.

Battery Management Controller (BMC)



- Controls entire battery system.
- Controller of single or multiple HV battery systems.
- Shares data with main system controller.
- Some BMCs have serviceable parts (fuses, relays, control boards)

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Description:

- The BMC controls the entire battery system.
- It is the overall controller of a single or multiple high voltage battery systems.
- This controller will share data with the main system controller.

Some BMS's have serviceable parts

- Fuses
- Relays
- Control Board

HV Isolation Safety

- **Essential for HV safety.**
- Isometer sensor placed in ESS.
- Leakage triggers fault which opens ESS contactors.
- If triggered, a “high voltage exposure” indicator illuminated on bus operator panel.

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- Essential for high voltage safety
- An isometer is a sensor that detects possible high voltage or ground potential into the bus chassis.
- The isometer is typically placed in the ESS and detects potential between high voltage (positive or negative) cables/components and ground.
- Any leakage potential triggers a fault which will then open ESS contactors.
- If isolation fault is triggered, some sort of “high voltage exposure” indicator on the bus indicator light panel will be illuminated.

HV Isolation Detection

- ✓ Isolation detection catches most severe faults in HV system.
  - Coolant leak
  - Damaged HV cables
  - Cell leakage
- ✓ HV system damaged by vehicle crash or impact.
  - Performed inside ESS packs.

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- 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
  - Possible cell leakage
- Performed inside ESS Battery Packs
- Each pack can perform isolation detection.

HV Isolation Detection

- ✓ Measures resistance/voltage drop between
  - HV+ and chassis
  - HV- and chassis
- ✓ > 500 Ohms/volt = no fault
- ✓ 100-500 Ohms/volt = warning light, propulsion and HV disabled when vehicle stops
- ✓ <100 OHMS./volt = warning light, propulsion and HV immediately disabled.

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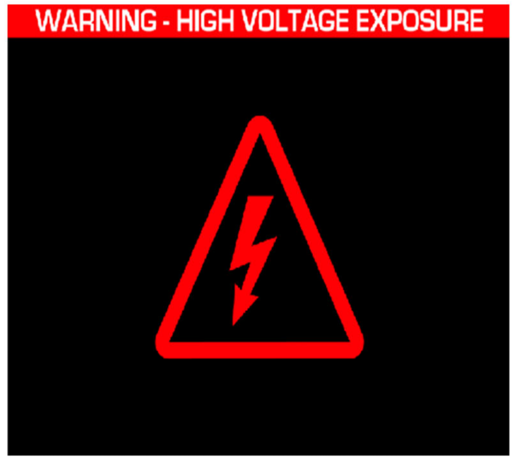
- Frequently measures resistance between
  - HV+ and chassis
  - HV- and chassis **[ADVANCE FOR BULLET TO FLY IN FROM LEFT]**
- If resistance is above 500 Ohms/volt, then no fault **[ADVANCE FOR BULLET TO FLY IN FROM LEFT]**
- If resistance is between 100 Ohms/volt and 500 Ohms/volt, then sets warning light and disables high voltage and propulsion when the vehicles comes to a stop.
- If resistance is below 100 Ohms/volt, then sets warning light and propulsion and high voltage immediately disabled
- Each OEM has slight variations to the isolation shutdown protocols.

System Indicator Lights (MFD)

- Warning systems vary by OEM.
- “EV Stop” indicates major fault.
- “Warning – High Voltage Exposure” illuminated when bus speed drops drops below 3 mph.



