JOULEY-201

High Voltage Safety & Maintenance Review

Course Code: TBIEV-201

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FOREWORD

Jouley Electric Bus and High Voltage Safety

The Jouley Electric School bus is a battery powered, electric vehicle powered by Proterra technology. It operates like other buses, with the exception of the motor/propulsion system. Two battery packs located under the floor provide power to the electric drive motor at the center of the bus.

During normal driving conditions, the batteries provide energy to the traction motor to turn the wheels on the drive axle. During a "Regenerative Braking" event, this flow of energy is reversed. In this sequence, the traction motor becomes a generator. The motion of the wheels on the drive axle turns the traction motor, which charges the batteries. Providing this additional charge to the batteries will extend the driving range of the electric vehicle.

NOTE: The regenerative braking feature is automatically controlled and is optionally disabled. In the event of slippery conditions, it will automatically deactivate and reactivate. During a regenerative braking event, the bus will undergo a deceleration similar to that of a traditional "retarder" where the vehicle slows down without the use of frictional brakes.

Electrical Shock Hazard

This electric vehicle utilizes a direct current (DC) energy storage and power distribution system that operates at up to 400 volts. **An electrocution hazard exists if humans come in contact with parts of this system.**

⚠ **– WARNING**

This bus contains areas of high voltage that should only be accessible by authorized personnel: under the hood, and under the bus. If necessary, get assistance from the maintenance manager for help.

⚠ **– IMPORTANT**

All access and servicing of this vehicle must be performed by properly trained and qualified personnel who are equipped with personal protective equipment (PPE) appropriate to the task at hand.

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Glossary of Terms

Commission

This term means to place the high voltage system of a vehicle back into service. This task can only be performed by Specialists for High Voltage Vehicles (SH), and involves several tests and checks to ensure the safety of the personnel and the vehicle.

Decommission

This term means to "turn off" the high voltage battery of a vehicle, so that the ONLY high voltage present is within the battery housing and isolated from any vehicle wiring. This is a step of the lock-out-tag-out process, and the SH verifies that no high voltage remains after installing the padlock and signage.

Live Parts / Live Work

Live work is performing work on the high voltage system of the vehicle while high voltage is applied. A live part is one that has a difference in voltage compared to its surroundings. This voltage difference creates a safety hazard. Live work is not allowed under any circumstances.

Specialist for High Voltage Vehicles (SH)

SH designation is a narrow-scope high voltage electrician qualification that is attained by successfully completing the HV3 instructor-led course (CVE13). This course gives the technician the skills needed to safely work on vehicular high voltage systems, and to make such high voltage systems safe for others to work on.

Supervision and Direction

When an HV2-qualified person assists an SH with a service task, the SH is required to fully brief the HV2-qualified person on the task and direct the service effort in accordance with an established, written procedure.

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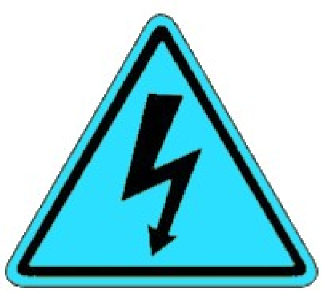
High Voltage Safety Training (HV2)

1. Introduction to HV2 Training

Target Audience

The HV2 course was created to give technicians the knowledge they need to stay safe when servicing vehicles that are equipped with high voltage drivetrains. The HV2 technician performs troubleshooting and repair of low-voltage and mechanical systems, and can provide assistance to the HV3-trained technician when performing some service procedures on the high voltage system.



As an HV2-trained technician, you can drive a high voltage vehicle, as well as do any repair or maintenance on it that *doesn't* involve the high voltage systems.

In order to perform any work on any high voltage system, or to de-power the vehicle to lock-out/tag-out the high voltage system, you must complete Jouley-301 (HV3) course.

2. Technician Safety Training Roles

Employee Job Classification	Jouley 101 (HV1)	Jouley 201 (HV2)	Jouley 301 (HV3)
Driver production HV Vehicle	✓	✓	✓
Driver of pre-production HV Vehicle	✓	✓	✓
Fleet/ Customer Technician(working HV eVehicle but non-HV Components)		✓	✓
Fleet/ Customer Technician (working HV eVehicle and working on HV Components)			✓
Fleet/ Customer Maintenance Employees not working on eVehicles (Awareness)	✓	✓	✓
Dealer Technician (working HV eVehicle but non-HV Components)		✓	✓
Dealer Technician (working HV eVehicle and working on HV Components)			✓
Dealership Technicians not working on eVehicles (Awareness)	✓	✓	✓
Anyone moving in and around (inside physical safety barriers) a HV eVehicle while maintenance is being performed. Anyone that must go beneath a HV eVehicle for any reason, inspections or other purposes.		✓	✓
HV-System modifications / troubleshooting energized HV eVehicle			

Throughout DTNA, High Voltage Safety training falls into three categories - High Voltage 1 (HV1); HV2, and HV3.

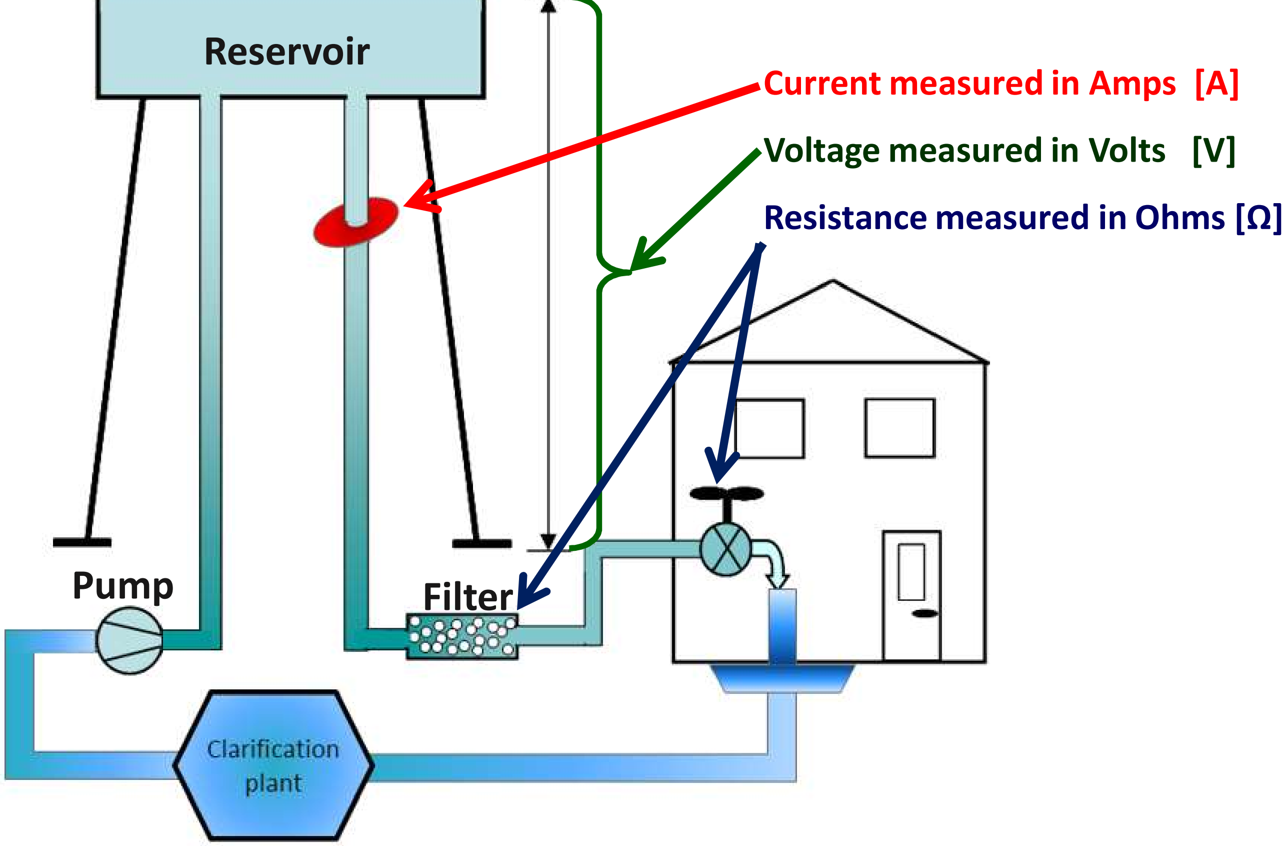
This chart allows you to identify the level of training that matches your job responsibilities. Customers and Dealers should have a high voltage electrical safety organization that coordinates their safety program.

3. Basics of Electricity

Current ≈ Amount of water / second

Voltage ≈ Water pressure

Resistor ≈ Water filter or Faucet



Current (A)

In this analogy, electric current can be compared to the flow rate of the water. More water flowing equates to more current. Current is measured in Amperes (amps).

Resistance (Ω)

Resistance is the circuit or component's opposition to the flow of electricity. It is represented in our water model by a filter, partially-closed valve, or other flow obstruction. Resistance is measured in Ohms, and represented by the Ω symbol.

Voltage (V)

Electromotive Force (EMF) is measured in Volts (V). In the water analogy, this is represented by water pressure. Higher pressure is equivalent to higher voltage. Higher voltage causes more current (A) to flow if the resistance is kept constant.

4. Defining High Voltage

According to the OSHA, a hazard for humans starts at:
50 V alternating current (AC)
120 V direct current (DC)

OSHA 29 CFR 1910.303(g)(2)(i) / NFPA 70E limit is **50V**, AC or DC.

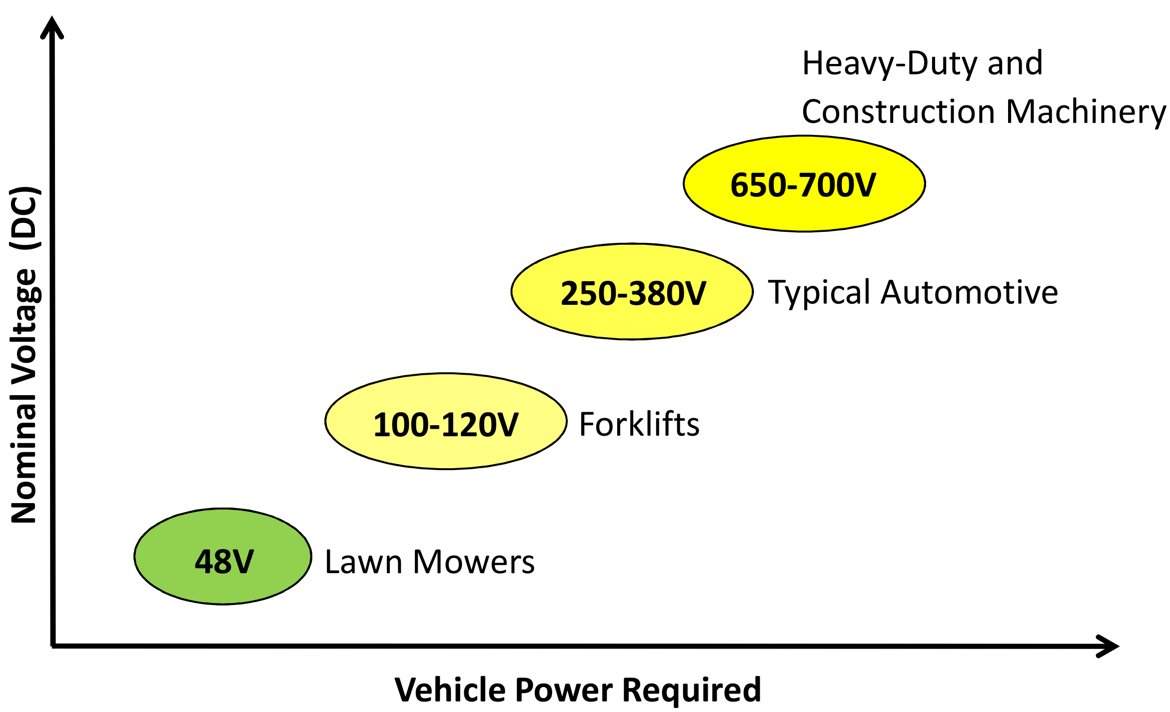
How much voltage is *High* Voltage?

According to the DIN VDE 0100 Part 410 standard, electrical hazard for humans starts at 50 V of alternating current (AC) or 120 V of direct current (DC). The updated / released OSHA standard 1910.303(g)(2)(i) applies, and specifies that the maximum voltage that can be left unguarded/unshielded as **50 V AC *or* DC**.

5. Electric Vehicle – Why High Voltage?

One equation for electrical power is **P = V x A**. From this equation, you can see that as power demands rise, voltage, current, or both, must rise proportionally. Raising current is the more problematic of the two, because it necessitates larger, heavier electrical components and conductors. Also, raising current increases **I2*R** losses, which lower overall system efficiency and elevate cooling requirements. To create 600 HP from a 12V electrical system would require over 37,000 amperes!

