P3010
Los Angeles LRV

PROPULSION

Section 0700
RUNNING MAINTENANCE & SERVICING MANUAL

LIST OF EFFECTIVE PAGES

Insert latest changed pages; dispose of superseded pages in accordance with applicable regulations.

NOTE: On a changed page, the portion of the text affected by the latest change is indicated by a vertical line.

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SAFETY SUMMARY

Some of the procedures in this section are preceded by warnings/cautions regarding potential hazards in handling this equipment. These warnings/cautions should be carefully read and understood before proceeding. Failure to observe these precautions may result in serious injury to personnel performing the work and/or bystanders. The key warnings for this equipment are as follows:

Electrical - The electrical equipment described in this section operates at voltages and currents that are extremely dangerous to life. Personnel should closely observe all generally prescribed cautions and warnings before performing any work on the LRV.

Chemicals – Follow safety precautions for handling hazardous chemicals as provided by the manufacturer. The manufacturer's warnings should be closely heeded to avoid personal injury.

Location – Special caution should be taken when accessing or servicing equipment located on the roof and under the car.

Weight – To prevent possible personal injury when attempting to remove or install equipment on the vehicle, adequate support of a lifting device must be used to prevent the equipment from falling. Personnel's failure to heed these warnings could result in severe injury or death and or damage to the equipment.

Contact – Some components in this equipment attain temperatures that can cause severe burns. Closely follow all warnings and recommended procedures for handling these components.

Electrostatic Discharge - Static electricity is a problem to the electronics industry because it can damage certain electronic parts. If the discharge goes through an integrated circuit and the transient current pulse is not effectively diverted by protective circuitry, the resulting current flow through the device can raise the temperature of internal junctions to their melting points. The resulting damage can range from complete internal destruction of the circuit to latent degradation that result in limited life and/or premature failure.

Static electricity is always present in the environment. A person working at a bench, sliding around on a stool, or walking across a floor can develop a charge of many thousand volts. Devices sliding around in nonconductive handling containers or across work bench tops can develop a static charge. The amount of static potential developed depends on the rate of generation of the charge, the rate of leakage of the charge, and the capacitance of the body holding the charge. Discharge yourself at a well-grounded point immediately before you touch any circuit board or electronic device.

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CHAPTER 1.0

GENERAL DESCRIPTION

1.1 Introduction

This manual describes the operating and maintenance characteristics of the Toyo Denki supplied components for the P3010 vehicle propulsion system. This manual also describes the function of each item, how the equipment accomplishes this function, how the propulsion equipment relates to other vehicle equipment, and how you perform maintenance and troubleshooting procedures.

1.2 Maintenance Philosophy

Two objectives of any maintenance program are to keep the propulsion equipment in good running order and to repair or replace faulty equipment as quickly as possible after a failure to maximize vehicle availability. Meeting these objectives requires properly trained personnel using the proper tools and test equipment. The periodic maintenance schedule in this manual has specifications for lubrication, contact replacement, and inspection items.

This manual contains information for the lubrication, maintenance, troubleshooting, and removal of equipment while it is installed on the vehicle. These activities are considered running maintenance. Troubleshooting, repair, and maintenance of equipment performed off the vehicle in a repair shop environment are considered heavy maintenance. Refer to the Heavy Repair Maintenance Manual for these procedures.

Many of the propulsion system components are located on Line Replaceable Units. LRUs are used to quickly replace a failed component and return the vehicle to service as soon as possible with a minimum of troubleshooting. The following is a listing of the line replaceable units.

Inverter Unit – contains six inverter power circuit IGBTs, two brake chopper IGBTs, an aluminum heat sink (for the cooling of the IGBT's), two filter capacitors and four gate driver circuit boards. The Fan Unit is mounted to the Inverter Unit.

Fan Unit - mounted to the Inverter Unit, contains the four Inverter Unit cooling fans.

Relay Unit – contains all of the control relays used by the propulsion system.

Current Transducer Unit 1 (CT Unit 1) – contains CTL, CTG, CTB and magnetic Noise Suppression Cores.

Current Transducer Unit 2 (CT Unit 2) – contains CTU, CTV, CTW, CTU2 and magnetic Noise Suppression Cores.

Propulsion Logic Unit (PLU) – Contains all of the propulsion logic circuit boards.

1.3 Safety

The importance of safe operation and maintenance cannot be over stressed. Safety is an integral part of all service activities and should be strictly enforced at all times.

The following are some important points to observe:

1. Because this equipment operates at lethal power levels, warnings and reminders about removal of power, in accordance with LA Metro regulations, are especially important. All such warnings should be completely understood before any work is begun.

2. Never work on equipment while electrical power is applied unless it is necessary as part of the maintenance procedure. Verify power is removed by checking with reliable equipment.

3. Attach a lock-out tag with the name of the person who removed the power from the equipment. That person knows why the power was removed and when it will be safe to restore it. Only the individual whose name appears on the lock-out tag or a person who has his or her direct approval should remove the tag and restore power.

4. Nearly all of the propulsion equipment on the P3010 is located on the roof and under the floor. Special caution should be taken when accessing or servicing items in these locations.

    a. Wear an insulated hard hat when working under the vehicle.

    b. Wear safety shoes and hard hats when working where objects might fall.

5. Use the proper lifting equipment to remove and replace heavy components. Also make sure the component is securely fastened to the lifting device.

6. Never attempt to perform a two person operation alone. Know and follow emergency procedures.

7. Do not allow fingers, hands or the body to approach a rotating part.

8. Dirt or solvent particles can become airborne. Use personal eye protection and protective clothing to guard against airborne particles.

9. Some components may contain hazardous chemicals, or their use may be required in cleaning or servicing such components. In these cases, the manufacturer’s warnings should be closely heeded, and only those items specifically and currently approved for use by LA Metro should be employed, regardless of any recommended use in the procedure.

10. Some components in this equipment attain temperatures that can cause severe burns, and others, if mishandled, may cause serious cuts or produce toxic fumes or residues. Closely follow manufacturer’s warnings and recommended procedures for handling these components.

11. Never take any shortcuts that are not clearly defined and approved.

12. If WARNING statements are not present, there may be hazards present anytime propulsion equipment is activated or when working on items with inherent hazards.

Some of the procedures in this manual are preceded by Warnings or Cautions regarding potential hazards in handling this equipment. These Warnings or Cautions should be carefully read and understood before proceeding. Failure to observe these precautions may result in serious injury to personnel performing the work and/or bystanders. The key warnings for this equipment are as follows:

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Location – Special caution should be taken when accessing or servicing equipment located on the roof and under the car.

Weight – To prevent possible personal injury when attempting to remove or install equipment on the vehicle, adequate support of a lifting device must be used to prevent the equipment from falling. Personnel's failure to heed these warnings could result in severe injury or death and or damage to the equipment.

Contact – Some components in this equipment attain temperatures that can cause severe burns. Closely follow all warnings and recommended procedures for handling these components.

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Static electricity is always present in the environment. A person working at a bench, sliding around on a stool, or walking across a floor can develop a charge of many thousand volts. Devices sliding around in nonconductive handling containers or across work bench tops can develop a static charge. The amount of static potential developed depends on the rate of generation of the charge, the rate of leakage of the charge, and the capacitance of the body holding the charge. Discharge yourself at a well-grounded point immediately before you touch any circuit board or electronic device.

1.4 AC Drive Terms

The following are explanations to terms common to AC drive propulsion and used in this manual.

Regenerative Braking is the power produced by the traction motors in dynamic braking that is returned to the catenary supply.

Rheostatic Braking is the power produced by the traction motors in dynamic braking that is dissipated as heat using the brake chopper resistor circuits.

Blended Braking is a combination of dynamic braking (either regenerative or rheostatic) and friction braking.

Synchronous Speed is the speed (calculated as a frequency) at which the magnetic field within the traction motor stator windings is rotating. The faster the synchronous speed, the faster the motor rotor speed.

Slip is the difference between the synchronous speed (frequency of the stator magnetic field) and the actual speed of the traction motor rotor (given in percentage). Positive Slip is the inverter frequency higher (faster) than the traction motor rotor frequency which produces traction. Negative Slip is the inverter frequency less (slower) than the traction motor rotor frequency which produces dynamic braking.

Receptive Line is the condition when all of the regenerative energy produced by the traction motors during dynamic braking is returned to the catenary supply.

Unreceptive Line is the condition when the line supply has risen to such a level that the regenerative energy from the traction motors cannot be added to the catenary supply and is dissipated as heat by the brake chopper circuits.

Electrical impedance is the total opposition to current flow. It includes both a resistive, or DC component and a reactive, or frequency dependent component. Impedance is the same as resistance if the applied voltage is DC. For AC voltage, the reactive components (traction motor coils) opposition to current flow increases as the applied frequency increases.

RMS (root mean square) is a method of denoting an AC waveform voltage or current which specifies the amount of DC voltage or current that will produce the same amount of work. The RMS denotes the Average value of the AC waveform (0.707 of sine wave peak).

1.5 Definitions, Acronyms and Abbreviations

The following acronyms and definitions apply to each section of this manual except for Chapter 8 which has its own acronyms and definitions.

208VDK	Inverter Fan Relay
AC	Alternating Current
AMP	Amperes
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
AW	Axle Weight
BCH	Brake Chopper 1 and 2
CHR	Charging Resistor Unit
cN/cm2	Centinewton per centimeter squared
CPU	Central Processing Unit
CTB	Current Transducer Brake Chopper
CTG	Current Transducer Return Current
CTL	Current Transducer Line Current
CTU	Current Transducer Output Current U-Phase
CTV	Current Transducer Output Current V-Phase
CTW	Current Transducer Output Current W-Phase
CTU2	Current Transducer U-Phase Both Inverters (mis-connected motor)
DBA	Dynamic Brake Achieved
DC	Direct Current
DCVD1	Line Voltage Detector
DCVD2	Filter Capacitor Voltage Detector
DCHR	Filter Capacitor Discharge Resistors 1 through 4
EB	Emergency Braking
EBR	Emergency Brake Relay
EBRT	Emergency Brake Relay Timer
ECU	Electronic Control Unit
EMI	Electro Magnetic interference
FC	Filter Capacitor
ft-lbs.	Foot-Pounds
FM1R	Inverter Fan Motor Relay

FSB	Full Service Brake
FWD	Forward
GR	Gear Ratio
HB24	HSCB Control Panel Power Supply (28.5 Vdc)
HB28	HSCB Control Panel Power Supply Abnormality
HP	Horsepower
HSCB	High Speed Circuit Breaker
HSCBCK	High Speed Circuit Breaker Control Relay
Hz	Hertz
IGBT	Insulated Gate Bipolar Transistor
I/O	Input and Output
in-lbs.’	Inch Pounds
KBPS	Kilo Bites Per Second
kg	Kilogram
km	Kilometer
km/h	Kilometer per hour
kn	Kilo Newton
kW	Kilowatt
LACMTA	Los Angeles County Metropolitan Transportation Authority
lbs.	Pounds
LCC	Line Charging Contactor
LED	Light Emitting Diode
LW	Load Weight
LRV	Light Rail Vehicle
LS	Line Switch Contactor
LSR	Line Switch Relay
LVD	Low Voltage Detection
M-axle	Motored or Powered Axle
MDS	Monitoring and Diagnostic System
MM	Millimeter
MPH	Miles Per Hour
MPH/PS	Miles Per Hour Per Second
MPH/S/S	Miles Per Hour Per Second Per Second
MSEC	Millisecond
m/s	Meters per second

m/s/s	Meters per second per second
MVB	Multi-functional Vehicle Bus
N/A	Not Applicable
Nm	Newton meters (torque)
NMRK	Propulsion equipment case No-Motion Relay
NPT	National Pipe Thread
NSC1 - 4	EMI Noise Suppression Cores 1 through 4
OCS	Overhead Catenary System
PBED	Power and Brake Effort Demand
PDF	Propulsion and Dynamic Brake Fault
PIU	Propulsion Inverter Unit (equipment case)
PLU	Propulsion Logic Unit
PSI	Pressure per Square Inch
PSU	Power Supply Unit
PTU	Portable Test Unit
PWC	Power Cut
PWM	Pulse Width Modulation
RAM	Random Access Memory
ROM	Read Only Memory
RPM	Revolutions Per Minute
RTC	Real Time Clock
SCEB	Slide Controlled Emergency Brake
SGR	Speed Governor Relay
T-axle	Trailer or Unpowered Axle
TACH	Tachometer (Speed Sensor)
TCN	Train Control Network
TL	Trainline
TOD	Train Operator’s Display
USB	Universal Serial Bus
Vac	Volts, Alternating Current
VC	Voltage at Filter Capacitors
Vdc	Volts, Direct Current
WTB	Wire Train Bus
ZNR	Zener Diode

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CHAPTER 2.0

EQUIPMENT DESCRIPTIONS

Chapter 2 contains drawings and explanations of the location and purpose of the propulsion system components. How the components function and are controlled will not be explained in Chapter 2. See Chapter 3 Theory of Operation for the details on how each device functions and is controlled.

2.1 Inverter Equipment Case

Most of the propulsion system components are located inside the propulsion equipment case with one case located under each section of the vehicle. Each propulsion equipment case contains one propulsion power circuit powering one truck (two traction motors).

Figure 2-1 shows the layout of the equipment inside the propulsion equipment case. The Inverter Unit is a line replaceable unit that can be accessed (and removed) from the side of the equipment case. The Inverter Unit contains six inverter power circuit IGBTs, two brake chopper IGBTs, an aluminum heat sink (for the cooling of the IGBT's), two filter capacitors and four gate-drive circuit boards.

The Fan Unit is a line replaceable unit attached to the Inverter Unit that contains the 4 Inverter Unit cooling fans.

Capacitor Unit 1 and 2 contain two of the four power circuit filter capacitors. The remaining two filter capacitors are built into the Inverter Unit.

CT Unit 1 and CT Unit 2 are line replaceable units that contain all of the power circuit current transducers. These LRUs are accessed from the equipment case bottom cover.

The Line Switch contactor (LS) isolates the power circuit from the catenary supply when a fault condition is detected.

The Relay Unit is a line replaceable unit that contains the propulsion system control relays.

The Propulsion Logic Unit (PLU) is a line replaceable unit which contains the circuit boards used to control and monitor the propulsion system.

The Power Supply Unit supplies 38 Vac to the PLU Power Supply Board and gate driver boards in the Inverter Unit.

The Gateway Unit is required to connect the PLU to the vehicle circuits over the Multi-functional Vehicle Bus.

Figure 2-2 shows the bottom of the propulsion equipment case. The bottom of the case contains the cooling air exhaust vents for the Inverter Unit cooling fans and an access cover to many of the power circuit components.

From the bottom cover, the high voltage components in the equipment case can be accessed. The following components can be accessed from the bottom cover:

- Line Current Transducer CTL
- Ground (Return) Current Transducer CTG
- Brake Chopper Current Transducer CTB
- Line Voltage Detector DCVD1
- Filter Capacitor Voltage Detector DCVD2
- Inverter Output Current Transducers CTU, CTV and CTW
- Reverse Connection Current Transducer CTU2
- Filter Capacitor Discharge Resistors DCHR1 through DCHR4
- Filter Capacitor Charging Resistors CHR
- Magnetic cores NSC1 through NSC4 (EMI suppression)

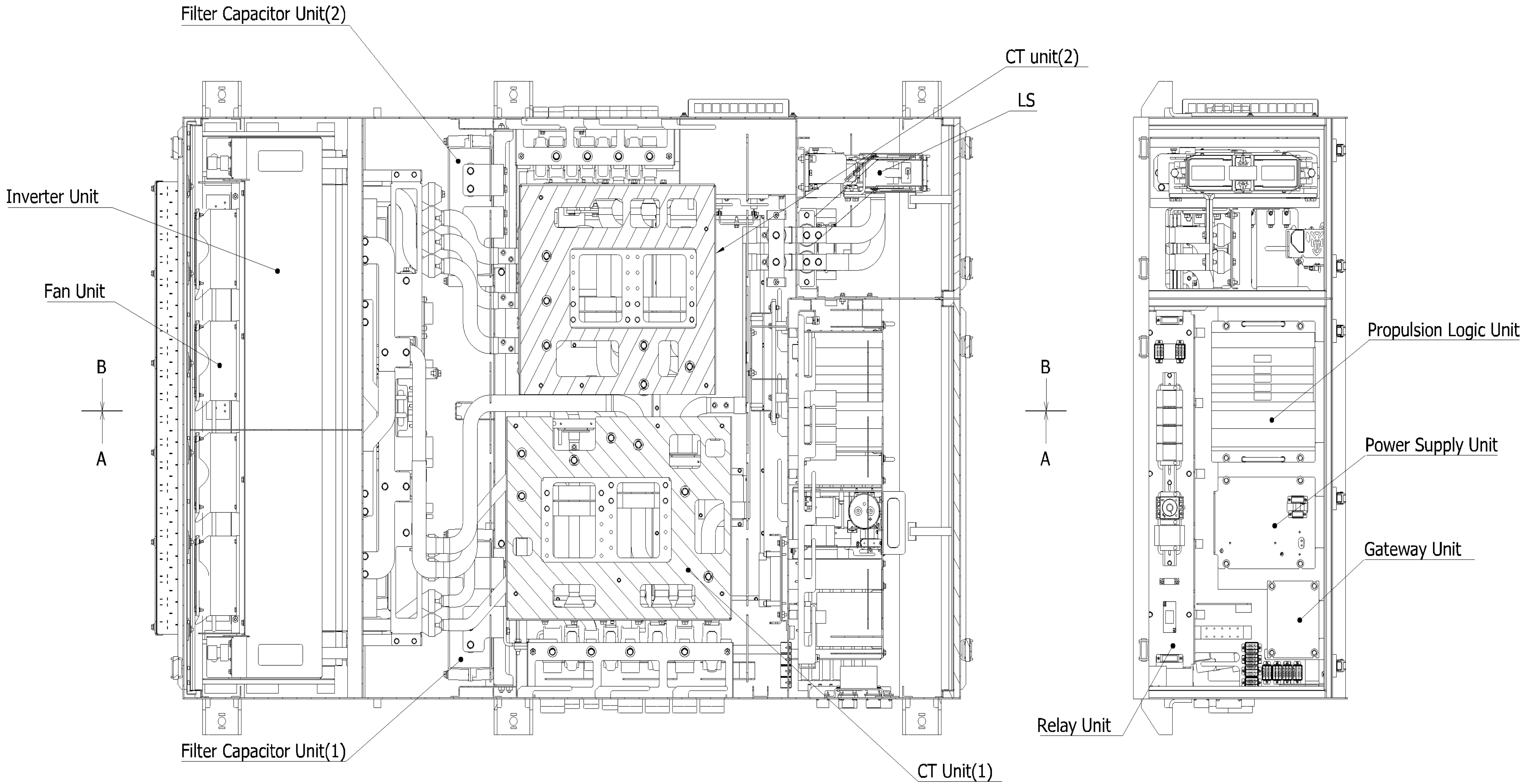


Figure 2-1: Inverter Equipment Case (Viewed from Above)

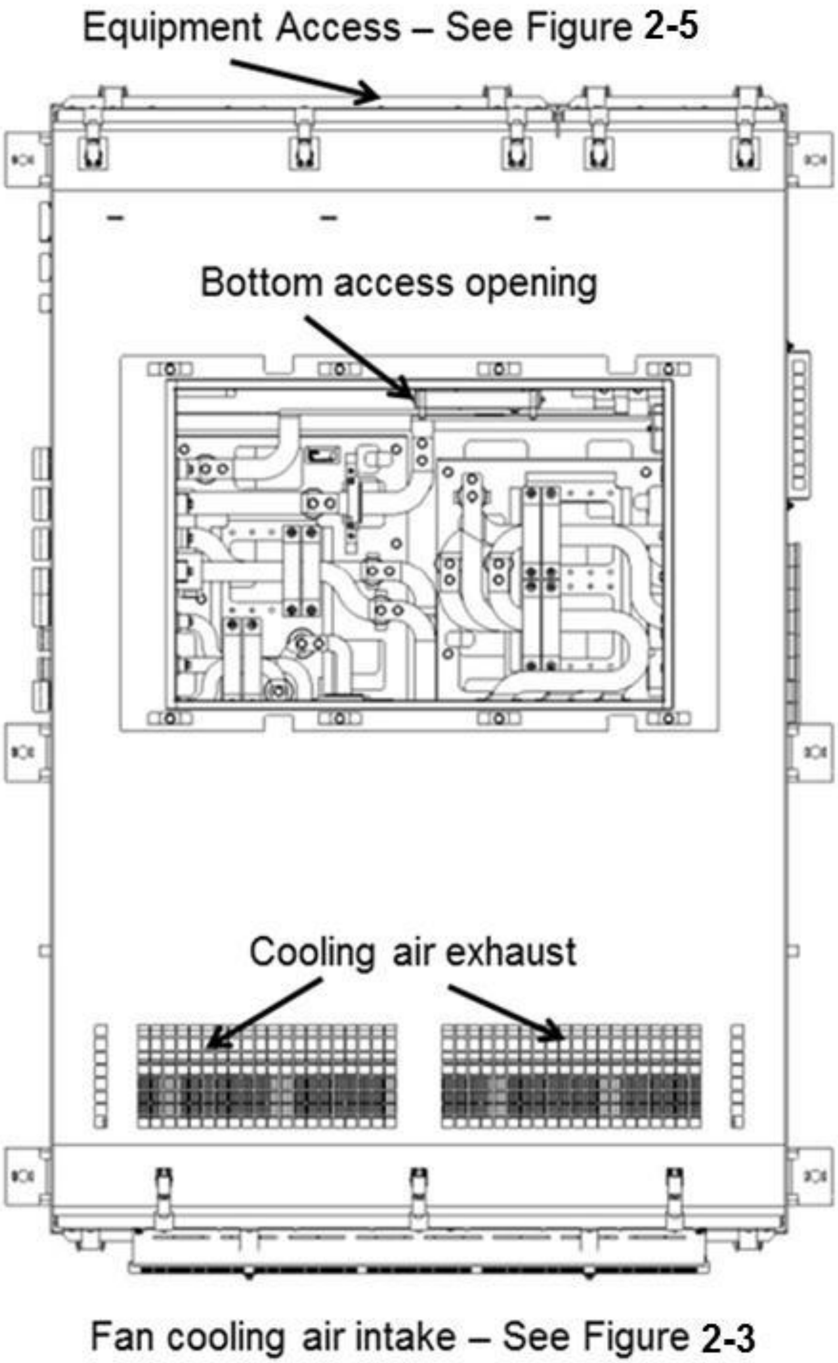


Figure 2-2: Inverter Equipment Case Bottom View

Figure 2-5 shows one side of the propulsion equipment case that contains the Gateway Unit, the Power Supply Unit, the Propulsion Logic Unit the Line Charging Contactor and the Line Switch contactor.

The Gateway Unit has all of the external communications paths to the propulsion system except for the hardware signals at the CN connectors on the propulsion equipment case. The PLU has an RS-485 interface. The Gateway Unit converts the MVB and Ethernet communication signals to/from RS485 serial communication signals. The MDS uses Ethernet to monitor the status of all devices on the train and for general communication. The MDS also has a Train Control Network (TCN) that complies with IEEE 61375. The TCN consists of a Multi-Functional Vehicle Bus (MVB) and Wire Train Bus (WTB). Both of these are required to control the P3010 in a single or multiple consist.

The Power Supply Unit is a DC-AC converter. The Input is vehicle batteries. The Power Supply Unit output supplies 38 Vac to the Propulsion Logic Unit Power Supply board and the gate drivers in the Inverter Unit.

The Propulsion Logic Unit houses all of the electronics needed to control and monitor the propulsion equipment for one truck of the vehicle and the circuitry required to interface to other subsystems on the vehicle.

2.1.1 Inverter Unit

The Inverter Unit, as seen in Figure 2-6, is a Line Replaceable Unit within the equipment case. The Inverter Unit is the main element of the propulsion system. The Inverter Unit contains the inverter power circuit IGBT's, heatsink assembly, two filter capacitors, four cooling fans and the gate driver boards.

The Inverter Unit is removed from the propulsion equipment case through the side that contains the cooling fans by using a special lifting tool. The weight of the Inverter Unit is approximately 182 kg (400 lbs.). Use of the lifting tool is explained in the Propulsion Heavy Repair Manual.

The Heavy Repair Manual Section 3.2.4 explains how to remove the Inverter Unit from the equipment case, replace all components located inside the Inverter Unit and then to install the Inverter Unit back to the equipment case.

2.1.1.1 Fan Unit and Air Filter

The Fan Unit is part of the Inverter Unit as seen in Figure 2-6. The Fan Unit contains four cooling fans which provide cooling air to the heatsink in order to cool the IGBTs. The Fan Unit is composed of four (4) water-resistant AC motor fans.

The fans force cooling air into a filter as seen in Figure 2-3. The air then flows through the Inverter Unit Heatsink assembly (cooling the power circuit IGBT's) and is ventilated to outside the equipment case as seen in Figure 2-2.

The Fan Unit can be detached from the Inverter Unit without removing the Inverter Unit from the propulsion equipment case.

The air filters, as seen in Figure 2-3 and Figure 2-4, are located just in front of the cooling fans. As seen in Figure 2-4, the filter consists of a mesh screen outer filter and a self-cleaning filter under the mesh filter.

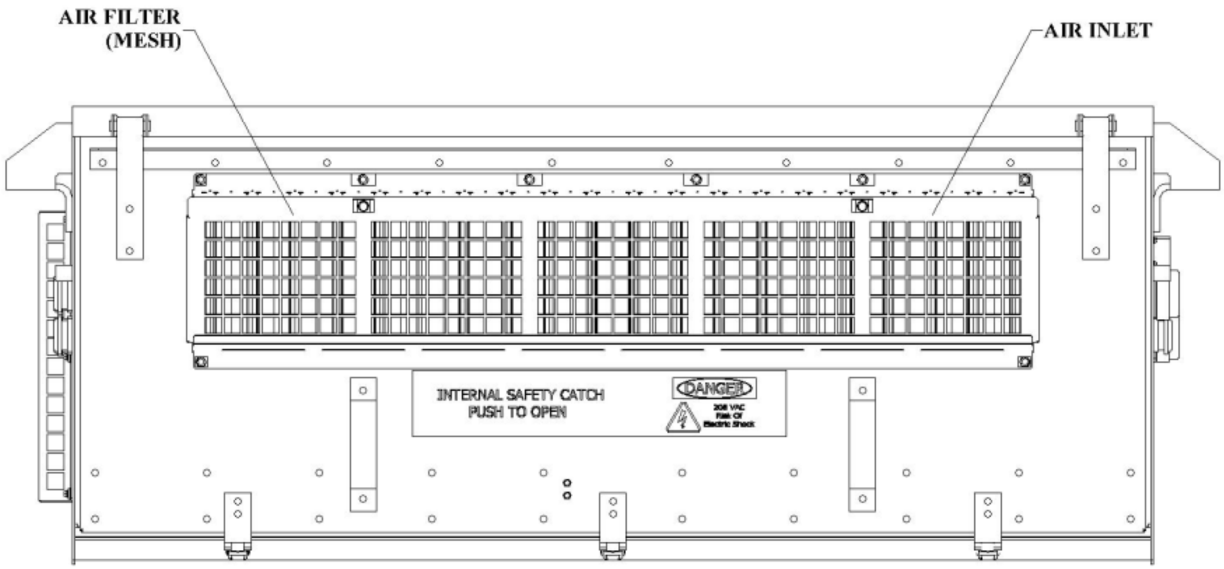
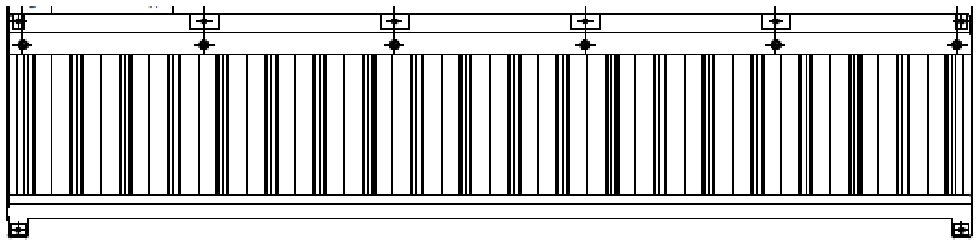
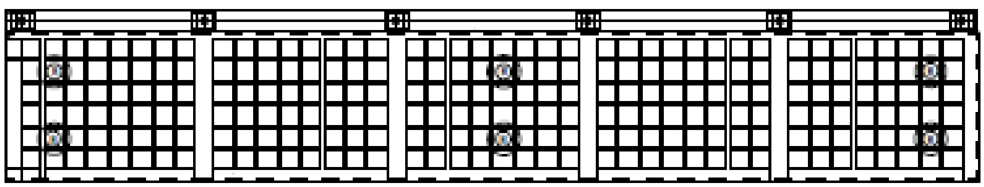


Figure 2-3: Inverter Unit Air Filters Attached to Door

The air filter mesh screen assembly and the self-cleaning filter are shown in Figure 2-4. The self-cleaning filters are mounted on the removable door panel. The design of the filters is such that the air flows through the filters and combined with the vibrations created with the motion of the vehicle, causes much of the dirt to be expelled before it enters the equipment case. This filter is designed to be capable of capturing debris larger than 2.0 mm in diameter.



Self-Cleaning Filter



Mesh Outer Filter

Figure 2-4: Inverter Unit Filters

The four Inverter Unit cooling fans as seen in Figure 2-6 are accessed by removing the equipment case side door as seen in Figure 2-3. This is the long door that also supports the air filtration system.

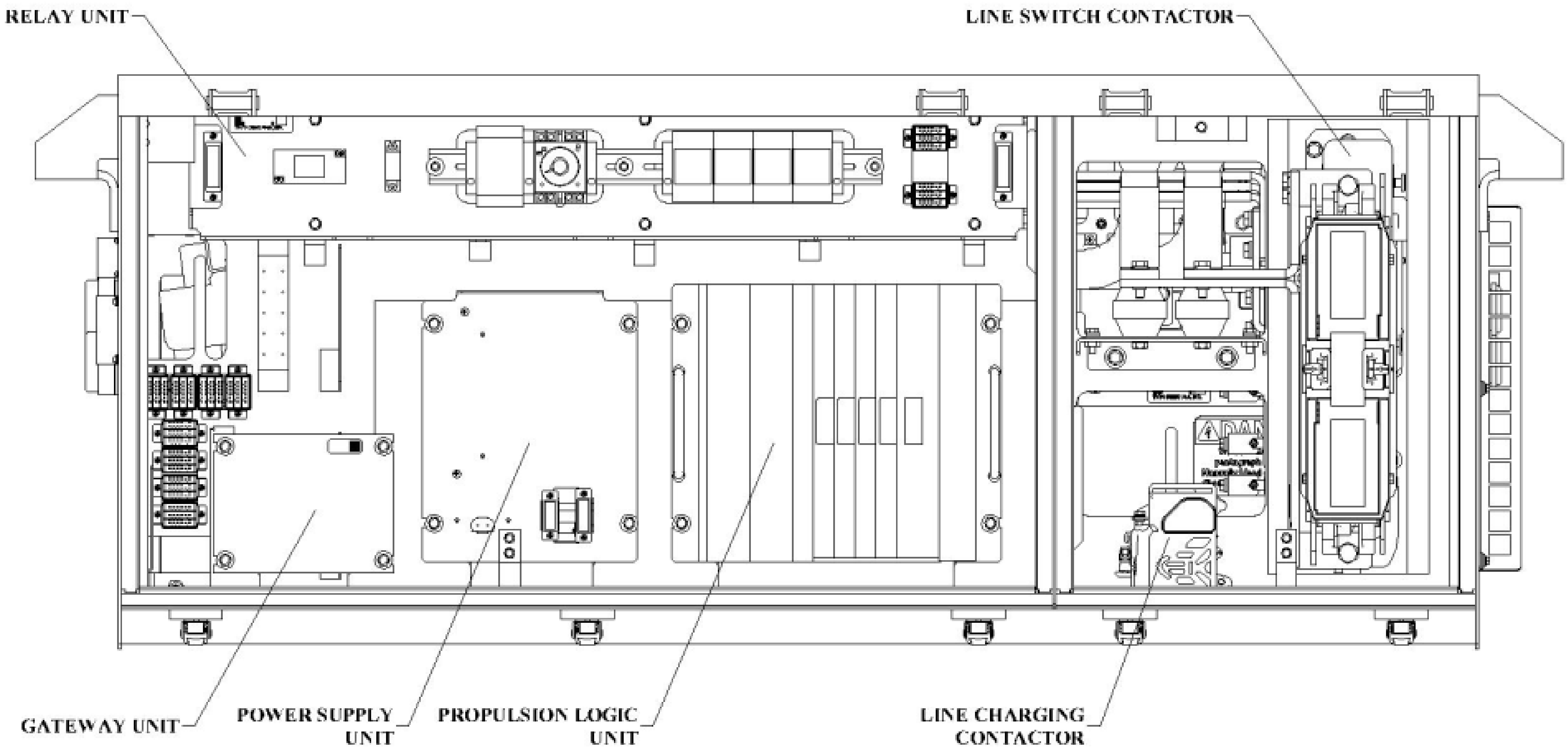


Figure 2-5: Inverter Equipment Case Side View

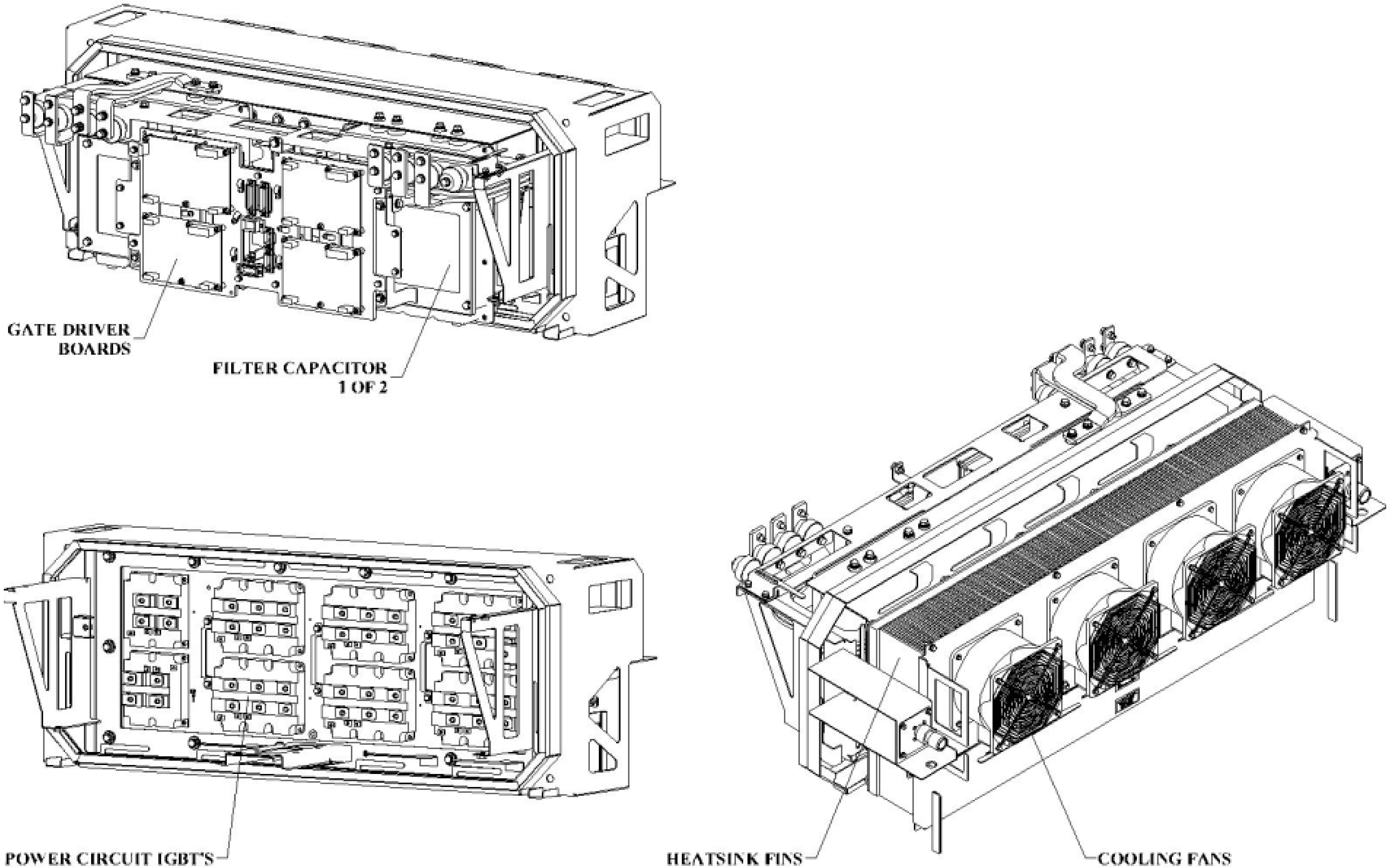


Figure 2-6: Inverter Unit

2.1.1.2 Gate Driver Unit

The Gate Driver Unit, as seen in Figure 2-6 and Figure 2-7, is a line replaceable unit that contains four gate driver boards and is part of the Inverter Unit. The purpose of the gate driver boards is to turn On and Off the power circuit IGBT's as commanded from the PLU. Transformers on the gate driver boards provide galvanic isolation between the control signals and IGBTs.