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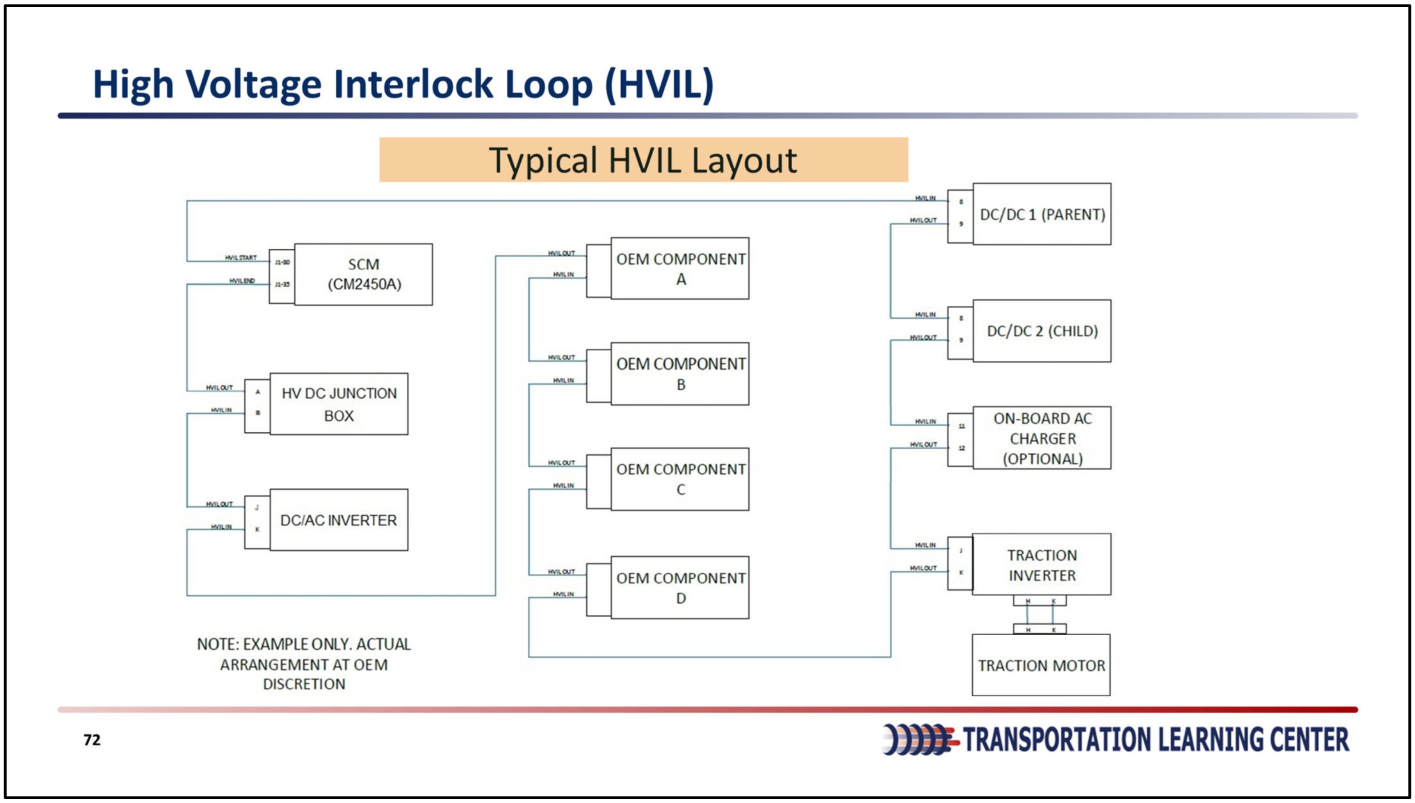
“Warning - High Voltage Exposure”
If the EV System senses a major fault, a red “EV Stop” Indicator will turn on. Once bus speed drops below 3 mph, “Warning - High Voltage Exposure” indicator will inform the driver. Once the bus stops, propulsion will be disabled and you will not be able to move the bus.

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 full DC voltage potential of the EV Battery Packs (Isolation Fault). If a person exits the bus and touches the bus and a ground, they could be electrocuted, possibly fatally.
All OEM’s have a slightly different way of conveying the message.
Please refer to the manual provided with your bus for operation.



- The High Voltage Interlock Loop (HVIL) is a single low voltage circuit which passes in series through high voltage connection point on the vehicle.
- The HVIL system starts and ends inside a low voltage controller. The responsible controller outputs a low voltage signal onto HVIL circuit and looks for the signal to be returned to the controller after going through the loop.
- If a high voltage connection to a high voltage component is removed, the HVIL loop will be broken. The controller 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 whenever someone tries to access high voltage
- The HVIL system loop is always active whenever the bus 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.
- All OEM’s handle HVIL slightly different. Please refer to the electrical schematic manual supplied with the bus for correct operation and wiring of the HVIL circuit.

HVIL – Driver Display

- HVIL circuit break
- Troubleshooting tip: check HVIL low voltage circuit.

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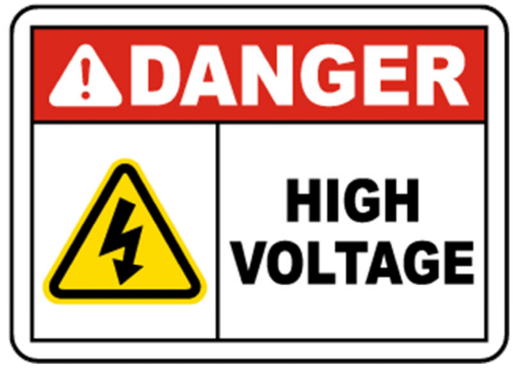
Driver Display:

- There will be a indicator in the drivers display when the HVIL circuit is broken. The message "Warning – High Voltage Exposure" may appear along with a flashing lighting bolt.
- This is driven by the "High Voltage Warning Lamp" status communicated via CAN.
- Commonly caused by an HVIL circuit break, but this is not the only root cause. Start by troubleshooting the HVIL low voltage circuit.