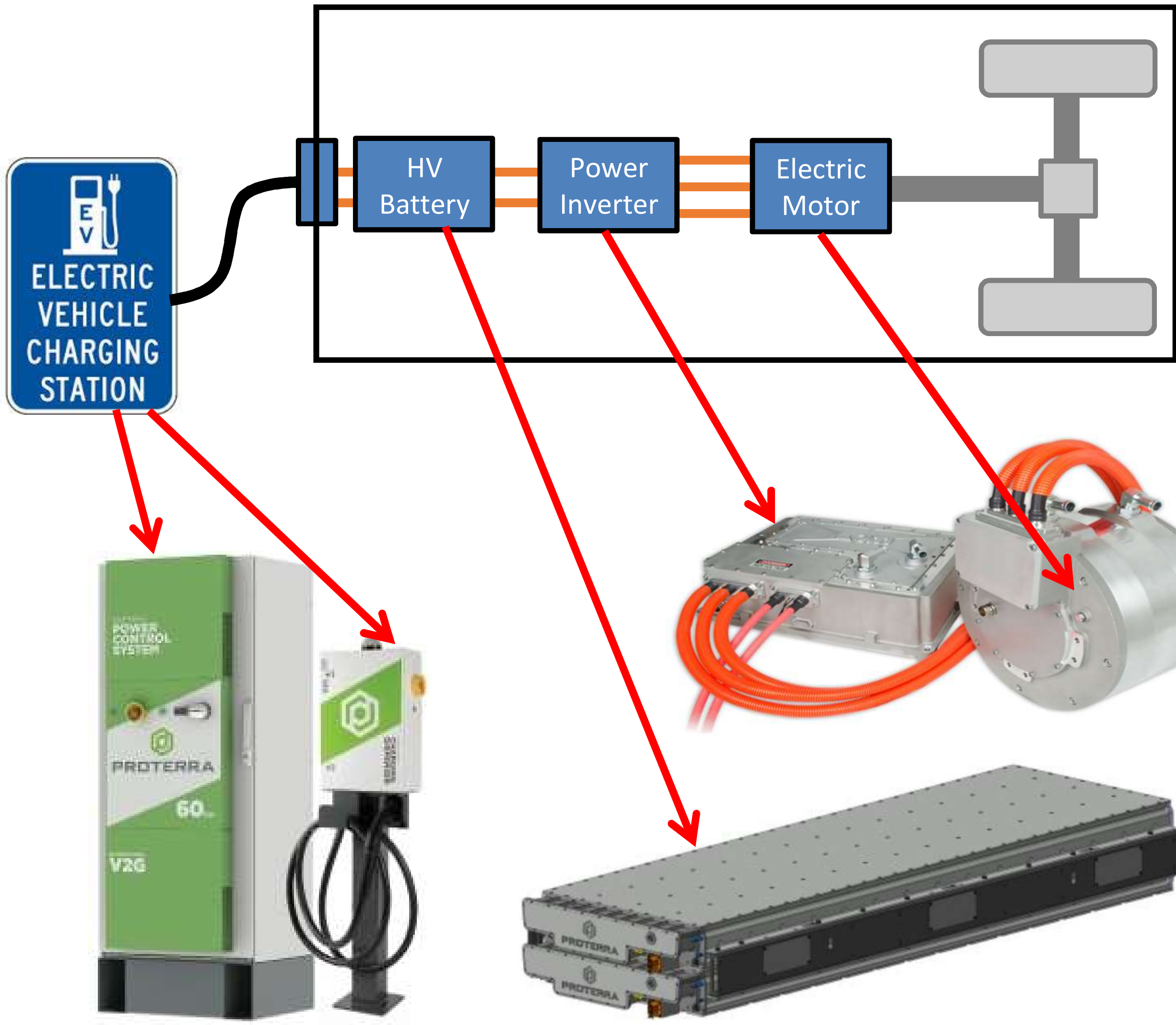
Of course, raising voltage to astronomical levels in order to keep current low is also impractical. This is primarily due to the increasing shock hazards involved, and also the physical limitations of insulation, controls, and battery construction materials.



6. Jouley Power Specifications

Vehicle:	**Jouley School Bus – C2 Electric Bus**
Power E-motor cont. :	120KW/161HP (Proterra)
Voltage level / energy content	400V, 220 - 226 kWh
Range:	138 miles (estimated range)

7. Electric Drive Vehicle Basic Layout



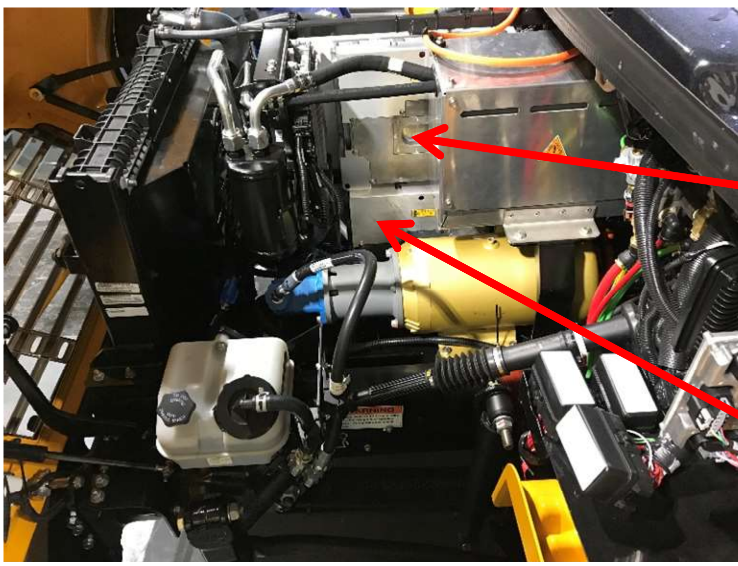
EV charging stations supply DC power straight to the battery. The HV battery supplies the current that is used to propel the vehicle and maintain the low voltage (12v) features and components. The drive power inverter converts the DC current that is supplied by the battery into AC current that is used by the motor, and controls the motor's speed. When braking, it acts as a rectifier to convert the motor's AC output into DC current in order to charge the battery. The drive motor is a 3-phase AC synchronous motor.

8. Jouley Electric Bus Components

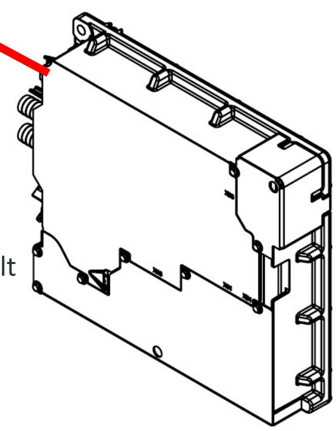
Accessory Variable Frequency Drives

VFD – Dual Output

The Variable Frequency Drive (Dual Output) is mounted under the front hood on the drivers side / back of the High Voltage Junction Box. This liquid-cooled VFD supplies high-voltage three phase AC power to the air compressor and power steering motor. It is CAN controlled by enable and speed commands from the Main Body Controller.



VFD – Dual Output



VFD – 14 Volt

VFD – 14 Volt (DC - DC Converter)

The VFD – 14 Volt is a DC to DC Converter mounted under the front hood on the drivers side below the VFD Dual Output. This liquid-cooled converter steps down the high-voltage supplied by the battery packs and provides a 14-volt DC output to the two low-voltage (12 volt) batteries and body accessories. A version of this unit will also supply AC voltage to the cabin A/C compressor motor if passenger A/C is ordered.

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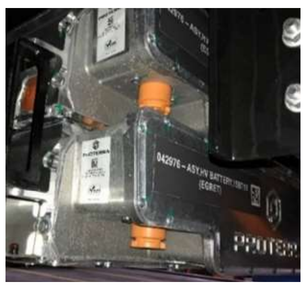
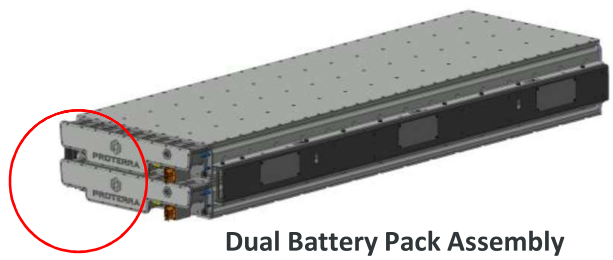
High Voltage Battery Packs

There are two (2) battery packs powering the high voltage systems on the vehicle. They also maintain the low voltage 12 volt system through a DC to DC converter. The battery packs are cooled by an internal heat exchanger and are connected to an external heat exchanger and HVAC chill plates by a dedicated cooling loop. The battery packs contain vent to prevent pressure buildup within the packs. A Manual Service Disconnect (MSD) is located on the driver's side rearward end of each pack.

OR



Manual Service Disconnects (MSD)

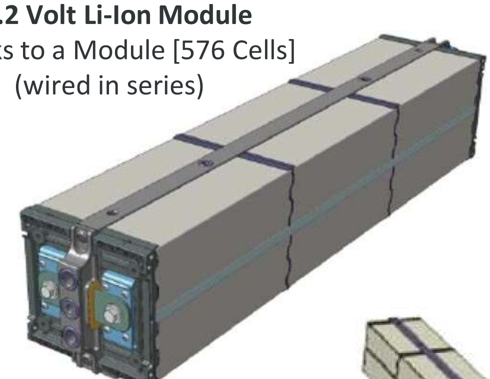


Dual Battery Pack Assembly
(17,280 Li-Ion Cells per Bus)

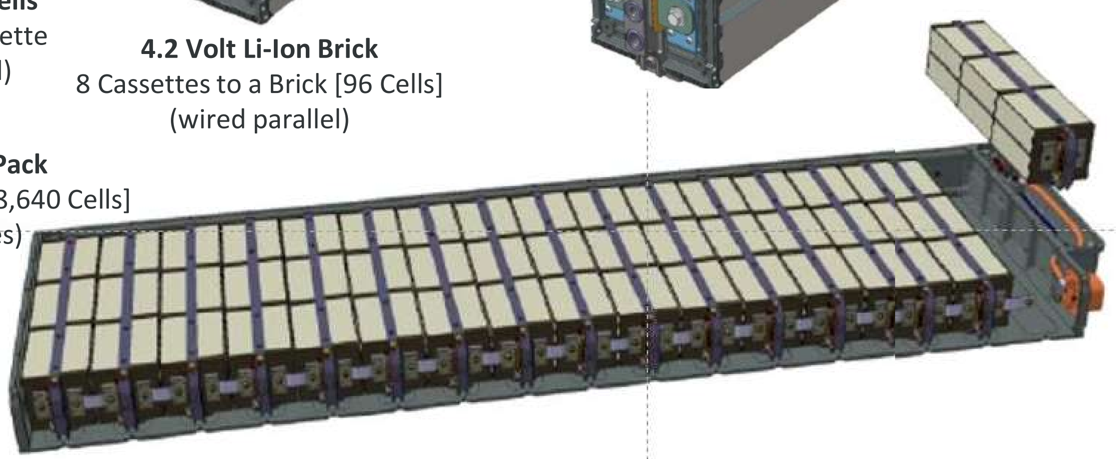
4.2 Volt Li-Ion Cells
12 Cells to a Cassette
(wired parallel)

4.2 Volt Li-Ion Brick
8 Cassettes to a Brick [96 Cells]
(wired parallel)

25.2 Volt Li-Ion Module
6 Bricks to a Module [576 Cells]
(wired in series)

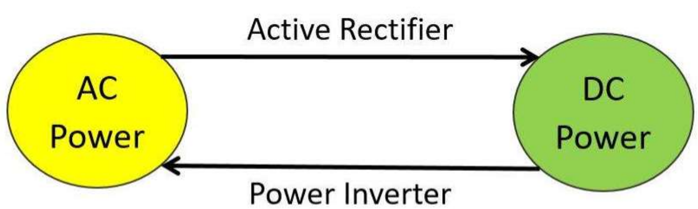


378 Volt Li-Ion Pack
15 Modules to a Pack [8,640 Cells]
(wired in series)



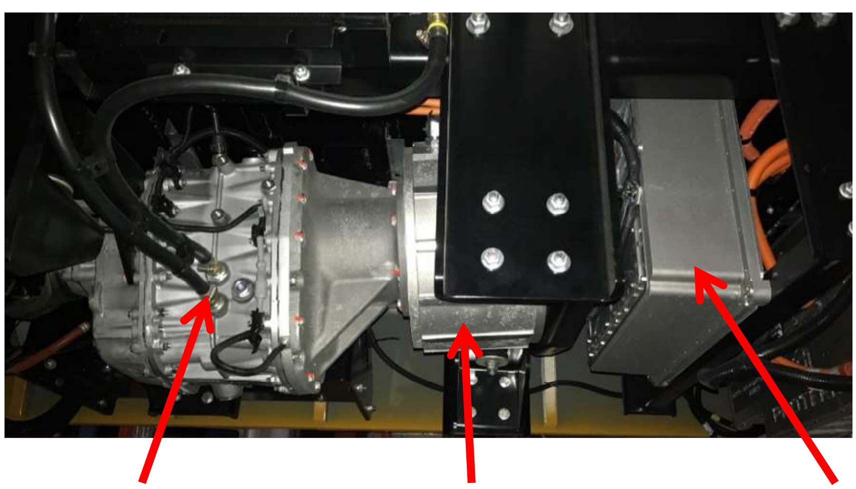
Traction Motor, Motor Controller/Inverter, and Transmission

Power flow through the inverter is bidirectional. When accelerating, DC power flows from the main battery pack to the inverter. The Inverter converts HV DC from the main battery into variable frequency, variable current, three-phase AC power to turn the traction motor at the desired speed and power level.



When decelerating, the traction motor generates AC electricity which flows to the inverter, gets converted to DC, and recharges the main battery. Regenerative braking significantly improves vehicle energy efficiency.

The drivetrain includes a two-speed, automated-manual transmission. An air actuated shifter controls gear selection. When no air is applied the transmission defaults to neutral. Reverse is achieved simply by turning the main traction motor in reverse. An oil cooler ensures fluid temperature remains within limits for a long life.