There are three gate driving printed circuit boards for propulsion inverter IGBTs and one gate driving printed circuit board for brake chopper IGBTs mounted to a steel frame. Each circuit board controls two (2) IGBT's. The three inverter gate driver boards are identical and interchangeable but the brake chopper gate drivers are not interchangeable with the inverter boards.

The IGBT is turned On with a 20mA current loop through the gate – emitter from the gate driver board. The emitter - collector junction carries the load current. Current flow is always from the Collector to the Emitter.

A positive signal from the gate driver to the IGBT gate-to-cathode will cause the IGBT to conduct. A negative voltage from the gate driver (gate-to-cathode) will cause the IGBT to be turned off. When the inverter is not operating, a negative bias is impressed on the IGBT gate-to-cathode. This negative voltage is used to ensure that a transient or spike voltages will not turn on the device when it is not intended. For an IGBT to conduct, a positive voltage must be on the anode and a negative voltage on the cathode.

These printed circuit boards are mounted on an insulation board and connected to the IGBTs with a wiring harness and associated connectors.

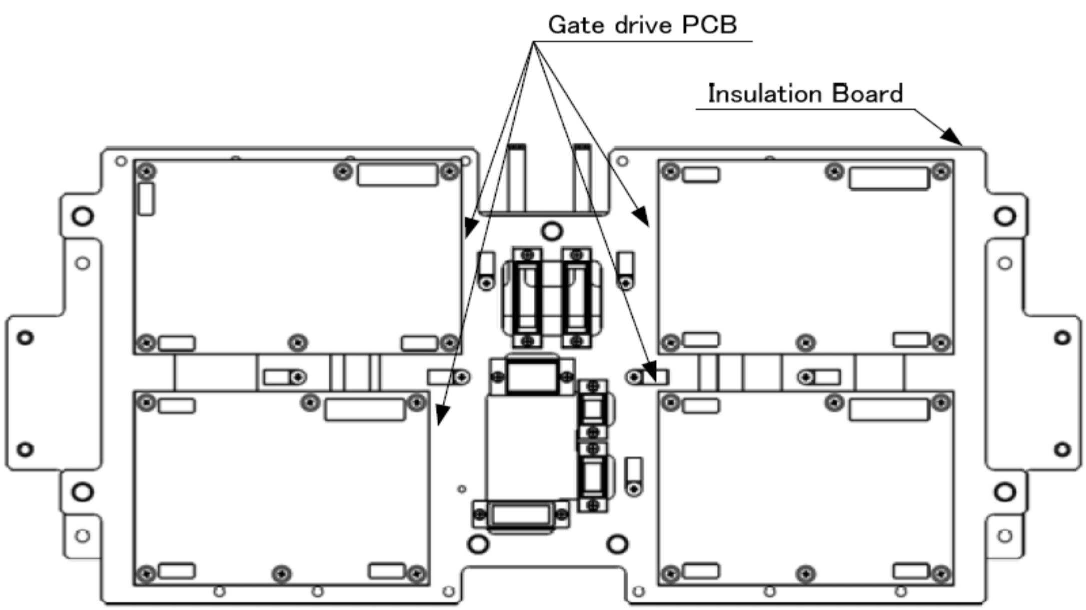


Figure 2-7: Gate Driver Unit

2.2 Line Switch Contactor

The Line Switch contactor (LS), as seen in Figure 2-8, is used to connect / disconnect the catenary supply from the propulsion system. After the pantograph, the power first goes through the HSCB, then the Knife Switch, and then the Line Switch contactor located in each propulsion equipment case, The HSCB provides overcurrent protection to the propulsion system. The Line Switch contactor is rated for 450 amps continuous current and 1200 Vdc continuous operating voltage. The maximum current breaking capacity is 2500 amps for 1 msec and 1200 amps for 15 msec.

The Line Switch contactor is a two-pole contactor. The contactor stationary contacts are built into the contactor arc chute and are accessed by removing the high voltage connections. The contactor movable interlock (bridge) is built into the contactor base. The movable contact (bridge) completes the circuit between the stationary contacts. The bridge is driven by the contactor coil.

The contactor is driven from the Propulsion Logic Unit using a Line Switch Relay which when energized, will energize the Line Switch contactor coil. The Line Switch contactor is equipped with auxiliary interlocks that provide a feedback signal indicating that the contactor is closed.

The location of the Line Switch contactor can be seen in Figure 2-5. The contactor is accessed through a removable door panel on the side opposite the inverter cooling fans. This door is marked as High Voltage.

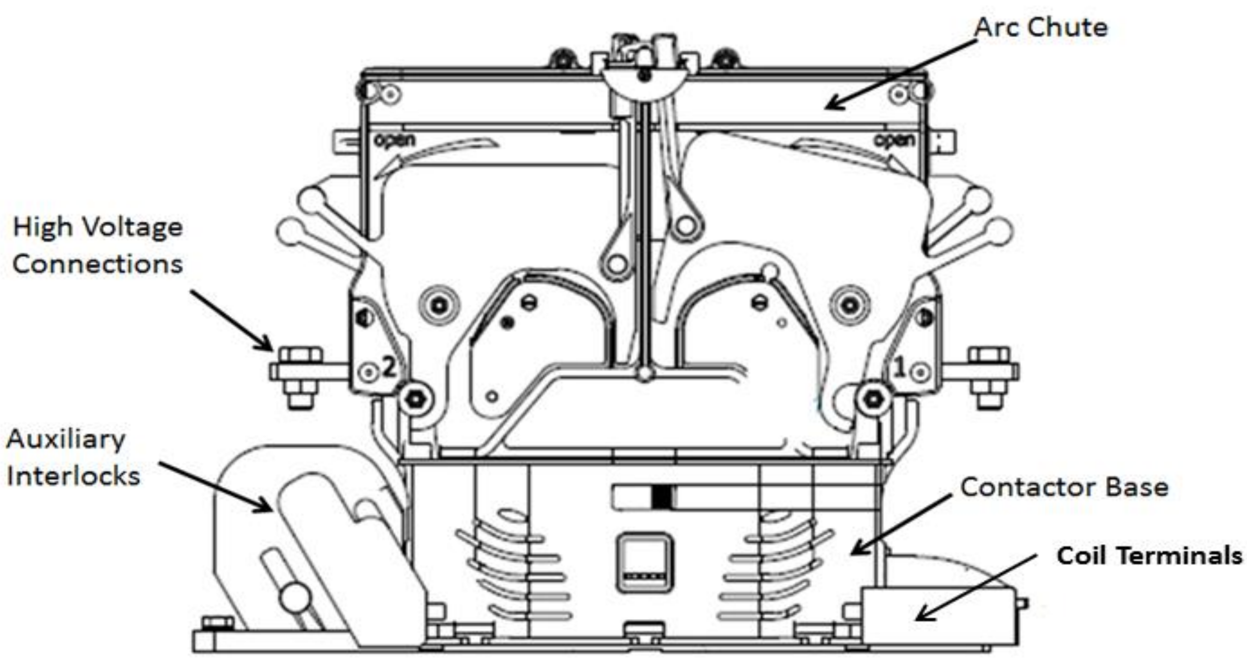


Figure 2-8: Line Switch Contactor

2.3 Line Charging Contactor

The location of the Line Charging Contactor (LCC) can be seen in Figure 2-5 adjacent to the Line Switch Contactor. The Line Charging Contactor, as seen in Figure 2-9, is used to insert a 4.3 ohm current limiting resistor into the charging circuit of the filter capacitors. The charging resistor is used to limit the inrush current to the filter capacitors as they are being charged from zero volts.

Discharged capacitors in a DC circuit act as a short circuit. If the charge rate to the capacitors was not regulated, an overcurrent condition would exist when the Line Switch contactor is closed.

Once the filter capacitors are charged to 80 percent of the line voltage, the Line Switch contactor closes and one second later the charging contactor opens. This contactor is rated for 50 amps continuous current.

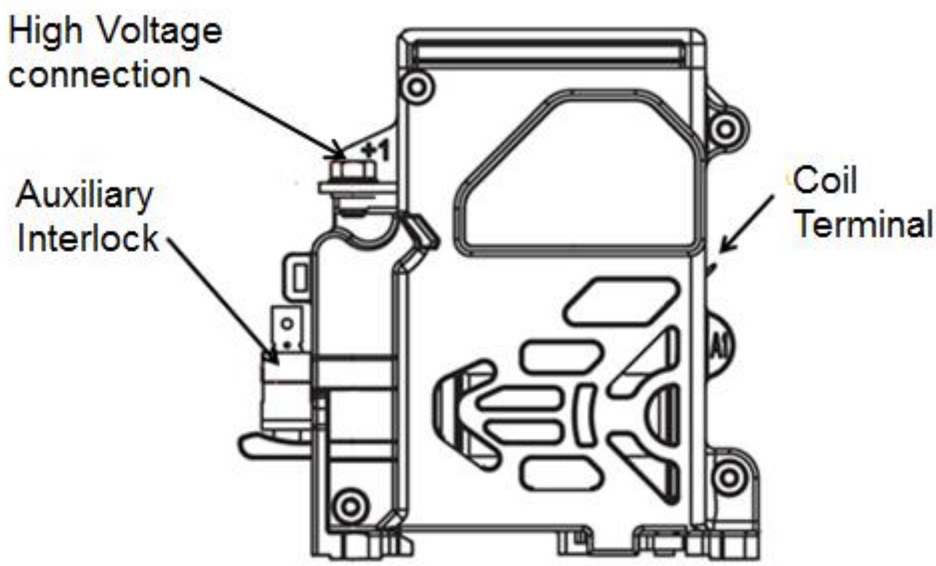


Figure 2-9: Line Charging Contactor

The contactor is driven by the PLU Digital Output board OBA54A1. An auxiliary interlock on the contactor provides a feedback signal indicating that the contactor is closed.

This contactor requires no maintenance and has no serviceable parts. The contact tips cannot be accessed. The contactor is accessed through a removable door panel on the side opposite the inverter cooling fans. This door is marked as High Voltage.

2.4 Filter Capacitors

There are four 10.5 mF dry metal film capacitors, as seen in Figure 2-10, located in the equipment case. The propulsion equipment case has two filter capacitors and the Inverter Unit also has two filter capacitors. Each capacitor is connected to the main power circuit by copper bus bars.

The filter capacitors work as part of an EMI filter with the two line reactor inductors to minimize noise created by the turning On and Off of the power circuit IGBT's from getting back to the catenary supply.

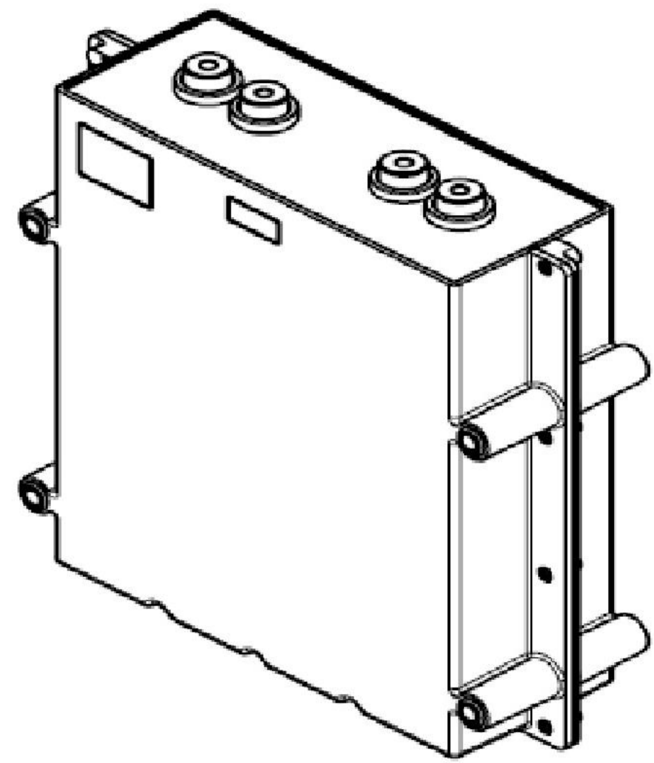


Figure 2-10: Filter Capacitor

2.5 Current Transducer (CT) Units

The Current Transducer (CT) Units are line replaceable units which are located in the center section of the equipment case. Access is through the removable door on the bottom of the equipment case. Refer to Section 8.4, Drawing B519943 at Zone A7 through C7 for the current transducer control circuits. The current transducers are powered from the +15 Vdc and –15 Vdc supplies from the power supply board AVR39B1 in the PLU.

To replace a transducer, the CT Unit 1 or CT Unit 2 must be removed from the propulsion inverter. The CT units are composed of EMI noise suppression cores (NSC) and hall-effect current transducers. The high voltage DC positive and negative supplies pass through the cores which provide noise suppression on the line input to the inverter.

CT Panel 1, as seen in Figure 2-11, consists of noise suppression magnetic cores (NSC) for the main power circuit and the current transducers CTL, CTG, and CTB. The brake resistor bus bars pass through the core which provides common mode noise suppression on the bus bars to the brake resistor. CTL provides line current detection and is used to measure input current to the inverter. CTG provides return current detection and is used to measure the return current of the Inverter Unit. CTL and CTG are monitored by the PCB MCB108B1 to provide ground fault protection for the propulsion system. The CTB is used to monitor the current flow through both brake chopper resistor circuits.

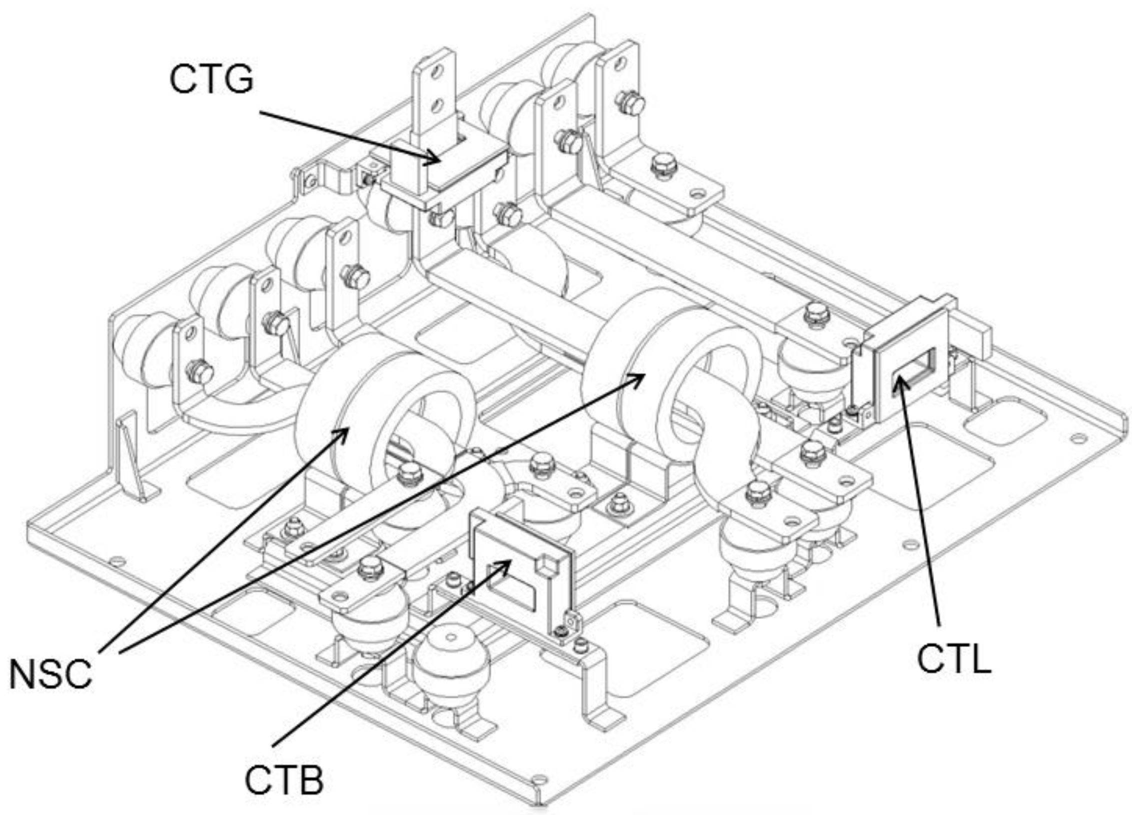


Figure 2-11: Current Transducer Panel 1

CT Panel 2, as seen in Figure 2-12, consists of noise suppression magnetic cores (NSC) as well as the motor circuit and output phase current transducers (CTU, CTV, CTW, and CTU2), which provides motor current detection. Motor wiring misconnection is detected by checking these motor currents through CTU2.

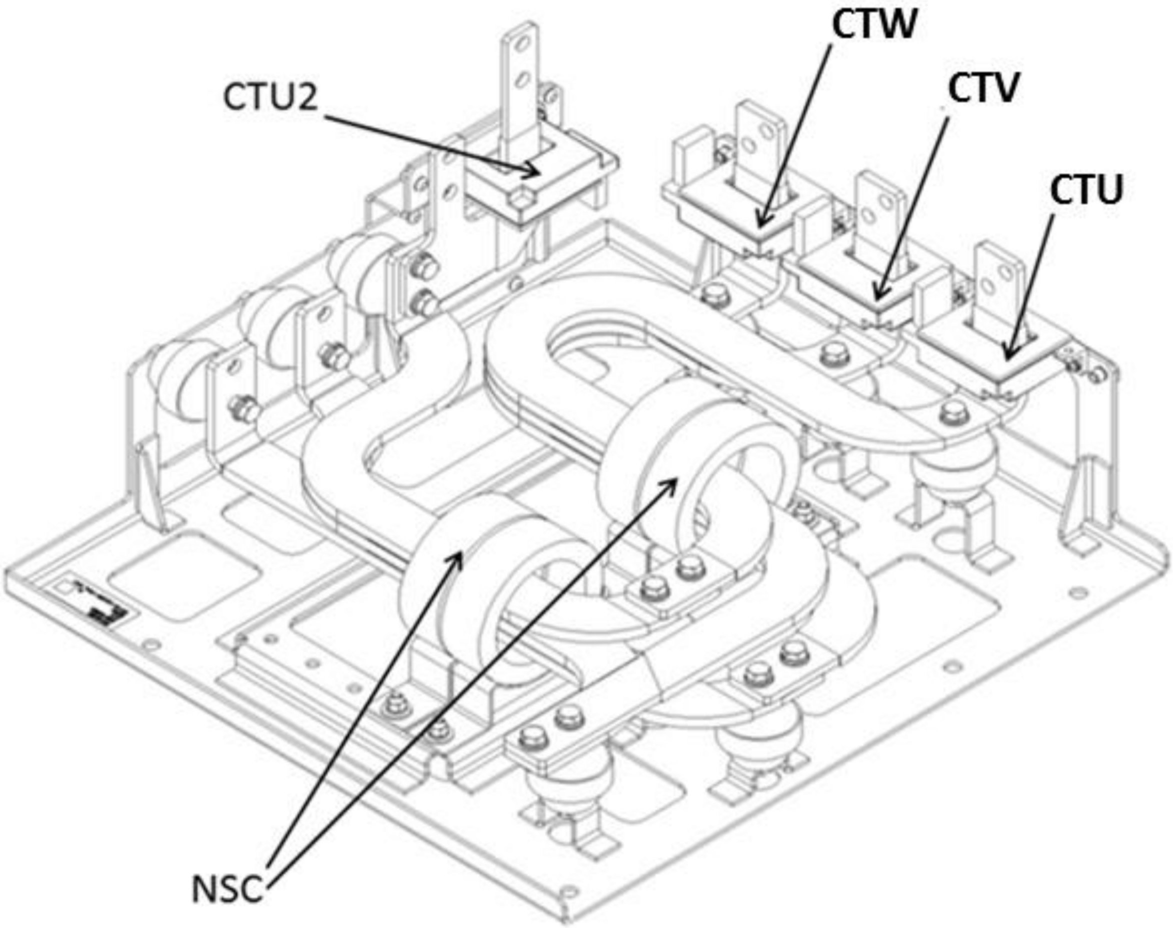


Figure 2-12: Current Transducer Panel 2

Use the bench test equipment to qualify which transducer to replace.

2.6 Direct Current Voltage Detectors (DCVD)

The DC Voltage Detector Unit is a line replaceable unit located in the center section of the equipment case and access is through the removable door on the bottom of the equipment case. The DCVD Unit, as seen in Figure 2-13, consists of two DC voltage detectors to measure the line voltage and filter capacitor voltage.

DCVD1 is the line voltage detector. With the High Speed Circuit Breaker closed, DCVD1 is used to monitor the line voltage and then to allow the power circuit contactors to close.

DCVD2 is the filter capacitor voltage detector. DCVD2 is used to monitor the voltage level at the filter capacitors to control the brake chopper circuits as the filter capacitor voltage rises during dynamic braking.

The two voltage detectors are identical and interchangeable. Refer to Section 8.4, Drawing B519943 at Zone A7 for the voltage detector control circuits. The voltage detectors are powered from the PLU AVR39B1 Power Supply board +15 Vdc supply.

The output signals from the voltage detectors feed into the PLU at the Inverter Control Board MCB108B1. A fault is declared and the inverter is shut down with opening the LS by the system CPU if the FC voltage exceeds 950 volts for 1 second or 1000 volts, or drops below 435 volts, or the Line Voltage drops below 475 volts.

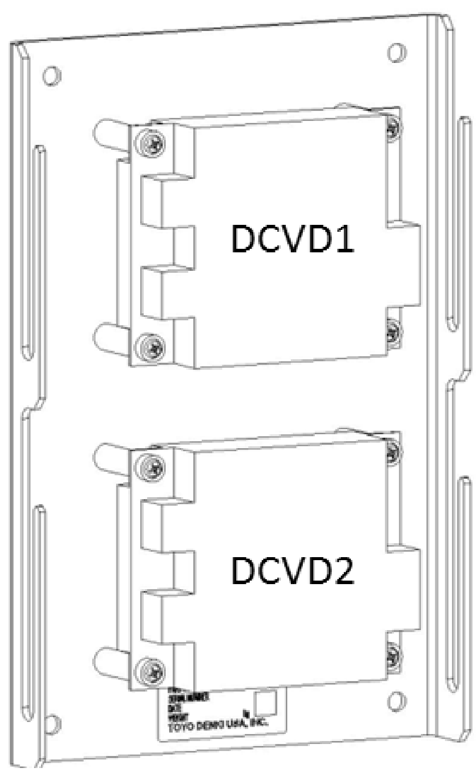


Figure 2-13: DC Voltage Detector Unit

2.7 Discharge Resistor Unit (DCHR Unit)

The discharge resistors are located in the center section of the equipment case. Access is through the removable door on the bottom. As seen in Figure 2-14, there are four resistors (with one connected across each filter capacitor) in a parallel configuration.

Each of the four discharge resistor circuits is made up of 2 resistor elements connected together using a bus bar. Each resistor circuit is 1,250 Ohms, 250 Watts. The equivalent power dissipation at 750 volts is 450 watts. Refer to Section 8.4, Drawing B446242 at Zone A4. The filter capacitors are discharged through the DCHR once line voltage has been isolated from the propulsion system.

The resistor is sized to discharge the filter capacitors to a voltage of less than 50 volts in three minutes. The back of the resistor unit contains a heatsink assembly with cooling air drawn from the outside of the propulsion equipment case through vent holes that allows cooling by convection. The resistors are sealed by gaskets on the inside of the equipment case to prevent water, dust and moisture from entering the central area of equipment case. The resistors will get hot during use.

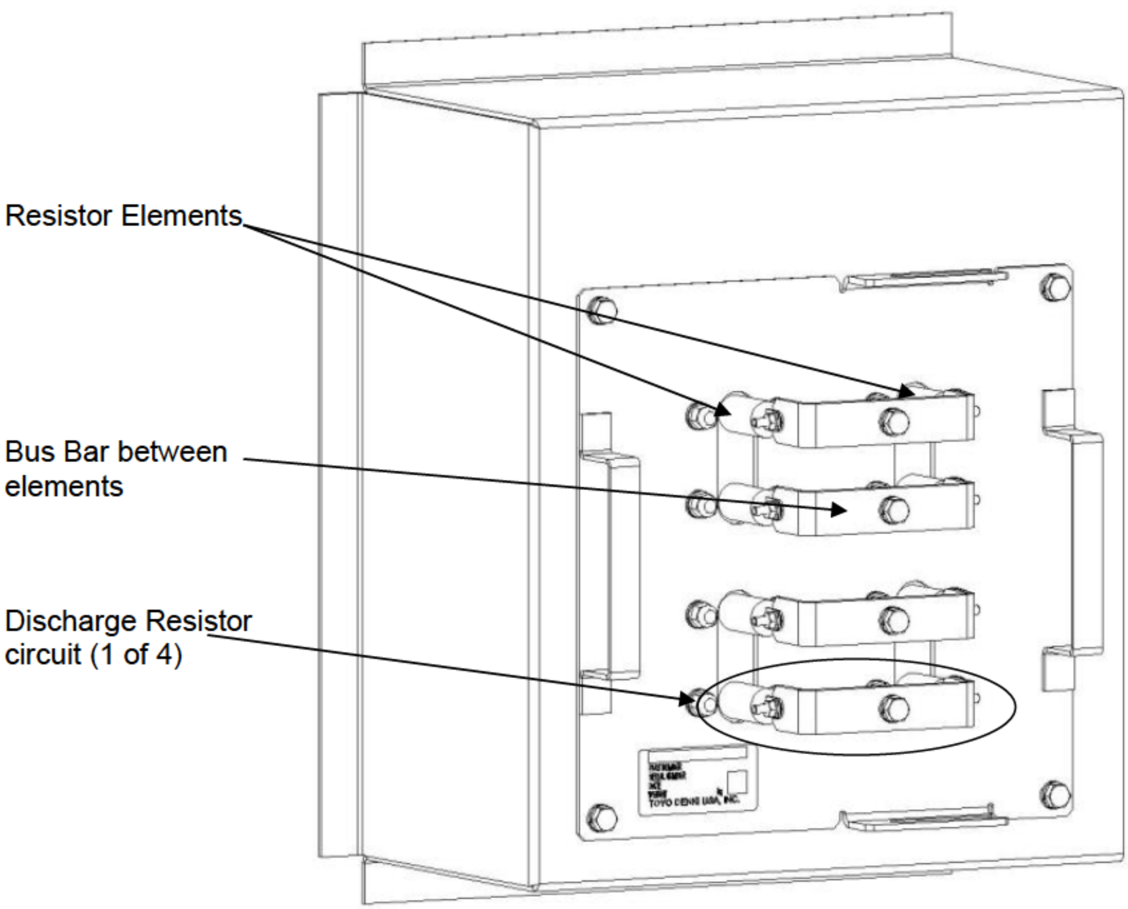


Figure 2-14: Discharge Resistor Unit

2.8 Charging Resistor Unit (CHR Unit)

The charging resistor is located in the center section of the equipment case and access is through the removable door on the bottom. Refer to Section 8.4, Drawing B446242 at Zone A2. The charging resistor, as seen in Figure 2-15, is used to limit the current when the filter capacitors are being charged. When the Line Charging Contactor is closed, with the Line Switch contactor open, this resistor is inserted into the power circuit to provide current limiting as the filter capacitors are being charged from zero volts. Resistance is 4.3 ohms. The CHR is mounted on stand-offs in an open area to allow natural convection cooling. If the CHR is used 3 times in one minute, the inverter shuts down for 60 seconds to allow the CHR to cool.

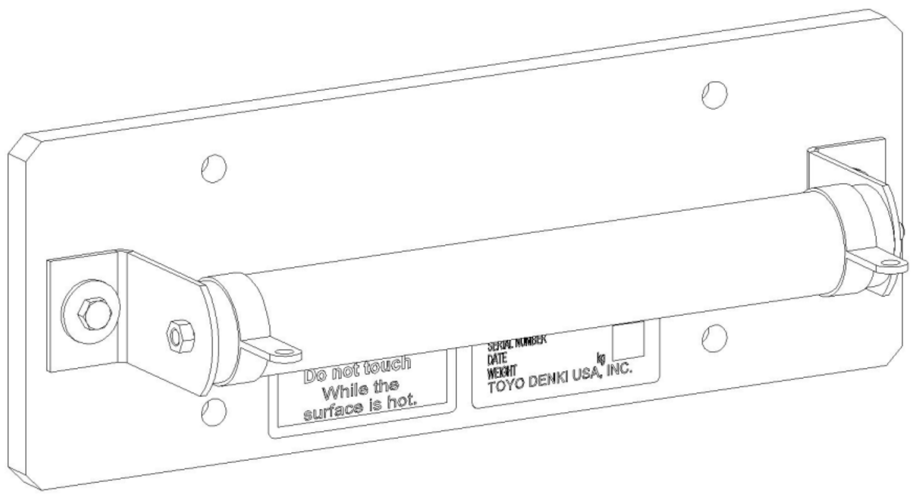


Figure 2-15: Charging Resistor Unit

2.9 Relay Unit

The Relay Unit, as seen in Figure 2-16, is a line replaceable unit which is located in the end panel above the PLU as seen in Figure 2-5. Access to the Relay Unit is through the hinged door on the side of the equipment case. Refer to Section 8.4, Connection Drawing B3018019 for internal wiring of the Relay Unit. The Relay Unit contains seven relays.

EBR - Emergency Brake Relay

EBR is energized when the Emergency Trainline is activated. The EBR status is monitored from the PLU digital input signal ER. An interlock of EBR is used in the control circuit for the Emergency Brake Relay Timer (EBRT). Refer to Section 8.4, Drawing B519943 at Zone C4 for the EBR relay coil and Zone C3 for the EBR interlock (wire marker EBRS). The EBRS circuit goes to EBRT connection 6 as seen in Zone C4. When the EB Trainline is lost, the EBR coil is deenergized and the EBR interlock opens. When the EBRS (Emergence Brake Relay Start) connection 6 input is lost, the 3 second timer starts that will open the EBRT interlocks 3 seconds later and act as a backup to disable the Line Switch contactor.

EBRT - Emergency Brake Relay Timer

This is a 3 second off delay relay. EBRT is energized when the EB Trainline is active. The EB Trainline energizes the Emergency Brake Relay (EBR) and an EBR interlock completes a circuit to EBRT. The EBRT relay interlocks control the return circuit to Line Switch Relay (LSR) and the Line Charging Contactor (LCC). The relay interlocks close immediately when the coil is energized and open 3 seconds after the coil is deenergized. This relay is used 3 seconds after an Emergency Brake application to ensure that the Line Switch contactor is disabled even if the LS closing command from the PLU is involuntarily activated after receiving EB command, while avoiding current breaking at the LS in normal EB operation which may roughen the contact surface. EBRT is found on drawing B519943 Zone C4 and the interlocks controlling LSR can be seen at Zone C5.

As seen in Connection Drawing B3018019, EBRT has three function blocks.

The Power Supply (connection 2 and 10) is supplying all the energy used in the relay including coil energizing power, logic control, time counting and LED indications.

The Start Input (connection 6 and 2) is the trigger signal input to start the 3 second timer function.

The Reset Input function is not used.

The PLU should open the Line Switch Contactor by disabling the Line Switch Command signal. EBRT is used to back-up this function. The EBRT timer relay is controlled from the Emergency Brake Trainline using the EBR Relay. As seen in Drawing B519943, EBRT is seen in Zone C4. Just above EBRT is the EBR coil which is controlled from the EB trainline. The EBR interlock (wire marker EBRS – Emergency Brake Relay Start) is used to control the input to EBRT connection 6.

EBRT has a numbered dial on the front that allows the changing of the time delay. The setting must always be 3 seconds. This device has two LED indicators.

- Power LED (red) - On when control power is supplied and the timer function is not triggered. This LED is flashing when the 3 second time counting is activated.
- Output LED (green) – On when the relay is energized and the contacts are closed.

FM1R - Fan Motor Relay

This relay is controlled by the PLU from the digital output signal FAN1K. When the PLU energizes the relay, a circuit is completed from the vehicle 208 volt 3-phase supply to the four Inverter Unit cooling fans. For this relay to be energized, the 208VDK – Inverter Fan Relay interlock input to the PLU (208VD) must be active. Refer to Section 8.4, Drawing B519943 at Zone C5 for the relay coil and Zone D3 for the relay interlocks.

HSCBCK – High Speed Circuit Breaker Relay

The command to close the HSCBCK relay comes from the System CPU on the MCB107B1 Inverter System Control board to the OBA54A1 Digital Output Board HBCC output signal. Refer to Section 8.4, Drawing B519943 at Zone B5 for the relay coil.

Contacts of the relay complete a B+ circuit into the HSCB Control Panel allowing the HSCB to be energized closed. The following must be true for the PLU to energize the HSCBCK:

- Cab keyed up and direction set
- HSCB open and not locked out
- Line Switch contactor open
- Line Charging Contactor open
- Propulsion inverters must not be cut out

When detecting any of the following condition, the PLU deenergizes the HSCBCK:

- Ground Fault is detected
- HSCB or LS or LCC Fault is detected
- HSCB Power Source Fault is Detected
- Input Overcurrent (more than 1600 amps of Line Current) is detected

With the HSCB commanded open for any reason or an overcurrent trip, the HSCB can be reclosed using the PROP/ HSCB Reset button on the TOD.

HSCBCK does not have a Status feedback circuit back to the PLU. The detection of the HSCBC signal is proof that the relay is energized.

LSR – Line Switch Relay

This relay is driven by the PLU from the OBA54A1 Digital Output board signal LSRC and is used to energize the Line Switch contactor. Refer to Section 8.4, Drawing B519943 at Zone C5 for the relay coil. LSR is energized with the following conditions:

- Cab keyed up and direction set
- HSCB closed
- Line voltage greater than 525 volts
- No propulsion faults detected
- Propulsion not cut-out
- Cab keyed up and direction set
- Filter capacitor voltage within 80% of line voltage

When the Emergency Brake Trainline is disabled (Emergency mushroom depressed), the PLU disables the LSR to open the Line Switch contactor.

The LSR has no Status feedback circuit back to the PLU. The closing of the Line Switch contactor is proof that LSR is closed.

NMRK – No-Motion Relay

This relay in each inverter equipment case as well as the matching relays from the friction braking system ECU's are used to control the vehicle No-motion Relay. The command to close the No-motion relay comes from the System CPU on the MCB107B1 Inverter System Control board to the OBA54A1Digital Output board NMRC output signal. See B519943 Zone C5. Refer to Section 8.4, Drawing B519943 at Zone C5 for the relay coil.

The A-unit PLU monitors Tach 1 and Tach 4 and controls the A-unit NMRK relay. The B-unit PLU monitors Tach 10 and Tach 5 and controls the B-unit NMRK relay. Only when all the speeds measured by operational speed sensors from both the propulsion system (and friction braking system) are less than 0.5 mph will the No-motion Relay be energized.

The status of the NMRK relay is monitored from the IBA130A2 Digital Input 2 board from the NMRS signal.

208VDK – Inverter Fan Relay

This relay is activated when the vehicle 208V 3-phase output is active as seen from Drawing B519943 at Zone D3. As seen in Zone B5, the relay interlock is used as an input to the Digital Input Board 2 IBA130A2. The AC 208V Detected signal must be active to allow the Fan Motor Relay FM1R to be energized.

Zener – Used to prevent vehicle APS voltage spikes from entering the Relay Unit. It is normally not conducting. The Zener diode will turn On when the AC voltage exceeds 430 volts.

2.9.1 Troubleshooting Relay Logic

To troubleshoot the relay logic, it may be necessary to qualify the feed to the coil or the interlock circuit through each relay on the Relay Unit. This can be done using a number of documents.

The circuits for each relay can be seen on Inverter Connection drawing B519943. Find the relay coil or interlock and note the wire marker number associated with the suspect circuit.

Go to Section 8.4 Relay Unit Connection Drawing B3018019 and find the relay. Match the wire marker from the B519943 drawing and qualify the relay circuit from the relay connection terminals.

As needed, the Relay Unit Wire List as seen in Section 8.4 can also be used to further qualify the circuit.

The mechanical actuator as noted in Figure 2-16 is not fitted to any of the original equipment Relay Unit relays. The actuator is fitted to replacement NMRK, HSCBCK and EBR relays because the relay replacements are from a different manufacturer.

CAUTION

DO NOT USE THE MECHANICAL ACTUATOR DURING MAINTENANCE. SEE FIGURE 2-16.