High Voltage Safety

- Safety works in theory.
- Any built-in safety system can potentially fail.
- Refer to OEM manuals.



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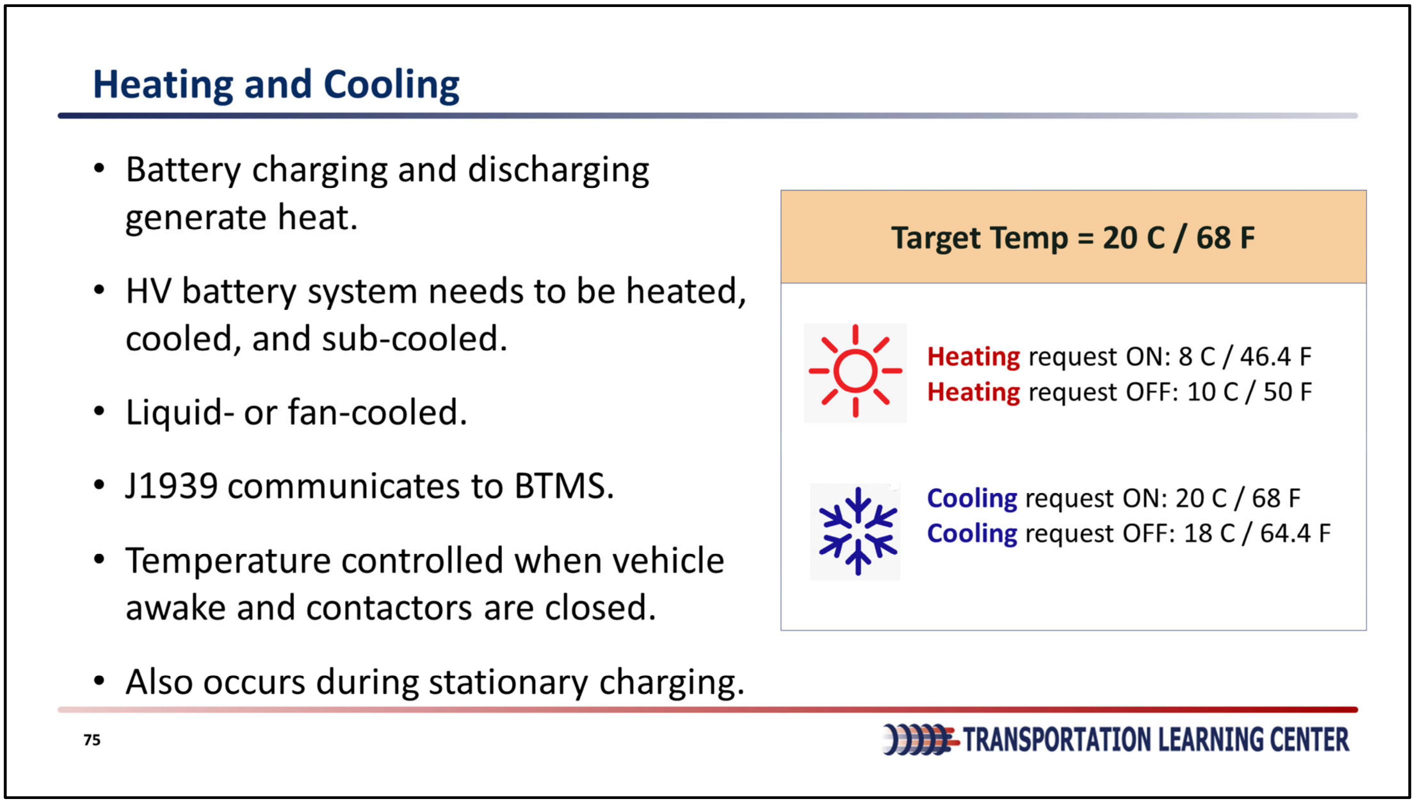
Although we have discussed the two main HV safety systems used on a BEB bus, it is important to note that these systems could possibly fail.

Although that is highly unlikely, it must always be kept in mind.

Therefore, I always say that the safeties work in theory.

Before proceeding with any high voltage service, refer to the OEM manuals for the correct procedure for checking and ensuring that the HV system is dead and safe to work on.