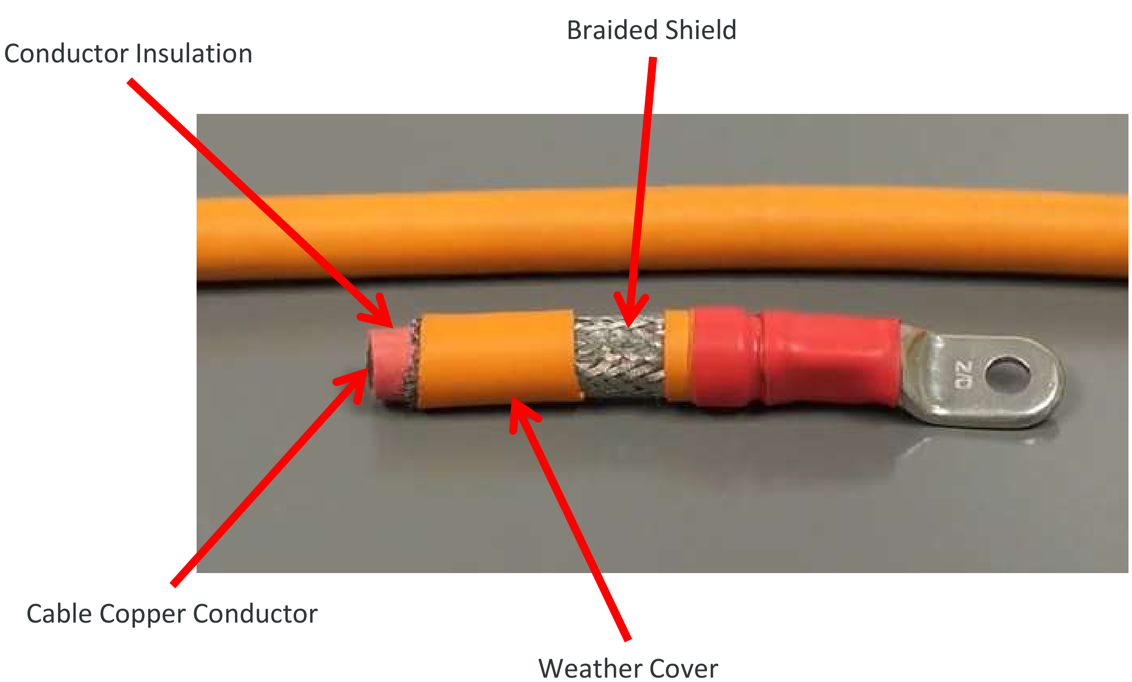
Transmission   Traction Motor   Motor Controller / Inverter

High Voltage Cables

The high voltage cables consist of a copper conductor sized for the load to be carried. Around the conductor is the red insulation of the cable. Outside the insulation is a stainless steel braided shield. This functions as a EM shield and a ground path to the chassis if the insulation fails. The outside layer is an Orange weather covering. For any High Voltage cable, this cover is always Orange to identify it as a HV cable.

Care should be taken when bending or supporting the HV cables as they do not have tight bend radiuses. Any movement or excessively tight bends can cause the braided shielding to wear into the conductor insulation.

One cable can hold multiple conductors.

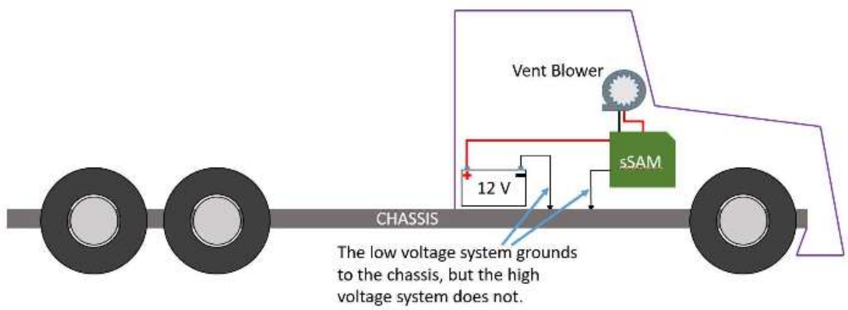


9. High Voltage System Safety Features

Separated High Voltage Electrical System

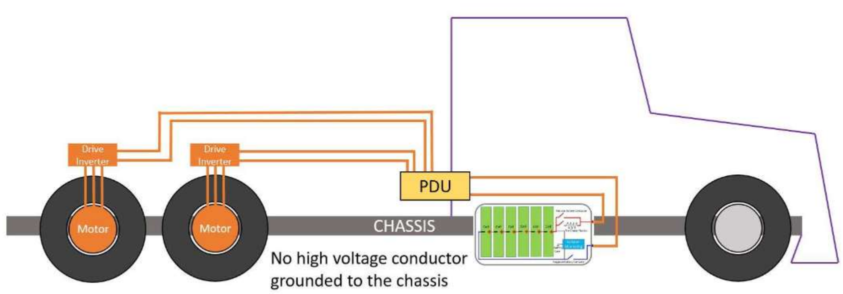
Grounded Low Voltage System

We'll start with the familiar. Low voltage components often have the negative terminal of the component grounded to the cab or chassis. This makes a reliable, convenient connection point, and presents no safety hazard due to the low voltage involved.



Separated High Voltage System

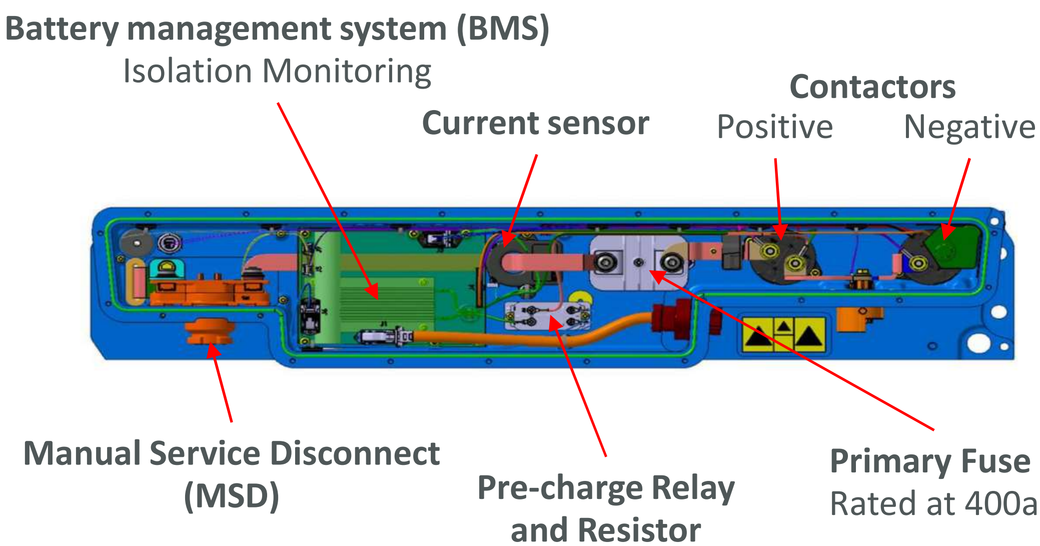
Although the outer metal cases of all high voltage components *are grounded* to the chassis, the high voltage electrical system itself is not. The benefit of this system is that no single fault or short circuit to chassis will cause a battery short circuit, or pose a dangerous shock hazard.

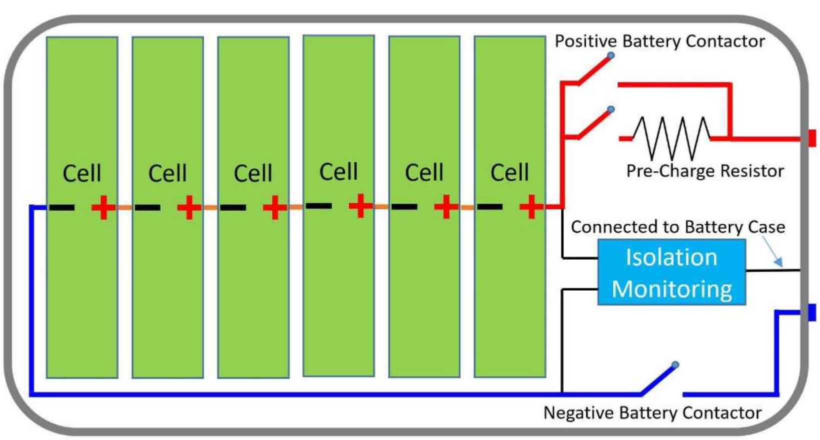


Safety Starts with YOU
...and the Battery

The design of the high voltage battery enables many of the electrical safety features of the vehicle. Most important are the **battery contactors**. These large switches isolate the voltage of the cells from the connections on the outside of the battery casing, effectively turning the battery off. The contactors can be caused to open in many different ways; both automatically, and manually. When the contactors are open, all high voltage is confined inside the battery casing making the rest of the vehicle electrically safe.

Battery Ancillary Bay





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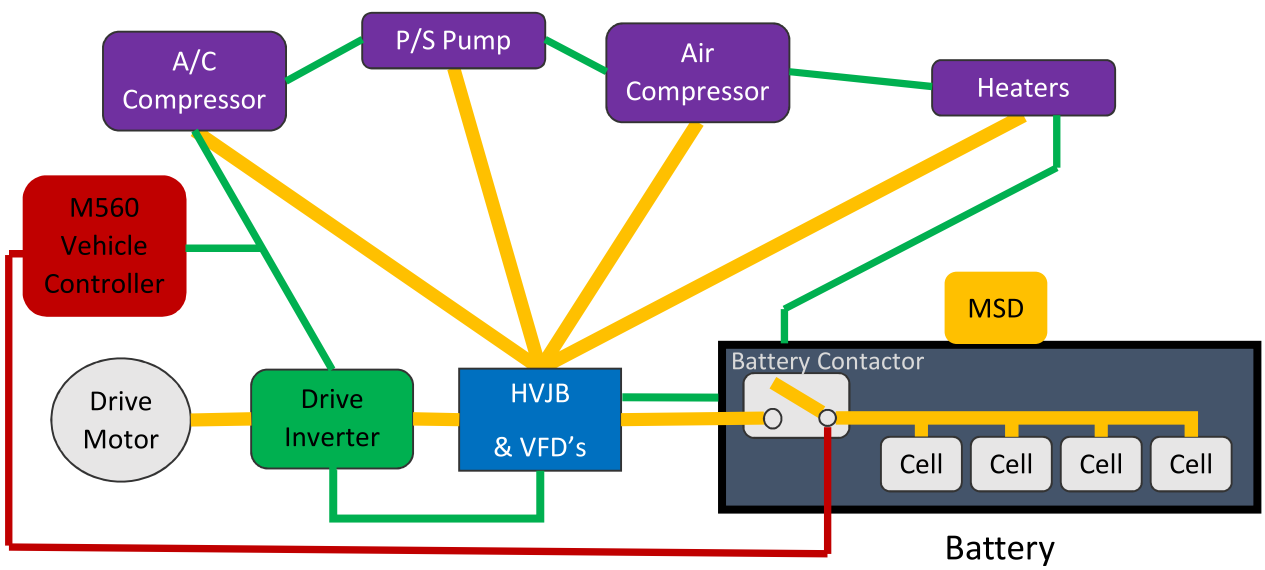
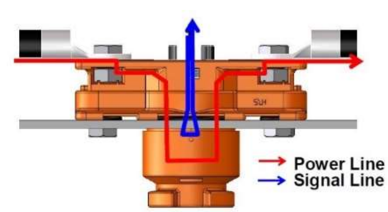
High Voltage Interlock Loop (HVIL)

There are multiple vehicle interlocks that can cause the battery contactor to open, such as a disconnected high-voltage connector, or other problem with high voltage component. The M560 Vehicle Controller provides a signal to *de-energize* the high voltage system when a connector or cover is removed, and *prevents re-energizing* the high voltage system if the connector or cover is not properly fastened. It is a continuous series loop that if continuity is broken, it is sensed by the vehicle controller, which in turn signals the battery contactors to open.



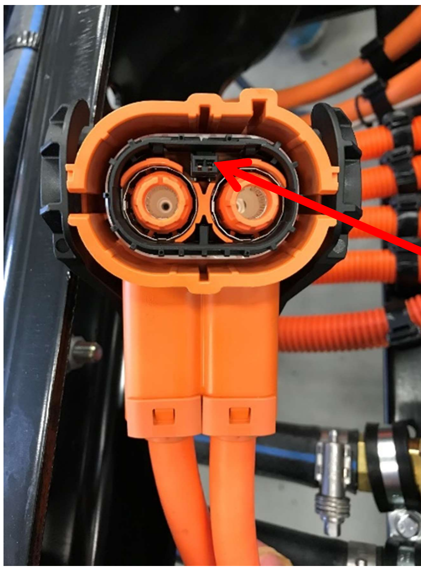
MSD Interlock

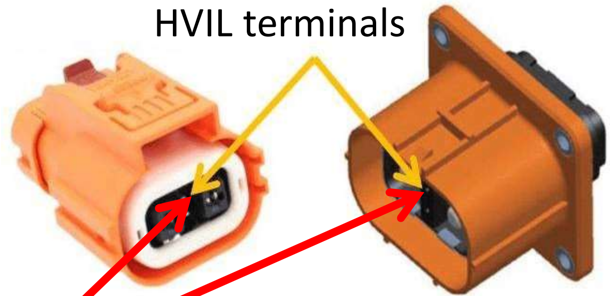
OR



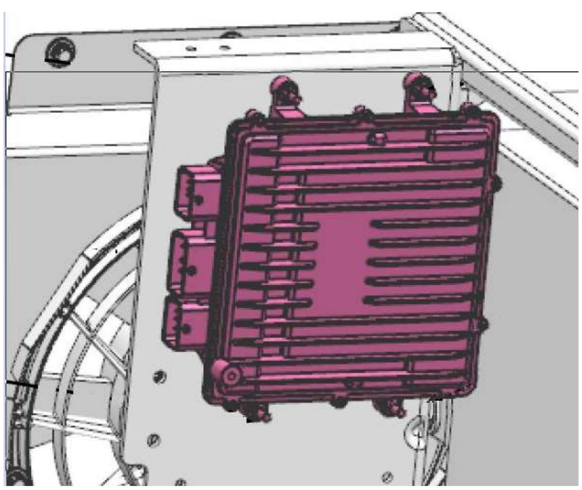
High Voltage Interlock Loop (HVIL) contacts on high voltage power connector

HVIL terminals

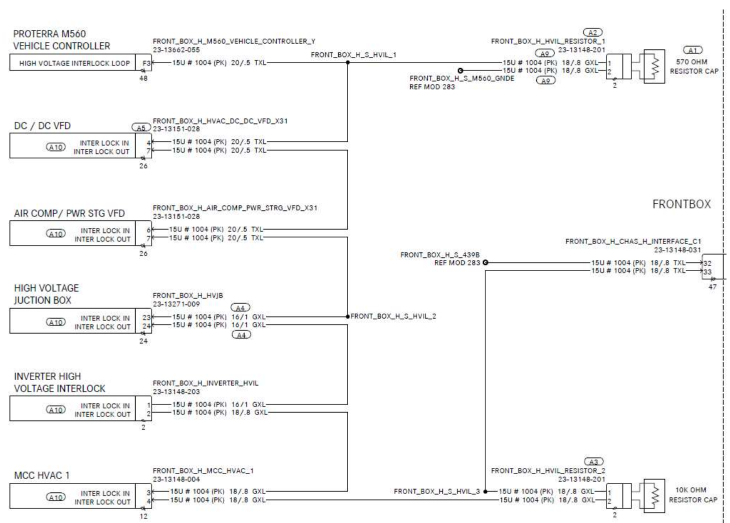




HVIL terminals are recessed to be the last to make contact when connecting and the first to break contact when disconnecting.