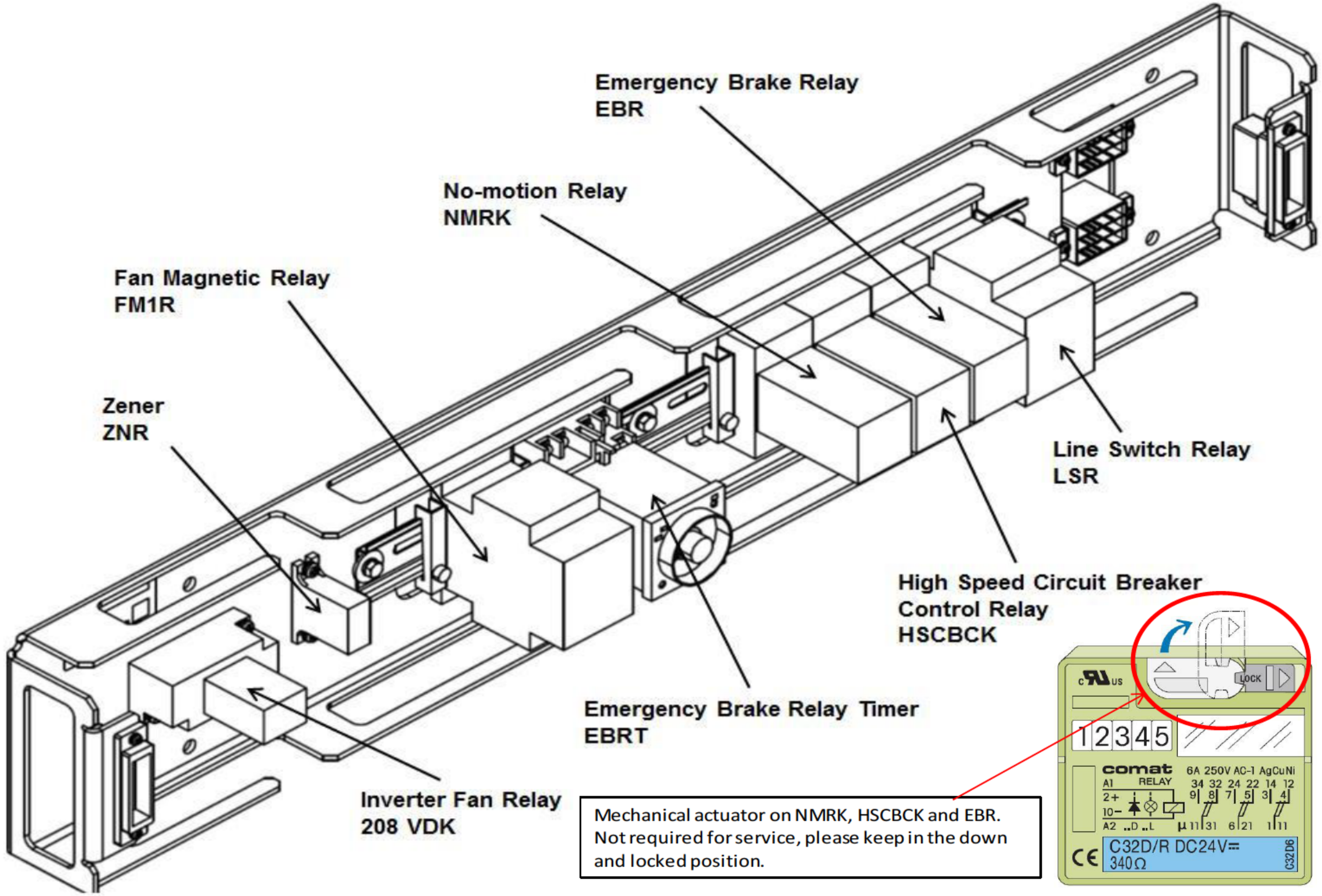


Figure 2-16: Relay Unit Layout

2.10 Battery Voltage Noise Filter

This device, as seen in Figure 2-17 and Figure 2-1, filters any noise (EMI) that may be on the vehicle 28.5 Vdc battery voltage input to the Power Supply Unit in the inverter equipment case. Refer to Section 8.4, Drawing B519943 at Zone A1 for the Noise Filter and Zone E4 for the Power Supply Unit. The vehicle battery + input supply to the filter (as well as the battery + circuits not going through the filter) are labeled as 20. The battery + supply at the output of the filter to the Power Supply Unit is labeled as 32. The device is located in the main compartment on the left side wall above the external equipment case connectors as seen in Figure 2-3. It is rated at 250 Vdc and 15 amps.

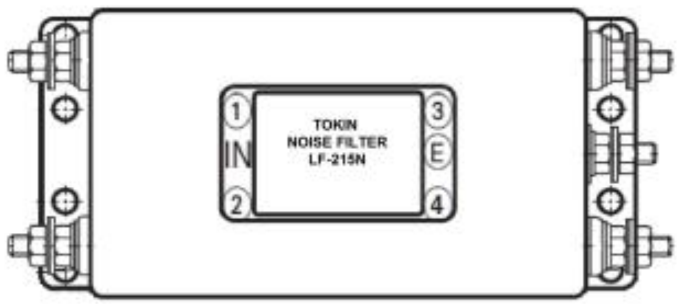


Figure 2-17: Battery Voltage Noise Filter

2.11 Propulsion Logic

As seen in Figure 2-18, the propulsion logic is made up of the Propulsion Logic Unit, Gateway Unit and the Power Supply Unit. There are also four gate driver boards that are located in the Inverter Unit as seen in Figure 2-7.

2.11.1 Propulsion Logic Unit

The PLU receives signals from the vehicle controls and through the Gateway Unit MVB circuitry. The PLU controls the propulsion power circuit semiconductors, contactors and relays. The PLU is composed of nine circuit boards which are removed by loosening the screws at top and bottom and then disengaged from the rack using the locking handles.

Five of the circuit boards contain microprocessors. The other circuit boards are two Digital Input boards, one Digital Output board and one Power Supply board.

The PLU receives signals from the vehicle trainlines and controls as well as over the MVB through the Gateway Unit.

2.11.2 Gateway Unit

The Gateway Unit has all of the external communications paths to the propulsion system. The MVB and WTB communications use redundant pairs of twisted cables. The Ethernet communication signals are redundant 10/100 Base T Ethernet. The communications to the Propulsion Logic Unit are based on RS485 and use the HDLC protocol. All of these signal ports are located at the face of the Gateway Unit.

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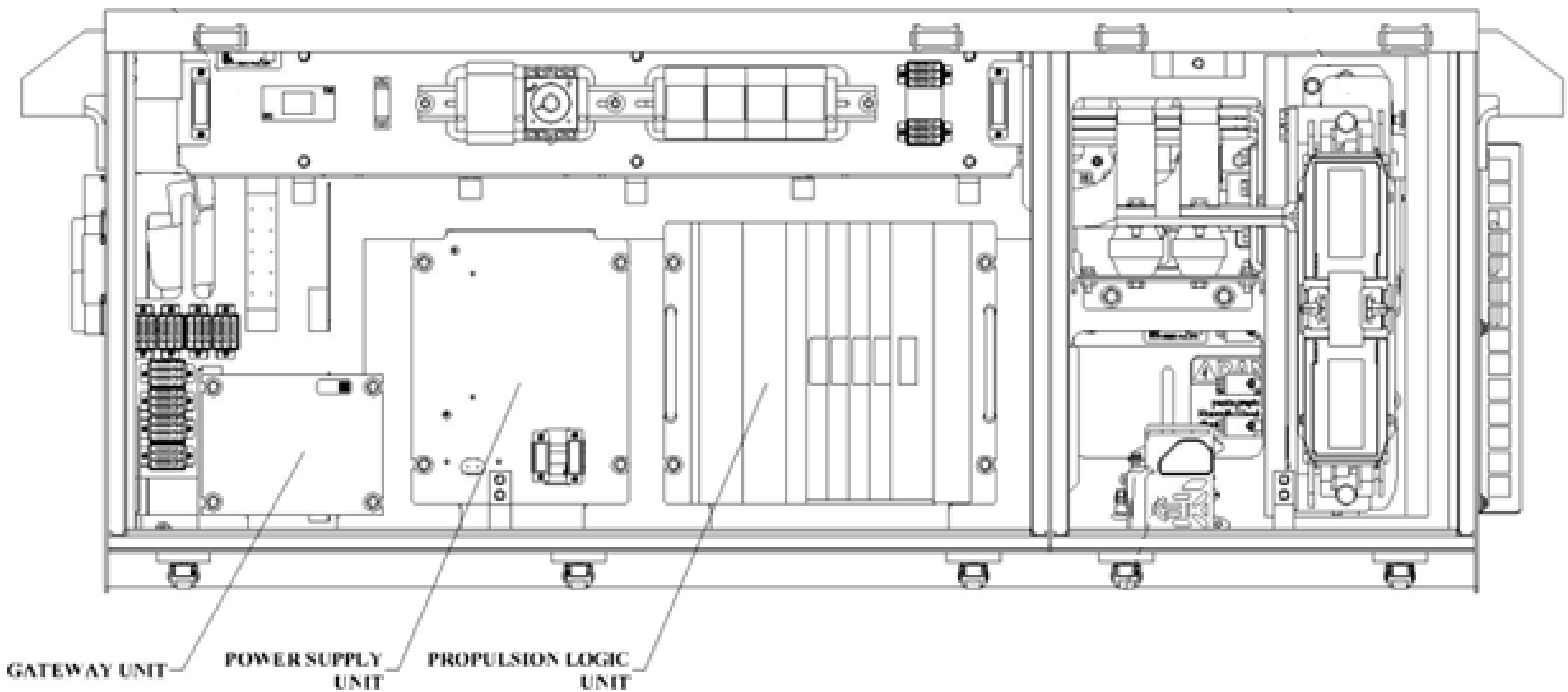

Figure 2-18: Propulsion Logic, Power Supply Unit and Gateway Unit Locations

2.11.3 Power Supply Unit

The Power Supply Unit is a DC to AC converter. The input is vehicle batteries at 28.5 Vdc. The power supply output is 38 Vac (square-wave, 25 kHz, duty cycle of 50%) to the PLU Power Supply board AVR39B1 and the gate driver boards in the Inverter Unit.

2.12 Equipment Case Connectors

The propulsion control signals that interface with the vehicle circuits are located within connectors CN1 through CN6 on the propulsion equipment case. The layout drawings of these connectors are shown in Chapter 8 of this manual.

CN1 is for the vehicle battery power.

CN2 has the 208 Vac three-phase power to run the Inverter Unit cooling fans.

CN3 is for both channels of the MVB communications.

CN4 contains the Ethernet communication signals.

CN5 are the trainlines and HSCB control signals.

CN6 is for the tachometer input signals and power supply voltages as well as the analog output signals for the chart recorder.

See the following connection drawings in Section 8.4:

B3018031 Propulsion Inverter CN1 Connection Drawing

B3018032 Propulsion Inverter CN2 Connection Drawing

B3018033 Propulsion Inverter CN3 Connection Drawing

B3018034 Propulsion Inverter CN4 Connection Drawing

B3018035 Propulsion Inverter CN5 Connection Drawing

B3018036 Propulsion Inverter CN6 Connection Drawing

The circuits for each connector can also be seen in drawing B519943 Zone A/F2.

Layout drawings for each of these connectors are in Section 8, Figures 8-1 through 8-6.

2.13 Lightning Arrestor

The lightning arrestor, as seen in Figure 2-19, is located on the roof of the vehicle. The lightning arrestor is a metal oxide varistor. The lightning arrestor will prevent lightning strikes from the catenary supply from entering any of the high voltage systems on the vehicle. The lightning arrestor is normally open circuit but will conduct with 1000 volts across it. The lightning arrestor has a maximum energy dissipation of 2600 Joules for currents 500 amps or less.

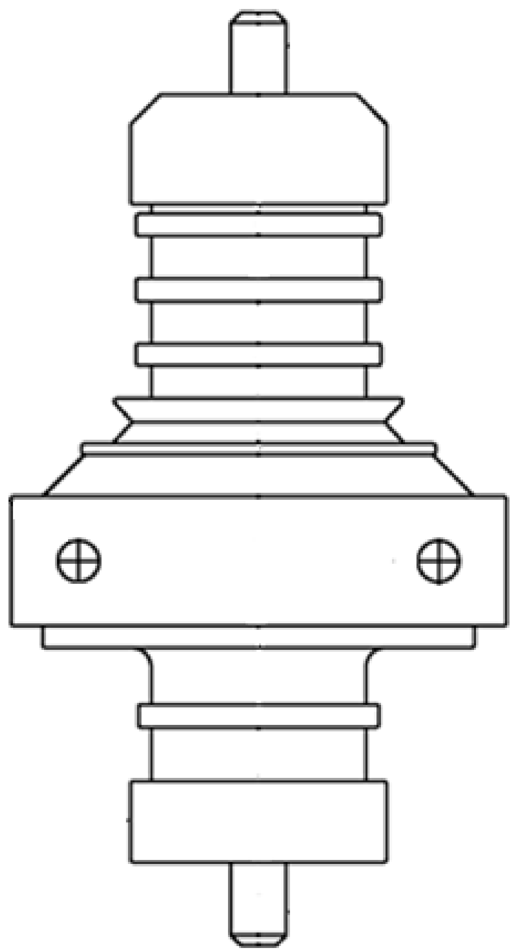

Figure 2-19: Lightning Arrestor

2.14 High Speed Circuit Breaker

The High Speed Circuit Breaker (HSCB) designed and built by Toyo Denki is located on the roof of the vehicle. This device provides rapid interruption of the 750 volt catenary supply to the vehicle when tripped (at 3200 amps) by an overcurrent fault.

The necessary HSCB information is split between the RMSM (inspections and running maintenance repair), the HRM (overhaul) and the Parts Catalog.

The HSCB is a single-pole DC circuit breaker, bi-directional with electromagnetic control and natural cooling. As seen in Figure 2-20, the HSCB is enclosed and protected from water and dust by a shell. The shell is composed of two parts, upper and lower. The lower shell contains the circuit breaker, arc chute, power circuit cable buses, auxiliary switches and control circuit connector. The upper shell contains vents allowing any ionized gases created to be vented outside of the shell. The vents are a fine mesh material which prevents water from entering.

The rated operational current is 1000 amps. Direct overcurrent trip response time is rated at approximately 20 milliseconds for a current flow of 3200 amps.

WARNING

DO NOT TAMPER WITH ANY ADJUSTMENTS OF THE HSCB WHILE IT IS ON THE VEHICLE.

The trip setting of the HSCB is 3200 amps. The trip setting is pre-set at the factory and is not intended to be adjusted on the vehicle.

The adjustment of the HSCB trip current is from the bottom of the HSCB. The HSCB must be removed from the frame to make this adjustment. This adjustment is not incremented so if adjusted on the vehicle, there is no way of knowing the exact value set. Turning the screw counter clockwise increases the trip current. Turning the screw clockwise decreases the trip current.

If the trip settings of the HSCB or the HSCB interlock positions or gaps are suspect, the HSCB should be replaced with a known good device.

The opening and closing functions of the HSCB are described below:

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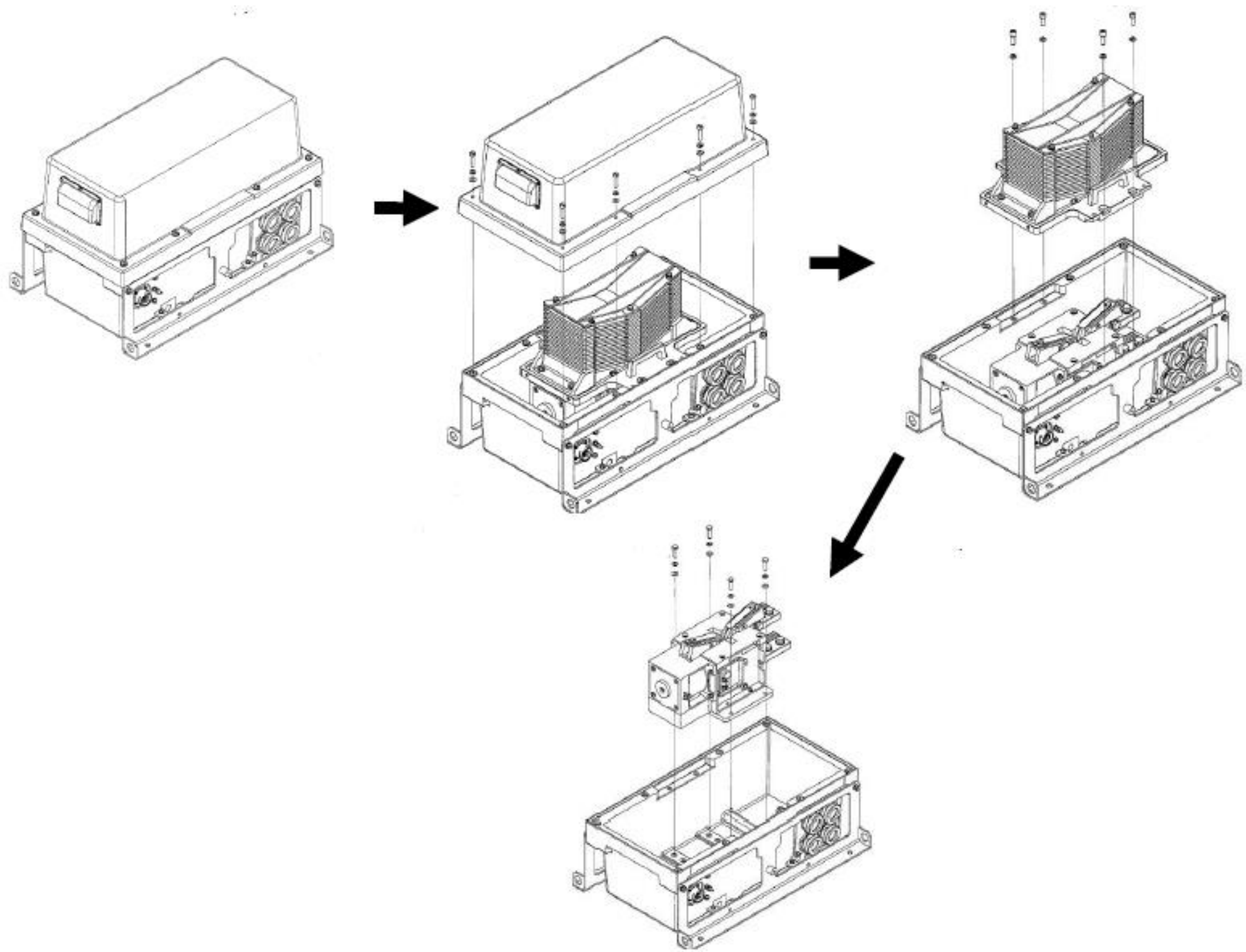

Figure 2-20: High Speed Circuit Breaker

2.14.1 Closing the HSCB

When the HSCB coil is energized and magnetized, as seen in Figure 2-21, the moving contact overcomes the spring force and the main contacts are closed. There are two shock absorbers in the HSCB that engage the movable contact as the contacts close. The spring remains in tension until the coil is deenergized.

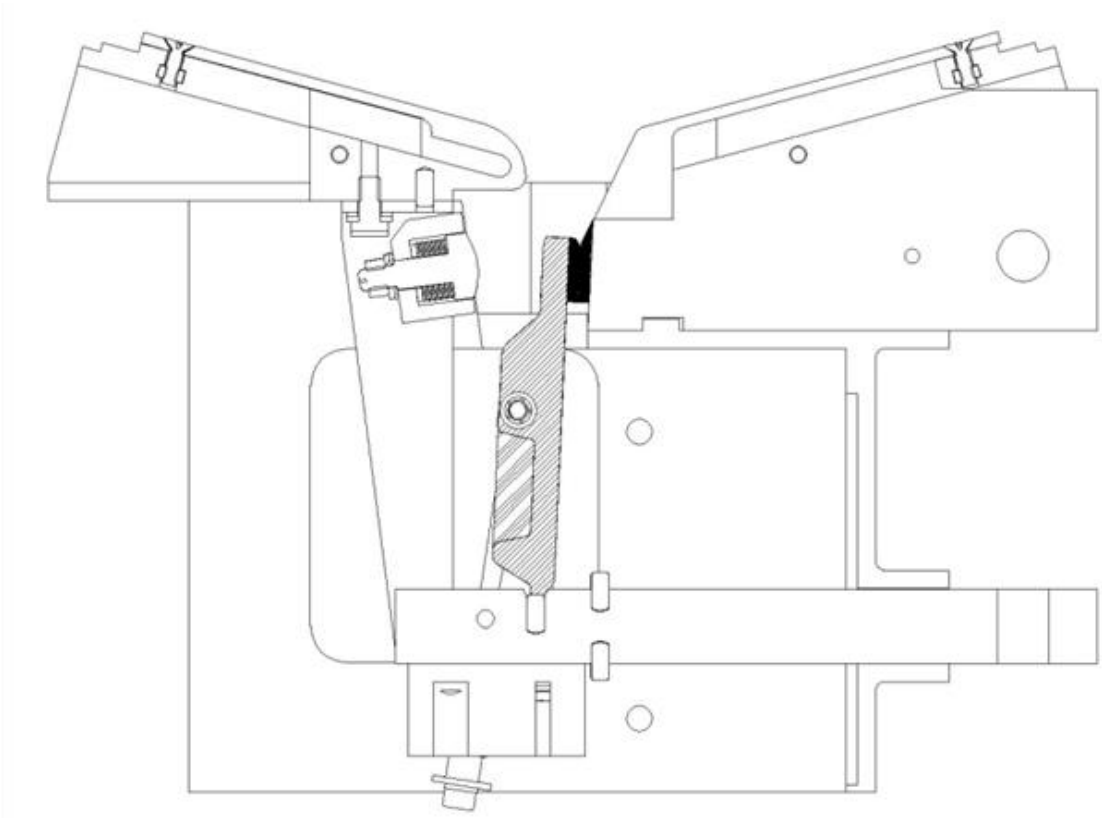

Figure 2-21: HSCB Closed

As seen in Figure 2-22, when energized, the HSCB coil current of 40 amps flows for up to 1 second to close the contacts. Once the HSCB contacts are closed the coil current stabilizes. A momentary control signal at 28.5 Vdc (approximately one second) to the HSCB coil input will force the HSCB contacts closed.

Once closed, battery voltage is removed from the coil and replaced with 5 Vdc from the control panel current limiter circuit board. The 5 volt supply provides a holding current of approximately 2 amps.

The removal of voltage on the HSCB coil will cause the HSCB to open.

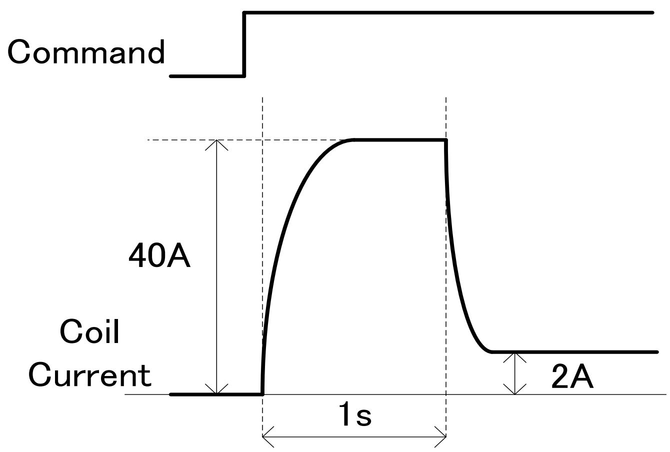

Figure 2-22: HSCB Coil Current

2.14.2 Opening the HSCB

When the coil is deenergized, as seen in Figure 2-23, the moving contact is pulled away from the stationary contact by the spring and the main circuit becomes an open circuit.

When the current flow through the HSCB exceeds 3200 amps, the HSCB Overcurrent trip is activated which opens the HSCB. When a propulsion ground fault is detected (50 amp difference between Line current and Return current for longer than 200 msec), the coil is deenergized by the PLU opening the HSCB. When the PLU detects line current of 1600 amps for 1 second, the PLU will de-energize the HSCB open.

The HSCB will also be commanded open upon detection of disagreement between command and feedback of the HSCB, Line Switch Contactor or Line Charging Contactor. The HSCB will also trip if the 28.5 Vdc control voltage to the Control Panel is less than 14.4 Vdc. For this fault condition, the HSCB will be reset when the voltage rises to above 16.8 Vdc.

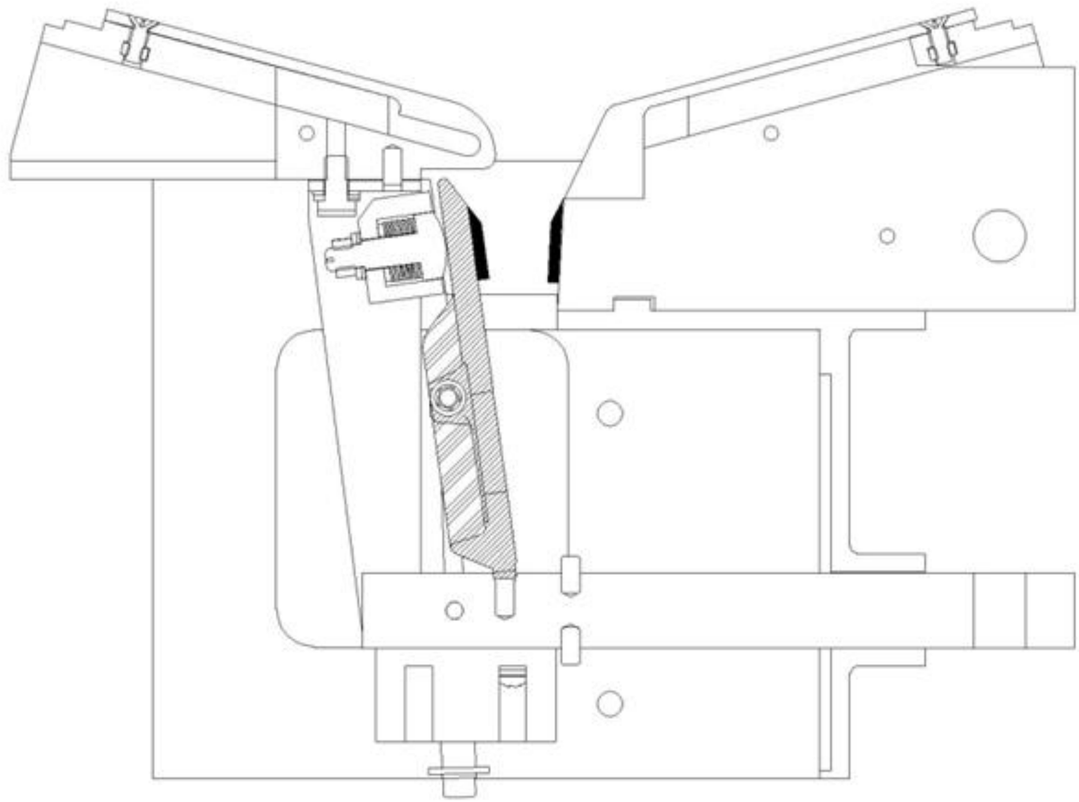

Figure 2-23: HSCB Opened

2.15 High Speed Circuit Breaker Control Panel

The HSCB Control Panel is mounted inside a locker inside the vehicle near the articulation on the A-Unit.

Functionally, the HSCB and HSCB Control Panel form an integrated assembly. Physically, they are located in different locations. The HSCB Control Panel operates the HSCB remotely using signals from the Propulsion Logic Unit and the High Speed Circuit Breaker control relay HSCBCK from either propulsion equipment case.

Both the A-unit and B-unit logic energize the HSCB using the HSCBCK relays in each propulsion equipment case. When he HSCB coil is energized from the control panel, the device closes. Once the HSCB is closed, vehicle battery voltage is removed from the HSCB coil and a 5 Vdc supply from the current limiter PCB is put on the coil to establish the two amp holding current. When control power to the HSCB coil is removed in the control panel, the HSCB opens. The HSCB Control Panel operates on 28.5 Vdc battery voltage.

Figure 2-24 shows the locations of the noise filter, terminal block, capacitor, and current limiter circuit board inside the HSCB Control Panel assembly.

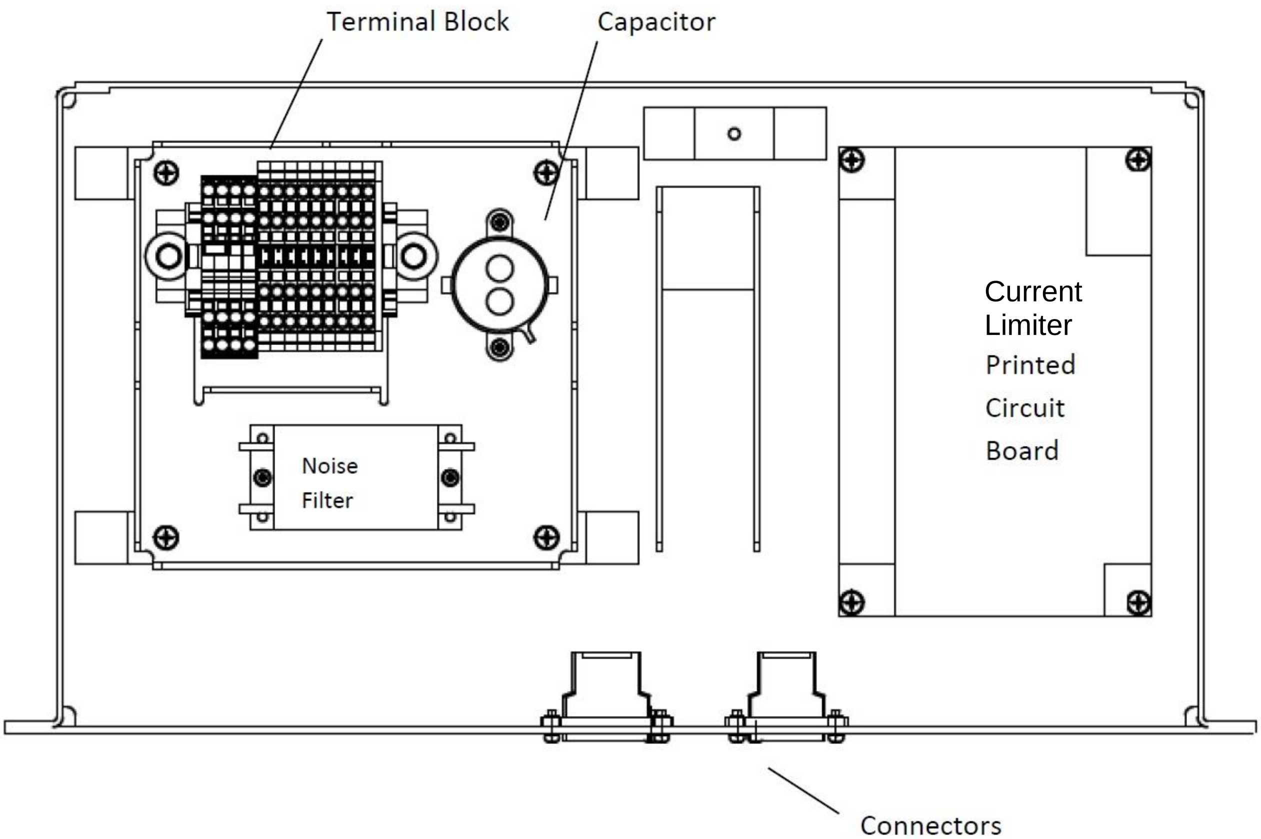

Figure 2-24: HSCB Control Panel

2.16 Knife Switch

The Knife Switch is a two-blade, four-position switch located under the vehicle frame as shown in Figure 2-25. The Knife Switch disconnects the high voltage power for the propulsion inverter high voltage components for maintenance purposes. It is the only box under the car with a red cover. The positions are Normal, Auxiliary, Open and Shop Power. Three sets of jaws and pivots contact the blades and provide connections for the high voltage power, propulsion, and auxiliaries.

The shop power plug is mounted on the left side of the Knife Switch box. The Shop Power plug is connected to the auxiliary power clip located at the right side of the Knife Switch box using the Auxiliary Power blade when the switch is in the Shop position.

The high voltage power (750 volts DC nominal) is fed from the High Speed Circuit Breaker through the Knife Switch to the propulsion inverter box, and the auxiliary fuse on the roof feeds 750 Vdc through the knife switch to the auxiliary power supply. Two parallel 373 MCM cables run from the HSCB to the Knife Switch propulsion connection.

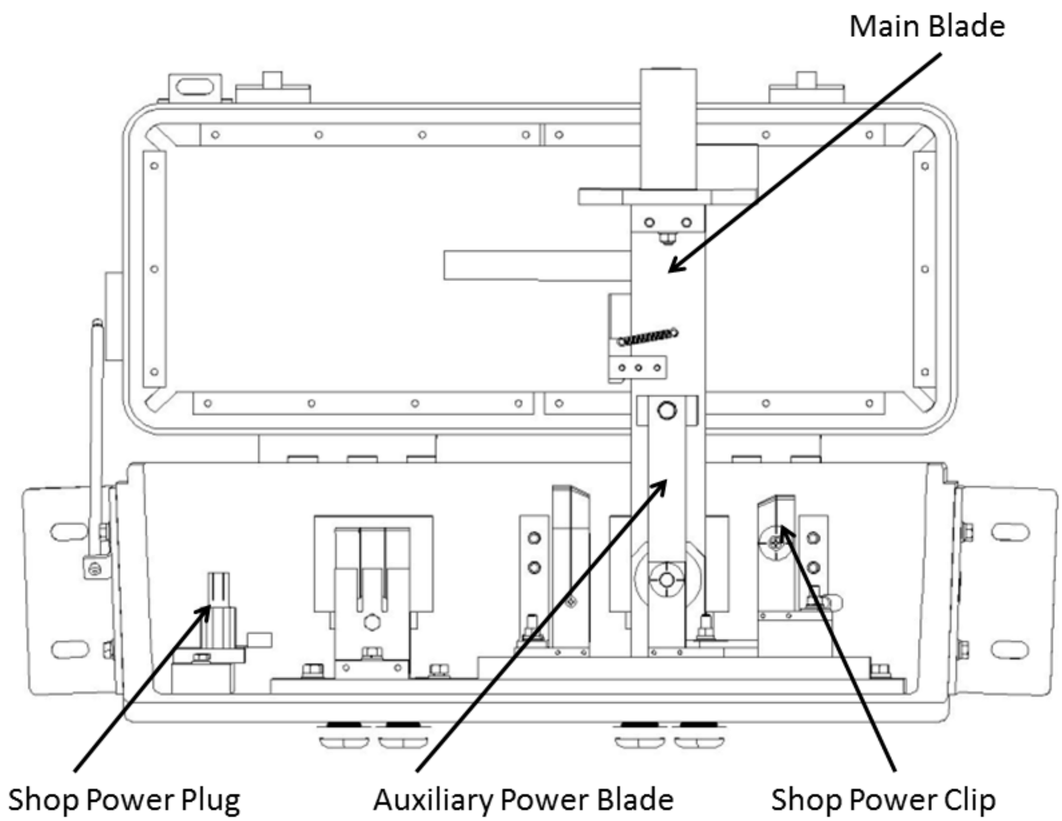

Figure 2-25: Knife Switch Box

The Knife Switch enclosure is a molded, fiber reinforced, plastic box. The cover of the Knife Switch can be held open by 90 degrees. The cover cannot be closed except in Normal position. The Shop plug is connected with the switch in the Shop position. Non-metallic cable grips are used to provide a water tight seal and strain relief for each cable.

Figure 2-26 shows the four possible positions that the Knife Switch can be placed in.

Run Position - Power is supplied to the propulsion and auxiliary circuits via the pantograph feed.

Auxiliary Position - Auxiliaries are connected to the pantograph feed and the propulsion equipment is isolated.

Off Position - No power is fed to the propulsion or auxiliary circuits.

Shop Position - Power is supplied to the auxiliaries via the Shop Power receptacle through the Auxiliary Power blade. The Main blade is isolated and no power is fed from the pantograph to the propulsion systems.