- A by product of charging and discharging a battery is the generation of heat.
- All batteries also have a desired target temperature for optimum operation and charging efficiency.
- Therefore the batteries must have a temperature control system.
- A High voltage battery needs to be heated, cooled, or sub-cooled.
- This can be accomplished in multiple ways, liquid and fan cooled systems are the most common.
- Communication to BTMS is done through J1939
- Battery is temperature controlled whenever the vehicle is awake and contactors are closed. This includes stationary charging.
- Approximate Target Temp: 20o C/68 F
  - Heating request ON: 8o C/46.4 F
  - Heating request OFF: 10o C/50 F
  - Cooling request ON: 20o C/68 F
  - Cooling request OFF: 18o C/64.4 F

Regenerative Braking

- Activated when driver gets to lower percent of acceleration and increases up to zero accelerator position.
- Vehicle slows and energy is being recuperated.

Regen-braking depends on battery state of charge. The following will limit regen-braking:

- High battery temperatures
- Low battery temperatures
- High battery state of charge
- Towing

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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

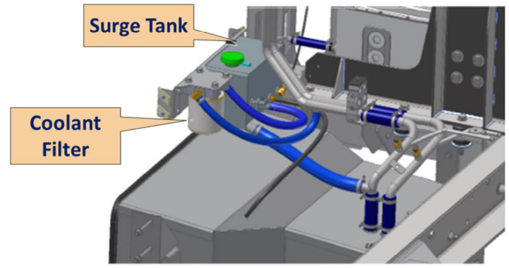
- Regenerative braking is dependent on the battery’s state of charge -The following will limit regen-braking
- High battery temperatures
- Low battery temperatures
- High battery state of charge
- Towing (When towing axle or drive shaft should be removed)

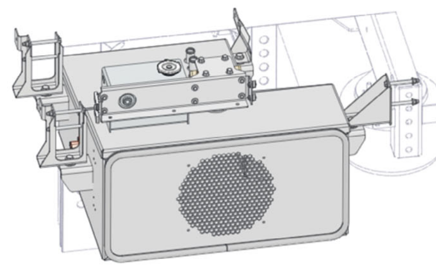
If Regen-braking is limited, the driver will get an indicator stating Regenerative braking is being effected.

If regen-braking is reduced the driver may have to increase the force of the bus foundation braking system

Battery Thermal Management System (BTMS)

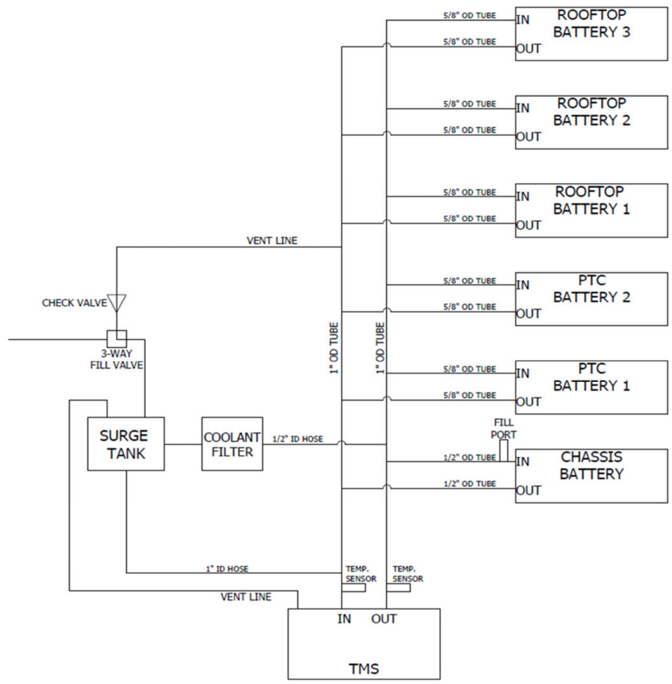
- Maintains battery cell temperature.
- Circulates chilled and heated coolant.
- Components – refrigerant loop, coolant heater, radiator, pump.
- Vehicle-mounted surge tank and coolant filter.
- HVDC compressor and coolant heater.
- LVDC pump and fans.





- Maintains battery cell temperature by circulating chilled or heated coolant
  - Standard 50/50 engine coolant (Ethelene Glycol)
  - Coolant temperature will be approximately 50°-70°F
- Basic components include a refrigerant loop, a coolant heater, a radiator, and pump.
- Surge tank and coolant filter mounted on the vehicle.
- High Voltage Direct Current compressor and coolant heater
- Low Voltage Direct Current pump and fans

BTMS Schematic



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End Gillig's presentation.
Q&A next.

Questions and Answers

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Wrap Up

- Session available for download.
- Evaluate today's session.
- Stay tuned for further BEB sessions.

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Updated 07/06/2020
Video link to session https://vimeo.com/433010060