M560 Vehicle Controller



HVIL Wiring Diagram

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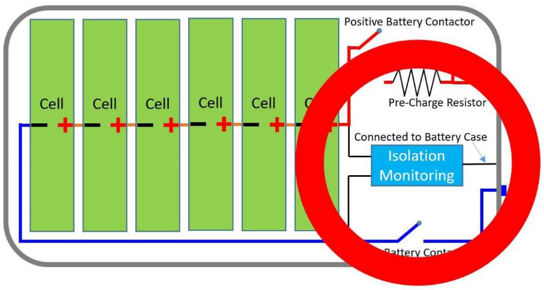
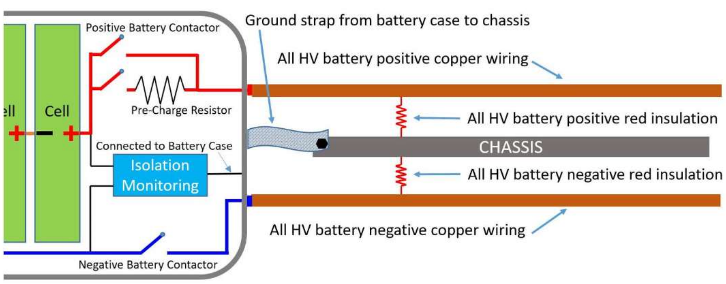
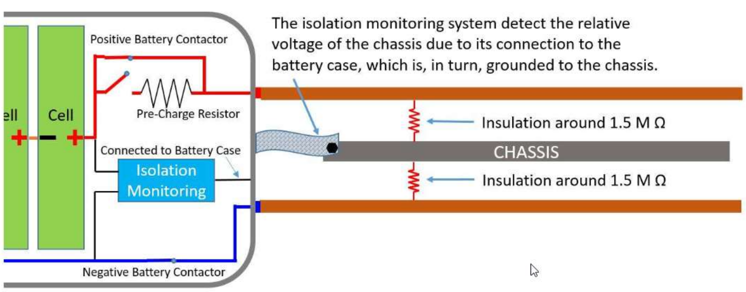
Isolation Monitoring System (IMS)



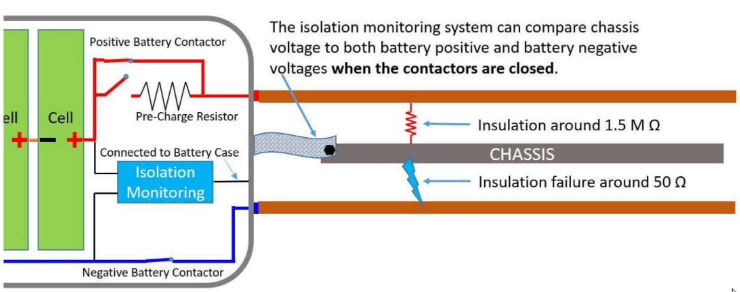
The isolation monitoring system constantly measures the resistance between the high voltage conductors and ground. It warns the vehicle operator if the resistance falls below a set threshold.



Simplified Model of the Electrical System
In this model, the resistors represent the red insulation layer of the high voltage cable that we looked at in the HV cable section.



Monitoring of Intact Insulation
With intact insulation and a 400 volt battery, the isolation monitoring system reads around 200 volts across the battery (+) insulation and around 200 volts across the battery (-) insulation.



Readings with an Insulation Failure
In the case of an insulation failure on the battery negative wiring, the isolation monitoring system will read around 400 volts across the battery (+) insulation and around 0 volts across the battery (-) insulation. Note that there is still **no battery short circuit**.

Other Vehicle Safety Features

High Voltage Safety Software

Primary Function

- Prevent energizing the HV system until all the necessary signals are valid

Application

- Provide a signal to de-energize the HV circuit when a necessary CAN signal from a critical component is invalid

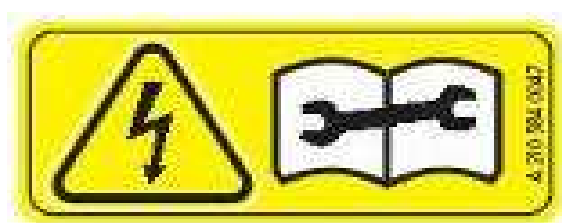
- The system shall inhibit re-energizing the HV circuit until a necessary CAN signal from a critical component is valid

Touch-Safe Connectors and HVIL Pins

Male High voltage terminals are tipped with a plastic boot to prevent contact if HV system was active.

High Voltage Component Labels

High voltage components are marked with this label. For safety, these components are constructed such that tools and deliberate action are required to access their internal workings.



10. Hazards of Electric Current

Electrical ArcFlash

Arc flash is likely the primary hazard present with high voltage vehicles. It is often caused by the interruption of a large electrical current in an inductive circuit (as shown in the example below). This interruption forces electrons through the air, heating it and surrounding materials to extremely high temperatures. It can throw sparks and molten material up to 6 feet away. The flash is extremely bright, and can permanently damage your vision.

o Per NFPA 70E Table 130.5(G), the **Thomas Built eC2 HV System is *not* considered an Arc Flash hazard**

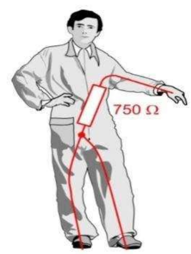
- Electric arc radius ca. 10 in
- Flying sparks up to 6 ft.
- Electric arc temperature > 1,000 °C

Electrical Arcs in HV Battery during Short Circuit Test

Electrical Shock

Electric current passing through the human body can cause shock, burns and in extreme cases, death. The body's electrical resistance can be affected by many factors. Skin moisture, body size, and body composition can cause these values to vary. Also, the more voltage that is applied, the lower the body's resistance value.

Current Path	Resistance
Hand – to - hand	1000Ω
One hand – two feet	750Ω
Two hands – two feet	500Ω

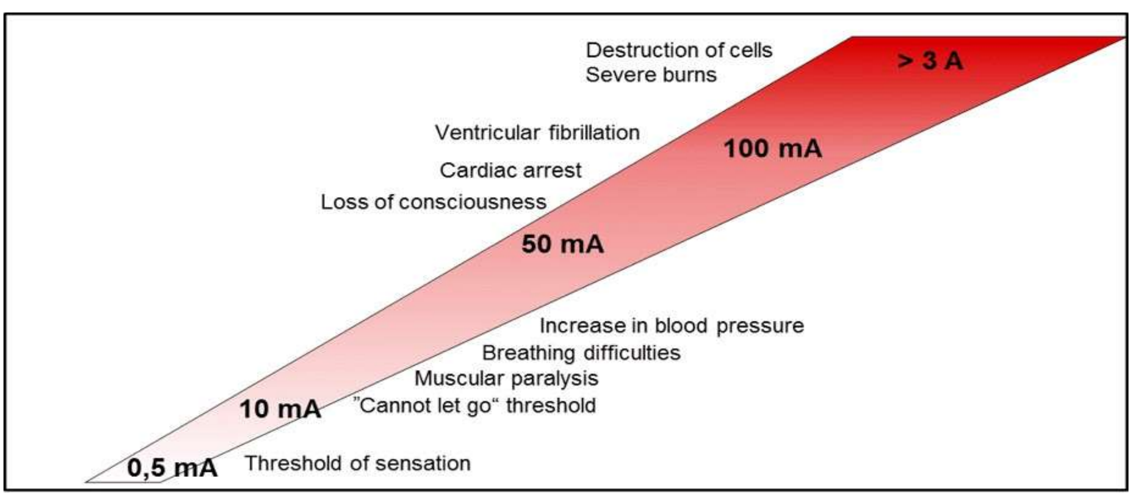


Typical electrical resistance for different paths through the body

Using the nominal voltage value for a commercial vehicle battery, and the best-case resistance, Ohm's Law shows a 600 mA current.

$$I = \frac{V}{R} = \frac{600V}{1000\Omega} = 600\ mA$$

The 600 mA that we calculated above would be in the most dangerous part of this chart



Effects of current on the body. Length of exposure increases severity.

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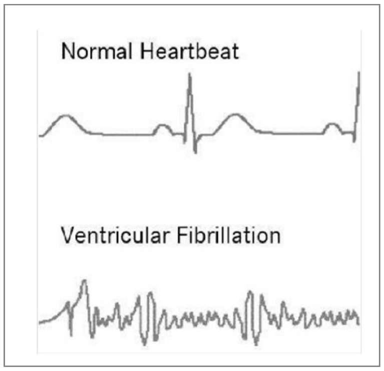
Effects of Electric Shock



Alternating current can cause uncoordinated twitching of the heart, resulting in no blood flow.

Current flow can cause severe burns, and bursting of blood vessels

Current flow (particularly DC) can cause a breakdown of the cell chemistry. This effect is toxic, and can manifest days after the shock.

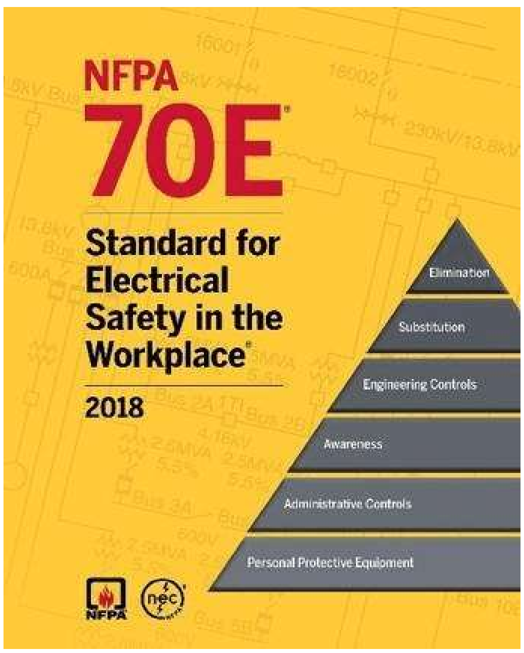
Secondary hazards

These hazards can be caused due to electric shock, electric arcs, etc. For example, falling down from a ladder due to electric shock.

11. Safety Regulations

NFPA 70E

The NFPA 70E lists requirements for safe work practices that protect personnel by reducing exposure to electrical hazards. Originally developed at OSHA's request, NFPA 70E helps companies and employees avoid workplace injuries and fatalities due to shock, electrocution, arc flash, and arc blast, and assists in complying with OSHA 1910 Subpart S and OSHA 1926 Subpart K.



Some NFPA 70E Topics

- Guidelines for electrical safety in the workplace
- Electric safety related work practices
- Hazard identification and assessment
- Selection of appropriate of Personal Protective Equipment (PPE)
- Requirements for special equipment

The important basic rule that serve the goal of avoiding accidents at work:

Never perform work on live parts.

Before performing any work on the above mentioned live parts, the voltage-free condition has to be tested by approved means and has to be safeguarded while at work.
NFPA 70E also complies with IEC EN60903, an International Standard for Safety

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12. Work on High Voltage Vehicles

Who can work on high voltage vehicles?

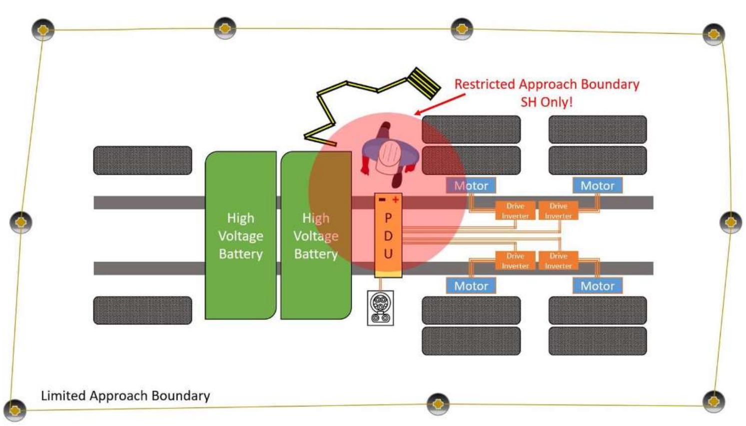
The first prerequisite to working on high voltage vehicles is completion of either the HV2 or HV3 course. Additionally, before performing any work on these systems or components, the technician must be thoroughly familiar with the vehicle systems, briefed on the job, and must be working from a safety-approved work procedure.

The High Voltage Work Area

The Restricted and Limited Approach Boundaries

The Specialist for High Voltage Vehicles working on the vehicle will set-up the barriers appropriate for the job at hand. There may be a Restricted Approach Boundary with a Limited Approach Boundary, or a Limited Approach Boundary by itself. Your HV2 qualification allows you to enter and work in the Limited Approach Boundary under the supervision and direction of an SH.

Electrical Safety Area



The SH may set-up an additional barrier inside of the Limited Approach Boundary while decommissioning the vehicle in order to create a Restricted Approach Boundary. Do not enter the Limited Approach Boundary or distract the SH until the vehicle is fully locked-out and tagged-out.