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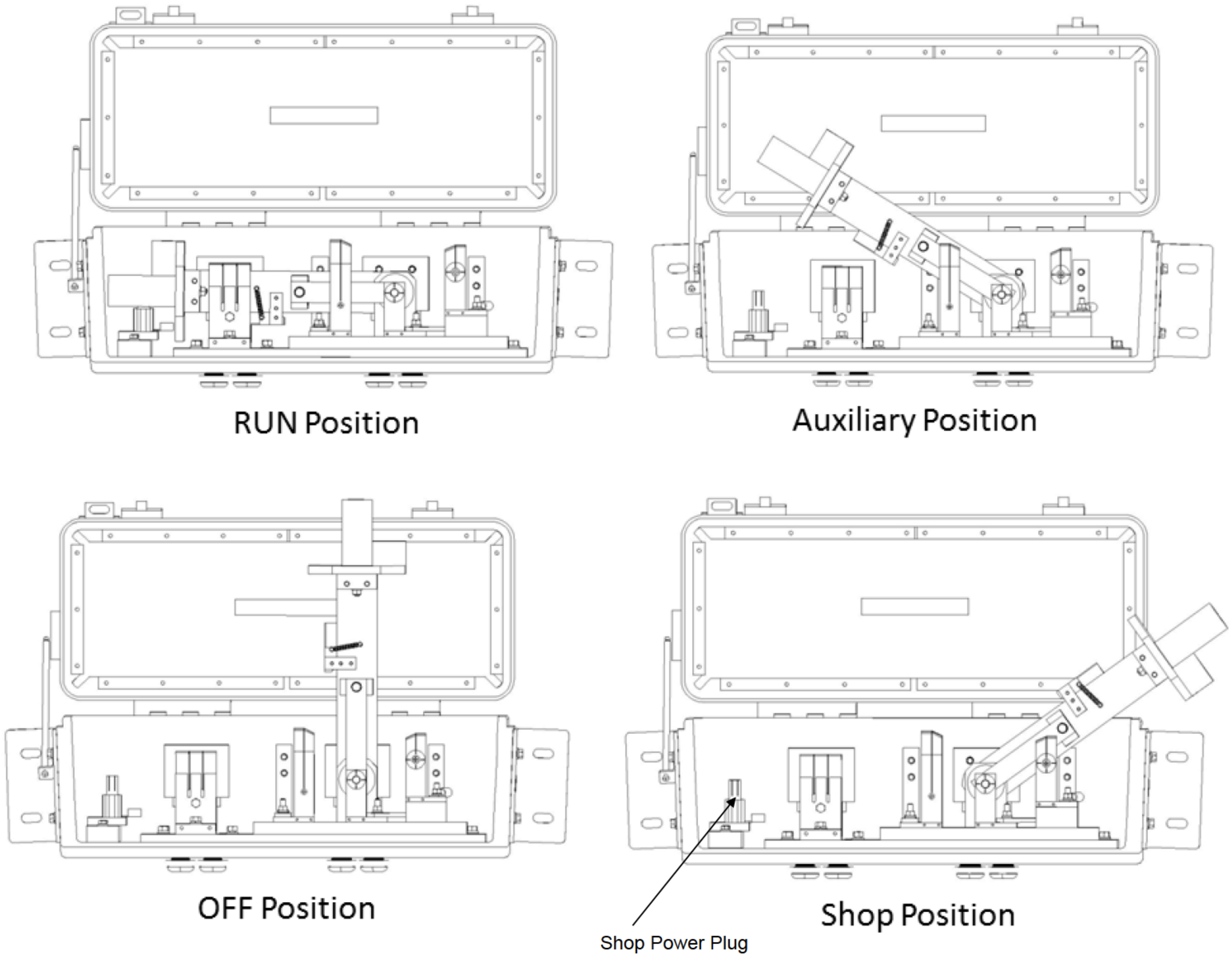

Figure 2-26: Knife Switch Positions

2.17 Line Reactor

The operation of the inverter can create harmonic currents that can adversely impact the signaling system equipment through conducted and electromagnetic emissions.

Refer to Section 8.4, Drawing B446242 at Zone A3.

The two line reactors, along with the filter capacitors, makes up a filter which reduces the effect of these harmonics on wayside signaling. The filter circuit is a four-pole filter that consists of two reactors and four capacitors to achieve proper attenuation characteristics.

The line reactor housing, as seen in Figure 2-27, has two inductive coils. L1 is 1.25 mH and L2 is 0.50 mH. Using two line reactor coils provides greater EMI suppression at higher frequencies.

The maximum peak current is 1,114 amps and the continuous current rating is 414 amps rms. The line reactor weights approximately 174 kg (383 lbs.) and there is one on each section of the vehicle. The line reactor is located under the car and is attached with safety hangers to the vehicle frame. When lifting, support from the bottom and position onto the safety hangers.

Each line reactor is cooled by natural convection. The construction provides for a waterproof insulation system.

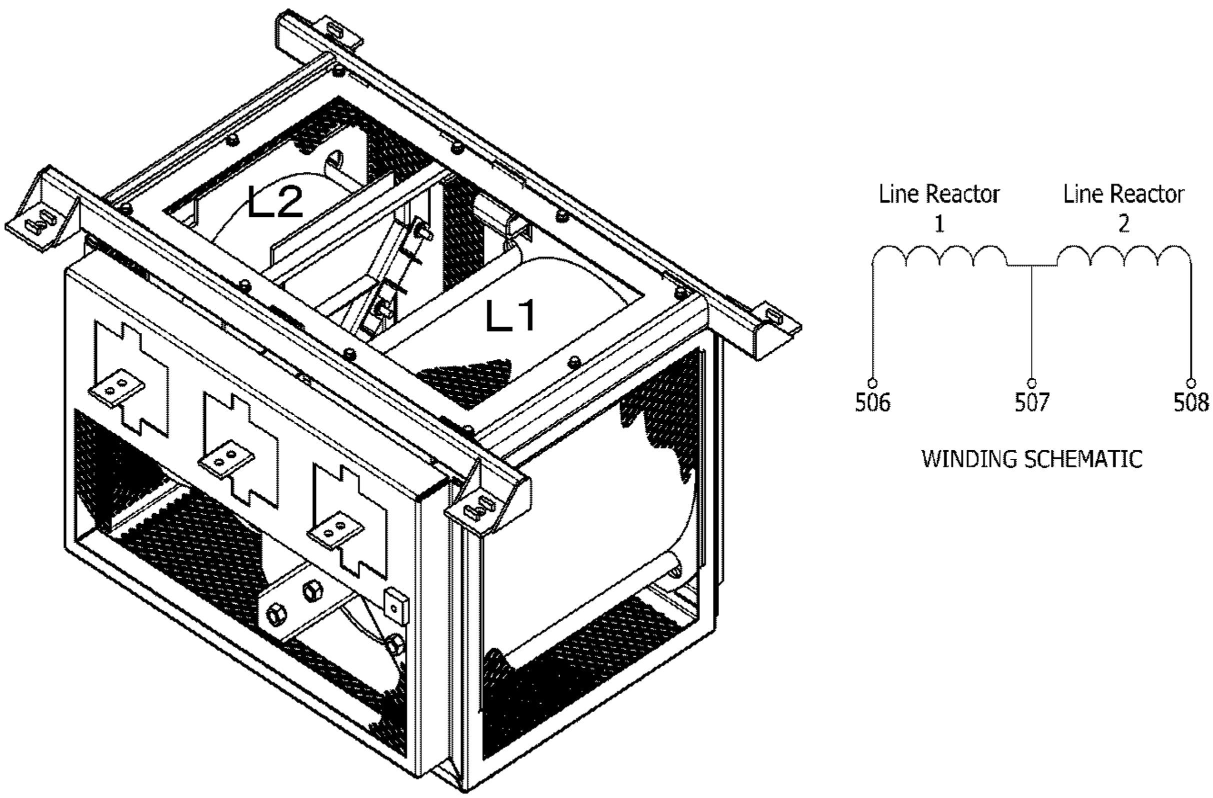

Figure 2-27: Line Reactor

2.18 Brake Resistor Assembly

The Brake Resistor Assembly contains two brake resistors which are each controlled by separate brake chopper IGBT's.

Refer to Section 8.4, Drawing B446242 at Zone B2.

There is one resistor assembly for each inverter, two per vehicle. When the brake chopper IGBT's are turned On, the brake resistor is used to dissipate the dynamic brake energy as the catenary supply becomes unreceptive and during Overhead Catenary System (OCS) gaps.

The resistor assemblies are roof mounted and air-cooled, shown in Figure 2-28. Each assembly is provided with a perforated cover and sides to prevent debris from entering the resistors and a solid metal heat shield to prevent heat from being transmitted to the roof of the LRV. When lifting, use the designated lift points shown in the figure. The weight is 116 kg (255 lbs.).

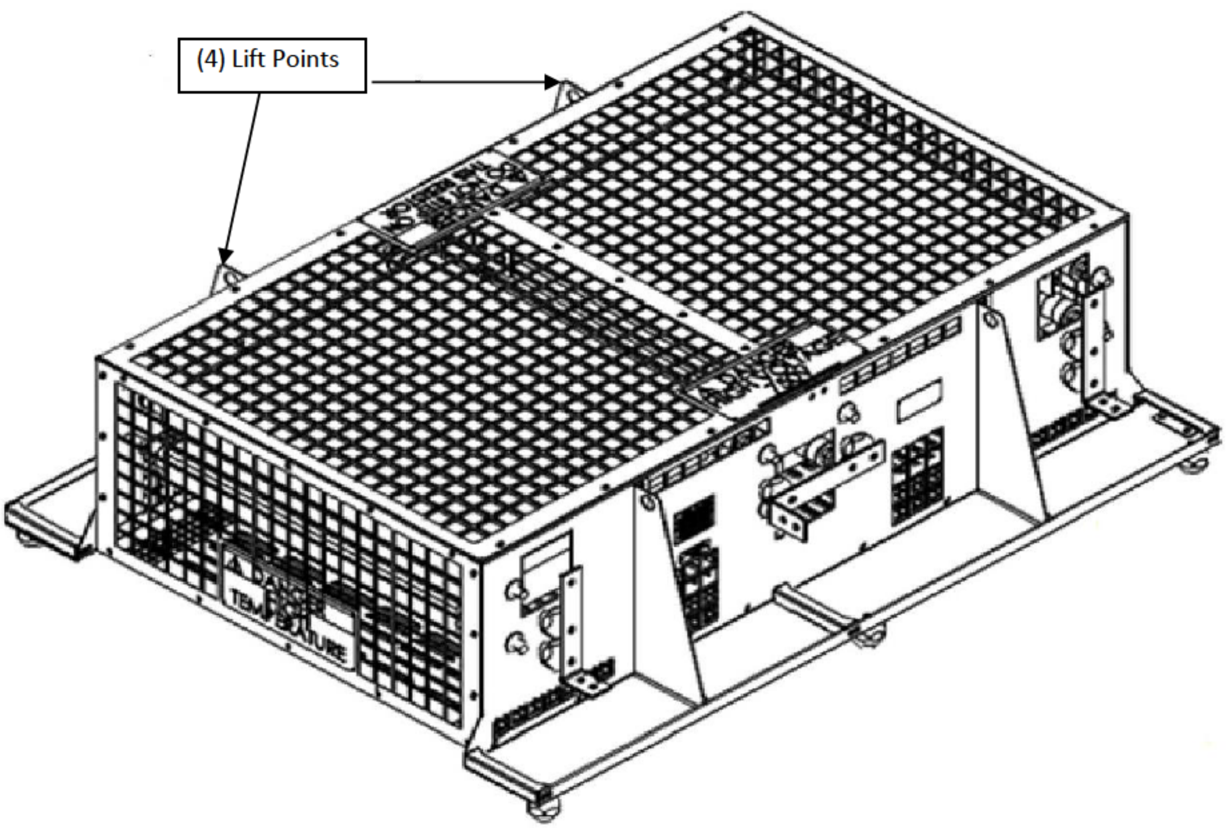

Figure 2-28: Brake Resistor Assembly

2.19 Traction Motors

The traction motors are 145 kW 3-phase 4 pole motors as seen in Figure 2-29. The traction motor transforms electrical power into mechanical power during traction mode and transforms mechanical power into electrical power during braking.

There are two traction motors on each powered truck and the motors are connected to the propulsion inverter in parallel.

Refer to Section 8.4, Drawing B446242 at Zone B6.

The traction motor specifications are shown in Table 2-1. When lifting, use the rings build into the casting. Each motor weighs 595 kg (1309 lbs.).

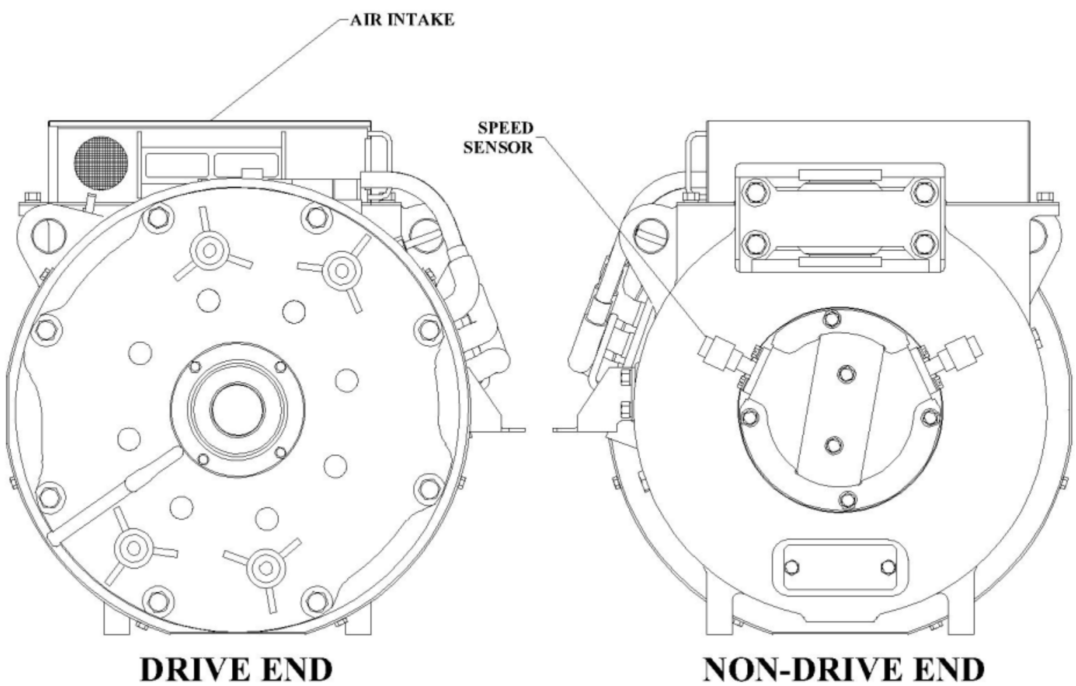

Figure 2-29: Traction Motor

The traction motor is mounted to the truck and the gear unit. Electrically, the traction motor is connected to the 3-phase variable amplitude, variable frequency output from the propulsion inverter. The traction motor frame is grounded to the truck.

The traction motors are fitted with speed sensors. These speed sensors are active devices that require an input voltage to operate. Each speed sensor provides two output channels (Channel A and channel B) for rollback detection.

The traction motor is self-ventilated with an internal fan that pulls air in when the motor rotor is rotating. The air input filter is located on the top of the motor and must be removed for cleaning. The air intake filter is constructed of steel mesh and is shown in Figure 2-30.

Air enters the inlet and any dirt sucked into the filter is then removed by the filter element, vibration and gravity. The clean air passes through the air filter into and then through the traction motor.

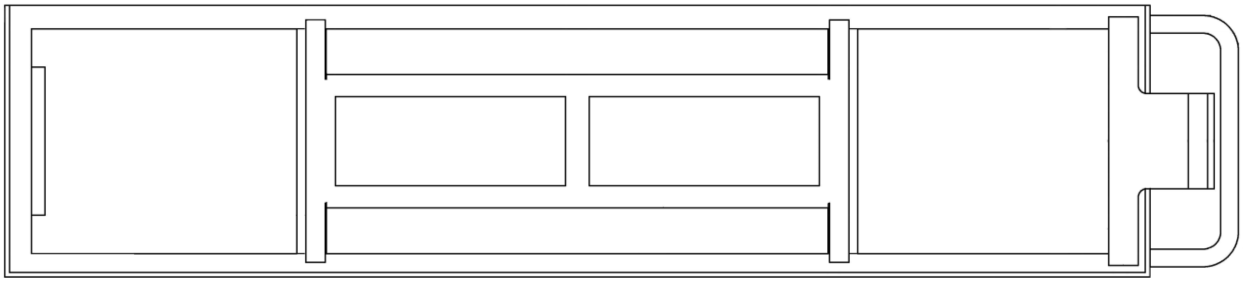

Figure 2-30: Traction Motor Air Intake Filter

When removing a truck from the vehicle, the Quick Disconnect (not supplied by Toyo Denki) is used to disconnect the traction motor wiring from the vehicle wiring. The high voltage cable connections located within the junction box located on the top of the traction motor connects the quick disconnect to the traction motor wiring.

Minimum resistance to ground = 10 megohms. Resistance between motor terminals T1-T2, T2-T3, and T1-T3 = 0.03339 ohms ± 5% (measured with a milliohm meter at room temperature).

Table 2-1. Traction Motor Specifications

Items	Rating for 1 Hour	Rating for Continuous	Maximum Power
Output (kW)	150	145	198
Torque (Nm)	645	624	1233
Voltage (V)	550	550	433
Current (A)	209	203	333
Frequency (Hz)	75	75	53
Speed (min^{-1})	2218	2220	1534
Slip (%)	1.4	1.4	3.3
Pole	4	4	4

2.20 High Speed Coupling

The High Speed Coupling, as seen in Figure 2-31, is used to connect the traction motor rotor shaft to the Gear Unit pinion shaft. This device permits transmission of pure torque across the coupling even when the centers of the traction motor and gear unit shafts are not perfectly aligned. This permits the bearing system on the traction motor and gear unit to be completely independent of each other.

There are two coupling hubs which have external teeth cut on their outer periphery. One hub is fitted to the motor shaft extension and the other is fitted to the gear unit pinion shaft extension. These two hubs are not identical or interchangeable. The hubs transfer their torque to the shafts by the use of interference tapered fits. The gear teeth on the hub are crowned to permit approximately 1.8 degrees of angular misalignment between the hub and outer sleeve at each gear mesh.

The coupling is lubricated by grease which is forced into the tooth contact zone by centrifugal force. The required lubricant is a special gear coupling grease. The normal maximum fill of the coupling is 360 grams (0.793 pounds). The coupling does not require checking grease levels or adding of grease in typical maintenance.

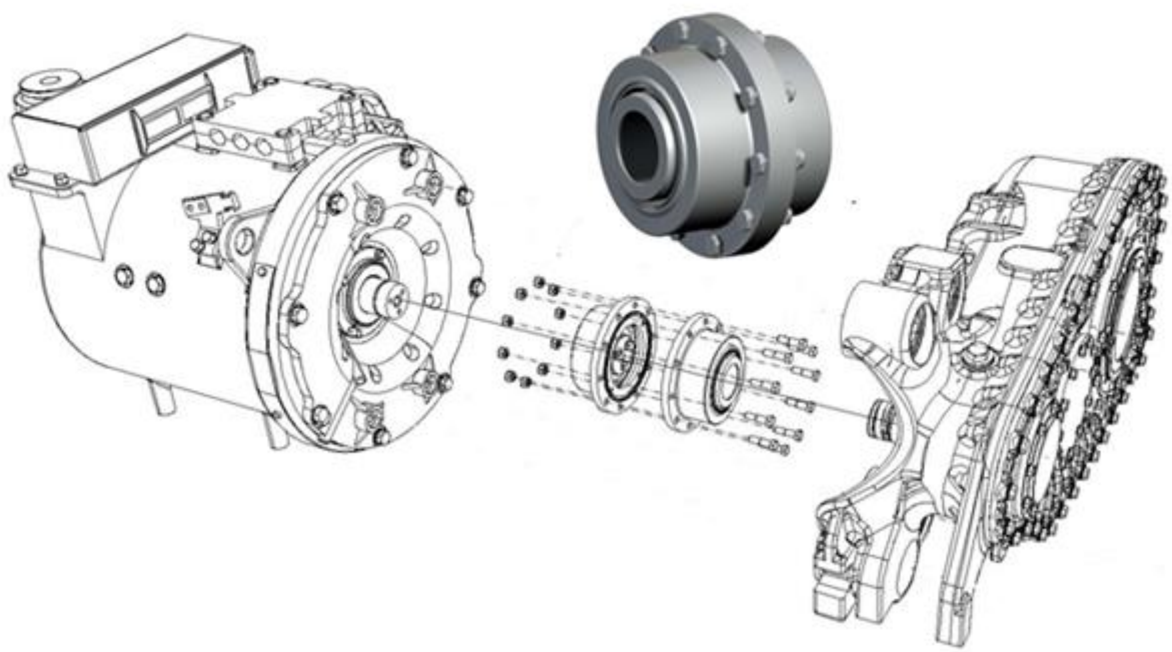

Figure 2-31: High Speed Coupling

2.21 Gear Unit

The Gear Unit, as seen in Figure 2-32, is mounted to the axle and the traction motor. The Gear Unit is a double-reduction, parallel-type, helical gear reduction unit with a ratio of 6.426 to 1. The weight is 345 kg (760 lbs.).

The primary function of the Gear Unit is to efficiently transmit the total output mechanical power of the traction motor to the axle for the propulsion and electric braking of the vehicle. The Gear Unit alters the input torque and rotational speed of the traction motor into a more useful combination of torque and speed at the axle and wheels.

The gear unit is splash lubricated with drainage of lubricant directed to vital components that require continuous lube feed. The low speed gear acts as a pump which is constantly immersed in the oil sump at the bottom of the gear box. Positive feed to the high speed bearings is accomplished by a special reservoir pocket above the gears with drilled drainage holes that meters the flow of lubricant through passages to the gears. A magnet is located on the Fill plug.

There are labyrinth seals at the Gear Unit axle interface (output labyrinth) and the High Speed Coupling interface (input labyrinth) as seen in Figure 2-32. As the gears increase in speed, the air pressure inside the gear unit increases and air is expelled. The gear unit is ventilated using the labyrinth seals that allow the gear unit to breathe without extracting lubricant. As the gear unit decreases speed, the internal air pressure decreases and air is drawn back inside the gear unit through the labyrinth seals.

A labyrinth seal is a seal which creates a complicated path for the gear unit lubricant to pass through, making it challenging for the lubricant to cross the barrier created by the seal. At higher speeds, a fine mist of lubricant gets through the labyrinth seals which may cause a film of lubricant on the outside of the gear unit. The high speed mist of lubricant is also the reason the lubricant level must be checked from the sight glass in scheduled maintenance.

CAUTION

ONLY LIFT, TRANSPORT, AND PUT DOWN THE GEAR UNIT WHILE IT IS IN ITS INSTALLATION POSITION. IF THE GEAR UNIT IS TILTED, RESIDUAL OIL CAN FLOW INTO THE LABYRINTH SEALS. THIS CAN LEAD TO LEAKS ON THE GEAR UNIT.

The gear unit has a half-coupling installed. The other half of the coupling is part of the traction motor.

Replacement and overhaul of the gear unit is covered in the Heavy Repair Maintenance Manual.

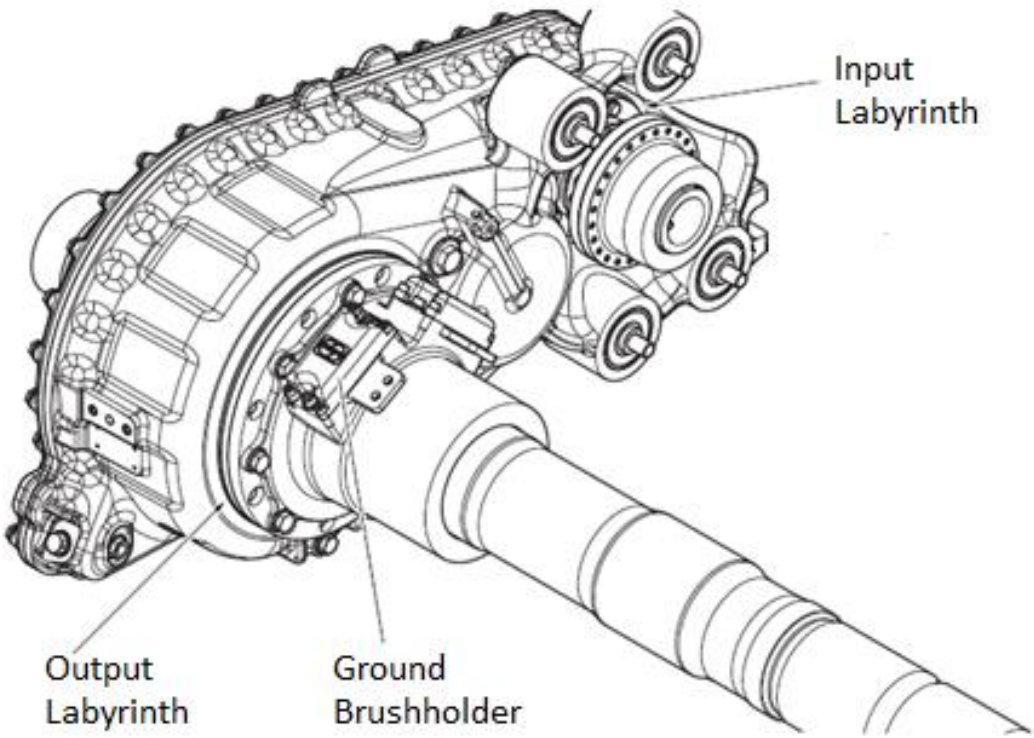

Figure 2-32: Gear Unit and Ground System with Axle Assembly

2.22 Grounding System

There are two ground brush housing per powered axle (see Figures 2-33 and 2-34). The motorized axle housing, as seen in Figure 2-33, contain three ground brushes, two for the primary power return circuits (in one brush housing) and one for the safety ground circuits (in the other brush housing).

The high voltage return ground brush holder shunts return current around the gear unit, traction motor and axle journal bearings to minimize the likelihood of electrical pitting and arcing caused by current flowing through the bearings, which can reduce the life of the bearings.

The center truck axle ground brush assembly has two speed sensors and one ground brush for the safety ground as seen in Figure 2-34.

The ground brushes are spring-loaded to maintain constant pressure on the axle. The brush pressure from the pressure device is 300 cN/cm^2 (4.2 psi). The current load (effective current) is 260 amps per brush. The ground brushes have a wear indication to indicate when they should be replaced and must be periodically inspected to ensure that the wear on the brush and on the axle is not abnormal.

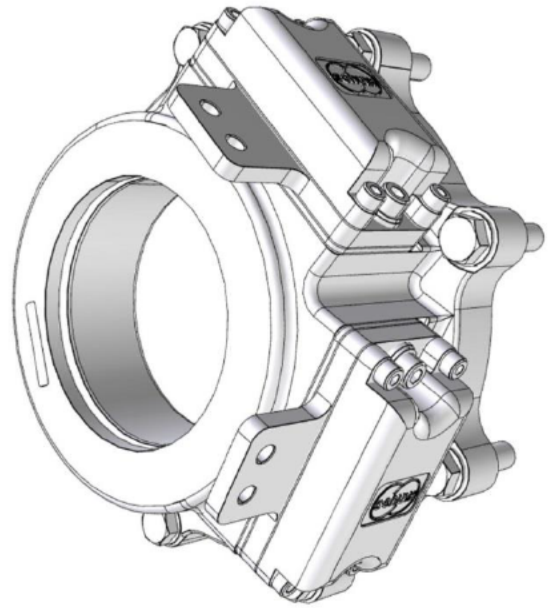

Figure 2-33: Ground Brush Housing for Powered Axles

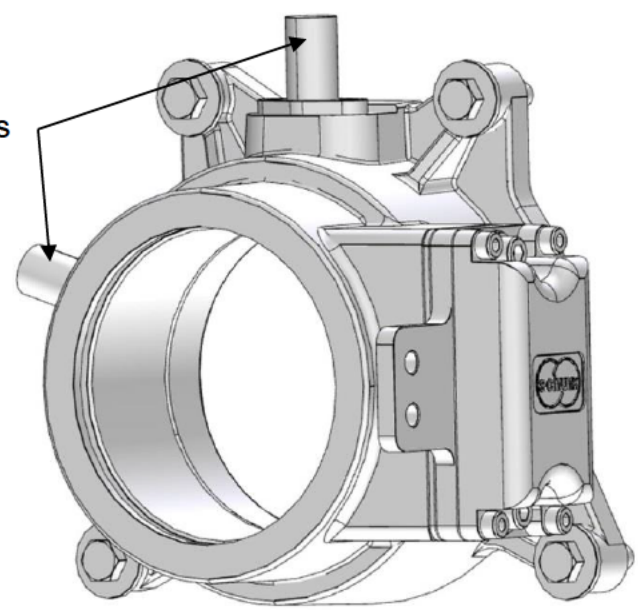

Figure 2-34: Ground Brush Housing for Center Truck Axles

Figure 2-35 shows an exploded view of the powered axle brush holder as seen in Figure 2-33.

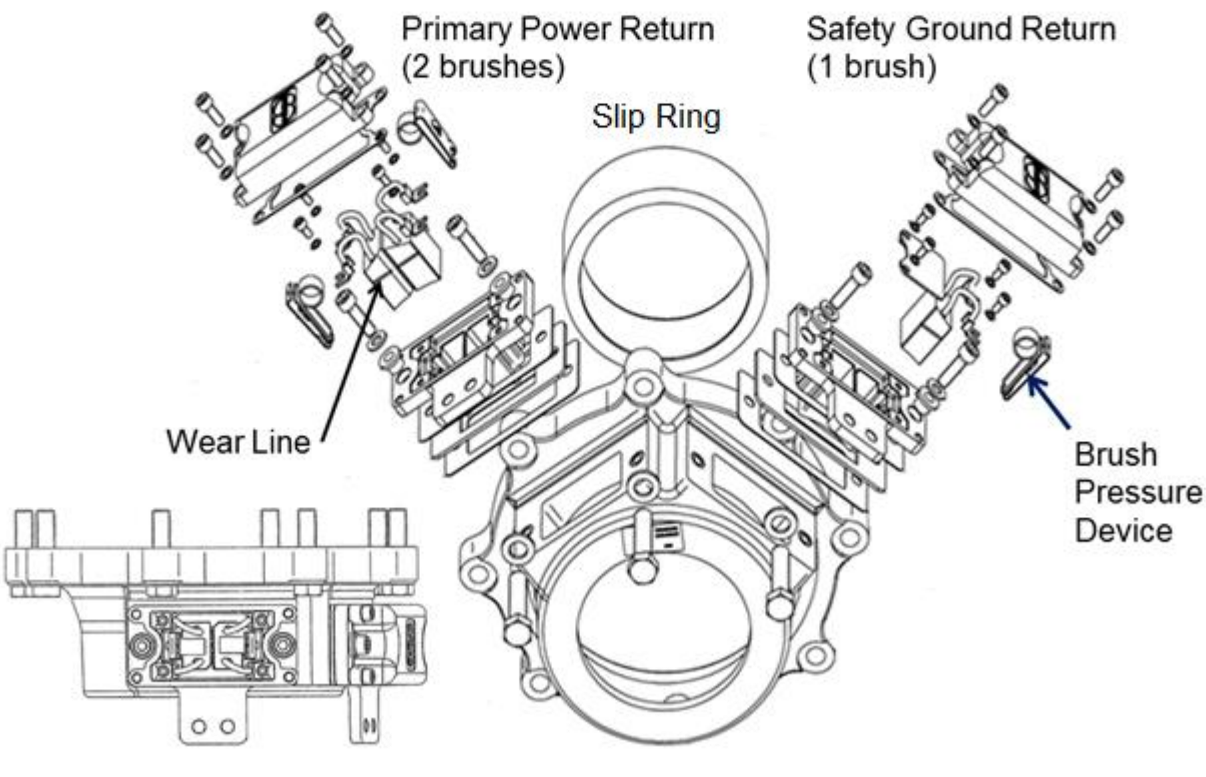

Figure 2-35: Powered Axle Ground Brush Holder Exploded View

Looking through the brush holder, visually check the slip ring for grease, pitting, and scoring on the surface. Some wear marks are expected. Deep grooves or burn marks on the slip ring are not acceptable. If the slip ring needs to be replaced, see the carbuilder documentation.

2.23 Auxiliary Fuse Box

The Auxiliary Fuse Box is mounted on the roof of the vehicle. As seen in Figure 2-36, this box contains the 175 amp fuse used in the high voltage input circuit for the vehicle Auxiliary Power Supply. The Auxiliary fuse is connected between the pantograph and the Knife Switch in order to protect the vehicle auxiliary power supply circuit when excess current flows through the vehicle Auxiliary Power Supply circuit.

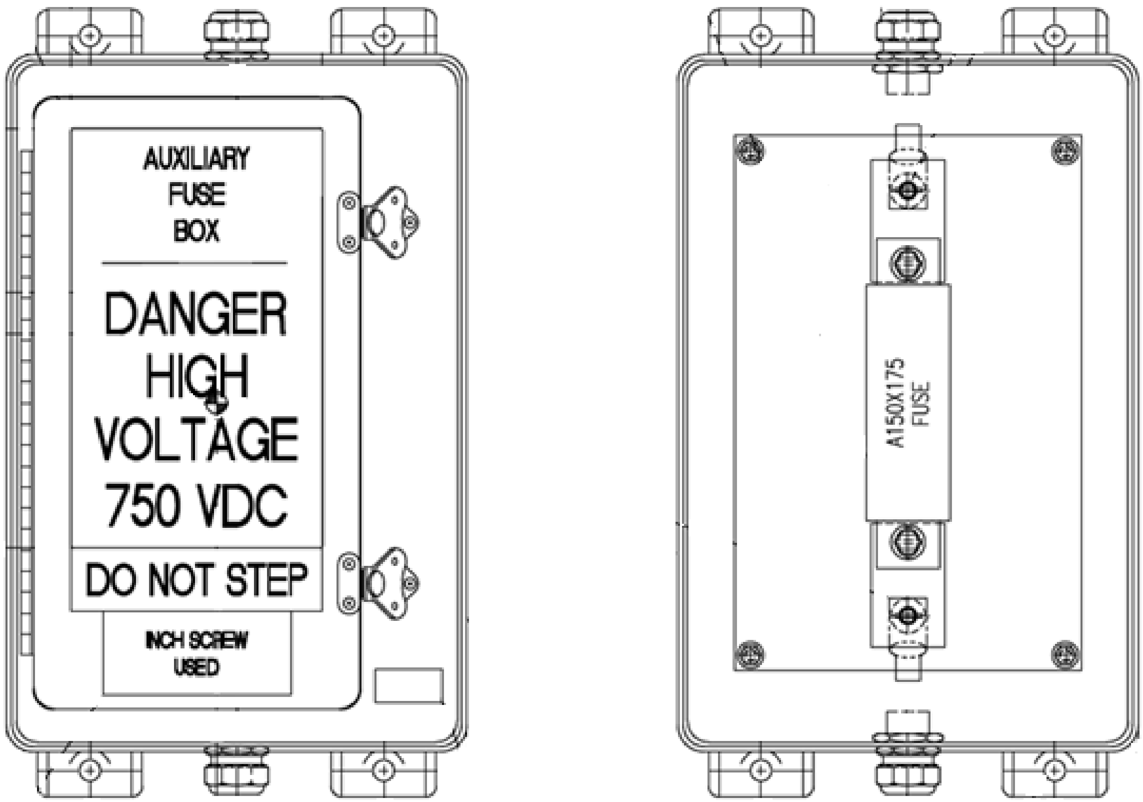

Figure 2-36: Auxiliary Fuse Box

2.24 Reference Data

Table 2-2. Reference Data Per Inverter

Control System	Variable-Voltage and Variable-Frequency control 2-level IGBT converter
Operating Line Voltage	Nominal voltage: 750 volts Fluctuation range: 475/525 (with hysteresis) to 1000 Vdc
Maximum Operating Current	Line Current: 1,600 amps (including dynamic braking), per inverter Motor Current: 321 Amps
Continuous Operating Current	Line Current: 410 Amps rms per inverter Motor Current: 193 Amps rms
Nominal continuous power rating	145 kW (194.5 HP) per motor
Control voltage	Nominal voltage: 28.5 Vdc Fluctuation range: 17 to 30 Vdc
Fan Motor Voltage	Three (3) phases, 208Vac
Operating Ambient temperature	-7 to 46 ℃ (19 to 115°F)
Humidity	5 to 100 % (with no condensation)
Water Resistance	IP55
Vibration	IEC 61373 (2010)
Dielectric withstand voltage	Main Circuit – Frame 3,700 Volts Control Circuit – Frame 1,500 Volts Main Circuit – Control circuit 3,700 Volts
Specification of the vehicle	
1) Maximum speed	105 km/h (65 mph) (in design: 113 km/h, 70 mph)
2) Maximum vehicle weight (AW3)	61,234 kg (134,998 lbs.) (222 passengers boarding)
3) Nominal vehicle weight (AW1)	51,096 kg (112,647 lbs.) (69 passengers boarding)
4) Empty Vehicle weight (AW0)	46,266 kg (101,999 lbs.)
5) Load capacity	0 - 222 passengers boarding load compensation control
6) Acceleration rate	1.34 m/s^2 (3.0 mph/ps)
7) Deceleration rate	Service brake: Max.1.56m/s^2 (3.5mph/ps)
8) Gear ratio	6.4264 to 1
9) Wheel diameter	711 mm (28.00 in) when New. Minimum is 660 mm (26.00 in)
Auxiliary Fuse Box Fuse Rating	175 Amps at 1500 Vac
Line Reactor Inductance Ratings	Coil 1: 1.25 mH, Coil 2: 0.50 mH
Filter Capacitor Rating	10.5mF, each capacitor, four total
Brake Resistor Resistance	1.42 ohms per resistor
Brake Resistor Current Rating	115 Arms, 621.5 Amps peak, per brake resistor
Brake Resistor Power Rating	53 kW x 2 Con1tinuous, 445 kW x 2 Peak, per brake resistor
Discharge Resistor Rating	1250 Ohms, 250 Watts each, four total in parallel
Ground Brush Current Capacity	260 A continuous, 390 Amps for 1-hour, per brush
Charging Resistor Rating	4.3 Ohms, 300 W
Lightning Arrestor Energy Rating	2.6 kJoules,
Lightning Arrestor Voltage Rating	1000 Vdc, Maximum Continuous Operating Voltage
High Speed Circuit Breaker Trip Point	3200 Amps

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CHAPTER 3.0

THEORY OF OPERATION

3.1 Introduction

The propulsion inverter controls the output voltage and frequency to the traction motors in order to accelerate or decelerate the vehicle as commanded by the operator from the Master Controller. Each of the two Master Controllers generates the rate commands and controls the trainlines. Only the Master Controller in the lead cab will provide this control, although the Emergency Pushbutton in all cabs can initiate an Emergency Brake application.