Do I need to have an SH decommission the vehicle in order for me to fill the washer fluid? When is it necessary to lock-out/tag-out the high voltage system?

As an HV2-trained technician, you can service any system or component on the vehicle that is not part of the high voltage system. Working on the brakes, air system (after the compressor outlet), any low-voltage power or controls, etc. is allowed. However, if you need to dismount or move a high voltage component in order to gain/improve access to a component, or if your task has the potential of damaging the high voltage system (e.g. welding in close proximity), the vehicle must be decommissioned for safety.

What can I actually *do* on the high voltage system if I am helping an SH?

As an HV2-trained technician, when you are assisting an SH with a task involving the high voltage system, you can perform any actions that don't involve the electrical conductors or contacts. For example, if you are assisting an SH with a high voltage battery swap, the SH would be required to decommission the vehicle and disconnect the battery. You could assist by disconnecting and draining the coolant piping, dismounting and removing the battery, and then reversing those procedures for the installation of the new battery.

Safety at All Times

When working in the Limited Approach Boundary, always remember to pay extra attention to safely completing your task. There is an extra source of danger inside that boundary, and nobody wants to become its victim. Ensure that you and your SH are following an approved work procedure, and the danger will stay safely locked away inside the battery.

- Safety by Organization

When working on a high voltage vehicle, access to these high voltage systems is restricted to personnel that are properly trained, and are actually performing maintenance or repair.

When the high voltage sign is posted at the vehicle, there is a possibility of contacting live high voltages. Do not enter the Limited Approach Boundary.

When this sign is posted on the vehicle, it is safely locked-out and tagged-out. You may work on this vehicle under supervision of the SH in charge.

A lock properly installed on an eCascadia's emergency stop switch.

- Personal Protective Equipment (PPE)

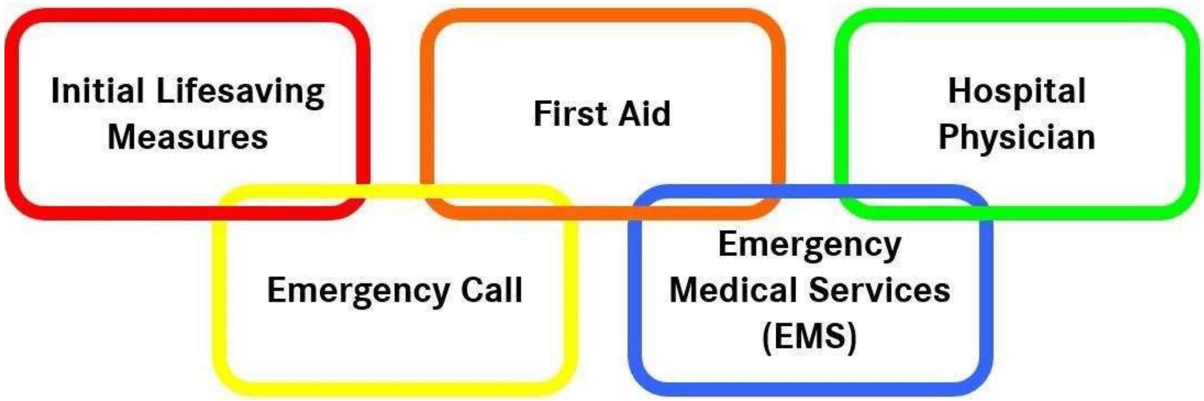
In addition to the PPE that is normally worn in a shop environment, PPE that protects the wearer against high voltage contact or arc flash must also be worn when appropriate.

- Behavior-Related Measure

High voltage work must be conducted by trained personnel according to approved, risk-assessed work instructions.The shop must have a culture of safe work habits. Shop personnel must know first aid.

13. First Aid

The Rescue Chain



When there is a mishap at the workplace, having a strategic plan to quickly move from one end of the chain to the other can greatly enhance your ability to contribute to a positive outcome for the victim. **These steps are only a suggestion. Please follow your companies / location safety processes.**

Initial Lifesaving Measures

This step involves getting the victim out of danger and preventing further injuries. If a person is in contact with a live electrical conductor, shutting off the power is the easiest, quickest, and safest way of preventing further injury. If this is not possible, a rescue hook could be used, if available, to separate the victim from the conductor, but you could also don electrical safety gloves and accomplish the same thing with more control. The most important thing to remember is **do not become a casualty yourself.** Relocate the victim to a safe space for evaluation (away from fire, traffic, etc.)

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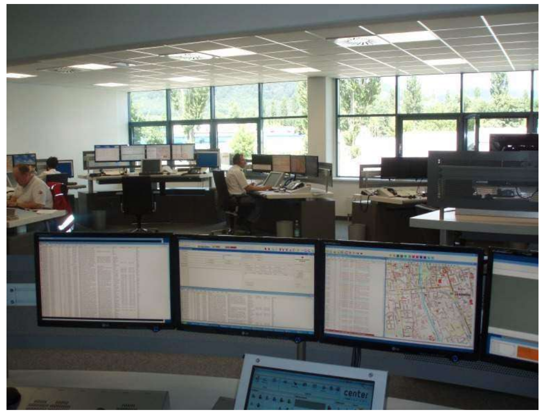
Emergency Call



Know the address of your building, or where to find it. A great place to post the address is above the exit doors, especially in shop areas. Give the emergency operator all of the information they ask for, and wait for them to hang-up at the completion of the call. The next call you should make is to corporate security (if applicable). They will help first responders quickly find the area where you are located.

First Aid

Determine if the victim has a pulse and respiration. If not, have an assistant retrieve an AED while you perform CPR. Remember that the AED may still require you to continue CPR after it has stopped any heart fibrillation. Use cool water on burns to stop the heat damage of tissue. Cover any burns with a clean, dry gauze dressing. The purpose of this dressing is only to prevent the burn from getting dirty.

Emergency Medical Services (EMS)

Open any necessary doors to allow EMS access. Don't get in their way, but render any assistance that they ask for.

Hospital Physician

This step is performed at a hospital or other medical care facility.

Summary

The key to effectively providing aid to a person that has been involved in a workplace mishap is preparation. Know the locations of first aid and firefighting equipment in your building, and get first aid training when available. Calm, determined action will provide the most help to a colleague in need.

JOULEY™

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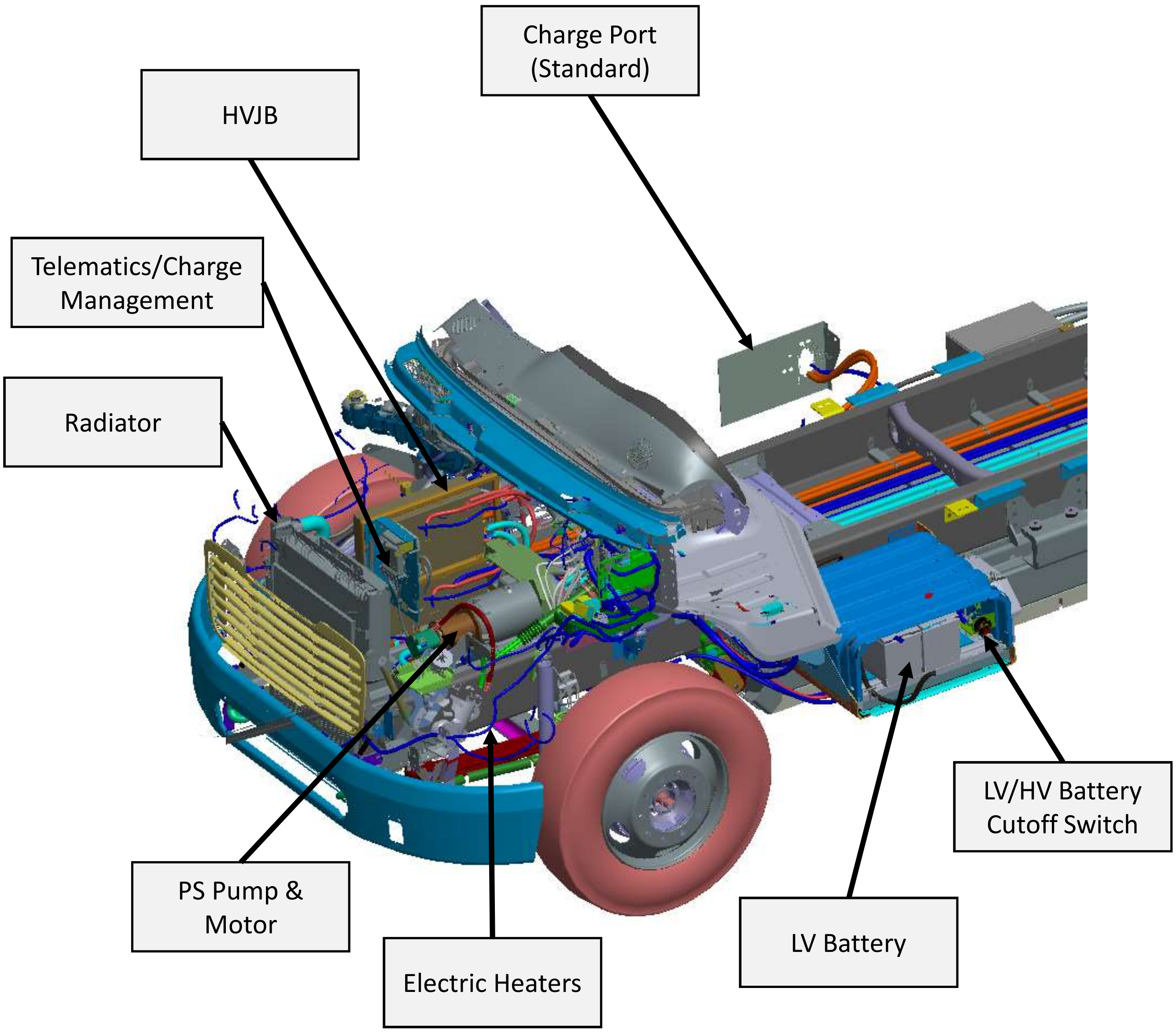
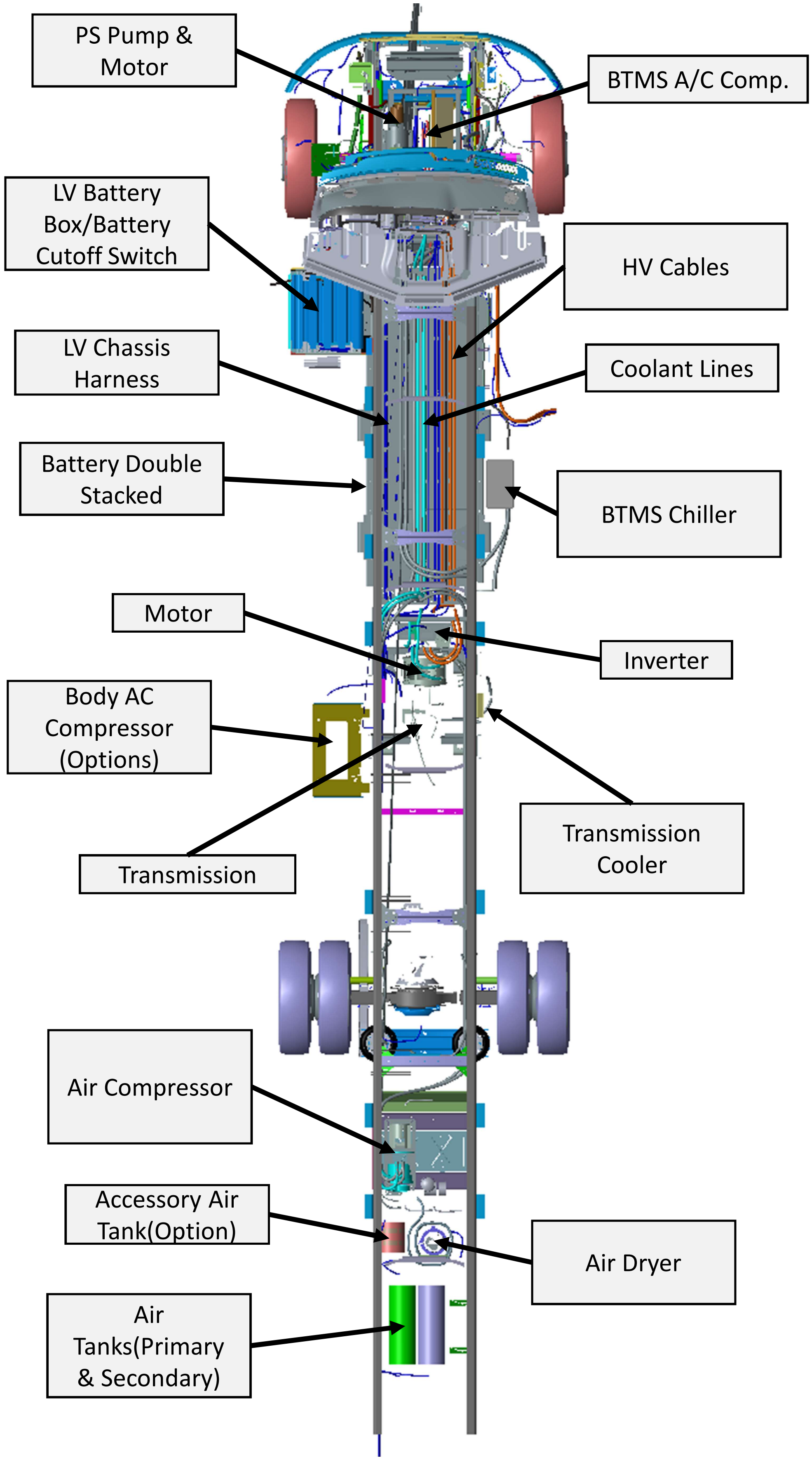
Maintenance Review

1. Component Locations

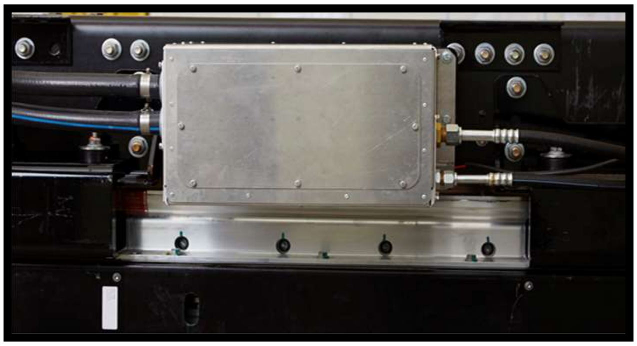
Jouley Front Compartment Layout



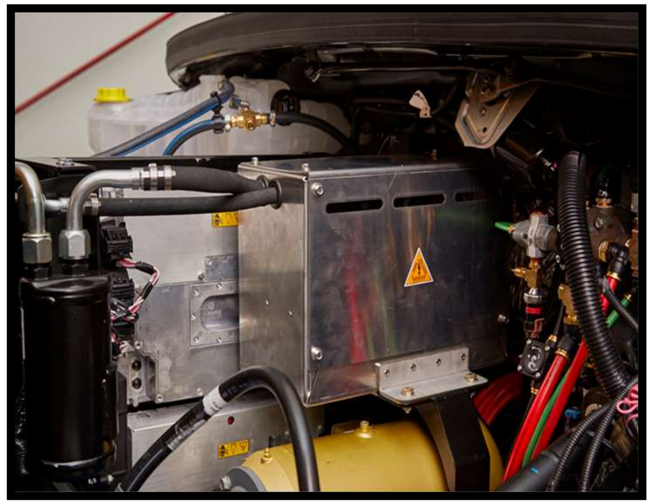
Jouley Chassis Layout



BTMS Chiller



BTMS A/C Comp.