The propulsion inverter converts the catenary DC nominal 750 volt power into variable frequency, variable amplitude AC power by using IGBT power semiconductors.

3.2 Power Circuit Explanation

3.2.1 Power Circuit Block Diagram

The main power circuit block diagram is shown in Figure 3-1. From the catenary supply, the line voltage goes through the pantograph into 3 circuits. The lightning arrestor is normally open and will conduct to ground when the line voltage exceeds 1000 volts. There is an auxiliary fuse circuit which goes through the Knife Switch and is the line voltage overcurrent protection for the vehicle Auxiliary Power Supply. The third path is through the High Speed Circuit Breaker, through the Knife Switch and then to both of the propulsion systems on the vehicle.

From the Knife Switch Box the circuit goes to the A-unit and B-unit Propulsion Inverter. The propulsion inverters contain the power circuit IGBT's, the power circuit contactors as well as the DC link filter capacitors. The output of the inverter is a variable frequency, variable amplitude AC voltage which is sent to the traction motors.

The Line Charging Contactor is closed first to provide a current limited path to charge the filter capacitors. Once the filter capacitors are charged, the Line Switch contactor is closed and the Line Charging Contactor is opened.

The line reactors are used with the filter capacitors to reduce EMI noise caused by the turning On and Off of the IGBT's. The Inverter Unit contains the power circuit IGBTs that are used to create the variable amplitude, variable frequency 3-phase output voltage sent to the traction motors. The brake chopper circuit which is part of the Inverter Unit controls the path to the Brake Resistors. The Brake Resistors control the maximum voltage on the filter capacitors during dynamic braking.

The primary power return circuit goes through the axle ground brush holders to ground (the running rail). The primary power return circuit is separated from the carbody for passenger safety reasons and to protect the carbody and equipment from high voltage return currents. Also, each axle ground brush holder shunts return current around the gear unit, traction motor and axle journal bearings to minimize the likelihood of electrical pitting and arcing caused by current flowing through the bearings, which can reduce the life of the bearings.

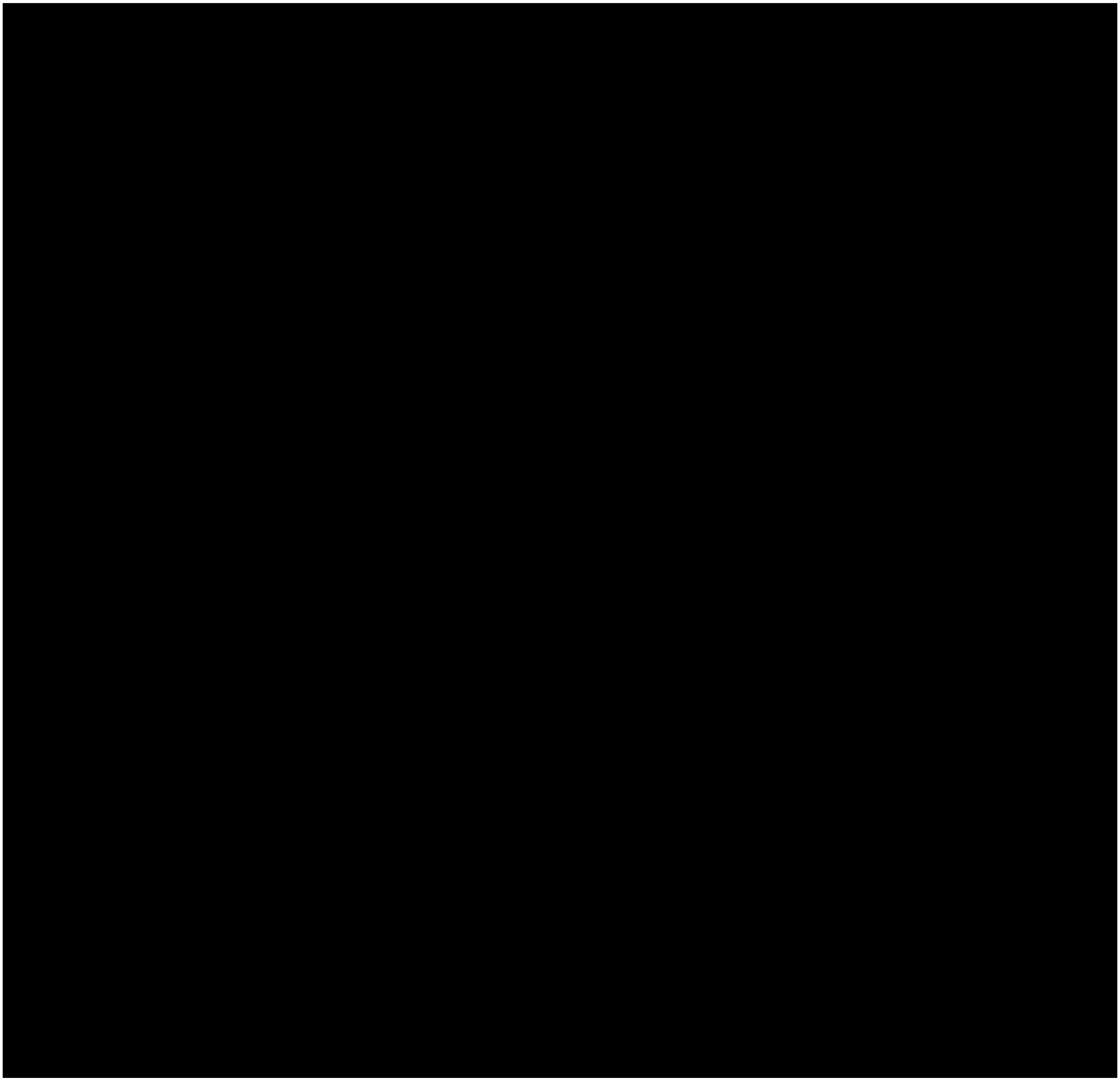

Figure 3-1: Power Circuit Block Diagram

3.2.2 Power Circuit Semi-Conductors and Pulse Width Modulation

The main power circuit device is the IGBT. As seen in Figure 3-2, the IGBT brick is made up of a bi-polar transistor (IGBT) with a freewheeling diode in parallel. The number of IGBT / diode circuits inside the brick can vary. If the brick has 2 sets of power connections (such as the brake chopper IGBT), there are 2 sets of IGBT / diode circuits. If the brick has 3 sets of power connections (such as the inverter IGBT), there are 3 sets of IGBT / diode circuits.

The IGBT will conduct when a pulse is put on the gate **G** with the collector **C** positive and the emitter **E** negative. The diode will conduct with the emitter **E** positive and the collector **C** negative.

[redacted]

A diode is seen in Figure 3-3. For a diode to conduct (called forward biased) a more positive voltage must be impressed on the Anode than on the Cathode. Current flow is always from the Anode to the Cathode.

[redacted]

As seen in Figure 3-4, the IGBT has a Gate, Emitter and Collector. The emitter - gate junction is the control function and must be forward biased from the logic for the IGBT to operate. The IGBT is turned On with a 20mA current loop through the Gate - Emitter. The Emitter - Collector junction carries the load current. Current flow is always from the Collector to the Emitter.

[redacted]

Pulse Width Modulation is seen in Figure 3-5. PWM is a fixed frequency square wave signal in which the relationship of the On time to the Off time of the signal is varied. This is often referred to as the Mark/Period Ratio (or Duty Cycle). The top waveform has a 20% mark/period ratio and the bottom waveform has an 80% mark/period ratio.

PWM is used to control the three-phase and brake chopper IGBT's.

[redacted]

3.2.3 Power Circuit Description

The main power circuit diagram is shown in Section 8.4, Drawing B446242.

The DC line voltage is carried through the pantograph to the Lightening Arrestor, the Auxiliary Fuse Box or the High Speed Circuit Breaker. The lightning arrestor will conduct to ground with 1000 volts on the catenary supply preventing the voltage spike from entering any high voltage circuits on the vehicle. The HSCB provides rapid interruption of the 750 volt primary supply to the propulsion system when tripped by an over current fault of 3200 amps or commanded open by the Propulsion Logic Unit. The Auxiliary Fuse Box contains a 175 amp fuse protecting the high voltage input to the vehicle Auxiliary Power Supply.

The line power circuit then runs through the Knife Switch (with the switch in the Run position). Next, the power runs into the propulsion equipment case to the line voltage detector DCVD1. DCVD1 is used to allow the Line Switch contactor LS and Line Charging Contactor LCC to close only when the line voltage is within limits.

The LCC is closed first inserting the 4.3 ohm current limiting resistor CHR as the filter capacitors are being charged. With the filter capacitor voltage at 80% of line voltage, LS is closed and LCC is opened one second later. The LS remains closed in normal operation and is opened when the logic detects a propulsion fault. The circuit continues through the line current transducer CTL.

The power circuit then leaves the propulsion equipment case to go to the Line Reactors. The line reactors, with the filter capacitors act as a line filter to prevent noise (EMI) created with the turning On and Off of the power circuit IGBT’s from getting back to the catenary supply.

There are two line reactors in the power circuit. The LACMTA system is unique in that it employs differing signal systems on several lines each with different operating frequencies. The propulsion inverter must consider the signal system on three separate lines. This filter is achieved with 2 pairs of 10500 µF filter capacitors and reactors of 1.25mH and 0.5mH. The dual-coil line reactor used on the P3010 is different from other LACMTA cars that have only a single inductive coil in the line reactor. The P3010 line reactor provides greater EMI suppression at higher frequencies.

The power circuit next goes back into the propulsion equipment case to the three-phase inverter IGBTs. EMI filtering takes place with the Filter Capacitors FC1 through FC4. The ferrous magnetic cores (NSC1 through NSC3) are magnetic material with a high permeability used to confine magnetic fields to minimize EMI. Filter capacitor voltage is monitored with DCVD2. Discharge resistors DCHR1 through DCHR4 are used to discharge the filter capacitors with the loss of line voltage.

The 3-phase inverter IGBTs SPU, SPV and SPW create the positive portion of the AC waveform and SNU, SNV and SNW create the negative portion of the AC waveform for the traction motors. Each phase of the AC power is monitored with a current transducer, CTU, CTV, or CTW. The output of the inverter goes through NSC3 to minimize the EMI.

Motor output current IU is measured by CTU and motor output current IU2 is measured by CTU2. The traction motor misconnection protective operation is activated when the current value detected by CTU2 is more than 60% or less than 40% of the value of CTU. This protective operation is activated in the first five seconds of the first powering after the power up of the Propulsion Logic Unit.

The brake choppers are designated as BCH1 and BCH2. The two brake chopper circuits are turned On and Off at the same time to complete a circuit to the two brake resistors. This will dissipate as heat the regenerative energy created by the traction motors as the line supply becomes unreceptive. The circuit to the brake resistors goes through NSC2 to minimize the EMI. Current transducer CTB is used to monitor the brake return current that is sent through the two brake resistors.

The Ground Current Transducer CTG monitors the current flow in the power circuit return (B500) going to the insulated ground plate and then to the axle ground brushes. The output signals of current transducers CTG and CTL are compared and used to detect power circuit grounds. The insulated ground plate is isolated from the carbody and contains the return circuits for the high voltage circuits on the vehicle. This is done for passenger safety and to prevent damage to traction motor and axle journal bearings.

Once the filter capacitors are charged, the Line Switch contactor is closed but the propulsion system is not enabled. The power circuit remains in this state until the Power and Brake Effort Demand (PBED) from the Master Controller is input. The purpose of the Powering and Braking Effort Command is to allow the train to accelerate and decelerate, depending on the rate request signal sent over the MVB, and detect illegal command signals.

The following table is a quick reference to the functions of the cables found in the Power Circuit diagram B446242.

Table 3-1. Power Cables

Cable	Description
504	Main Input Cable to the Inverter Box
500A	Main Output Cable (Return Current)
506	Input Cable from Line Reactor 1
507	Input / Output Cable from / to Line Reactor 1 and 2
508	Input Cable from Line Reactor 2
509A	Dynamic Brake Cable to the Brake Chopper 1 Resistor
519A	Dynamic Brake Cable to the Brake Chopper 2 Resistor
500C	Dynamic Brake Return Cable to the Resistor Box
551U	Motor #1 Phase U (A-Unit), Motor #4 Phase U (B-Unit)
551V	Motor #1 Phase V (A-Unit), Motor #4 Phase V (B-Unit)
551W	Motor #1 Phase W (A-Unit), Motor #4 Phase W (B-Unit)
500E1	Motor #1 Earth (A-Unit), Motor #4 Earth (B-Unit)
561U	Motor #2 Phase U (A-Unit), Motor #3 Phase U (B-Unit)
561V	Motor #2 Phase V (A-Unit), Motor #3 Phase V (B-Unit)
561W	Motor #2 Phase W (A-Unit), Motor #3 Phase W (B-Unit)
500E2	Motor #2 Earth (A-Unit), Motor #3 Earth (B-Unit)

3.2.4 Power Circuit Protection Functions

The following is a listing of the power circuit conditions that can disable the propulsion system.

3.2.4.1 Filter Capacitor Voltage Monitoring Protection

The filter capacitor low voltage protective operation will protect the equipment from malfunctions due to the line voltage drop. The propulsion system is disabled when the filter capacitor voltage drops below 435 volts and is enabled when the voltage is above 435 volts.

The filter capacitor voltage rising protective operative prohibits the dynamic brake energy from being sent to the overhead lines when the filter capacitor voltage is rising to greater than 950 volts for 1 second or longer.

The filter capacitor over voltage detect protective operation protects the equipment when greater than 1000 volts is detected. When this filter capacitor overvoltage condition is detected, the LS is opened, firing of the propulsion IGBTs are stopped and the brake chopper is operated until the filter capacitor voltage is dropped to 50 volts. Discharging with the Brake Chopper will be activated even if a Brake Resistor Overtemperature is detected.

3.2.4.2 Filter Capacitor Value Calculation

During the charging of the filter capacitors with LS open and LCC closed, the line voltage, filter capacitor voltage and line current are monitored. Using these values, the logic calculated the value of the filter capacitors. Every time the filter capacitor is charged from discharged condition, the PLU will confirm that the capacitance is not decreased.

Capacitance fault is detected when the calculated capacitance is less than 37,800uF (90% of the initial capacitance as stored in memory). With this failure, LCC is opened. A capacitor charging fault is detected which requires a PROP / HSCB reset from the TOD. Once the filter capacitors are at 0 volts from the discharge resistors, the calculation can begin again. The reset command is received after the fault detection and LCC is closed again to pre-charge the capacitors.

With this failure, the Propulsion Logic Unit cannot determine which of the four filter capacitors may have failed or if the fault was caused by a control system abnormality.

The calculated value of the filter capacitors can be further tested using the PBTU. The value can be checked by measuring the capacitance of a capacitor with the LCR meter. To measure the capacitance, each capacitor needs to be measured individually.

The charging circuit path is through the Line Charging Contactor, the Line Charging Resistor to the four filter capacitors. The circuit is monitored by the Line Current transducer, the Line Voltage transducer and the Filter Capacitor Voltage transducer.

The discharge circuit is through the capacitor discharge resistors. The circuit is monitored by the line voltage detector DCVD1 and the filter capacitor voltage detector DCVD2.

3.2.4.3 Voltage Sensitive Current Limiting

The purpose of the voltage sensitive current limitation is to automatically reduce the current demand and performance level of the propulsion system as the catenary voltage level decreases below 600 volts. This reduction is intended to reduce further catenary voltage drops and maintain the line voltage within operating parameters. As line voltage falls below 600 volts, the maximum allowable line current is reduced 5 amps for each volt below 600 volts. This current limitation is automatically deactivated when the line voltage is 600 volts or more.

3.2.4.4 Phase Current Imbalance

The purpose of the phase current imbalance is to protect against current imbalance in the inverter output circuit or traction motors. The PLU detects a current imbalance if the absolute value of the sum of each phase current is greater than 300 amps (± 10 amps) for longer than 20 msec. When a current imbalance is detected, the propulsion inverter is disabled and opens the Line Switch contactor. Reset from the PROP / HSCB Reset from the TOD with a Full Service Brake application at zero speed.

3.2.4.5 Propulsion Ground Fault

A ground fault is declared with a difference between the CTL and CTG of more than 50 amps for longer than 200 msec detected from the Inverter Control Board MCB108B1. When a ground fault is detected, the propulsion inverter is disabled, the Line Switch contactor is opened and the High Speed Circuit Breaker is commanded open. The opening of the HSCB will cause the other propulsion inverter to be disabled and that Line Switch contactor to open. Reset from the PROP / HSCB Reset from the TOD with a Full Service Brake application at zero speed.

3.2.4.6 Inverter Input Overcurrent

The inverter input current flow is monitored by the line current transducer CTL. If the inverter input current flow exceeds 1600 amps for 1 second, (but does not exceed 3200 amps), the inverter is disabled, the Line Switch contactor is opened and the HSCB is opened. The opening of the HSCB causes the other vehicle propulsion system to be disabled and that Line Switch contactor opened.

With a current flow of greater than 3200 amps, the HSCB is tripped first causing both Line Switch contactors to be commanded open.

Reset from the PROP / HSCB Reset from the TOD with a Full Service Brake application at zero speed.

3.2.4.7 Inverter Output Overcurrent

The purpose of the Inverter Output Overcurrent Protection is to provide continuous monitoring of the traction motor current from current transducers CTU, CTV and CTW. An inverter output over-current fault will be detected when the inverter output current exceeds 2600 amps. The inverter is shut down and the Line Switch contactor is opened. A Frequent Output Overcurrent condition is detected with an overcurrent condition detected 3 times since the last time the reverser was placed in Neutral.

Reset from the PROP / HSCB Reset from the TOD with a Full Service Brake application at zero speed.

3.2.4.8 Line Voltage Monitoring

Using the line voltage detector DCVD1, the PLU monitors the line voltage. When the line voltage falls to below 475 volts or goes above 950 volts, both inverters are disabled and the Line Switch contactors are opened. Recovery is with Line voltage between 475 and 525 volts.

3.2.4.9 Traction Motor Misconnection

The purpose of the motor misconnection protection is to detect the misconnection of motor leads. A mis wired traction motor will cause the motor to attempt to rotate in the opposite direction of the other motors.

After the PLU is powered up (Hard Reset), on the first power request of the propulsion system, the current transducers CTU and CTU2 outputs are compared within the first 5 seconds when traction power is applied. Motor current IU is measured by CTU and motor current IU2 is measured by CTU2. This protective operation is activated when the current value detected by CTU2 is more than 60% or less than 40% of the value of CTU. This protective operation is activated in the first five (5) seconds of the first powering after the launch of the Propulsion Logic Unit. This fault condition must be corrected before the propulsion system can be enabled again.

3.2.4.10 Adhesion Failure

An adhesion failure is a condition that causes a wheel Spin condition in power or a wheel Slide condition in braking.

A wheel Spin condition exceeding 1.92 m/s/s (4.3 mph/s/s) in power or a wheel Slide condition exceeding 2.59 m/s/s (5.48 mph/s/s) in braking will cause the Tractive Effort Request to be ramped back causing less torque at the powered truck wheels which should correct the condition. This is not considered an adhesion failure. With all of the conditions explained below, the tractive effort has already been reduced.

There are two types of adhesion failure which are a Speed Differential Condition and a Major Spin or Major Slide Detection.

A Speed Differential Condition is detected in either power or braking when there is more than a 25% difference in speed between the motored axle and trailer (center truck) axle. When this type of adhesion failure is detected, the PLU will disable the propulsion system for 1 second and apply sand for 2 seconds. After 1 second, the PLU will reapply torque.

A Major Spin is detected when the acceleration rate from a powered axle exceeds the set limit of 5.49 m/s/s (12.2 mph/s/s). When this type of adhesion failure is detected, the PLU will disable the propulsion system for 1 second and apply sand for 2 seconds. After 1 second, the PLU will reapply torque.

A Major Slide is detected when the deceleration rate exceeds the set limit of 3.94 m/s/s (8.8 mph/s/s). When this type of adhesion failure is detected, the PLU will disable the propulsion system for 1 second and apply sand for 2 seconds. After 1 second, the PLU will reapply torque.

3.3 Simplified AC Drive

This section explains how the DC catenary voltage is converted to variable amplitude, variable frequency 3-phase AC voltage sent to the traction motors.

Figure 3-6 shows a simplified 3-phase inverter. There are 6 power circuit IGBTs that are used to convert the catenary voltage to a variable amplitude, variable frequency three-phase supply.

Different combinations of firing of these devices will create the variable voltage variable frequency three phase output. Each inverter has three identical phase outputs (U, V, and W). Each phase consists of one upper (positive) and one lower (negative) IGBT. A freewheeling diode is built into each IGBT brick and is connected across each IGBT.

The insulated gate bipolar transistor (IGBT) is a semiconductor that allows current flow in only one direction. The IGBT is turned on and turned off from the gate lead (transistor base). For an IGBT to conduct, a positive voltage must be applied to the base (gate). When a control voltage is applied to the gate, a circuit is established from the IGBT collector to the emitter. Remember that the current flow follows the arrow on the emitter. The control voltage and line voltage do not come in contact with each other.

The freewheeling diode is needed to maintain current through the stator windings when the IGBTs are pulsed off during each cycle. For the dynamic braking system to be regenerative, the output voltage of the inverter (supplied by the motors acting as generators) must be greater than the supply voltage.

The collector of each upper IGBT in each of the three-phases is connected to the positive side of the filter capacitor. The emitter of each lower IGBT in each phase is connected to the negative side of the filter capacitor. The emitter of the upper IGBT and the collector of the lower IGBT in each phase are connected to one of the three traction motor phases. The upper (positive) IGBT in a phase and a lower (negative) IGBT is pulsed on to create a circuit path to the stator windings.

Under no circumstance will the control system turn on a positive IGBT and negative IGBT from the same phase at the same time. There is a delay between the time that one IGBT in a phase is turned off and the opposite IGBT in that same phase is turned on. This is to ensure that the upper device and lower device of any given phase are not both conducting at the same time. This delay is called Dead Time.

[redacted]

As seen on Figure 3-7, the U positive and V negative IGBT's are turned on to create a direction of current flow through the stator windings. Also on this figure, the upper V (V positive) and lower U (U negative) IGBT's are turned on to create a direction of current flow in the opposite direction through the stator windings.

It is the IGBT firing patterns controlling the direction of current flow through the stator windings that determines the direction of travel of the car. By reversing the phase sequence of the voltage applied to the motor, the direction of rotation of the rotor is reversed.

[redacted]

As seen in Figure 3-8, if the positive U-phase IGBT is turned on, a circuit is established from the supply positive through the U-phase stator winding to the motor neutral.

To complete a return circuit, either the negative V-phase or the negative W-phase IGBT must be turned on. With the positive U-phase IGBT on, if the negative W-phase IGBT were turned on, a current path is established through the U-W windings of the motor. The current flow is from the U-phase winding through the W-phase winding.

[redacted]

As seen in Figure 3-9, when the IGBT's are turned off, the motor stator current is interrupted and the stator magnetic fields begins to collapse. The collapsing magnetic fields produces a counter EMF reversing the polarity on the motor windings and causing the freewheeling diodes to conduct.

The counter EMF (reverse polarity voltage) is a higher voltage than the link voltage and decreases as the magnetic field dissipates. As long as the CEMF is a higher potential than the DC link filter capacitors, the freewheeling diodes will conduct maintaining the current flow through the motor in the same direction. The IGBT's are turned on again before the CEMF falls below link voltage.

3.3.1 Speed Sensorless Drive

Other than low speed operation, the speed sensors are not used in Vector Control to turn On and Off the power circuit IGBT's. It is the calculated velocity of the traction motor rotors that is used to control the power circuit IGBT's. The rotor velocity is calculated from the traction motor phase current and the filter capacitor voltage and not from the speed sensors. Speed of wheel rotation can be calculated from the traction motor angular velocity, and so the vehicle speed.

The calculated velocity is used for traction control except for between 0 to 10 mph. The PLU uses the speed sensor signals for traction control up to 6 mph, and then starts blending the speed sensor signals out and the vector control calculated in between 6 and 10 mph. Above 10 mph, the vector control uses only the calculated velocity to control the power circuit IGBTs.

As the vector calculation speed is not available when the inverter is shut down, speed sensor signals are used for the functions which are not relative to traction control (no - motion detection, odometer output, etc.).

In order to prevent wheel spin/slide conditions where motor axle rotation speed differs from the vehicle speed, speed sensor signals are used as a failsafe backup to monitor the speed difference of each axle.

When the speed difference between M and T axle is more than 25% while powering or braking, the PLU detects an adhesion failure.

NOTE: Angular velocity of a rotating body (traction motor rotor) is defined as the rate of change of angular displacement, and is a vector quantity that specifies the angular speed (rotational speed) of an object and the axis about which the object is rotating.

3.3.2 Vector Control

Vector Control is used to determine when and for how long the power circuit IGBT’s are turned On. Tractive effort is controlled by means of Vector Control based on the torque-current pattern and excitation-current pattern of the traction motors. The purpose of the Pulse Mode Switching is to control the traction motor voltage and inverter frequency while compensating for the increase of impedance as motor speed increases. When there is more than 5% difference between the target value and achieved value of the tractive effort calculated in the vector control sequence for 1 second, the PLU will detect a Tractive Effort Feedback Failure condition.

The pulse mode will be switched in accordance with the inverter frequency ratio as speed increases as seen in the graphic below. Asynchronous means IGBT switching will be done at a fixed frequency (lower speed operation). Asynchronous is 0 to approx. 45 km/h (72Hz), switching frequency of 800Hz.

At speeds above 28 mph (72 Hz), the inverter frequency is single pulse, synchronized with the traction motor rotor rotation. Speed sensor less Vector Control also modulates the Slip frequency and measures (and compensates for) wheel Spin or Slide by determining the amount of current in phase with the inverter output voltage for torque control. This ensures the traction motor keeps running at the targeted speed even under varied loads.

Table 3-2. Propulsion Inverter Operating Modes

Inverter Output Frequency		
Pulse Mode	Powering	Braking
Asynchronous mode	0 to 72 Hz 0 to 28 MPH	72 to 0 Hz 28 MPH to 0
1-Pulse mode	72 Hz and up 28 MPH and above	72 Hz and up Down to 28 MPH

[redacted]

When there is more than 5% difference between the target value and achieved value of tractive effort calculated in the vector control sequence for 1 second, the PLU will detect a Tractive Effort Feedback Failure condition. While the propulsion inverter is detecting a wheel spin/slide condition, this function is nullified.

3.4 Traction Motor Theory and Operation

For the AC traction motor, the stator (stationary) winding is excited by a three-phase voltage source that is the output from the propulsion inverter. The inverter creates a rotating magnetic field in the air gap between the stator windings and the rotor (rotating member). The rotating magnetic field can be thought of in terms of a rotating bar magnet. The speed of rotation of this field depends on the number of poles of the stator winding and the frequency of the inverter output. The traction motors are 3-phase 4-pole motors.

The rotating magnetic field in the air gap between the stator and rotor induces a voltage in the squirrel cage winding in the rotor. The resulting current, which flows in the squirrel cage winding, creates a magnetic field. This magnetic field reacts with that produced in the stator. The reaction of these opposing magnetic fields creates motor torque.

To create torque in an AC traction motor, two things must happen:

- First, a magnetic field must be generated at the motor stator windings,
- Second, a positive Slip must be maintained as the vehicle speed increases.

From the motor speed sensor signals, the logic calculates motor revolutions per minute (rpm) and the achieved frequency of the motor rotor. The logic then controls the inverter IGBTs to maintain a higher inverter frequency than the achieved motor frequency.

The difference between the output frequency of the inverter and the motor frequency is called Slip.

Positive Slip is the condition in which the inverter frequency is higher (faster) than the achieved frequency of the traction motors. Negative Slip is the condition in which the inverter frequency is lower (slower) than the achieved frequency of the traction motors.

The amount of torque that an AC motor can produce is a function of air gap flux and motor current. Air gap flux is the magnetic field in the air gap between the motor stator windings and the motor rotor. The logic controls the inverter IGBTs so as to maintain a constant ratio of volts to frequency. That is, the inverter applies a constant volts-per-hertz ratio to the stator winding. This ensures that the air gap flux remains constant and produces optimum torque.

When the lines of magnetic force originating in the stator cut across the short-circuited bars of the rotor, a voltage is induced in the rotor by transformer action, resulting in a heavy current flow in the rotor. Induced voltages from transformer action are the reverse polarity to the voltages creating them. As a result, the magnetic field in the rotor is opposite to that in the stator. The combined electromagnetic effects of the stator and rotor currents and their magnetic fields produce the torque to create rotation.

The propulsion inverter frequency controls motor speed. Changing the inverter fundamental frequency changes the speed of the traction motors. In motoring (propulsion mode), the frequency of the rotating magnetic field must be adjusted to be higher than the achieved frequency of the rotor as the rotor speed increases. The rotor frequency (speed of the rotor) must always be kept at a slightly lower frequency than the inverter frequency to permit a voltage to be induced in the rotor windings. This is why propulsion is a variable frequency system.

Traction motors operate in two speed regions. The first region is constant torque as input voltage and output power increases, which is called Asynchronous Mode. During low-speed operation, the volts-per-hertz ratio is held constant by controlling the voltage amplitude impressed on the stator windings. As speeds increase, the amplitude of the link filter capacitor voltage determines the voltage impressed on the stator windings.

The second region is achieved at about 28 mph (45 kph) called 1-Pulse and is characterized by constant power. As speed (motor rotor frequency) increases and the link voltage remains constant, the air gap flux and motor torque will decrease because of the increased motor RPM resulting in an increased back EMF. As the rotor speed and achieved frequency of the motor increase, the impedance of the stator circuit also increases. The voltage applied to the stator windings must therefore be increased to increase the percentage of Slip to maintain full torque.

An AC motor can also act as a generator to produce a braking effort to stop the train. For dynamic braking, the operator requests a negative tractive effort. The inverter applies a voltage and frequency to the stator winding that result in a rotating magnetic field that rotates slower than the rotor achieved frequency.

The control of the traction motors uses a speed sensor less drive. The system uses the measurements of the traction motor rotor flux to calculate the angular speed of the motor. This method is faster than using the speed sensors for spin and slide control. The motor speed sensors and trailer axle speed sensors are used for vehicle speed reporting, direction control, wheel wear compensation, no motion detection and distance traveled calculations. The failure of a traction motor speed sensor will cause the propulsion system to shut down.

3.5 Power Circuit Contactors Control and Monitoring

3.5.1 High Speed Circuit Breaker

The High Speed Circuit Breaker provides a rapid interruption of the 750 volt primary supply to the vehicle propulsion systems when tripped. Refer to Section 8.4, Drawing B446242 at Zone A1. The HSCB provides the following protections:

- Over current trip protection at 3200 amps.

Additionally, the HSCB will be commanded open (coil deenergized) with any of the following conditions:

- Lowering of the pantograph.
- A propulsion ground fault detected. A Ground Fault is declared when the difference between the input current (CTL) and the ground (return) current (CTG) exceeds 50 amps for longer than 200 msec.
- Line current flow of greater than 1600 amps for longer than 1 second from either inverter.
- HSCB Control Power Supply Fault for 1 second (HB28).
- HSCBCK control relay command does not match the HSCB Status signal for longer than 1 second.
- LS Operation Command does not match LS Status for longer than 1 second.
- LCC Operation Command does not match LCC Status for longer than 1 second.
- Propulsion Cutout Signal (PCO) from both PLU's.

With the loss of the command to close the HSCB (as listed above), the HSCB will open in 20 msec. Any condition that causes the opening of the HSCB will then cause the opening of both propulsion line switches.

The command to close the HSCB comes from the System CPU on the MCB107B1 Inverter System Control board to the OBA54A1 Digital Output board HBCC output signal. The HBCC signal energizes the HSCBCK relay coil. With the HSCBCK interlock closed, the High Speed Circuit Breaker Command signal (HSCBC) is sent to the Control Panel.

The High Speed Circuit Breaker Control Panel and the HSCB control relays HSCBCK in each inverter equipment case provides the interface circuitry needed for remote operation (close/open) of the HSCB. See Figure 2-24 for the layout of the components in the HSCB Control Panel.

The HSCB is closed automatically once a Forward or Reverse direction is set from the controlling cab or re-closed from the PROP / HSCB Reset on the TOD. The HSCB command (HBCC) is found on Drawing B519943 at Zone A2 and Zone B5 to energize HSCBCK.

As seen in Figure 3-11 vehicle batteries go through a 10 amp circuit breaker (located in the cab) and then to a noise filter device at connection 1. The battery 0 volt return is from connection 2. The term LVGA is the low voltage ground. Noise filter connections 3 and 4 feed battery voltage and return circuit to the Current Limiter connections 2 and 3.

The HSCB Control Panel operates at vehicle battery voltage (28.5 Vdc). The vehicle battery voltage is monitored by each PLU to ensure the voltage is within limits from input HB28A (A-unit) and HB28B (B-unit). With the monitored battery supply out of limits, the HSCB will not be commanded closed.

Both the A-unit PLU and the B-unit PLU command the HSCB closed using the HSCBCK relay. The A-unit HSCBCK relay is energized by the A-unit PLU by the HBCC signal from the OBA54A1 Digital Output board. The B-unit HSCBCK relay is energized by the B-unit PLU by the HBCC signal from that section Digital Output board.

With the HSCBCK relays energized, the interlocks are closed. The A-unit HSCBCK interlock inputs B+ to diode D1 in the HSCB Control Panel. The B-unit HSCBCK interlock inputs B+ to diode D2 in the HSCB Control Panel.

From either the D1 or D2 diode the circuit continues to the Current Limiter connection 8. The current limiter then regulates the current flow to the HSCB coil energizing the coil at connections 6 and 7.

If there is an active fault detected in either PLU, the HSCBCK control relay from the effected inverter will not be energized. The control of the HSCB is then done by the remaining PLU and HSCBCK in the functioning car.

When the Current Limiter command input signal (terminal No. 8) becomes high, the output voltage for the energizing coil (terminal No. 6) starts to rise to 24 Vdc. When the HSCB is closed, the HSCB status input signal (terminal No. 10) goes high. At this time, the current limiter recognizes that the HSCB is closed, and vehicle battery voltage is then removed from the HSCB coil and a 5 Vdc supply from the control panel is put on the coil to establish the two amp holding current.

The HSCB remains closed as long as the HSCBCK is energized. The removal of voltage from the coil will cause the HSCB to open. When the command input signal (terminal No. 8) becomes low, the output voltage for energizing coil (terminal No. 6) drops to 0 volts and the HSCB opens.

With the HSCB closed, HSCB auxiliary interlocks R3 / R4 close sending a status signal back to the A-unit Propulsion Logic Unit (HSCBS). With the HSCB closed, HSCB auxiliary interlocks L5 / L6 close sending a status signal back to the B-unit Propulsion Logic Unit (HSCBS).

HSCB auxiliary interlocks L3 / L4 go back to the HSCB Control Panel current limiter. With the closing of the HSCB, there is a momentary surge current. With the contactor fully closed, the surge current is removed.

The HSCB Status signal (HSCBS) monitored by the PLU is found on Drawing B519943 at Zone A2 and Zone A5.

Each PLU (and HSCB Control Panel) controls only the HSCB on that car. The opening of one HSCB on a train will not cause any other HSCB in the train to open.

With a fault condition detected from only one PLU (explained above), the HBCC output driver from the PLU that detected the fault will be disabled. A signal is then sent to the other PLU (signals CBTF1 or CTBF2) that disables the HBCC output signal from the PLU that did not detect the fault condition causing the HSCB to open (both HBCC drivers disabled).

The control circuit for the HSCBCK control relay is seen on diagram B519943 Zone B5 found in Chapter 8.

The following must be true for the PLU to energize the HSCBCK control relay:

- Cab keyed up and direction set
- HSCB open
- Line Switch contactors open
- Line Charging Contactors open
- The HSCB is not locked out
- Propulsion inverters must not be cut out
- No Fault or Protection conditions detected

HSCB Tripped is detected when the HSCB is opened unexpectedly. The HSCB opens even though there is a Close HSCB Command being sent from the PLU.

Defective hardware such as the control system wiring or the HSCB coil, or a failure of the HSCBCK relays (or digital outputs driving the relays) can trigger this fault.

Another cause is that the HSCB has tripped from an overcurrent condition (3200 amps). The most likely cause of an overcurrent condition would be a short circuit IGBT.