Air Comp & Air Dryer

Electric Heaters

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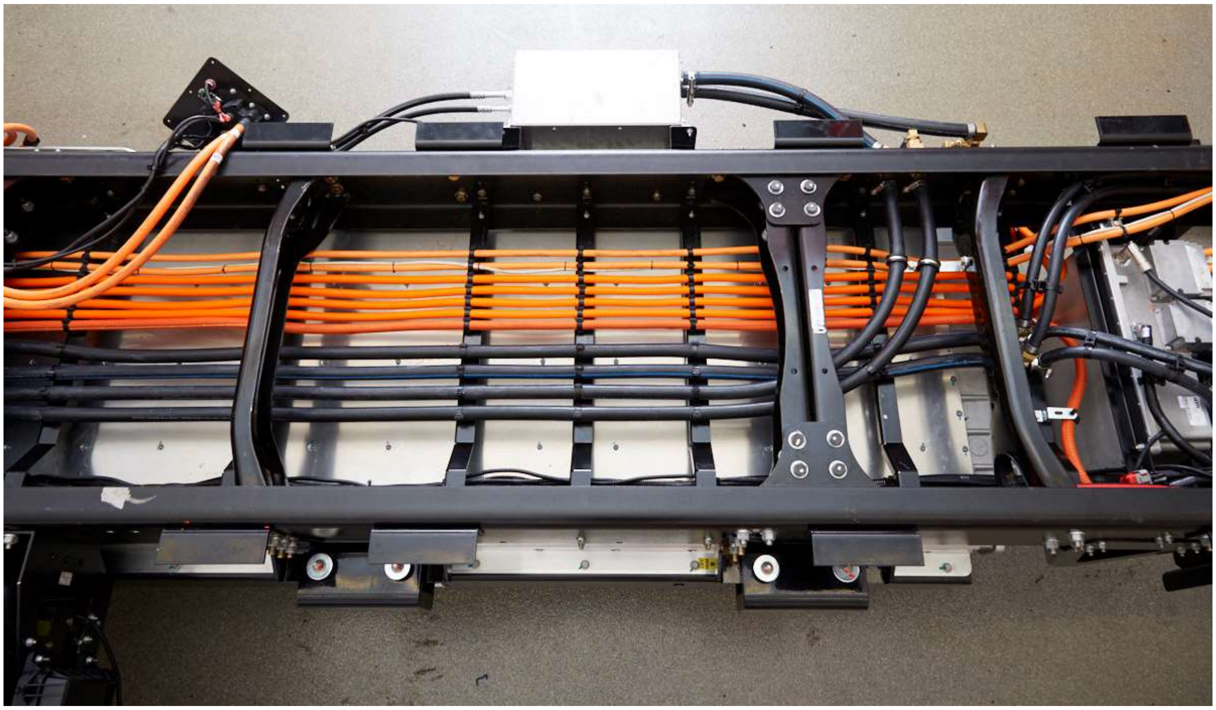
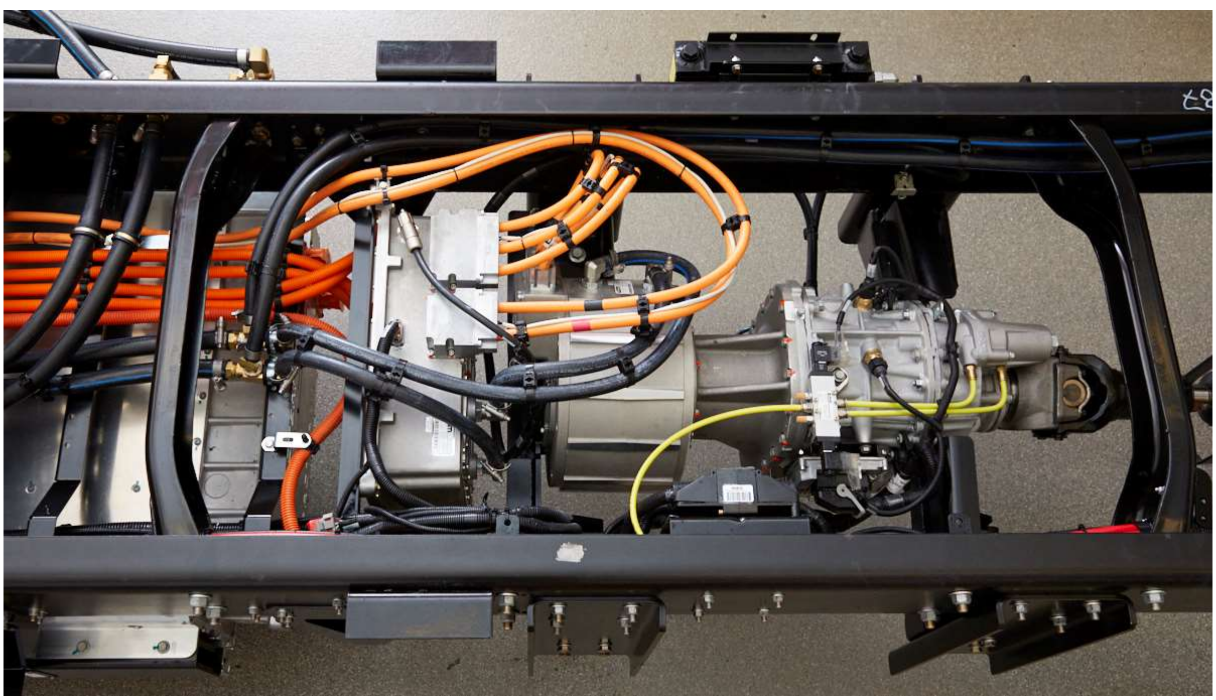
HV Cables & Coolant Hoses



Inverter, Drive Motor & Transmission



2. Aftermarket Add-ons

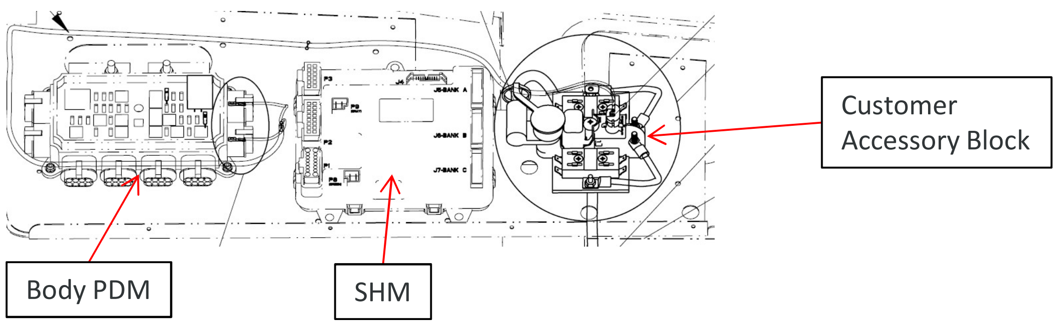
During instrumentation of a vehicle, technician mistakenly drilled into a battery. You must review all mounting positions of accessories, above the surface and below. Know your tool depth and use the minimum needed to accomplish the job.

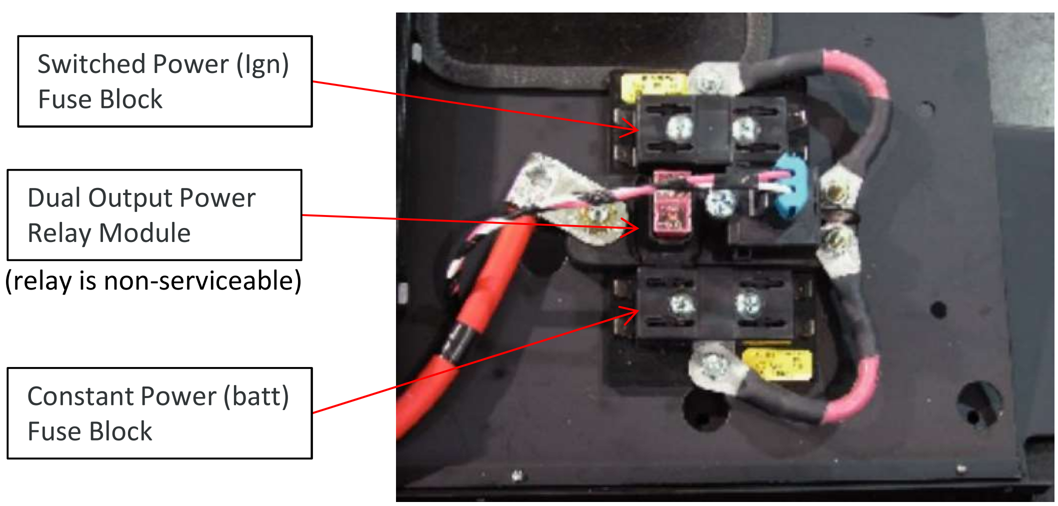
Customer Accessory Block

Any customer / aftermarket option being added to the bus that requires power (battery or ignition) should be connected to the Customer Accessory Block. The block is located to the right of the driver, below the control panel, forward of the Switch Hub Module.
The assembly consist of a Dual Output Power Relay Module and two four position fuse blocks. One output is constant battery while the other is switched ignition. Each fuse block is powered through one of the two 50 amp fuses in the dual output power relay module. Accessory wiring connects to the fuse blocks by spade terminals.

⚠ **– IMPORTANT**

It is the installers responsibility to install amp appropriate fuses and wiring for the accessories being powered. Never splice into the Ignition Switch wiring!





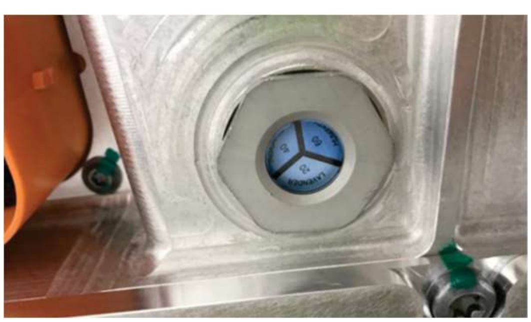
3. Maintenance Guide Reference

Reference the “EB2 Service and Maintenance “ guide for step by step instructions on the following:

1. Air Compressor Filter Replacement
2. Air Compressor Oil Separator Element and Main Seal Replacement.
3. Rebuild Air Compressor Air End.
4. Battery Ancillary Bay Desiccant Plug Maintenance
5. Battery Pack Desiccant Maintenance
6. Coolant System Maintenance.
7. Coolant Pump Removal and Replacement.
8. Power Steering Motor Lubrication.
9. Transmission Oil Level Inspection
10. Transmission Oil Drain and Refill.

⚠ **– IMPORTANT**

Fully follow the work instructions to remain safe performing general service and maintenance on the Jouley Electric Bus.



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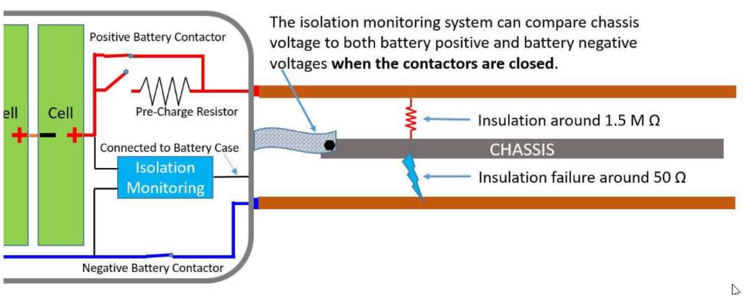
4. High Voltage Cables and Coolant Hoses

The majority of the High Voltage Components are liquid cooled or heat coolant. HV cables and hoses are routed in close proximity due to the need to maintain operational temperatures. In other words, on the chassis a HV cable will have a coolant hose close by and coolant hose will more than likely have a HV cable near by.

The IMS
(Isolation Moniting System)
is very sensitive.

Coolant (50/50 water and Ethylene glycol) is conductive.



We have already had any issue where a HV component was being replaced for testing. The unit was decommissioned. Coolant from an open hose dripped on to a disconnected HV cable connector.

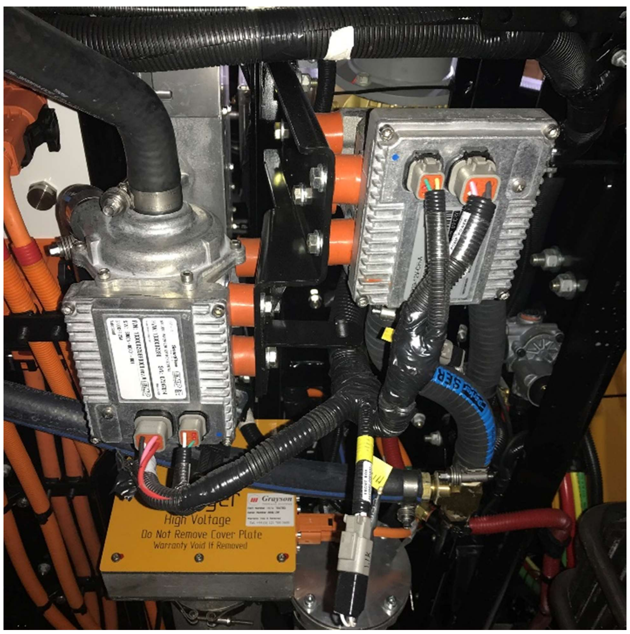
The Techs dried it off and hooked everything back up performing the safety checks as they went. All check OK. Power up. **IMS fault.**

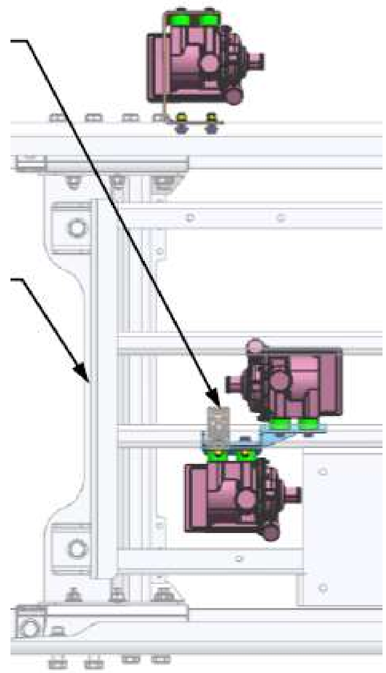
No matter how well they cleaned and dried the cable, the fault remained until the cable was replaced!

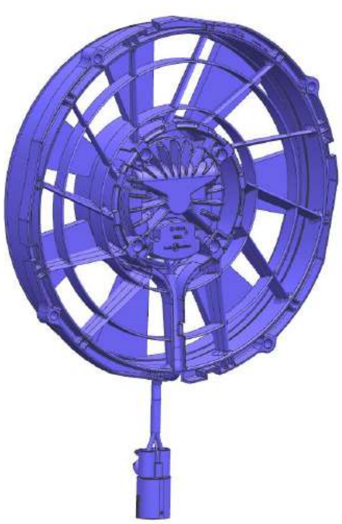
5. Jouley Component Details

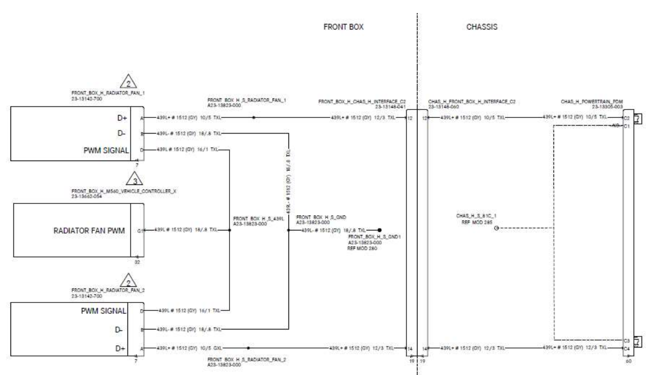
Radiator, Cooling Fans, Coolant Pumps

Verses engine driven components, all the cooling components are electrically controlled and powered. Three electric pumps circulate coolant through the radiator, passenger heaters, and BTMS cooling circuits. Two cooling fans may operate at any time as needed by the BTMS in route or during charging.



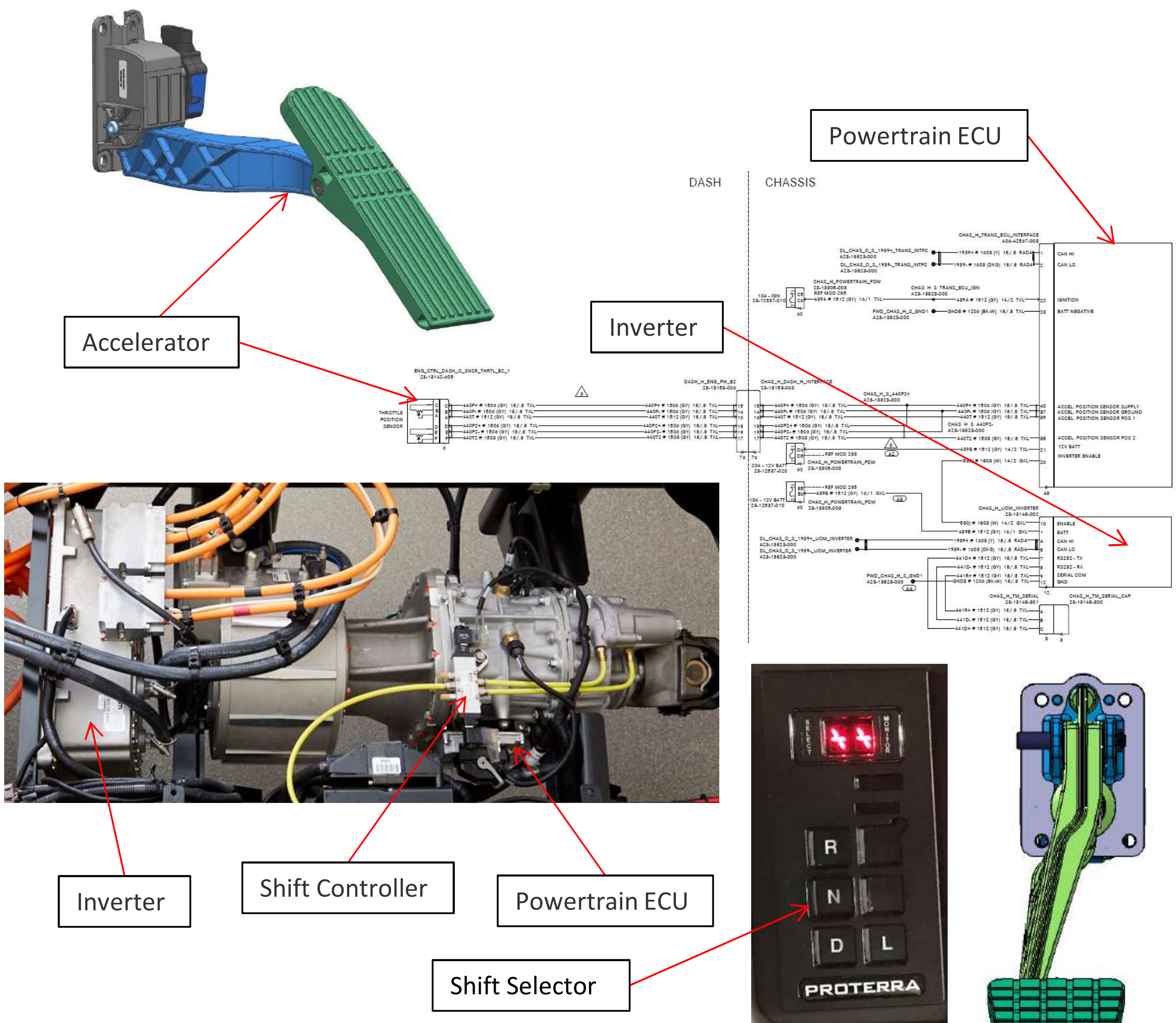






Drivetrain Controls

Operational control limits are maintained by the Proterra M560 Controller. The accelerator is wired directly to the Powertrain ECU mounted to the side of the transmission. This controls the drive inverter for forward motor control or receives brake signal to increase regenerative braking. The transmission is pneumatically controlled by a dual solenoid control valve.



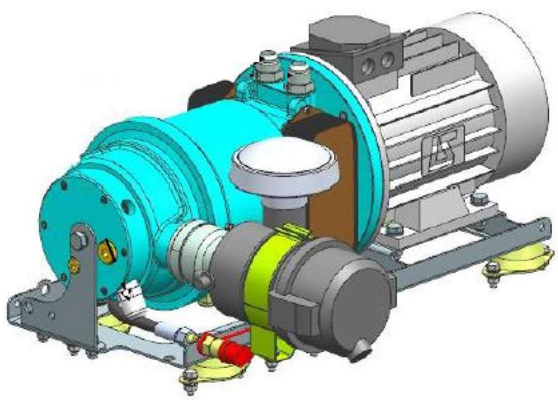
Air Compressor

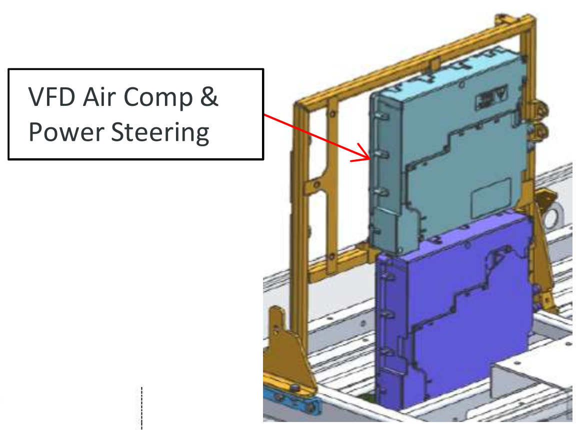
The pneumatic (air) system on the vehicle consists of the following components:

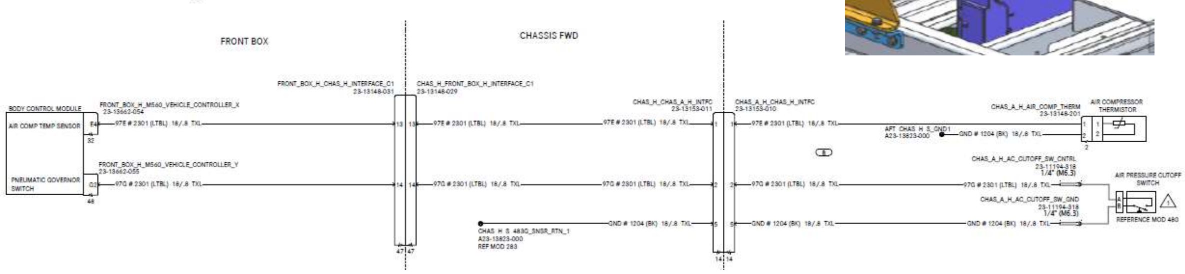
- Rotary, oiled, vane-style air compressor
- 3 phase AC (3.2 kW) induction motor directly coupled to the compressor
- High-Voltage Variable Frequency Drive (VFD) to provide the HV electricity to the variable speed compressor. This VFD is a dual output device that also power the power steering motor.
- Air dryer
- Air tank and distribution system
- Pressure sensors and controls needed to operate the system

When vehicle controller detects low air pressure from either pressure sensors located in the air tanks or from the purge switch located on the air dryer, it commands the VFD to enable and provide the necessary power to spin the air compressor. The compressor speed is variable and will change based on the current air pressure and rate of fill. The compressor will stop when the tanks indicate full based on the pressure sensors or the purge switch.

The high pressure air from the compressor passes through an air dryer and then to the appropriate wet tank. The dryer contains a heating element that will activate automatically in cold weather to ensure the moisture relief does not freeze. Diagnostics monitor the performance of the VFD, compressor, air dryer, and sensors and will set faults in the event a problem is detected.







Powertrain

The power steering system is an electrically-driven, hydraulic type and consists of the following major components:

- Hydraulic pump used to generate high-pressure hydraulic fluid used by the steering gearbox
- 3 phase AC – 5 HP (3.7kW) induction motor coupled directly to the hydraulic pump
- High Voltage Variable Frequency Drive (VFD) to provide the HV electricity to the pump. This VFD is a dual output device that also powers the air compressor motor.
- Hydraulically assisted power steering gear box
- Fluid reservoir with level sensor
- Sensors and controls needed to operate the system

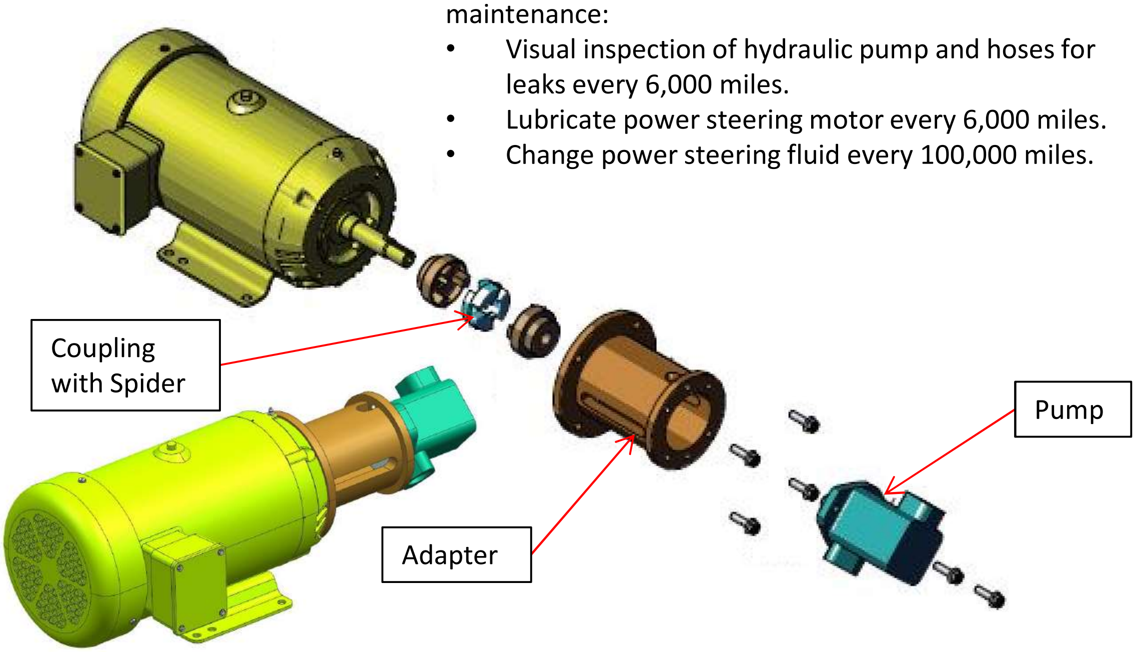
When the vehicle controller determines that the power steering system should be activated, it enables the VFD which in turn provides the necessary power to spin the hydraulic pump. The power steering system will be activated under the following conditions:

- Power Steering Pump ON __ [Vehicle speed detected OR Parking brake off OR gear selected (10sec hold)] AND HV on AND no faults
- Power Steering Pump OFF __ HV off OR fault active OR [Parking brake on AND no steering wheel torque detected]

The power steering pump speed may vary depending on driving conditions. This is done to ensure the driver has the proper level of steering assist while minimizing energy consumption of the system. Diagnostics monitor the performance of the VFD, hydraulic pump, and sensors and will set faults in the event a problem is detected.