With an overcurrent trip (3200 amps), the Overcurrent coil in the HSCB forces the HSCB power contacts open which disables the HSCB Status signal to the logic. With the loss of the Status signal, the Propulsion Logic Unit will disable the HSCBCK relay which removes the feed to the HSCB coil.

With the HSCB open (for any reason), there is an HSCB Tripped indication from the TOD. The operator selects the PROP / HSCB Reset from the TOD screen. The signal goes through the MVB to the Gateway to any HSCB in the train that is open will be commanded closed.

On the third HSCB overcurrent trip within 15 minutes, the HSCB is locked out. With an overcurrent fault called out on the TOD, cutout the appropriate propulsion inverter which will allow the HSCB to stay closed.

Once closed, when neither Forward or Reverse direction is selected (neutral selected at the Master Controller) the HSCB will open 60 seconds later.

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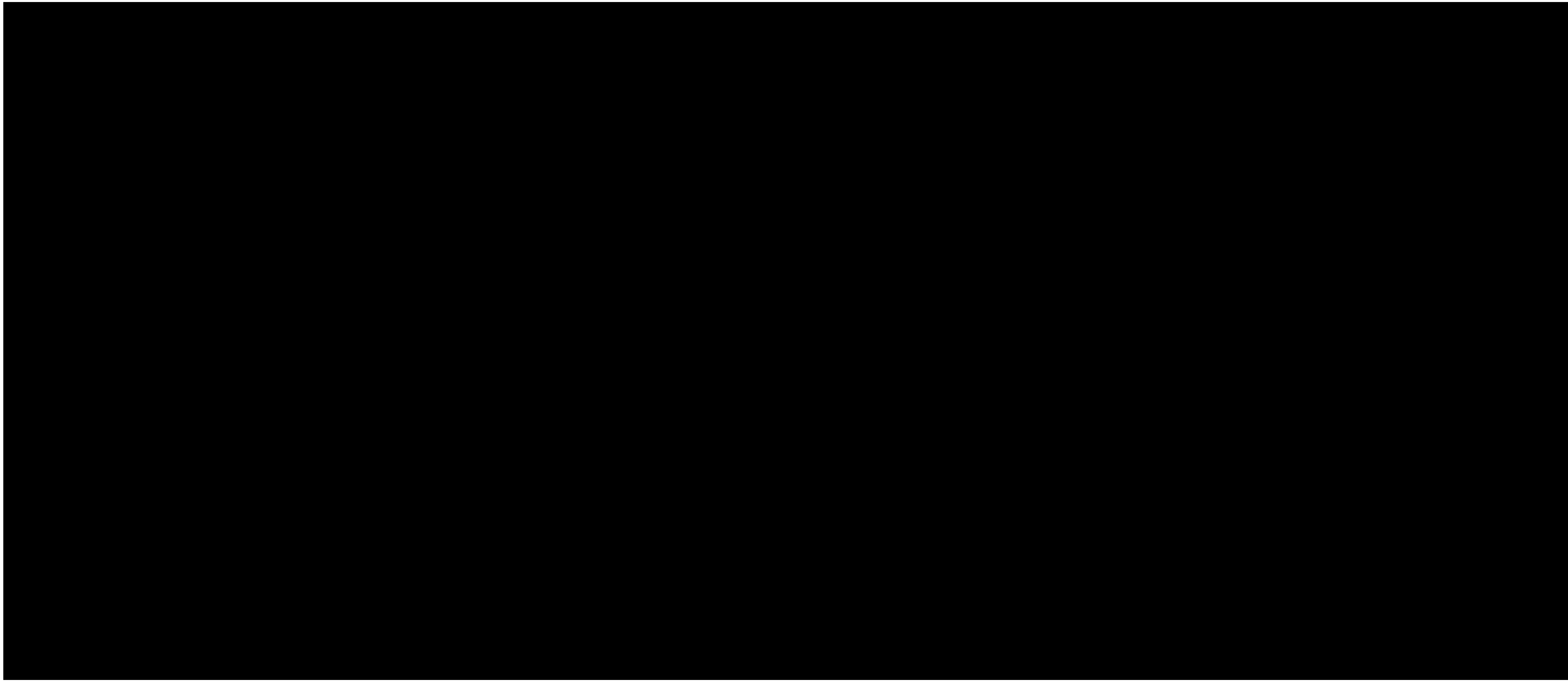


Figure 3-11: HSCB Control Circuit

3.5.2 Line Charging Contactor Control and Monitoring

The Line Charging Contactor (LCC) is used to insert the filter capacitor charging resistor CHR to provide current limiting as the filter capacitors are being charged. Refer to Section 8.4, Drawing B446242 at Zone A2 for the power circuit and Drawing B519943 at Zone C5 for the control circuit.

The LCC will not be allowed to close when the propulsion inverter is in cutout condition, any fault or protection function is activated or overvoltage is detected.

LCC is energized first to insert the current limiting resistor to pre-charge the filter capacitors. Once the filter capacitors have achieved 80% of the line voltage, the Line Switch contactor is energized closed removing the resistors. LCC is then deenergized one second later. With a line voltage of 750 volts, the current limiting resistors are removed from the power circuit at 600 volts.

When filter capacitor voltage falls below 435 volts, the Line Switch contactor is opened and the LCC is closed to provide a current limited rise to the filter capacitor voltage.

The command to close the LCC comes from the System CPU on the MCB107B1 Inverter System Control board to the OBA54A1 Digital Output board LCCRC output signal. The Emergency Brake Relay Timer (EBRT) interlocks control the return circuit of the coil. The EB Trainline must be high to allow EBRT to be energized closed. The Line Charging Contactor is closed from the Digital Output board with the LCCRC command.

The Line Charging Contactor has a normally closed interlock that feeds the LCC Status signal into the IBA130A1 Digital Input Board 1 confirming that the contactor is energized closed. With LCC deenergized, the Status signal to the PLU is active (vehicle 28.5 Vdc battery voltage). With the contactor energized closed, the LCC status signal is 0.

The LCC is controlled by the OBA54A1 Digital Output board with the following parameters:

- Cab keyed up and direction set
- HSCB closed
- EB Trainline active
- Slide Control Emergency Brake Trainline active (not applied).
- Line Switch contactor open.
- Line voltage greater than 525 volts
- No propulsion faults detected
- Propulsion system not cut-out

The PLU compares the Command signal and the Status signal. If the command and status disagree for longer than 1 second, an LCC control fault is declared and the HSCB is opened.

3.5.3 Line Switch Contactor Control and Monitoring

The Line Switch contactor (LS) connects the propulsion power circuit with the catenary supply once the High Speed Circuit Breaker is closed and the filter capacitors have been charged. Refer to Section 8.4, Drawing B446242 at Zone A2 for the power circuit and Drawing B519943 at Zone C5 for the control circuit.

When the propulsion inverter is in a protection or fault status, the LS will not be allowed to close.

The command to close the Line Switch contactor comes from the System CPU on the MCB107B1 Inverter System Control board to the OBA54A1 Digital Output board LSRC output signal. The LSRC signal drives the Line Switch Relay LSR coil on the positive side. The Emergency Brake Relay Timer (EBRT) interlocks control the circuit on the negative side. The EB Trainline must be high to allow LS to be energized closed. Interlocks of the Line Switch Relay then fed the Line Switch contactor coil. The Line Switch contactor has an interlock that feeds the LS signal into the IBA130A1 Digital Input Board 1 confirming that the contactor is energized closed.

The parameters that drive the Line Switch Relay (controlling the Line Switch contactor) are identical to the parameters to close the Line Charging Contactor with the addition of the last parameter listed below:

- Cab keyed up and direction set
- HSCB closed
- Slide Control Emergency Brake Trainline active (not applied).
- Emergency Brake Trainline active
- Line voltage greater than 525 volts
- No propulsion faults detected
- Propulsion system not cut-out
- Cab keyed up and direction set
- Filter capacitor voltage within 80% of line voltage.

The PLU compares the LS Command signal and the Status signal. If the command and status disagree for longer than 1 second, a LS control fault is declared and the HSCB is opened.

The PLU monitors the Emergency Brake Trainline. The Master Controller provides the supply and return circuits to the EB trainline through the ATP logic and the console EB pushbutton switch. When the EB Trainline is disabled, the PLU disables the Line Switch Relay which causes the propulsion system to be disabled and the Line Switch contactor to open.

With the loss of the EB Trainline, the Emergency Brake Relay EBR is deenergized. An EBR interlock opens and an input to the Emergency Brake Relay Timer (EBRT) is deenergized. This starts a 3 second delay before opening the EBRT interlocks. When EBRT times out, the interlocks break the return circuit to the Line Switch contactor coil as a backup to ensure LS has been disabled. When a TCN Fault is detected, the PLU disables the propulsion system deenergized the Line Switch Relay opening the Line Switch contactor.

With an overcurrent condition of 3200 amps, the HSCB is tripped open. The opening of the HSCB causes both line switches to open. With a reset of the PROP / HSCB reset from the TOD, LCC will be allowed to close to pre-charge the filter capacitors and then the Line Switch contactors will close.

Transition from Service Brake to Slide Controlled Emergency Brake (SCEB) may cause the Line Switch contactor to open under load. In service braking, the propulsion inverter activates dynamic brake and the regenerative current will flow into the catenary. If SCEB is applied in this condition, the inverter opens the LS under load. The LS can handle 20,000 times of current breaking at 1500 volts, 1200 amps.

3.6 Dynamic Braking

The preferred braking system on the car is dynamic braking. The friction braking system is used to provide any demanded braking effort that cannot be achieved by the dynamic braking. Under normal operating circumstances the dynamic brakes provide all or most of the braking effort up to and including AW2 weight. If a brake demand is initiated below 9.6 kph (6 mph), dynamic brake is not enabled and friction braking will achieve 100% of the demanded braking effort.

The propulsion system uses the rate request (over the MVB) and the vehicle load weight to determine the required level of dynamic brake effort. Depending on the demanded brake rate and passenger load weight, friction braking may be blended with the dynamic brake system above 50 mph. Above 50 mph and a high brake effort demand the dynamic brake is ramped up to a speed dependent maximum value before friction brakes are blended in.

During dynamic braking, the traction motors are converted into generators (with a Negative Slip). This regenerative energy is an AC output from the traction motors and rectified by the freewheeling diodes across each IGBT acting as a full wave bridge rectifier. The DC energy is returned to the DC link filter capacitors and then to the catenary supply (whenever the line is receptive). The brake choppers regulate the voltage of the filter capacitors and indirectly the catenary voltage.

In brake mode, the PLU will adjust the output frequency of the traction inverter so that a negative Slip will be produced (the inverter frequency is less than the traction motor rotor frequency) and the traction motors will become generators.

The Propulsion Control applies an adhesion limit to the dynamic braking effort. The purpose of the Adhesion Limited Control is to limit the dynamic braking effort of the vehicle so that the required adhesion reduces the potential of slides. The PLU limits the dynamic braking effort so that the required adhesion coefficient (coefficient of friction between rail and wheels) does not exceed 18.8% while braking and 16% while sliding or applying SCEB.

The friction braking system monitors the total brake effort demand as well as the dynamic brake effort achieved. If dynamic braking is not achieving all of the requested braking effort, friction braking is blended in.

There are two types of dynamic braking. In regenerative braking, the energy produced by the traction motors acting as generators is returned to the catenary supply. In rheostatic braking, the energy produced by the traction motors is dissipated as heat across the dynamic braking resistors. During any given dynamic brake application, there can be a mix of regenerative and rheostatic braking as well as blended braking.

During electric braking, the regenerative energy from the traction motors is returned to the filter capacitors. The output voltage from the inverter is set higher than the catenary voltage to ensure a current flow from the inverter to the catenary supply. If the catenary supply in not fully receptive, the filter capacitor voltage will rise.

When the catenary voltage starts to increase (becomes unreceptive), the DC link voltage (output of the traction motors) is regulated by the dynamic brake choppers BCH1 and BCH2 as seen in Figure 3-12 (part of drawing B446242).

Each brake chopper (BCH1 and BCH2) controls a circuit to a dynamic brake resistor through current transducer CTB, and then to the return circuit 500B (connected to 500D). The two brake chopper circuits are turned On and Off at the same time to cancel EMI from each circuit. If one of the brake chopper resistor circuits should fail, dynamic braking will be disabled. With the brake choppers On, each brake resistor (1.42 ohms) is connected across the filter capacitors and dissipates the energy as heat. With both chopper circuits conducting at the same time, the total resistance is 0.71 ohms with a current flow through CTB of 1,338 amps at 950 volts.

[redacted]

The brake choppers are controlled with pulse width modulation at 300 hertz as seen in Figure 3-13. For the brake chopper IGBT’s to turn On, there must be a brake request. As the filter capacitor voltage rises to 900 volts, the brake chopper IGBT’s turns On and Off together at minimum On time per cycle as seen on the waveform on the left. As the DC link voltage increases, the On time per cycle increases as seen in the middle waveform allowing more energy to be dissipated as heat and less energy returned to the catenary supply. The brake choppers regulate the voltage of the filter capacitors to a maximum voltage of 950 volts as seen in the waveform on the right side.

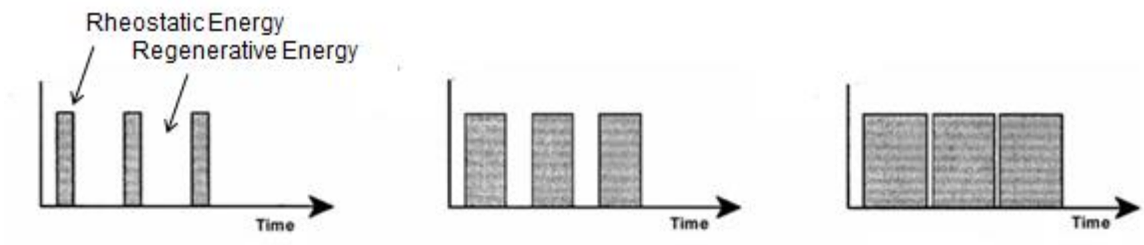


Figure 3-13: Brake Chopper Pulse Width Modulation

This allows as much power to be returned to the catenary supply as possible and still maintain electric braking. With a light brake application and light passenger load, the energy produced by the traction motors would be minimal and the brake chopper would be turned on later per cycle or possibly not turned on at all. With a Full Service Brake application and crush weight car, the output energy from the traction motors is greater. In this condition, the brake chopper cycle turn On point is shifted to earlier in the cycle.

Dynamic braking is capable of achieving the demanded braking effort to almost zero speed. The blending of dynamic braking to friction braking is done at approximately 6 mph to allow for the slower reaction time of the friction braking system valves.

Approximately 450 msec before the start of dynamic brake fade, a pre-fade signal is sent to the friction brakes. This will allow the friction brakes to prepare for the dynamic brake fade. The pre-fade signal is reset after the dynamic brakes have completed fading.

Between 8 and 1.6 kph (6 and 1 mph), the dynamic braking system is fading out and the friction braking system is blended in. At approximately 1.6 kph (1 mph), the brake application is full friction.

The conduction ratio of the pulse width modulation starts at 3% when the voltage is 900V, increasing to 95% when the voltage is 950 volts. When the filter capacitor voltage reaches 1000 volts, the brake choppers operate for 1 second On, 1 second Off until the voltage drops to 950 volts.

Output power from inverter to catenary is calculated from line voltage and line current. Input power from traction motor to inverter is calculated from motor current. Brake circuit power is calculated by subtracting inverter output power from input motor power and if the brake circuit power exceeds 350 kW, the fault is detected. If a fault occurs, the propulsion inverter is disabled. This is calculated by the PLU. Brake chopper fault monitoring is active whether the vehicle is in braking or not.

When dynamic braking is not available on any truck or vehicle, the vehicle and its associated train will be automatically limited to a nominal maximum operating speed of 56.3 kph (35 mph) and the fault / speed limit annunciated to the operator.

Dynamic braking does not immobilize a stationary vehicle. Physical locking with mechanical brakes is still required.

3.6.1 Overhead Catenary Supply Gap Detection

With the detection of an OCS gap (no line voltage detected), the Line Switch contactor is not opened. If in braking, the regenerative energy powers the vehicle Auxiliary Power Supply while in the gap. All of the remaining energy is dissipated as heat using the brake chopper and dynamic braking resistors (rheostatic braking).

If in power above 20 mph, the logic shifts from a positive Slip to a negative Slip in the gap allowing the traction motors to produce regenerative energy. This is a slight brake rate that has sufficient energy to power the vehicle high voltage loads such as the Auxiliary Power Supply and HVAC through the gap.

While in the OCS gap the dynamic brake reference is set to 750 volts. On the other side of the OCS gap, if the catenary voltage is greater than 750 volts, the propulsion system will shift to a positive Slip immediately and continue tractive effort.

If the catenary voltage is less than 750 volts, the PLU then begins ramping down the dynamic brake reference voltage from 750 volts. The propulsion system will remain in this slight brake mode until the decreasing reference voltage falls to the monitored catenary voltage or for up to 20 seconds and then shift to a positive Slip and resume power.

3.7 Friction Braking Interface

The propulsion system interfaces with the friction brake system over the Multi-functional Vehicle Bus. The dynamic braking system is described in Section 3.6.

The friction brake system has its own control electronics for each truck (ECU). Brake blending will be performed by the friction brake system. The PLU will report the amount of achieved dynamic braking effort per truck to both the motor truck and center truck friction brake electronic control units via the Dynamic Brake Achieved (DBA) MVB signal. This signal will be provided over the MVB network. The friction brake ECU will apply friction braking if the dynamic brake is not achieving 100% of the requested brake effort.

The friction brake system must ensure that the total braking request specified by the trainline commands is satisfied. The friction brake controller calculates the difference between the requested brake rate and the achieved dynamic brake rate. The friction brake systems blends in friction braking as needed so that electric braking plus friction braking is equal to the total brake effort requested.

The propulsion system and the friction brake system both control wheel slide protection independently. Load weigh, slide, fade, and tractive effort signals pass between the propulsion system and the friction brake system to aid in the wheel slide protection and braking functions.

When braking is initiated at speeds above 50 mph, the inverter provides the maximum dynamic brake effort and the friction brakes provide the remainder of the requested braking effort as needed.

Dynamic brake effort fades as speeds are reduced to zero. As seen in Figure 3-14, as speed falls below 6 mph, the propulsion control starts fading out the dynamic brake and the friction brake system provides the remainder of the requested brake effort (blended braking).

With car speed less than 9.6 kph (6 mph) when a brake request is made, electric braking is disabled and friction braking provides 100% of the requested braking effort until zero speed.

Above 9.6 kph (6 mph), the brake effort achieved should be all dynamic braking. At 450 msec before the start of dynamic brake fade, a Stopping Brake signal is sent to the friction brakes. This will allow the friction brakes to prepare for the dynamic brake fade. At 9.6 kph (6 mph) the dynamic brake request is reduced and the friction braking system automatically compensates (blended braking). As speed further reduces to 0.8 kph (0.5 mph) dynamic braking is reduced to 0 and friction braking achieves all of the braking request down to zero speed.

[redacted]

3.7.1 Friction Brake Interface Signals

Dynamic Brake Effort Achieved Propulsion to Friction Brakes

The PLU will report the amount of Dynamic Brake Effort Achieved per truck to both the motor truck and center truck friction brake electronic control units. This signal will be provided over the MVB network and indicates the amount of dynamic braking delivered by each truck. When the dynamic brake rate falls to less than the requested brake rate, friction braking is blended in.

Stopping Brake Propulsion to Friction Brakes

The Stopping Brake signal on the MVB is a notice of the fade-out of dynamic brake and is sent 450 msec before the dynamic brake starts to fade as speed falls to 9.6 kph (6 mph).

The Stopping Brake signal is also used to release the friction brakes with a tractive effort request at zero speed. This signal will only go low when the propulsion system has built up sufficient torque to move the train forward (about 30% of request torque). When the output signal goes low the friction brakes on the train will be released. With a small torque request from the operator, the train could roll back.

Rollback Signal Propulsion to Friction Brakes

In the event that 38 cm (15 inches) of rollback occurs, or the rollback speed reaches 1 mph after torque initiation, a rollback condition is detected. If the rolling back condition is detected, the PLU will disable the propulsion systems, activate the Rollback signal to the MVB and the friction brake system will apply brake.

Propulsion Slide Detected Propulsion to Friction Brakes

Wheel Slide control is active in all braking modes except Emergency Brake initiated by the Emergency Brake Trainline. Wheel Slide is declared based on differences in axle speeds or on the rate of change of the reference speed. In order to prevent unintentional rate effort changes by the friction brake system, the Propulsion Slip Detected signal is sent to the friction braking system over the MVB during a wheel Slide correction.

When the main braking effort is being supplied by dynamics and a slide happens the PLU sets the Wheel Slip Active signal high to the friction brakes. This tells the power truck friction brake to reduce its effort to zero while the PLU modulates its effort in order to recover from the slide. Once the slide is corrected, the PLU sets the Wheel Slip Active signal low and the friction brake will compensate for any difference in effort between the request and what the dynamic brakes are supplying. So above 50 mph where the friction is supplying more effort, the friction on the power truck reduces its effort to zero. The center truck during any slide will add effort while the dynamics have been reduced trying to recover the slide.

Load Weight Friction Brakes to Propulsion

This signal from the friction brake system indicates passenger load weight of the car. Three signals are input to the PLU over the MVB from the braking system: A-truck, B-truck and C-truck. The A-unit PLU monitors the pressure from the load weight transducer on the A-truck and one half of the pressure from the C center truck transducer. The B-unit PLU monitors the pressure from the load weight transducer on the B-truck and one half the pressure from the C center truck transducer.

For motoring, the load weight compensation is between AW0 and AW2. The propulsion system will adjust tractive effort to compensate for varying passenger loads. Compensation is calculated from the measured value of passenger loading provided from the friction brake unit. For braking, the load weight compensation is between AW0 and AW2.

The Load Weight value information used for load compensation is latched 2 seconds after receiving the doors closed signal on the MVB. While doors are opened, the load weight value will not be latched.

AW0 - The assigned weight of an empty car ready for service without crew or passengers. An empty car (AW0) is defined as 101,999 lbs. (46,266 kg).

AW2 - The assigned weight of a car ready for revenue service with a full crew, all passenger seats occupied, and standees at 4 persons per square meter. In terms of actual weight, AW2 equals AW0 plus 26,081 lbs. (11,830 kg)

AW3 - The assigned weight of a car ready for revenue service with a full crew, all passenger seats occupied, and with the largest number of passengers that can occupy the car (crush load). In terms of actual weight, AW3 equals AW0 plus 32,999 lbs. (14,968 kg)

With a failure of either the A-unit or B-unit pressure transducers (less than 50% of the AW0 value or more than 150% of the AW3 value), the logic will monitor the load weight from the other section of the vehicle (over the MVB) presuming the same load weight for both sections of the vehicle. When all the referring load weight values are out of lower/upper limit of psi range, the PLU will consider that the load value is AW0 if out of lower range and AW2 if out in upper range. Also, when load weights are out of the acceptable range, a message will be displayed on the TOD but the inverter operation will not be stopped.

A Load Weight Failure will not be detected for 1 minute after the booting up of the PLU.

3.7.2 Rollback Detection

The friction brake and propulsion systems will coordinate brake release and power application at zero speed such that the vehicle does not roll backwards during acceleration on grades. The purpose of Roll Back Detection is to limit the amount of rolling in the reverse direction from the commanded direction on startup. The friction braking systems monitor the Stopping Brake signal from the propulsion systems over the MVB. When the Tractive Effort Achieved goes above 30% of the requested value, the Stopping Brake signal from propulsion to the friction braking systems goes low allowing the friction brakes to release.

In the event that 38 cm (15 inches) of rollback occurs, or the rollback speed reaches 1 mph, a rollback condition is detected. If the rolling back condition is detected, the PLU will activate the Rollback Detection fault signal to the MVB and the friction brake system will apply brakes. When the PLU detects a Rollback condition, the PLU will disable the propulsion system and open the Line Switch contactor.

The Rollback Detection signal will be reset when No-motion is detected, Full Service Brake is applied and the Friction Brake Released signal (FBRRL) is low.

3.7.3 Emergency Brake Application

Emergency braking is provided by a combination of load weighed friction brake, dynamic brake and track brake. These track brakes provide a high tractive force and are used to augment the friction brakes and dynamic brakes. There is also an automatic application of sand. An emergency brake application can be done in 1 of 3 ways. It is done from the Master Controller (SCEB), from the ATP (EB) or from the mushroom button on the operator console (EB).

Slide Controlled Emergency Brake (SCEB)

> When an emergency brake is initiated via the Master Controller it is similar to a service brake application. The Slide Control Emergency Brake trainline is deenergized when the Master Controller handle is placed in the SCEB position. This conveys the Slide Controlled Emergency Brake request to all friction brake systems and the propulsion systems. The PLU Line Switch Command is disabled opening the LSR and causing the LS to open under load. The propulsion system remains enabled and producing rheostatic braking.
>
> This Emergency Brake application will override jerk rate limits and apply electric brakes (rheostatic), friction brakes, sand and track brakes. Wheel Spin / Slide control will remain active.

Emergency Brake (EB)

The Emergency Pushbutton in any cab or the ATP can initiate an Emergency Brake application. When the Emergency mushroom is depressed or the ATP activates Emergency Brake, the EB Trainline is disabled which is monitored by the PLU and de-energizes the Line Switch Command signal. With this condition, the Line Switch Relay is disabled which disables the Line Switch contactor.

When the EB trainline is de-energized, the EBR is de-energized which triggers the EBRT interlock timer. The EBRT interlocks open 3 seconds later to disable the LS return circuit as a backup. The propulsion system is now disabled and friction braking will achieve all of the requested braking to zero speed.

With an Emergency Brake application:

- Dynamic braking is disabled.
- Jerk Rate limits are disabled.
- Wheel Slide correction is disabled.
- Sanding is enabled.
- Track Brakes are On.

The trainline can only be reset to its normally high state by returning the Emergency Pushbutton to UP position and placing the Master Controller in the Full Service position or the ATP resets Emergency Brake command at 0 speed.

3.8 Equipment Cooling and Temperature Detection

3.8.1 Propulsion Equipment Case

The power circuit IGBT's, Heatsink Fins and four Cooling Fans are located on the Inverter Unit as seen in Figure 3-16. The fans are located under the cover and filters as seen in Figure 3-15.

When the power circuit IGBT's are turned On and Off, it creates heat. The heat is transferred from the IGBT's to the Inverter Unit heatsink fins through the plate the IGBT's are mounted on. Four AC fans force cooling air over the heatsinks to cool the IGBT's. The cooling air is then exhausted through the bottom of the equipment case.

The air used to cool the heatsink assembly is cleaned using self-cleaning filters on the outside of the equipment case as seen in Figure 3-15. The function of the air filter is to prevent larger debris, dust particles, and large quantities of water from entering the propulsion inverter. The cooling air does not enter the electrified sections of the propulsion equipment case.

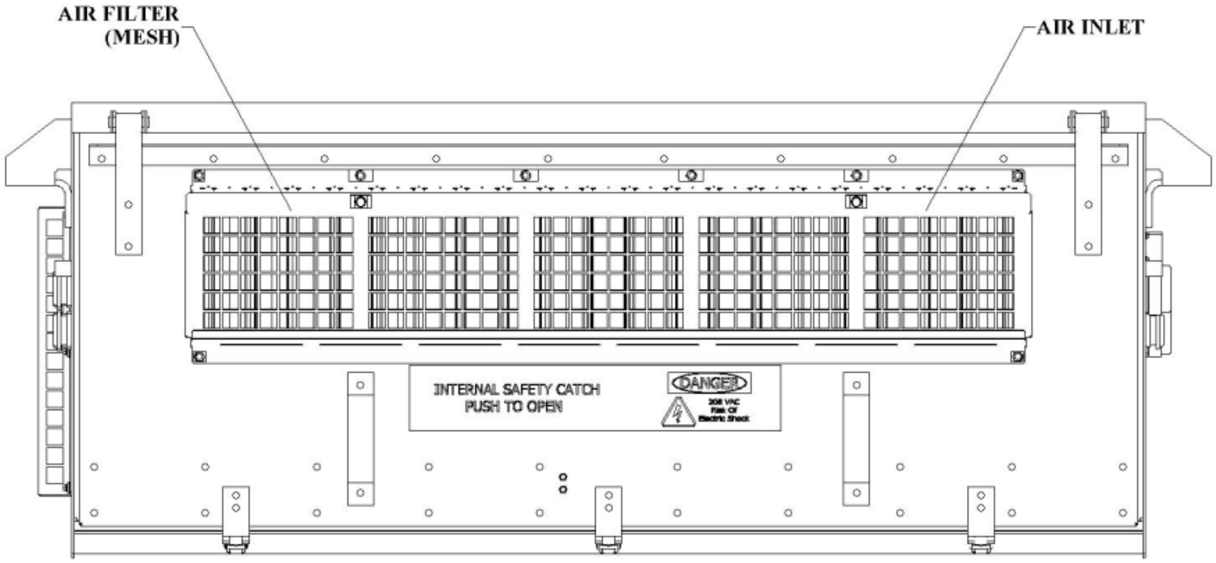


Figure 3-15: Equipment Case Filters

As seen in Figure 3-16, there are four inverter Unit cooling fans. Each fan is rated for 80 watts, 10.8 cubic meters per minute (380 cubic feet per minute), 3250 revolutions per minute. These fans force cooling air over the heatsink cooling the IGBT's.

To prevent the IGBT's from being damaged due to rising temperature, the temperature of the plate to which the IGBTs are mounted is monitored. As seen in Figure 3-16 there are three analog temperature sensors (thermistors) mounted on this plate designated as THBch, THVW and THUV monitoring the temperature of the plate.

The thermistors are powered from the 12 Vdc supply on the PLU Power Supply Board. Refer to Section 8.4, Drawing B519943 Zone F6. Each thermistor's resistance changes depending on the temperature of the plate changing the input signal to the Inverter System Control board MCB107B1. The scaling is 13.4 degrees C (56 degrees F) is 0 volts output and 128 degrees C (262 degrees F) is 10 volts DC output.

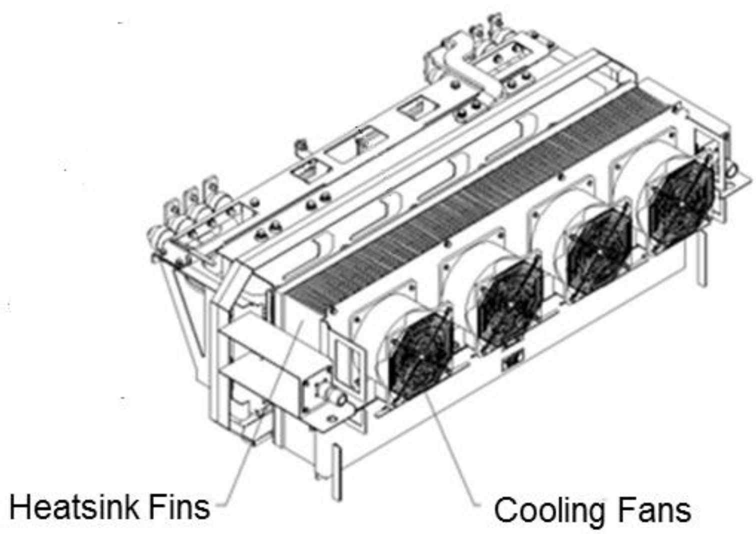
With a temperature of 76.4 degrees C (169 degrees F) from any of the temperature sensors, the propulsion system disables dynamic braking. Recovery is automatic once the temperature falls below 70 degrees C (158 degrees F).

With a temperature of 80.2 degrees C (176 degrees F) from any of the temperature sensors, the propulsion system is disabled and the Line Switch contactor is opened. Recovery is at 75 degrees C (167 degrees F). Inverter reset happens once the temperature has fallen below 75 degrees C with a PROP /HSCB reset command at the next Full Service Brake application at zero speed.

With a detection of less than -20 degrees C (-4 degrees F) from any of the temperature sensors, that temperature sensor is declared failed and the effected inverter is shut down.

Refer to Section 8.4, Drawing B519943 at Zone D4 for the control circuit for the cooling fans. The fans are powered from the vehicle 208 Vac 3-phase Auxiliary Power Supply. When the APS output is active, the Inverter Fan Relay 208VDK will be energized. The fan relay controls a digital input titled AC 208V Detection which confirms to the PLU that the vehicle APS is running. A failure of the vehicle 208 supply is not a fault condition that will disable the propulsion system. It sends an AC Fan Power Supply Fault to the MDS.

When the PLU does not detect AC208V fan motor power supply for 5 seconds, the PLU will detect an AC Fan Power Supply Fault. This will be automatically reset when AC208V is supplied to the propulsion inverter.



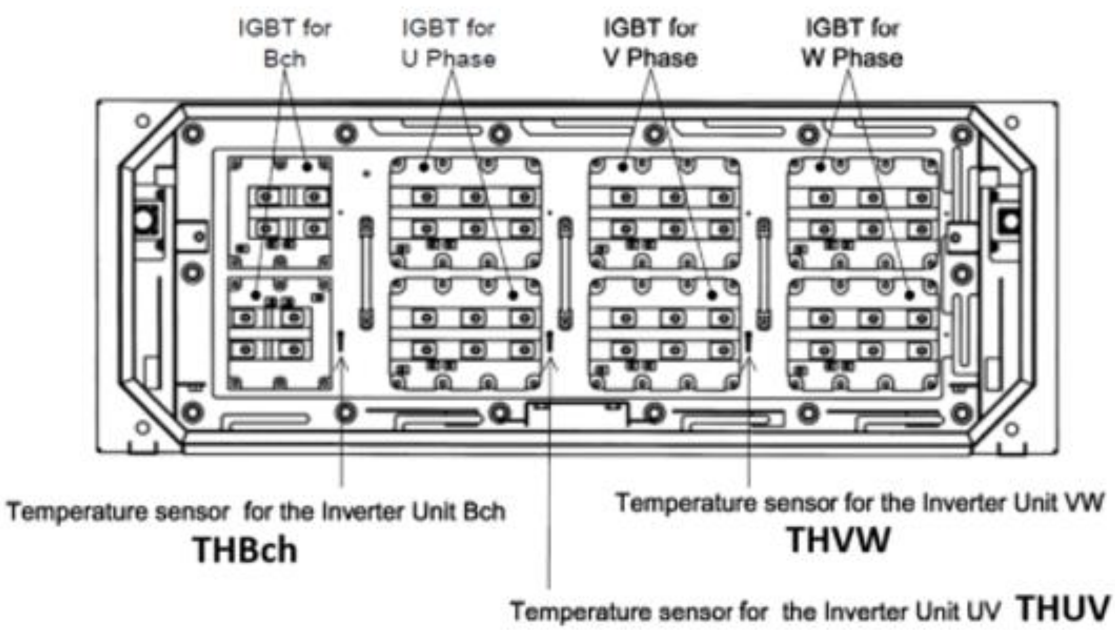


Figure 3-16: Inverter Unit Cooling and Temperature Detection

The fans are controlled from the Inverter Fan Motor Relay FM1R on the Relay Unit. The Inverter Fan Motor Relay is driven by the OBA54A1 Digital Output board signal FAN1K. With the vehicle 208 Vac three phase detected, the propulsion digital output energizes FM1R which energized the four cooling fans.

The cooling fans are not temperature controlled. When a direction is selected from the Reverser and the Fan Power Supply Status digital input ACOK is active, the fans are commanded On. The fans are turned Off after 3 minutes without a direction selected or when Car Wash is selected.

As seen on drawing B519943 at Zone D4, each Inverter Unit cooling fan has a circuit board that has a relay attached to it. The output of each relay feeds into the IBA130A Digital Input 1 board. Normal operating speed of the cooling fans is 3250 RPM which will energize the relay. With the relay energized, the input to the PLU is vehicle battery voltage (20). With the relay de-energized, the input to the PLU is 0 volts (100a1).

The purpose of the fan motor speed fault protective operation is to notice when fan rotation drops below 2000 RPM for more than 20 seconds on any of the fans. If the speed drops, the relay inside the fan circuit board is deenergized to indicate a fault.

A failed fan (or fans) will not immediately shut down the inverter, but is logged in the PTU and MDS. With a failed fan (or fans) the Inverter Unit heatsink temperature may increase. This condition can eventually cause an Inverter Unit Overtemperature condition that will shut down the inverter. The fan fault is reset when fan speed is detected above 2000 RPM for longer than 5 seconds.

3.8.2 Traction Motors

The traction motors are self-cooled by a fan attached to the traction motor rotor. Air is drawn into the motor through an input filter by the fan. Regardless of the direction of rotation of the rotor, the airflow is always through the air intake at the top of the motor and exhausted on the gear side of the motor. The faster the rotor rotation, the greater the cooling air flow through the motor.

The traction motors have no temperature sensors. The temperature is calculated by the MCB108B1 Inverter Control Board based on the inverter output current and vehicle speed. The motor temperature calculation is done on a per truck basis. Individual motor temperatures cannot be calculated.