Power steering system requires minimal periodic maintenance:

- Visual inspection of hydraulic pump and hoses for leaks every 6,000 miles.
- Lubricate power steering motor every 6,000 miles.
- Change power steering fluid every 100,000 miles.



Variable Frequency Drive (VFD)

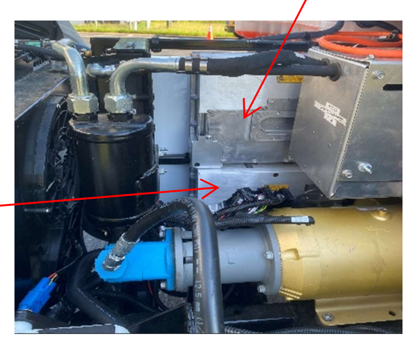
A Variable Frequency Drive (VFD) is a type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor. Frequency is directly related to the motor's speed (RPM). In other words, the faster the frequency, the faster the RPM, and the slower the frequency, the slower the RPM. Typical range for the VFD's used on the school buses is 1000 - 3200 RPM.

The VFD's used on the school buses convert high voltage DC to 3-phase high voltage AC. The electric motors controlled by the VFD's are on-demand motors, meaning that if the load controlled by the motor is not required, the VFD will not provide power to that motor. VFD 1 (top) provides power to the PS pump and the air compressor drive motors.

A VFD can also contain an integrated DC-DC converter. A DC-DC converter is a step down type transformer, converting high voltage DC to low voltage DC. VFD 2 acts as the "alternator" for the bus. It is capable of putting out up to 200 amps @ 14V for the low voltage system components and batteries.

- The VFD's are liquid cooled by the power electronics coolant loop on the bus.
- There will not be any exposed HV connections on the VFD's.
- The High Voltage Interlock Loop (HVIL) runs through the VFD's as a safety measure should any of the connections come loose or disconnected, or the phase cable cover is removed.
- Any service or diagnosis of the VFD's will require that the HV LOTO procedure be performed.
- The VFD's do not require any specific maintenance other than periodic visual inspections to check for coolant leaks.

VFD1 Air Comp & Power Steering



VFD2 DC to DC A/C Comp Cabin

Battery Thermal Management System (BTMS)

The temperature of the HV batteries need to be maintained at a temperature range of approximately 60º – 80º F. This is accomplished by pumping coolant in a continuous loop through the battery packs. The coolant is either heated or chilled, depending on inputs provided to the main vehicle controller.

Cooling

If the battery temperature input is high, the battery cooling system will be turned on to chill down the coolant. The chilled coolant will be pumped through the hot HV batteries to cool them down. Heat transfer is internal to the HV battery packs – no external radiator and fan is required.

The cooling system for the HV batteries is one of two refrigerant circuits. One of the circuits is for the HV battery temperature control, and the other is for the in dash A/C system. Both circuits are driven by a single compressor and condenser, but separate evaporators. The chill plate for the HV battery is a type of evaporator located on outside of passenger side frame rail approximately near the end of the HV battery packs. The battery chiller is rated up to 5.6 kW. This chiller system is provided power via a fused output from the high voltage junction box (HVJB).

The bus has a separate cooling system for the power electronics loop to remove heat from those devices and release the heat through the radiator and fan at the front of the engine bay. (Traction Motor, VFD's, Drive Inverter, Air Compressor)

Warming

If the battery temperature input is low, the battery heater will be turned on to heat up the coolant. The heated coolant will be pumped through the cold HV batteries to warm them up. Heat transfer is internal to the HV battery packs – no external radiator and fan is required.

There are two coolant heaters on the bus. One is to provide a method to warm up the HV batteries, and the other to provide heat to the interior cabin of the bus. Both are located under the hood, approximately where a conventional transmission would be located.

- The heater for the battery management system (BTMS) is rated at 10kW.
- The heater for the passenger cabin is rated at 20 kW.

Passenger A/C

If the bus is equipped with air conditioning for the passenger cabin, there will be a separate A/C system in addition to the A/C system that manages the battery temperature management. This chiller system will be provided power via variable frequency drive (VFD2).

6. Jouley Service Notes

"Low Voltage" Displayed in the Instrument Panel Message Center

Maximum output from the DC-DC converter VFD (equivalent to an alternator on a diesel bus) is 200A. Proper maintenance and care of the low voltage (LV) battery is required. Repeated high levels of current draw over time will degrade and affect the battery's ability to quickly or fully recharge and diminish the life of the battery. Operating the AC fans and the body heaters at the same time is unnecessary and creates a high current draw. As the battery life diminishes the voltage level will drop. If the battery voltage level drops to 11.9V, a low voltage warning will be displayed in the cluster. If the driver does not take action and the voltage continues to drop, vehicle components will begin to drop offline and eventually the bus may experience a loss of propulsion.

Tire Replacement

When replacing the tires on a Jouley Electric Bus, the replacement tires Revolutions Per Mile (RPM) must match the tires ordered from the factory. This maintains the Propulsion Drive Safety check performed by the Drivetrain ECU. It compares Vehicle speed, Traction (Drive) Motor speed, and ABS wheel sensor speed. If tires are mounted that differ from the factory Revolutions Per Mile (RPM), the Drivetrain ECU will detect an "Uncontrolled Acceleration" event and disable forward propulsion by shifting the transmission into neutral. Shutting down the Bus (ignition off) and restarting the system will clear the fault temporarily.

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6. Jouley Service Notes (cont.)

Distilled Water Only

It is critical to use only 50/50 coolant mixture matching the factory-installed coolant spec. Any tap water used in the system, even if tap water is used to make a 50/50 mix from a 100% ethylene glycol coolant solution, will lead to corrosion within the powertrain and battery coolant loops that could affect component warranty.

> **This included flushing: tap water cannot be used to flush the coolant system of the Thomas Electric Bus.**

Air Compressor Maintenance

Regular inspection (once a month) of air compressor oil level is needed to confirm an issue hasn't developed that could lead to premature failure. Reference the Maintenance Manual listed in DTNA Connect for procedures, part numbers, and fluid types.

CDL Brake Test - Intellipark

General Information

The following is the process to perform an air brake tests for vehicles equipped with Bendix Intellipark Park Brake System. For identification purposes, the park brake switch is equipped with upper and lower red LED lights, both lights will be illuminated when the parking brake is set and both lights off when the parking brake is released. For electric powered buses to not operate the high voltage system you simply turn the key to ignition on and not to the start position, to engage HV, turn the key to start position and release.

Work Instructions Subject: Air Brake Test

Air Brake Test Procedure

Step 1 Static Air Leakage test (start with the air system fully charged)

In order to perform this test you need chock the tires to prevent any unintended movement of the vehicle With the ignition key in the on position, engine off or if electric bus HV disengaged Release the parking brake and remove foot from the brake pedal Press the throttle pedal and hold it there Watch the air gauges and time the air pressure drop, after the initial stabilizing of the air pressure the loss rate should be no more than 2 psi in 1 minute. Set the parking brake for the remainder of the tests.

Step 2 Service Brake Air Leakage Test

With the ignition key in the on position, engine off or if electric bus HV system disengaged Firmly apply service brake pedal and hold steady After initial drop, pressure drop should be no more than 3psi in 1 minute.

Step 3 Low Air Warning System Check

With the ignition key in the on position, engine off or if electric bus HV system disengaged Depress the brake pedal repeatedly to fan off air pressure from the system Listen for the audible buzzer and watch for the visual low air warning light in the dash and the both LED lights on the parking brake switch will blink.

Step 4 Spring Bake Valve Test

With the ignition key in the on position, engine off or if electric bus HV system disengaged Continue to depress the brake pedal repeatedly to fan off air pressure from the system Observe the Park Brake Switch lights for parking brake set will be indicated by the top LED light will change from flash to solid.

Step 5 Air Pressure Recovery Check
Start the engine or turn ignition to start on electric powered vehicles Raise to operating RPMs or high idle for engine powered vehicles Observe that the pressure builds and measure the time from 85 lbs. to 100 lbs. within 45 seconds.

Step 6 Governor Cut Out Check
With the drivetrain still running or HV engaged Observe the governor Cut Out pressure is between 120 lbs. and 130 lbs.

Step 7 Governor Cut In Check
With the drivetrain still running or HV engaged Depress the brake pedal serval times to reduce the air pressure to around 90 – 100 lbs. Observe the compressor Cut In pressure.

Step 8 Spring Brake Test (In a safe location away from other vehicles)
With the HV system engaged and the parking brake engaged removed the wheel chocks Depress the brake pedal and hold Release the parking brake switch (both red LED lights will go out on the switch) Shift the transmission into drive and move forward to around 3 – 5 mph While in motion engage the parking brake switch (both red LED lights will be on) Vehicle should stop.

Step 9 Service Brake Test
In a safe location away from other vehicles With the drivetrain still running or HV engaged Wait for normal air pressure in the vehicle and while depressing the brake pedal release the parking brake Shift into drive and move forward to around 5 mph Firmly apply the service brake (depress the brake pedal) Note any pulling to one side, unusual feel, or delayed stopping action.

JOULEY ELECTRIC BUS

Maintenance Schedules:

* *Use mileage or months, whichever comes first.*

Maintenance Schedules					
Schedule	Maintenance Intervals				
	Maintenance Interval	Frequency	Mileage*	km	Months*
Schedule I vehicles that annually travel up to 20,000 miles (32 000 km)	Initial Maintenance (IM)	first	4000	6400	6
	Maintenance 1 (M1)	every	4000	6400	6
	Maintenance 2 (M2)	every	8000	12 800	12
	Maintenance 3 (M3)	every	16,000	25 600	18
	Maintenance 4 (M4)	every	32,000	51 200	24
	Maintenance 5 (M5)	every	48,000	77 200	30
Schedule II vehicles that travel over 20,000 miles (32 000 km) annually	Initial Maintenance (IM)	first	4000	6400	6
	Maintenance 1 (M1)	every	8000	12 800	6
	Maintenance 2 (M2)	every	16,000	25 600	12
	Maintenance 3 (M3)	every	32,000	51 200	18
	Maintenance 4 (M4)	every	48,000	77 200	24
	Maintenance 5 (M5)	every	64,000	103 000	36

Overview of Maintenance Operations:

***Review in DTNA Connect Saf-T-Liner C2 School Bus Maintenance Manual for updates / current schedule.**

Maintenance Operation Procedures and Intervals							
Maintenance Operation No.	Title of Maintenance Operation	Maintenance Intervals					
		IM	M1	M2	M3	M4	M 5
08–01	Torque Mark Inspection, Electric Vehicle			•		•	
08–02	Electric Motor Inspection, Electric Vehicle			•		•	
08–03	Transmission Inspection, Electric Vehicle			•		•	
13–03	Air Compressor Oil Separator Element and Main Seal Replacement, Electric Vehicle†						
13–04	Air Compressor Filter Replacement, Electric Vehicle‡		•	•	•	•	•
13–05	Rebuild Air Compressor Air-End, Electric Vehicle§						
13–06	Air Compressor Oil Level Checking and Filling, Electric Vehicle¶						
20–05	Coolant System Maintenance, Electric Vehicle			•		•	
20–06	Coolant Change, Electric Vehicle**						
26–05	Proterra Transmission Fluid Level Checking, Electric Vehicle			•		•	
26–06	Proterra Transmission Fluid Changing, Electric Vehicle§§						
46–06	Power Steering Motor Lubrication, Electric Vehicle‖‖‖						
46–07	Power Steering Fluid and Filter Changing, Electric Vehicle****						
54–02	Charge Port Inspection, Electric Vehicle			•		•	
54–03	Ancillary Bay Desiccant Plug Inspection and Replacement, Electric Vehicle		•	•	•	•	•
54–04	Battery Pack Desiccant Replacement, Electric Vehicle			•		•	

† Air compressor oil separator element and main seal replacement should be performed once a year.

‡ Inspect the filters every 3 months. Replace the filters every 6 months.

§ Rebuild the air compressor air-end every three years.

¶ Check the air compressor and thermal well oil levels once a month.

*** Change the organic acid technology (OAT) coolant in the electric vehicle every five years; supplemental coolant additives (SCAs) are not used with OAT coolant.*

§§ The Proterra transmission fluid should be changed every three years.

‖‖‖ Lubricate the power steering motor in the electric vehicle every 6000 miles (9654 km) or 12,000 operating hours, whichever comes first.

***** Change the power steering fluid and filter in the electric vehicle every 100,000 miles (160 900 km).*

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