When the propulsion system is powered up, the temperature detected from the Inverter Unit thermistors is taken as initial temperature for the traction motors. The traction motor temperature calculation will be reset to the current Inverter Unit temperature any time the PLU is powered down and back up (as with a Hard Reset). Upon recovery from a hard reset, it will take approximately 60 to 90 minutes of operation for the calculated traction motor temperatures to accurately represent the actual motor temperatures.

When the calculated temperature exceeds 220 degrees C (428 degrees F), the inverter is shut down. When the calculated temperature returns to 200 degrees C (393 degrees F), the inverter recovers with a PROP / HSCB reset command with a Full Service Brake application and zero speed detection.

Heavy passenger load weight or Tow Mode for an extended period of time will cause the traction motor temperatures to rise.

3.8.3 Brake Resistors

The Brake Resistor Assemblies are cooled with the movement of the vehicle. The Brake Resistor Assemblies have no temperature sensors. The Brake Resistor Assemblies temperatures are calculated by the IFB137B1 Serial Communications Board.

The logic knows the filter capacitor voltage, the current flow through the resistors from CTB and for how long per cycle each brake chopper is turned on. The Serial Communications board then calculates the temperature of each resistor. Overtemp is 500 degrees C (932 degrees F). With an overtemperature condition, which the MCB107B1 Inverter System PCB declares, dynamic braking is disabled with a brake request by inhibiting brake chopper gate driving signals and friction braking will achieve 100% of the braking on the effected truck. The inverter recovers automatically when the calculated temperature falls to 450 degrees C (842 degrees F).

3.8.4 Filter Capacitor Discharge Resistors

There are four discharge resistors (DCHR1 – DCHR4). One is connected across each of the four filter capacitors. With the loss of line voltage, the resistors will discharge the filter capacitors in 180 seconds (3 minutes). The resistor assembly is accessed from inside the equipment case and air cooled from outside. The resistors have no temperature sensors and the temperature is not calculated by the logic.

3.8.5 Filter Capacitor Charging Resistor

The filter capacitor charging resistor (CHR) is connected in series with the Line Charging Contactor LCC. With the Line Switch contactor open and the Line Charging Contactor closed, this resistor provides a current limited circuit to pre-charge the filter capacitors.

The resistor has no temperature sensors. The resistor is protected from overheating by identifying frequent use. If the LCC is operated 3 times within 1 minute, closing of LCC is inhibited for 1 minute, allowing the CHR time to cool.

3.8.6 Line Reactors

The line reactors are two air core devices which act with the filter capacitors to prevent noise (EMI) created by the turning On and Off of the IGBT's from getting back to the line supply. The value of the reactors is 1.25mH and 0.5mH.

The line reactors are cooled with convection with the movement of the vehicle. The line reactors have no temperature sensors and the logic does not calculate the reactor temperatures.

3.9 Speed Sensor Interfaces

The traction motor speed sensor provides motor torque control for each propulsion system. The propulsion system does not use the speed sensors for wheel spin or slide detection, as explained in Section 3.4. The friction brake systems also monitor the speed sensors. Refer to Section 8.4, Drawing B519943 at Zone D1 for the control circuits.

The speed sensor connections and wiring are not part of the Toyo Denki wiring diagrams. See KI drawing UD01450 Sheets 315 and 316.

Power for the speed sensors is from a 12 Vdc supply located on the Speed Signal Processing board IFB138B. The PLU powers only the speed sensors that are monitored by that PLU.

The speed sensors provide input data to the logic system to perform the following functions:

- Derive truck direction and indicate rollback by comparing Channel-A and Channel-B from Tach 1 (A-unit PLU) and Tach 10 (B-unit PLU).
- Provide a No-motion and zero speed detection.
- Generate the Speedometer output signal with ATP bypassed.
- Calculate wheel diameters.
- Drive the vehicle Odometer.

The layout of the tachometers is seen in Figure 3-17. As seen in Figure 3-18, the A-unit PLU monitors both channels of Tach 1 (rollback detection) and one channel of Tach 4. The B-unit PLU monitors both channels of Tach 10 (rollback detection) and one channel of Tach 5. The remaining sensors are monitored by the friction brake ECU's. The A-unit PLU calculates Axle 2 diameter from RPM data from the A-unit friction braking ECU. The B-unit PLU calculates Axle 4 and Axle 5 diameters from RPM data from the B-unit friction braking ECU.

Tach 1 (from Axle 1) is used for torque control for the A-unit propulsion system. Tach 10 (from Axle 6) is used for torque control for the B-unit propulsion system.

When the Axle 3 (Trailer Axle) Speed Sensor fault is detected (Tach 4 or Tach 5), the PLU will inform the TOD that the speed sensor monitored by the propulsion inverter is malfunctioned. In this condition, the propulsion inverter will continue operating but adhesion failure detection by speed differential will be disabled.

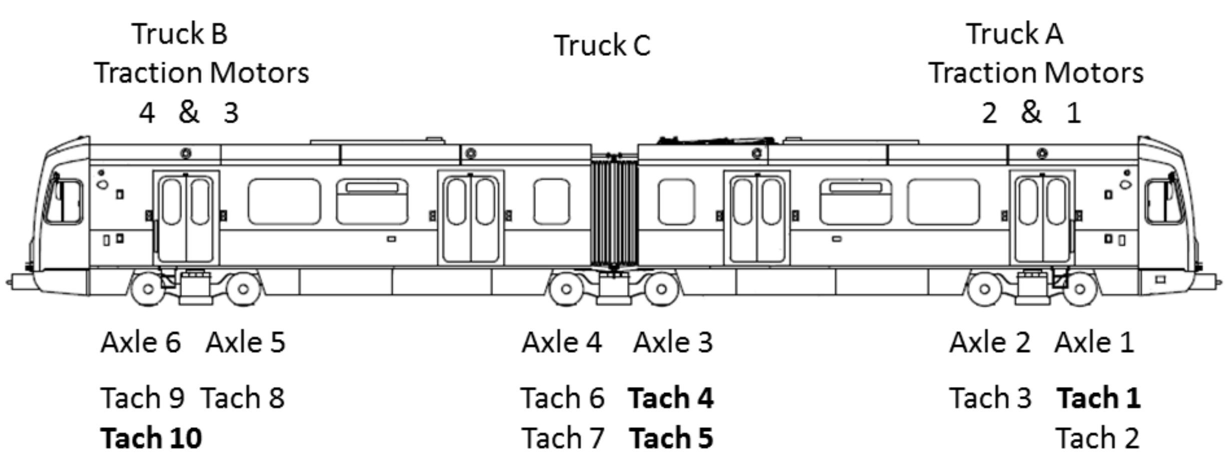


Figure 3-17: Speed Sensor Locations

[redacted]

3.9.1 Speed Sensor Output Channels

Each speed sensor produces two output signals as seen in Figure 3-19. Channel A and Channel B which are offset by 90 degrees so that the logic can determine direction of rotation on the axle (and direction of the vehicle).

The logic monitors the rising edge of each waveform. In one direction, Channel A will go high before Channel B. In the opposite direction, Channel B will go high before Channel A. Channel A and Channel B are also called out as Phase A and Phase B.

[redacted]

Connector CN6 is the connector at the side of the propulsion equipment case. The Tach 1 and Tach 10 speed sensors have both channels monitored by the PLU. Tach 4 and Tach 5 have only one channel monitored by the PLU. The following table shows the signals related to each of the speed sensor circuits.

Table 3-3. Speed Sensor Signals

CN6 Pin Number	Description
25	Wire Marker – VSP11 A-unit Tach 1 speed sensor channel A (VCC) B-unit Tach 10 speed sensor channel A (VCC)
26	Wire Marker – VS11 A-unit Tach 1 speed sensor channel B (H) B-unit Tach 10 speed sensor channel B (H)
27	Wire Marker – NA1 A-unit Tach 1 speed sensor channel A ground B-unit Tach 10 speed sensor channel A ground
28	Wire Marker – Tach11S A-unit Tach 1 speed sensor channel A shield B-unit Tach 10 speed sensor channel A shield
32	Wire Marker – VSP12 A-unit Tach 1 speed sensor channel B (VCC) B-unit Tach 10 speed sensor channel B (VCC)
33	Wire Marker – VS12 A-unit Tach 1 speed sensor channel B (H) B-unit Tach 10 speed sensor channel B (H)
34	Wire Marker – NB1 A-unit Tach 1 speed sensor channel B ground B-unit Tach 10 speed sensor channel B ground
35	Wire Marker – Tach12S A-unit Tach 1 speed sensor channel B shield B-unit Tach 10 speed sensor channel B shield
39	Wire Marker – VSP4 A-unit Tach 4 speed sensor channel B (VCC) B-unit Tach 5 speed sensor channel B (VCC)
40	Wire Marker – VS4 A-unit Tach 4 speed sensor channel B (H) B-unit Tach 5 speed sensor channel B (H)
41	Wire Marker – NA4 A-unit Tach 4 speed sensor ground B-unit Tach 5 speed sensor ground
42	Wire Marker – Tach4S A-unit Tach 4 speed sensor shield B-unit Tach 5 speed sensor shield

3.9.2 No-Motion and Zero Speed

No-motion and zero speed are not the same function.

The no-motion detection system is used to implement the various vehicle functions which require no-motion interlocking such as door control, track brake release, and de-coupling control. The no-motion circuits control the vehicle No-motion Relay. No motion is a speed detected by the speed sensors of less than 0.8 kph (0.5 mph). Motion is a speed greater than 2.4 kph (1.5 mph).

When Emergency Brake is commanded, No Motion detection is temporarily disabled for the amount of time which is calculated by dividing the vehicle speed when EB is commanded [mph] by 5.0 [mphps]. This is to prevent incorrectly detecting No Motion due to wheel lock by friction brake.

The Zero Speed signal is used internally by the propulsion system to enable fault reset. Zero speed is detected with both of the monitored speed sensors at 0.5 kph (0.3 mph) or less. Zero speed is still operational with one failed speed sensor. Both No Motion and Zero Speed functions are performed by the IFB138B1 Speed Signal Processing board.

The NMRK relay in each inverter equipment case as well as the matching relays from the friction braking system ECU's are used to control the vehicle No-motion Relay. See Figure 3-20.

The No-motion detection is based on the speed sensor signals. For the A-unit PLU, Tach 1 and Tach 4 are monitored to energize the A-unit NMRK relay. For the B-unit PLU, Tach 10 and Tach 5 are monitored to energize the B-unit NMRK relay. See Figure 3-17 for the locations of each of the speed sensors.

The speed sensors are monitored from the IFB138B1 Speed Signal Processing board containing the Speed CPU. When the Speed CPU calculates that speed is less than 0.5 mph, a signal is sent to the System CPU on the MCB107B1 Inverter System Control board. The System CPU then commands the OBA54A1 Digital Output board to energize the NMRK relay coil.

For either channel, if one of the two tachs fail, no-motion is still detected from the remaining speed sensor. If both tachs fail on either channel, no-motion will not be detected. With this condition, the propulsion inverter does not detect No-motion and the No-motion indication on the TOD in the controlling cab will not illuminate at zero speed. The No-motion Bypass Switch in the controlling cab must then be thrown to allow the doors to open.

The main contact of the No-motion Relay is connected between a low voltage power supply and the control coil of the No-motion Relay via relays in the friction brake system Electronic Control Units (ECU) and the Propulsion Logic Unit in both sections of the vehicle. The No-motion relay NMRK in each propulsion box is used in this circuit. See KI Schematic UD01450 Sheet 304 for this circuit.

As seen in Figure 3-20, the A-Unit PLU (controlling the A-unit NMRK) and friction brake ECU supply vehicle 28.5 Vdc battery voltage to the vehicle No-motion relay coil. The B-Unit PLU (controlling the B-unit NMRK) and friction brake ECU connect the return circuit ground to the vehicle No-motion relay.

See Friction Brake descriptions for the control of the ECU relays.

When No-motion is detected, the No-motion indicator on the TOD is illuminated.

[redacted]

3.9.3 Wheel Size Compensation

The Wheel Diameter Correction function is used to accurately calculate vehicle speed and distance. The function calculates the wheel diameter by comparing the speed information of the M-axle and T-axle on the MVB. The diameter of the center truck wheels (axle 3) is measured by maintenance and input using the TOD, and sent to the PLU over the MVB.

The propulsion equipment is designed to compensate for different wheel diameters between axles on a truck. The PLU in each section of the vehicle calculates the wheel diameters of both powered axles on each truck.

Axle 3 is the reference wheel. The wheel diameter for Axle 3 is measured and entered into the vehicle TOD. Only valid diameters of the wheel on axle 3 are accepted as an input. The information is sent over the MVB to both the A-unit and B-unit PLU.

When in Coast, the axle 3 wheel diameter is used by the A-unit PLU to calculate the diameter of the wheels on A truck. The B-unit PLU uses axle 3 to calculate the diameter of the wheels on B truck.

The A-unit logic gets axle 1 and 2 speed data from the A-unit friction brake ECU over the MVB to calculate wheel diameter. The B-unit logic gets axle 5 and 6 speed data from the B-unit friction brake ECU over the MVB to calculate wheel diameter.

If a wheel is smaller than the reference wheel, it counts the pulses for one revolution faster than the reference wheel for one revolution. If a wheel is larger than the reference wheel, it rotates slower than the reference wheel, and the speed sensor counts the pulses in one revolution in a longer time than the reference wheel. The difference in time to count pulses from the reference wheel diameter and the traction motor pulses allows the PLU in each section of the car to calculate the wheel diameter on A truck and B truck.

The diameter of a new wheel is 711 mm (28 inches). When the following conditions are detected, the PLU will declare a fault and shut down that propulsion inverter:

- The wheel diameter of the motor axle is less than 660 mm (26 inches).
- Difference of the wheel diameter between axles in one motor truck exceeds 6 mm (1/4 inch).

Once the wheel diameter fault is detected, maintenance needs to true the wheels of the power truck if there is a difference between axles or replace the wheels if diameter is less than 26 inches. Once completed, enter the center wheel diameter using the TOD. This will reset the fault. This calculation is done at the first Coast after the PLU is powered up and the train speed is above 15 mph.

The reference wheel diameter must be measured and entered into the TOD under the following conditions:

- With each scheduled maintenance interval.
- After installing new wheels on the reference axle 3.
- After truing the wheels on the reference axle 3.
- After replacing the PLU Inver Control Board MCB108B1 or the Propulsion Logic Unit.

The TOD permits only valid wheel diameters to be entered into the logic. If an invalid value is entered, the system including the PLU will leave the wheel diameter at the value that was set before the invalid value was entered. If a calculated wheel diameter is below the minimum size, the inverter will use the minimum size and send a fault message. The PLUs calculate wheel diameters only if the ECU axle speed status is “Valid Tach Signal”.

3.9.4 Overspeed

The Overspeed function is monitored by the lead PLU. If the vehicle exceeds the set overspeed point, it reduces the PLU_Overspeed_Torque_Command to the other PLU on the MVB (as explained below).

The propulsion control system will reduce tractive effort as the vehicle reference speed approaches the overspeed set point, beginning at 2 mph below the enforced speed and reducing the tractive effort to zero at 2 mph above the enforced speed point.

The overspeed set point is 65 mph and the overspeed condition will be detected by the lead PLU which is determined by the active Master Controller. When the leading PLU is cutout or malfunctioned, the PLU from the other section of the leading vehicle will take over the function by checking PLU_Leading_Indication signal on the MVB.

The Speed Governor Relay (SGR) is energized by a digital output from the controlling PLU with speed detected 4 mph above the speed limit.

SGR is also energized with a fault detected in the Propulsion Inhibit Trainline. This trainline is a summary of the friction brake faults and the door open status in the train. The Cab Propulsion Inhibit Relay will be de-energized when the PLU energizes the Speed Governor Relay output signal.

The SGR then de-energizes power to the Master Controller causing a Full Service Brake application. When the vehicle speed goes to 2 mph lower than the speed limit, and both M and CM trainlines are low, the SGR is deenergized.

There is an Overspeed_TL on the WTB which indicates whether the Speed Governing relays are energized or not. This is monitored as a PTU event Trace signal.

There is a Train Overspeed 1 signal at 63 mph. The powering torque starts to be reduced and the operator is to apply brakes to reduce speed.

There is a Train Overspeed 2 signal at 69 mph. Brakes automatically apply.

There is also a signal Overspeed_Torque_CMD_TL in the WTB, which is based on the signal from the lead PLU. This is the amount of torque allowed based on speed. If the train is 2 mph or more under speed limit this is set to 100%. If the train speed is at the speed limit it is set to 50%. If 2 mph or more over the speed limit this is set to 0%. It is linear in between speed limit +/- 2 mph.

In Limp Home Mode or if there is a propulsion fault or cutout or a friction brake fault or cutout, the speed limit is 35 mph. All the inverters in the train will monitor for overspeed individually and will be disabled when detecting overspeed above 35 mph in Limp Home mode.

3.9.5 Reasons for Tach Failure

25% speed difference between Tach 1 (axle 1) and Tach 4 (axle 3) for 1 second while in Coast will cause a tachometer to be declared as failed. The speed sensor which detects the lower speed is considered to be at fault. If Tach 1 is detected as failed (lowest speed), the A-unit propulsion inverter will be disabled.

25% speed difference between Tach 10 (axle 6) and Tach 5 (axle 3) for 1 second while in Coast will cause a tachometer to be declared as failed. The speed sensor which detects the lower speed is considered to be at fault. If Tach 10 is detected as failed (lowest speed), the B-unit propulsion inverter will be disabled.

With a powered axle speed sensor fault detected, the propulsion inverter is disabled and the Line Switch contactor is opened. A fault will be detected which requires a PROP / HSCB Reset from the TOD with a Full Service Brake application at zero speed. The propulsion system cannot operate with a failed tach on a motor truck since the direction may not be accurately calculated.

With a failure of either Channel-A or Channel-B (or both channels) from Tach 1 (to the A-unit PLU) the A-unit propulsion system will be disabled because of the loss of rollback detection.

With a failure of either Channel-A or Channel-B (or both channels) from Tach 10 (to the B-unit PLU) the B-unit propulsion system will be disabled because of the loss of rollback detection.

Trailer axle speed sensor faults have no impact on the propulsion system and will be reset when the speed difference becomes less than 25% and PROP / HSCB Reset command from the TOD is received with a Full Service Brake application at zero speed. With a failure of the center truck speed sensors (Tach 4 or Tach 5) wheel size calculation will be disabled and a message is sent to the TOD.

With any tach detected as failed, there will be a fault record registered in the PLU and the TOD.

NOTE: The speed sensors are pre-set at the factory and are not adjustable or repairable in the field. A speed sensor found to be defective must be replaced.

3.9.6 Speedometer

The propulsion system outputs a speed signal (PLU reference speed) to the MVB. The speedometer on the Aspect Display Unit (ADU) is driven by the ATP. The propulsion speed data is used by the ADU when the ADU loses communication with the ATP.

The reference speed is the minimum value of the operational speed sensors from the powered truck and center truck when powering and the maximum value of the operational speed sensors from the powered truck and center truck when braking.

3.9.7 Odometer

PLU-B drives the vehicle Odometer located on the Hour meter/Odometer panel. The B-unit Inverter System Control Board MCB107B1 creates the output command for the Digital Output Board OBA54A1. The Odometer is updated by a 500 msec signal activated every 161 meters (0.1 mile). The Odometer is driven based on the vehicle reference speed.

PLU provides a distance signal over the MVB for announcement purposes.

3.10 Wheel Spin / Slide Detection and Correction

Wheel Spin and Slide protection is provided on each vehicle whether random or synchronous on an individual truck basis, both in acceleration and braking. When a powered axle Spin or Slide occurs, it changes the magnetic flux of the traction motor and so will affect the current flow through the traction motor. By detecting this change of motor current from the inverter output current transducers, the PLU will detect a wheel Spin or Slide.

For a wheel Spin to be detected, the propulsion system must have a power request.

For a wheel Slide to be detected, the propulsion system must have a brake request.

The larger wheel on the truck will have a tendency to Spin more often in power because of the addition torque being applied to it and increasing the traction motor temperature. The smaller wheel on the truck will have a tendency to produce a higher dynamic brake effort because of the small wheel diameter and increasing the traction motor temperature.

The Propulsion Control applies an adhesion limit to the dynamic braking effort. The purpose of the Adhesion Limited Control is to limit the dynamic braking effort of the vehicle so that the required adhesion reduces the potential of slides. The PLU limits the dynamic braking effort so that the required adhesion coefficient (coefficient of friction between rail and wheels) does not exceed 16% while sliding or applying SCEB. The larger the wheel diameter mismatch, the more often a wheel Spin or Slide may occur.

Adhesion is detected by monitoring the magnetic flux from the traction motors and confirmed by monitoring and comparing the speed sensor output signals.

A braking adhesion failure is any wheel sliding greater than 14.2 mph/ps or more than 25% of a speed differential between M and T axle. When this condition is detected above 3 mph, the propulsion system is disabled for 1 second and Sand is applied to the lead truck on all cars. Braking adhesion failure is detected after the safety timer reaches 10 sec. Braking adhesion failure is not reset until the brake command is reset.

A powering adhesion failure is any wheel spinning greater than 8.9 mph/ps or more than 25% of a speed differential between M and T axle. When this condition is detected, the propulsion system is disabled for 1 second and Sand is applied to only the lead truck for 2 seconds.

With a wheel slide condition detected, the tractive effort command is once reduced then gradually ramped back up to the desired level.

During slide detection, the PLU outputs a Propulsion Slide Detected signal over the MVB to the friction brake system which will prevent the friction brakes from applying during the Slide condition. Regarding blended braking, the PLU continuously outputs a Brake Effort feedback signal to the ECU via the MVB so that the friction brake can apply additional brake effort as necessary.

When the Slide condition is detected and lasts longer than 1 second, the sanding is activated for 2 seconds. If the Slide condition continues, the PLU will keep the Slide Detection Signal low and sanding will continue for up to 8 seconds.

3.10.1 Sanding

The purpose of the Sanding operation is to increase the available adhesion. The spin/slide control is aimed to correct the spin condition by the control of inverter output, and to apply sand when detecting major spin/slide conditions. Sanding is applied while an Adhesion Failure condition or spin/slide is longer than 1 second and the actual braking effort achieved during spinning/sliding is less than 70% of the demanded effort. Sanding will be commanded when the vehicle speed is less than 105 kph (65 mph) in powering.

When a wheel Spin or Slide is detected, it changes the magnetic field of the motor as monitored by the output current transducers from that inverter. With this change of magnetic field, the PLU detects either a wheel Spin or wheel Slide from either traction motor on that truck.

There are two types of adhesion failures which are a Speed Differential Condition and a Major Spin Detection. The Speed Differential Condition is detected when there is more than 25% difference in speed between the motored axle and center truck axle with a Tractive Effort Request.

Major Slip is detected when the acceleration or deceleration rate exceeds the set limits of 3.94 m/s/s in powering and 5.49 m/s/s in braking. The Wheel Slip (spinning) indication will be high when any minor or major wheel spin is detected and the sanding command will be activated with any of the adhesion failure condition.

From each PLU, the Digital Output board OBA54A1 activates the Sanding command which goes Trainline and will energize the sanding magnet valves on the lead truck on each vehicle of the train. With a minor spin/slide condition, sanding is applied for at least 2 seconds and stops when the condition is corrected or 8 seconds have passed. With a major adhesion failure, the propulsion system is disabled for 1 second and the sanding remains active for 2 seconds. The propulsion system is then re-enabled and the slide condition is resampled.

Sanding control is a trainline function. If PLU-A or PLU-B detects a slide it outputs a signal to the sanding control circuit. This will energize relays WSSRB & WSSRA. This will in turn energize the sanding control train line. The lead truck’s magnet valve will then be energized due to the DCFR1A/B contacts closed for the lead truck. The PLU that detected a slide could be on the lead vehicle or a trailing vehicle. Sanding is only supplied on the lead truck.

Sanding can be commanded when vehicle speed is less than 32 kph (20 mph) in power and more than 4.8 kph (3 mph) in braking.

3.11 Fault Reset and Lockout

With a propulsion fault condition, the TOD operating screen Local Indicator Panel propulsion status screen will go red and the Propulsion Fault TL indicator will go red. There is a PROP / HSCB reset button that is part of the TOD Operating screen. To reset a fault in the propulsion system requires the propulsion system disabled, the Line Switch contactor open, Full Service Brake and no-motion detected.

Only the HSCB can be locked out. If the HSCB is tripped open with an overcurrent condition 3 times with 15 minutes in operation, the HSCB is locked out. There is no lockout function for the Line Switch contactors. The HSCB lockout is explained in Section 3.11.4.

The propulsion fault conditions that have no impact on the propulsion system are Wheel Diameter Fault, MVB 1 Fault, MVB 2 Fault, Ethernet Fault, Load Weigh Faults, cooling fan failure or a center truck speed sensor failure.

3.11.1 Automatic Reset

The following is a list of the fault conditions that reset automatically without the operators interface. The automatic fault reset resets any fault condition that is not related to a safety function. The reset occurs at Brake or Coast at any speed once the fault condition has cleared. There is no limit on how many times the following conditions can be repeated.

- Trainline and PBED Fault
- SCEB Fault
- Inverter Cooling Fan Fault
- HSCB Low Voltage Input Power Abnormality vehicle batteries (less than 14.4 Vdc, recovers above 16.8 Vdc).
- Charging Resistor operation disabled if used 3 times in 1 minute, available after a 1 minute delay to cool the resistor.
- Filter capacitor low voltage (Below 435 volts, recovers above 435 volts)
- Filter Capacitor voltage rising (above 950 volts for 1 second, recovers when less than 950 volts).
- Filter Capacitor High Voltage (above 1000 volts, recovers at 950 volts).
- Brake Resistor Overtemperature (above 500 degrees C (932 degrees F), recovers at 450 degrees C (842 degrees F).
- Adhesion failure in powering
- Adhesion failure in braking

- Rollback Detection 38 cm (15 inch) distance or speed more than 1 mph, recovers at No Motion and Full Service Brake application and the Friction Brake Released signal (FBREL) is low.
- Friction Brakes Not Released (recovers at No Motion and Brake command)
- OCS Gap Detected (recovers when the detected filter capacitor voltage is above 750 volts or after 20 seconds elapses).
- Filter Capacitor Low Voltage
- Filter Capacitor Voltage Rising
- Filter Capacitor Overvoltage
- Low Line Voltage (below 475 volts, recovers at 525 volts)
- MVB Fault (recovers when communication link restored)
- IGBT Temperature Rising
- Friction Brake Not Released
- Train Overspeed 1 (63 mph) torque reduced when -2 mph below speed limit

3.11.2 Faults Opening the Line Switch Contactor

The following is a list of the fault conditions that disable the propulsion system and open the Line Switch contactor. The HSCB is not opened. The PROP / HSCB Reset must be selected from the TOD or hard reset must be conducted to reset from any of these conditions. The cause of each event and corrective actions are explained in either the PTU screens or the TOD. The reset occurs at the next Full Service Brake application at zero speed.

- Inverter Output Overcurrent
- Frequent Output Overcurrent (detected three times since the last time the Reverser was placed in Neutral)
- Illegal Torque Detected
- Filter Capacitor Capacitance Fault
- Charging Resistor Protection
- Abnormal Filter Capacitor Charging
- Traction Motor Lead Misconnected
- Traction Motor Overtemperature
- M Axle Speed Sensor Fault
- Transducer or Speed Sensor Power Source Fault
- IGBT Fault (3-phase or Brake Chopper)
- IGBT Overtemperature

- IGBT Gate Fault (3-phase or Brake Chopper)
- Brake Chopper Fault
- Brake Resistor Overtemperature
- Gate Power Source Low Voltage
- Control Circuit Power Low Voltage
- Input Command Abnormality (both FWD and REV signals High at the same time)
- Thermistor Failure
- Phase Current Imbalance
- Watch Dog Fault
- Analog Signal Power Low Voltage
- Propulsion Power Effort Fault
- Truck ID Abnormality

3.11.3 Faults Opening the HSCB and Line Switch Contactors

The following is a list of the fault conditions that will open the High Speed Circuit Breaker and both propulsion Line Switch contactors. The Prop / HSCB Reset must be selected from the TOD or hard reset must be conducted to reset from these conditions. The reset of the HSCB and line switch contactors occurs at the next full service brakeFull Service Brake application at zero speed, while HSCB Tripped can be reset when in motion.

- High Speed Circuit Breaker Tripped (current greater than 3200 amps)
- HSCB Frequently Tripped (3 times in 15 minutes)
- Input overcurrent detected from either propulsion system of greater than 1600 amps for longer than 1 second
- Power Circuit Ground Fault (difference of 50 amps for longer than 200 msec between the input current and return current)
- HSCB, Line Switch or Line Charging Contactor Fault Detected
- HSCB Low Voltage (vehicle batteries) Power Source Failure

There are no propulsion fault conditions that will lock out the line switches. If the HSCB is tripped from an overcurrent condition 3 times within 15 minutes, the HSCB is locked out. If the HSCB trips once (or twice) and not again within 15 minutes the lockout count returns to zero (or drops by 1 every 15 minutes).

Cycling control power to the propulsion logic unit (Hard Reset) will clear the lockout.

The operators display shows which inverter is overcurrent so the operator can cutout the affected inverter and allow the HSCB to be reclosed and the vehicle moves with one propulsion inverter.

HSCB Close / Open cycling under no load conditions is 200,000 times.

3.11.4 High Speed Circuit Breaker Lockout and Recovery

With a HSCB tripped (or commanded open), the HSCB Tripped indicator on the TOD will go red. The HSCB is tripped from an overcurrent trip (3200 amps) or is commanded open from a number of fault conditions.

With the HSCB tripped or commanded open, both Line Switch contactors on that vehicle are commanded to open. There is no limit on how many times the HSCB can be commanded open from a fault condition.

On the third HSCB overcurrent trip within 15 minutes, the HSCB is locked out. With a HSCB lockout, there is a message on the TOD informing the operator that the HSCB is locked out.

If the HSCB trips once (or twice) and not again within 15 minutes the lockout count returns to zero (or drops by 1 every 15 minutes). The lockout count is not saved on Battery Backed Ram. Either control power to the PLU's is cycled (Hard Reset) or the PTU HSCB Lockout Reset can be selected to recover from the lockout.

3.12 Propulsion Logic

As seen in Figure 3-21, the component groupings that make up the propulsion logic are the Propulsion Logic Unit (PLU), the Gateway Unit, the Power Supply Unit and the Gate Driver Boards. The Gate Driver Boards are part of the Inverter Unit and not shown here.

The control software interfaces with the Multi-function Vehicle Bus (MVB) and Wire Train Bus (WTB) networks for train control, diagnostic, and status. The control software also interfaces to the Vehicle Ethernet Networks for diagnostic and status data.

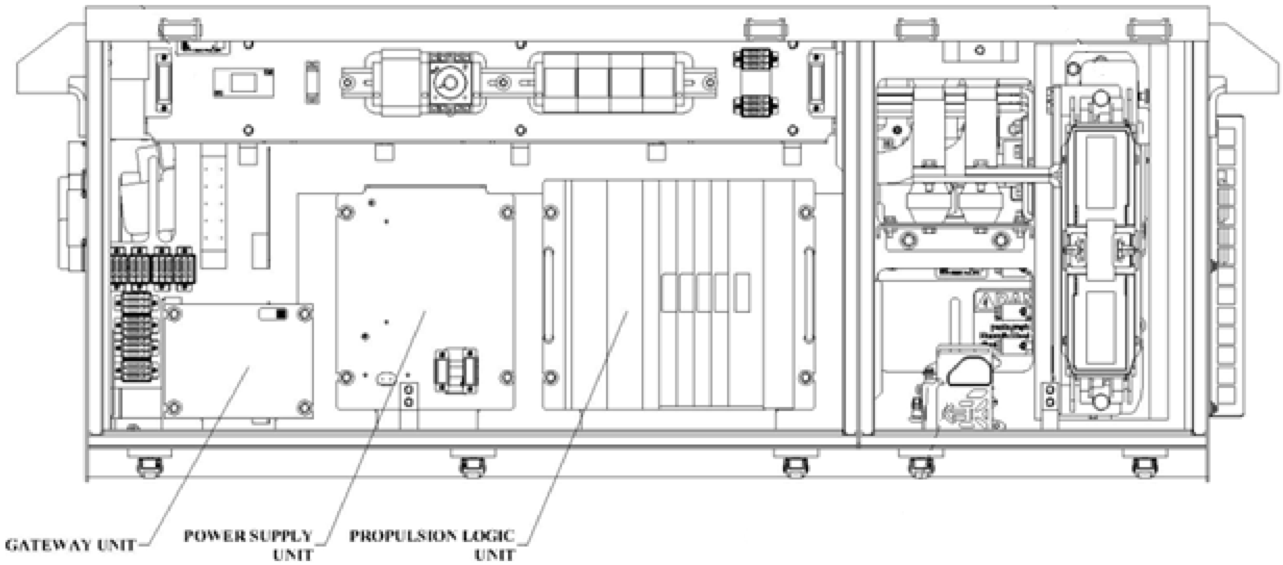


Figure 3-21: Propulsion Logic Components

3.12.1 Propulsion Logic Unit

The Propulsion Logic Unit (PLU) is seen in Figure 3-22. The PLU receives signals from the Master Controller and controls the propulsion power circuit semiconductors, contactors and relays. The PLU is composed of nine PCBs which are removed by loosening the screws at top and bottom and then disengaged from the rack using the locking handles.

The PLU circuit boards interface with the external circuits from connectors on the front plate. With the circuit board front connector latch in the upper position, the connector is locked in place. With the latch pulled down, the connector can be removed or installed.

Five of the circuit boards contain microprocessors. The other circuit boards are two digital input boards, one digital output board and one power supply board.

If any PLU printed circuit board is not installed properly, the PLU will not start. All of the input circuits to the logic and outputs from the logic go through the front connectors.

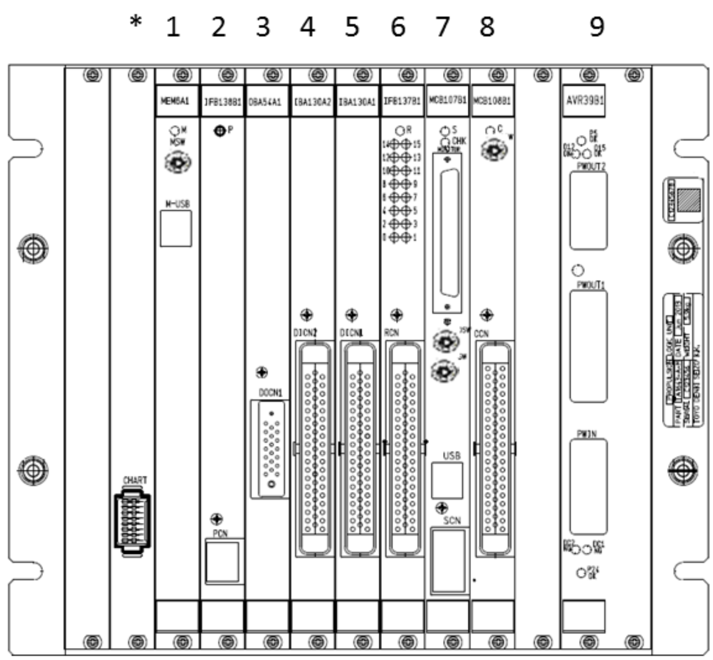
Table 3-4 lists the PLU circuit boards. There are also 2 blank slots. All circuit boards are 6U in size. In the following table, N/A means Not Applicable.

If updates to the PLU software are required, please refer to Section 0700 Portable Test Unit Manual.

Table 3-4. Logic Circuit Boards

Name	Part Number	Input	Output	Other Interface
Inverter System Control Board	MCB107B1	Analog	N/A	USB
Serial Communications Board	IFB137B1	Analog, Gate Driver I/O	Brake Chopper Gate Driver I/O	Serial Communications
Inverter Control Board	MCB108B1	Analog, Gate Driver I/O	Gate Driver I/O	N/A
Chart Output Board *	IFB139B1	N/A	Analog	USB, Serial Communications
Memory Board	MEM6A1	N/A	N/A	USB
Speed Signal Board	IFB138B1	Tach Pulses	N/A	N/A
Digital Input 1	IBA130A1	Digital	N/A	N/A
Digital Input 2	IBA130A2	Digital	N/A	N/A
Digital Output	OBA54A1	N/A	Digital	N/A
Power Supply	AVR39B1	38 Vac	+12 V, +/- 15 V	5V to backplane 24 volt reference

* = The Chart Output board IFB139B1 is not normally fitted in a revenue service car.



1 – Memory
MEM6A1
2 – Speed Signal Processing
IFB138B1
3 – Digital Output
OBA54A1
4 – Digital Input 2
IBA130A2
5 – Digital Input 1
IBA130A1
6 – Serial Communications
IFB137B1
7- Inverter System Control
MCB107B1
8 – Inverter Control
MCB108B1
9 – Power Supply
AVR39B1

* When needed, the Chart Output board IFB139B1 is fitted into this position.

Figure 3-22: Propulsion Logic Unit

In the Propulsion Logic Unit each circuit board is called out with a part number located on the upper handle as noted in the figure above and the Table 3-5 below.

Table 3-5. Logic Circuit Board Functions

Printed Circuit Board	Part Number	CPU	CPU Function	Input / Output Interfaces
Inverter System Control PCB	MCB107B1	System CPU	No Motion Detection Logic Control Torque Command Calculation Fault and Data Logger Communication with PTU Analog Data Input	USB interface for PTU, 3 analog inputs
Inverter Control PCB	MCB108B1	Control CPU	Inverter Control Spin / Slide Control Overheat detection Protective Operations	11 analog inputs
Serial Communications PCB	IFB137B1	Remote CPU	Brake Chopper Control Transmission with MVB Transmission with MDS Digital Data Input / Output Most of the interfaces to other components	Dual channel RS485 interface, Analog and digital I/O.
Memory PCB	MEM6A1	Memory CPU	Fault/Data logging	USB interface
Speed Signal Processing PCB	IFB138B1	Speed CPU	Speed Detection	3 analog interfaces from tach sensors, +12 Vdc output to the speed sensors monitored by the PLU.
Chart Output PCB	IFB139B1	Chart CPU	Chart Data Output NOTE: PCB is not typically installed, used for monitoring and testing only to drive a chart recorder.	8 output channels, RS485 interface, and USB interface
Digital Input 1 PCB	IBA130A1	No CPU	N/A	24 channel isolated digital inputs
Digital Input 2 PCB	IBA130A2	No CPU	N/A	24 channel isolated digital inputs
Digital Output PCB	OBA54A1	No CPU	N/A	16 channel digital outputs
Power Supply PCB	AVR39B1	No CPU	N/A	Input is 38 Vac from Power Supply Unit, Outputs: +5 Vdc to each PCB on the PLU, +15 Vdc and -15 Vdc to the voltage and current transducers, +12 Vdc to Inverter Unit thermistors

Input and Output signals from each PCB of the PLU are shown in Tables 3-6 to 3-10. Wire connection diagram is indicated on connection diagrams B3018019 to B3018048 (see Section 8.4 as necessary).

Table 3-6. Digital Input Signal List of PCB IBA130A1 (connector: DICN1)

Pin No.	Common Ground	Signal name	Function	Signal Specification
55	35	FAN1F	FAN No.1 Status	H(28.5V): Fan No.1 Normal Operation L(0V): Fan No.1 Fault Condition
16		FAN2F	FAN No.2 Status	H(28.5V): Fan No.2 Normal Operation L(0V): Fan No.2 Fault Condition
54		FAN3F	FAN No.3 Status	H(28.5V): Fan No.3 Normal Operation L(0V): Fan No.3 Fault Condition
15		FAN4F	FAN No.4 Status	H(28.5V): Fan No.4 Normal Operation L(0V): Fan No.4 Fault Condition
53	33	FWD	Forward Trainline	H(28.5V): Forward Direction (trainline) L(0V): Not Forward Direction (trainline)
14		REV	Reverse Trainline	H(28.5V): Reverse Direction (trainline) L(0V): Not Reverse Direction (trainline)
52		MCKSR	Master Controller Key Switch Relay	H(28.5V): Active Cab, L(0V): Not Active Cab
13		FBRRL	Friction Brake Released	H(28.5V): Friction Brake Released L(0V): Friction Brake Applied
51	31	LCC	LCC Status	H(28.5V): LCC Open, L(0V): LCC Closed
12		LS	LS Status	H(28.5V): LS Closed, L(0V): LS Open
50		HB28	HSCB control power supply status	H(28.5V): HSCB Control Power Supplied L(0V): HSCB Control Power Not Supplied
11		HSCBS	HSCB Status	H(28.5V): HSCB Closed, L(0V): HSCB Open
49	29	OCBT	HSCB Lockout	H(28.5V): HSCB Lockout L(0V): HSCB Not Lockout
10		PS	Pantograph Status	H(28.5V): Pantograph Lowering L(0V): Pantograph Not Lowering
9		SPRUN	Limp Home Mode	H(28.5V): Not Limp Home Mode L(0V): Limp Home Mode
8	28	-	-	-
7	27	-	-	-
6	26	-	-	-
5	25	-	-	-
4	24	-	-	-
3	23	-	-	-
2	22	-	-	-
1	21	-	-	-

Table 3-7. Digital Input Signal List of PCB IBA130A2 (connector: DICN2)

Pin No.	Common Ground	Signal name	Function	Signal Specification
55	35	EB	Emergency Brake TL	H(28.5V): EB Not Applied (trainline) L(0V): EB Applied (trainline)
16		SCEB	Slide Control Emergency Brake TL	H(28.5V): SCEB Not Applied (trainline) L(0V): SCEB Applied (trainline)
15		PCO	Propulsion Cutout	H(28.5V): Normal L(0V): Propulsion Cutout
53	33	-	-	-
14		IDIN	Truck ID input	H(28.5V): A Unit L(0V): B Unit
52		ATPBP	ATP Bypass	H(28.5V): ATP Bypass L(0V): Normal
13		PWC	Power Cut	H(28.5V): Normal L(0V): Coast Command
51	31	M	Motor (power) TL	H(28.5V): Powering Command (trainline) L(0V): Coast or Braking Command (trainline)
12		CM	Coast Motor TL	H(28.5V): Powering or Coast Command (trainline) L(0V): Braking Command (trainline)
50		TRBR	Track Brake Status	H(28.5V): Track Brake Applied L(0V): Track Brake Not Applied
11		TDU	TDU test mode	H(28.5V): TDU Test Mode L(0V): Normal Operation
49	29	IDIN2	Truck ID input 2	H(28.5V): B Unit L(0V): A Unit
10		NMRS	No Motion Relay NMRK status	H(28.5V): No Motion Relay NMRK Closed L(0V): No Motion Relay NMRK Open
48		ACOK	Fan power supply status	H(28.5V): 208 Vac Fan Power Supplied L(0V): Absence of the Fan Power supply
9		VNMRS	Vehicle No Motion Relay Status	H(28.5V): Vehicle No Motion Relay Closed L(0V): Vehicle No Motion Relay Open
8	28	-	-	-
7	27	-	-	-
6	26	-	-	-
5	25	-	-	-
4	24	-	-	-
3	23	-	-	-
2	22	-	-	-
1	21	-	-	-

Table 3-8. Digital Output Signal List of PCB OBA54A1 (connector: DOCN1)

Pin No.	Common Ground	Signal name	Function	Signal Specification
A	F	-	-	-
C		-	-	-
B		-	-	-
D		-	-	-
E	L	FAN1K	Fan Motor Rotating Command	H(28.5V): Fan Motor Rotating Command L(0V): Absence of Rotating Command
H		LCCRC	LCC Operation Command	H(28.5V): LCC Closing Command L(0V): Absence of Closing Command
K		LSRC	LS Operation Command	H(28.5V): LS Closing Command L(0V): Absence of Closing Command
J		HSCBRC	HSCB Operation Command	H(28.5V): HSCB Closing Command L(0V): Absence of Closing Command
N	R	-	-	-
M		NMRC	No Motion Relay NMRK Operation Command	H(28.5V): No Motion Relay NMRK Closing Command L(0V): Absence of Closing Command
P		FDRC	Propulsion Dynamic Fault	H(28.5V): Propulsion Normal Operation Condition L(0V): Propulsion Fault Condition detected
S		CBTF	HSCB Lockout Command	H(28.5V): HSCB Lockout Operation L(0V): HSCB Normal Operation
T	X	ODP	Odometer Pulse Output	This signal shall go high every 0.1 miles (only A Unit).
V		SGR	Overspeed Detection	H(28.5V): Overspeed Condition Detected L(0V): Overspeed Condition Not Detected
U		SND	Sand Command	H(28.5V): Sand Command
W		-	-	-

Table 3-9. Analog Signal List of PLU Circuit Boards

PCB No.	Connector No.	Signal Pin No.	Ground Pin No.	Signal name	Function	Signal Specification
MCB107B1	SCN	A4	-	TH11	Heatsink temperature (IGBTs Phase U/V)	0 – 10V
		A5	-	TH12	Heatsink temperature (IGBTs Phase V/W)	
		A6	-	TH13	Heatsink temperature (Bch IGBT)	
MCB108B1	CCN	1	2	V12P/V12N	Filter Capacitor Voltage from DCVD2	1250V/10V
		21	22	V11P/V11N	Line Voltage from DCVD1	1250V/10V
		3	4	CTB/CTBN	Brake Resistor Current from CTB	±3000A/±10V
		23	24	CTU/CTUN	Motor Current phase U from CTU	±3000A/±10V
		42	43	CTV/CTVN	Motor Current phase V from CTV	±3000A/±10V
		5	6	CTW/CTWN	Motor Current phase W from CTW	±3000A/±10V
		25	26	CTL/CTLN	Line Current from CTL	±3000A/±10V
		7	8	CTU2/CTU2N	Single Motor Current (Phase U)	±3000A/±10V
		46	47	CTG/CTGN	Return Current from CTG	±3000A/±10V
IFB137B1	RCN	12	13	V12P/V12N	FC Voltage (For Bch Control)	1250V/10V
		14	15	P12D/G12D	Speed Sensor Power Source	12V
		1	-	MN111	RS-485 Signal (MVB)	-
		21	-	MN121		-
		2	-	MN131		-
		3	-	MN311	RS-485 Signal (Ethernet)	-
		22	-	MN321		-
		4	-	MN331		-
IFB138B1	PCN	A2	B1	TACH1A	Speed Sensor Signal (TACH1/10 CH: A)	H: 15V, L: 0V
		B2	B1	TACH1B	Speed Sensor Signal (TACH1/10 CH: B)	H: 15V, L: 0V
		A5	B4	TACH4	Speed Sensor Signal (TACH4/7)	H: 15V, L: 0V
		A1	B1	VSP11/NA1	Speed Sensor Signal Power Supply (TACH1/10 CH: A)	12V
		A3	B3	VSP12/NB1	Speed Sensor Signal Power Supply (TACH1/10 CH: B)	12V
		A4	B4	VSP4/NA4	Speed Sensor Signal Power Supply (TACH4/7)	12V

Table 3-9. Analog Signal List of PLU Circuit Boards (cont'd.)

PCB No.	Connector No.	Signal Pin No.	Ground Pin No.	Signal name	Function	Signal Specification
AVR39B1	PWOUT1	A7	A9	P121/TH1N	Thermistor Power Supply (IGBT Phase U/V)	0 – 10V
		B7	B9	P122/TH2N	Thermistor Power Supply (IGBT Phase V/W)	0 – 10V
		A8	A10	P123/TH3N	Thermistor Power Supply (Bch IGBT)	0 – 10V
		A1	A3	P15L/CTLN	Line Current Transducer Power Supply (Positive)	15V
		A5	A3	M15L/CTLN	Line Current Transducer CTL Power Supply (Negative)	-15V
		B1	B3	P15U2/CTU2N	Single Motor Current Transducer Power Supply (Phase U, Positive)	15V
		B5	B3	M15U2/CTU2N	Single Motor Current Transducer Power Supply (Phase U, Negative)	-15V
AVR39B1	PWOUT1	A2	A4	P15G/CTGN	Return Current Transducer CTG Power Supply (Positive)	15V
		A6	A4	M15G/CTGN	Return Current Transducer CTG Power Supply (Negative)	-15V
	PWOUT2	A1	A4	P152/M152	FC Voltage Detector DCVD2 Power Supply	15V
		B1	B4	P151/M151	Line Voltage Detector DCVD1 Power Supply	15V
		A2	A5	P15B/CTBN	Brake Current Transducer CTB Power Supply (Positive)	15V
		A7	A5	M15B/CTBN	Brake Current Transducer CTB Power Supply (Negative)	-15V
		B2	B5	P15U/CTUN	Motor Current Transducer Power Supply (phase U, Positive)	15V
		B7	B5	M15U/CTUN	Motor Current Transducer Power Supply (phase U, Negative)	-15V
		A3	A6	P15V/CTVN	Motor Current Transducer Power Supply (phase V, Positive)	15V
		A8	A6	M15V/CTVN	Motor Current Transducer Power Supply (phase V, Negative)	-15V
		B3	B6	P15W/CTWN	Motor Current Transducer Power Supply (phase W, Positive)	15V
		B8	B6	M15W/CTWN	Motor Current Transducer Power Supply (phase W, Negative)	-15V

Table 3-10. Gate Firing Signal List

PCB No.	Connector No.	Pin No.	Signal name	Function	Signal Specification
MCB108B1	CCN	12	EX15UP1	DC15V Power Supply (Phase U)	DC15V Power Supply
MCB108B1	CCN	15	UPR1	Gate Firing Signal (Phase U, Positive side)	20mA current loop (Active: Firing the gate)
MCB108B1	CCN	16	UNR1	Gate Firing Signal (Phase U, Negative side)	20mA current loop (Active: Firing the gate)
MCB108B1	CCN	17	UPFO1	Gate Firing Feedback Output Signal (Phase U, Positive side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	18	UPFI1	Gate Firing Feedback Input Signal (Phase U, Positive side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	20	UNFO1	Gate Firing Feedback Output Signal (Phase U, Negative side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	19	UNFI1	Gate Firing Feedback Input Signal l (Phase U, Negative side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	13	EX15UG1	DC15V GND (Phase U)	DC15V Power Supply
MCB108B1	CCN	31	EX15VP1	DC15V Power Supply (Phase V)	DC15V Power Supply
MCB108B1	CCN	34	VPR1	Gate Firing Signal (Phase V, Positive side)	20mA current loop (Active: Firing the gate)
MCB108B1	CCN	35	VNR1	Gate Firing Signal (Phase V, Negative side)	20mA current loop (Active: Firing the gate)
MCB108B1	CCN	36	VPFO1	Gate Firing Feedback Output Signal (Phase V, Positive side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	37	VPFI1	Gate Firing Feedback Input Signal (Phase V, Positive side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	39	VNFO1	Gate Firing Feedback Output Signal (Phase V, Negative side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	38	VNFI1	Gate Firing Feedback Input Signal (Phase V, Negative side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	32	EX15VG1	DC15V GND (Phase V)	DC15V Power Supply
MCB108B1	CCN	51	EX15WP1	DC15V Power Supply (Phase W)	DC15V Power Supply
MCB108B1	CCN	54	WPR1	Gate Firing Signal (Phase W, Positive side)	20mA current loop (Active: Firing the gate)
MCB108B1	CCN	55	WNR1	Gate Firing Signal (Phase W, Negative side)	20mA current loop (Active: Firing the gate)
MCB108B1	CCN	57	WPFO1	Gate Firing Feedback Output Signal (Phase W, Positive side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	56	WPFI1	Gate Firing Feedback Input Signal (Phase W, Positive side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	59	WNFO1	Gate Firing Feedback Output Signal (Phase W, Negative side)	20mA current loop (Active: Gate not fired)
MCB108B1	CCN	58	WNFI1	Gate Firing Feedback Input Signal (Phase W, Negative side)	20mA current loop (Active: Gate not fired)

Table 3-10. Gate Firing Signal List (cont'd.)

PCB No.	Connector No.	Pin No.	Signal name	Function	Signal Specification
MCB108B1	CCN	52	EX15WG1	DC15V GND (Phase W)	DC15V Power Supply
IFB137B1	RCN	19	EXCH1	DC15V Power Supply (Bch)	DC15V Power Supply
IFB137B1	RCN	20	CHR1	Gate Firing Signal (Bch)	20mA current loop (Active: Firing the gate)
IFB137B1	RCN	59	CHFO1	Gate Firing Feedback Output Signal (Bch)	20mA current loop (Active: Gate not fired)
IFB137B1	RCN	39	CHFI1	Gate Firing Feedback Input Signal (Bch)	20mA current loop (Active: Gate not fired)
IFB137B1	RCN	38	EXCHG1	DC15V GND (Bch)	DC15V Power Supply

The status of each Propulsion Logic Unit is sent to the MVB. When the leading PLU (controlling cab) is not operational, the other PLU on that car will take over the function done by the disabled PLU (speed restriction, car wash mode activation and tow mode activation).

Each PLU is identified as IDIN (A-unit PLU) or IDIN2 (B-unit PLU) also noted as Truck ID. This identification is done by monitoring the configuration of a connector connected to each logic assembly. When a PLU ID abnormality is detected, the effected PLU will stop gate firing and open the Line Switch contactor.

The PLU software is located on six different CPUs, all interconnected by the CPU backplane (16 bit parallel bus) within the PLU. Each board with a CPU has a Watchdog function with an associated LED as seen in Figure 3-23. As long as the CPU is operating normally, the Watchdog LED will be blinking.

S LED on MCB107B1 Inverter System Control Board System CPU

C LED on MCB108B1 Inverter Control Board Control CPU

P LED on IFB138B1 Speed Signal Processing Board Speed CPU

M LED on MEM6A1 Memory Board Memory CPU

R LED on IFB137B1 Serial Communications Board Remote CPU

T LED on IFB139B1 Chart Output Board Chart CPU

The propulsion system operating conditions are monitored at every cycle of the propulsion logic processors (CPU's). The processors are 28 MHz, 32-bit, Super-H RISC (Reduced Instruction Set Computing) type SH7044. Each processor cycle time is 5 msec. The inputs are processed at every scan, with the exception of the Digital Input Module of the System CPU. This CPU has 24 input channels and requires four cycles to process the signals from the digital input boards, which is every 20 msec.

Some signals are processed by the CPU's on two or three different circuit boards. In this case the times are added serially. The System, Remote and Control CPU's process all of the critical signals. The Remote and Control CPU's send the analog data inputs to the System CPU.

The System CPU sends a Health Status signal to each CPU. If there is no reply from any of the CPUs within 200 msec, the System CPU will detect a Watchdog fault. The condition of the System CPU will be monitored by the Remote CPU, and the Remote CPU will send a fault condition message if there is no reply from the System CPU. When a Watchdog Fault is detected, the PLU will disable the propulsion system and open the Line Switch contactor.

If one Watchdog LED is Off or continually On, the CPU on that board has crashed. To correct this fault, cycle control power to the PLU. If all of the Watchdog LED's are out, the 5 Vdc supply from the AVR39B1 Power Supply board to the logic circuit boards is not active and possibly has gone into current limiting and shut down the power supply. If the Power Supply Unit is operational, replace each PLU board one at a time until the fault is corrected.

As seen in Figure 3-23 the Inverter System Control board MCB107B1, Inverter Control board MCB108B1 and Memory board MEM6A1 have rotary switches accessible from the front panel.

These are only to be moved during the software upgrade process and should not be changed during normal maintenance. In revenue service, the switches must be in the noted positions.

MEM6A1	Switch MSW in the **F** position
MCB107B1	Upper switch MDSW in the **F** position, and Lower switch SSW in the **1** position
MCB108B1	Switch CSW in the **0** position
IFB139B1	Switch STW in the **F** position (Chart Output board not shown)

CAUTION

IF ANY OF THESE SWITCHES ARE MOVED FROM THE NOTED POSITION ON ANY OF THE BOARDS (EXCEPT FOR THE CHART OUTPUT BOARD), THE PROPULSION SYSTEM WILL BE DISABLED. IF THE SWITCH IS MOVED ON THE CHART OUTPUT BOARD, THE OUTPUT SIGNALS WILL BE DISABLED.

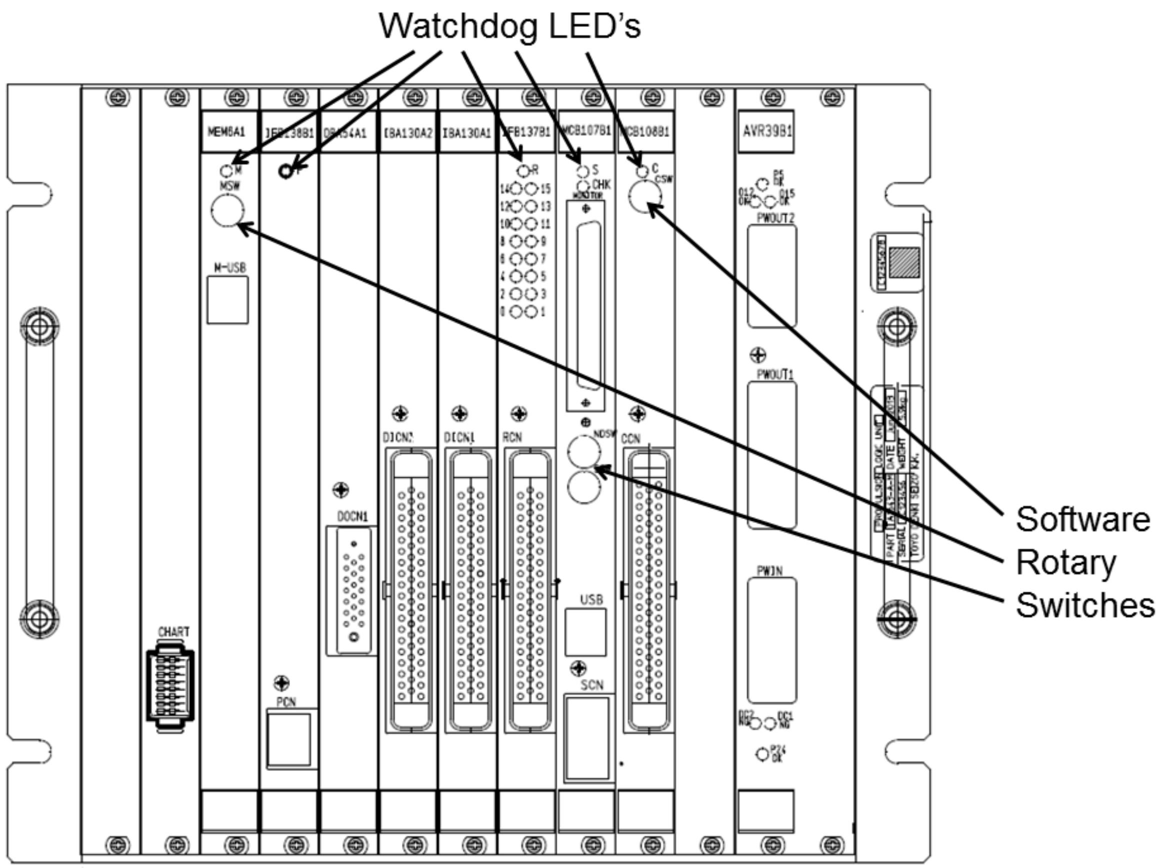


Figure 3-23: Software Rotary Switches and Watchdogs

Figure 3-24 and Figure 3-25 shows the external interface circuits to the Propulsion Logic Unit circuit boards. Figure 3-25 shows the interface circuits to the B-unit Propulsion Logic Unit circuit boards. The arrows indicate the direction of the signal (input or output).

The A-unit has different Tach numbers than the B-unit. There is an Odometer output from the B-unit PLU that is not in the A-unit PLU.

The Memory board MEM6A1 is not shown on Figures 3-24 and 3-25 because it has no external connections.

The Chart Output board IFB139B1 shown in Figures 3-24 and 3-25 is only used for data collection and is not normally fitted to revenue service cars. When used, this board is positioned in the slot to the left of the MEM6A1 board shown in Figure 3-23.

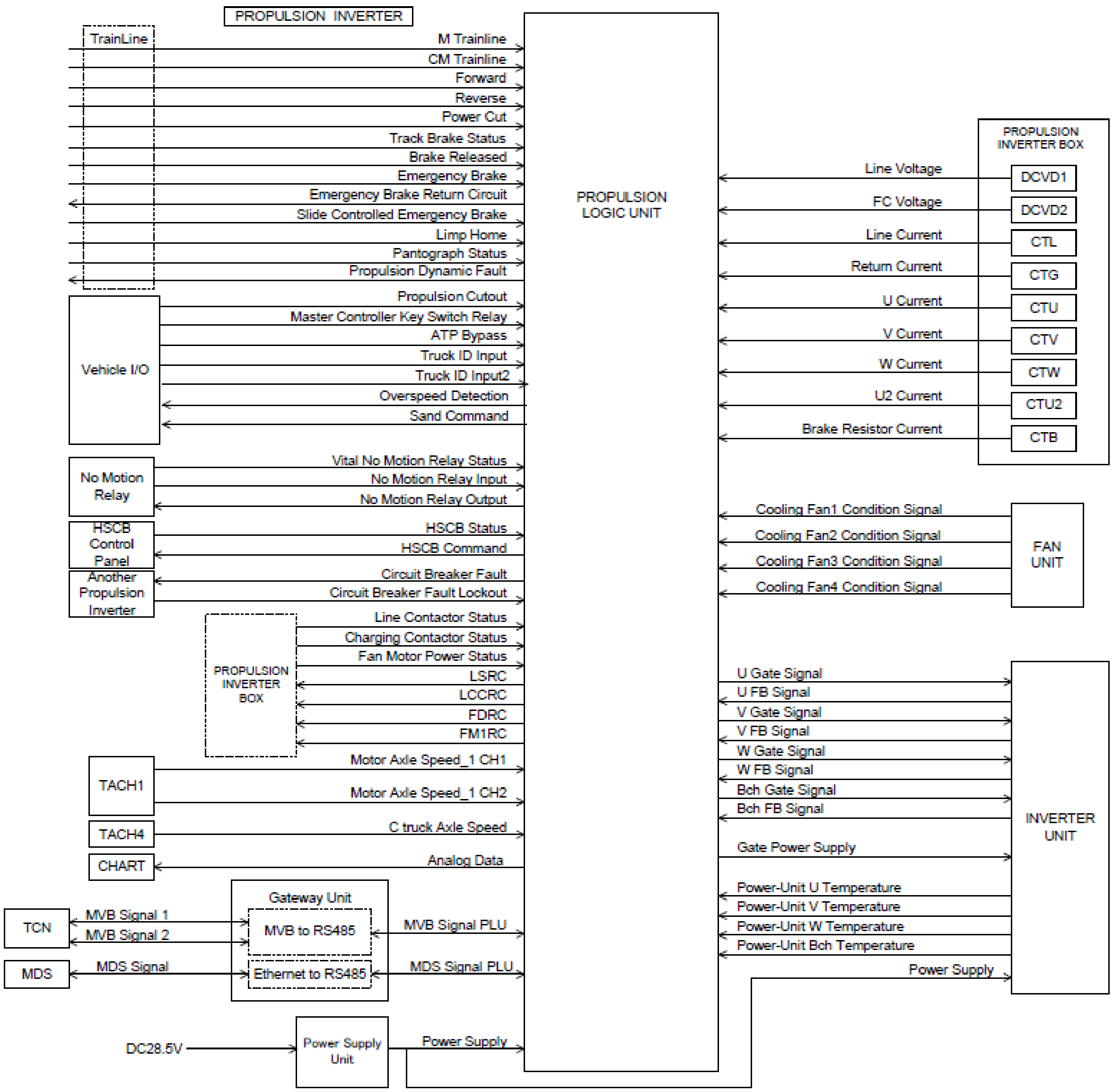


Figure 3-24: A-Unit PLU Interfaces

Figure 3-25 shows the interface circuits to the B-unit Propulsion Logic Unit circuit boards. The arrows indicate the direction of the signal (input or output). The B-unit has the Odometer output signal and different Tach numbers than the A-unit (Figure 3-24).

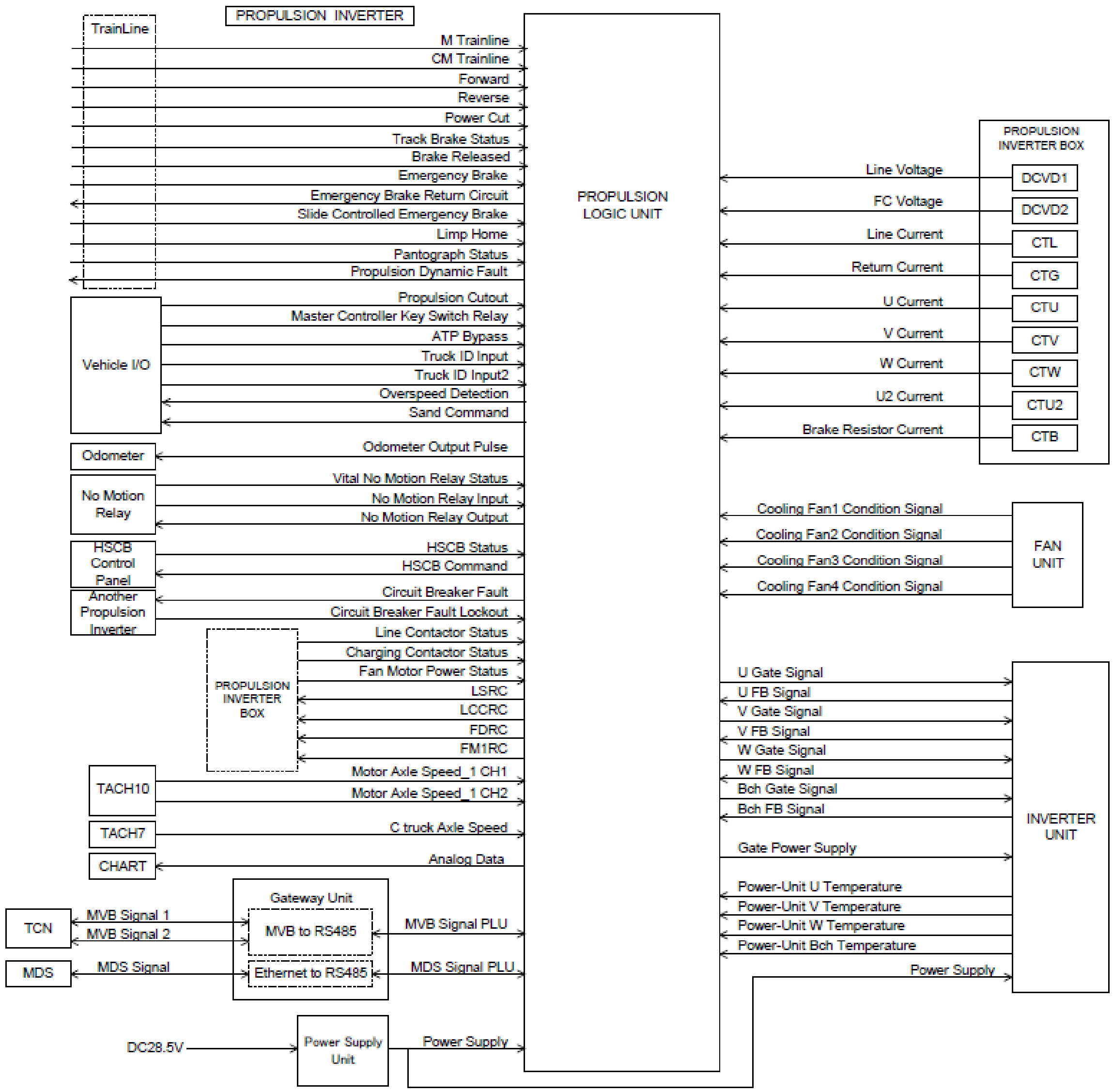
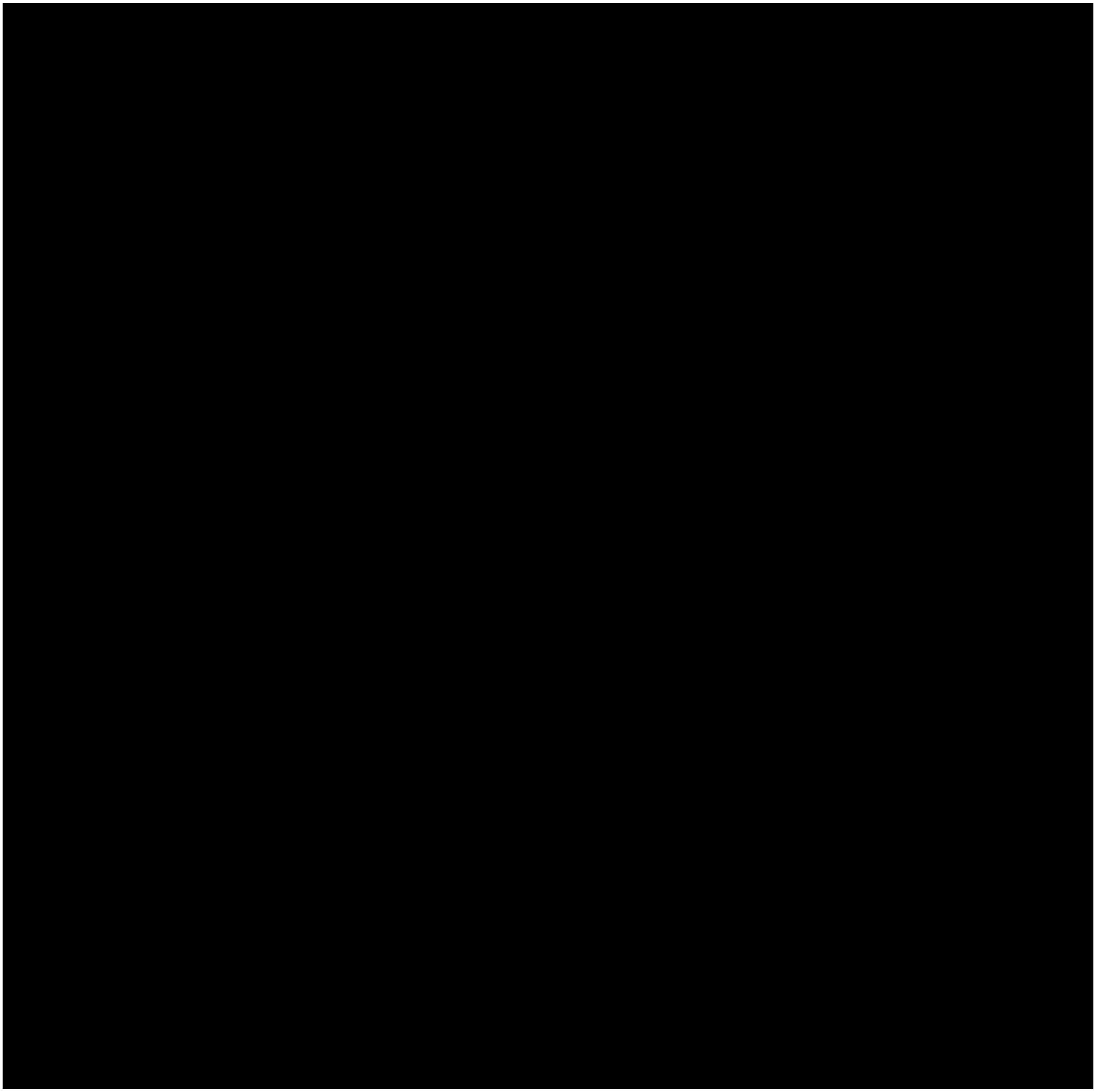


Figure 3-25: B-Unit PLU Interfaces

Figure 3-26 shows the block diagram of the internal circuits for each circuit board for the Propulsion Logic Unit.

[redacted]

Figure 3-27 shows the data flow diagram between the various circuit boards for the PLU. The Remote CPU is responsible for most of the interfaces to other components. The System CPU is the main CPU and communicates with all of the remaining CPU's. Necessary data to operate each function is transmitted between each CPU through the 16 Bit parallel Data Bus on PLU backplane.



3.12.1.1 Memory Board MEM6A1

This circuit board is for the PTU data logger. When propulsion events occur, data for 2 seconds before and 2 seconds after the occurrence are retained in Flash ROM. The sampling frequency is 200 Hz. The Memory CPU is located on this board for PTU data logging. The circuit structure of the Memory CPU is as follows.

Flash ROM

> Flash Read Only Memory is required to record the operational status when a protective operation (fault) occurs.

External RAM

> Static Random Access Memory is required to temporary buffer the operation status. Dual port RAM is required to share the data between the System CPU and the Memory CPU.

USB Interface

> A Universal Serial Bus interface is required for connecting with the PTU computer. The program for the Memory CPU can be downloaded in Flash ROM by using the PTU computer.

This board has a LED designated as **M** which is a software watchdog indicator which should be blinking.

This board should not be swapped between logics on the same car or between cars. The PTU data logger events are saved on this board and if the board is swapped, events will be displayed on a car that never had those events. The events can be erased from the memory as explained in the PTU Manual Section 2.6.

3.12.1.2 Speed Signal Processing Board IFB138B1

This board interfaces with the speed sensors monitored by the propulsion system. The interface is for two speed sensors for each PLU. The output signals from the speed sensors are isolated with photo-couplers, and converted into the pulse shape at a 5 volt level. This signal is provided directly to the Speed CPU located on this board. Dual port RAM is required to share the data between the System CPU and the Speed CPU.

The Tach Speed CPU software performs the following function:

- Speed Detection
- Speed Differential
- Direction Detected

This board has a LED designated as **P** which is a software watchdog indicator which should be blinking.

This circuit board contains a 12 Vdc power supply used to power the speed sensors that are monitored by the board in that section of the vehicle. The PLU powers only the speed sensors that are monitored by the PLU. If this power supply voltage should fall to 7 volts or less, it is detected as a failure. With a failure of the 12 Vdc supply, both speed sensors powered by the PLU in that section will fail and cause the propulsion system to be disabled.

With this failure, disconnect each of the appropriate speed sensors to see if the power supply output recovers. The A-unit Speed Signal Processing board powers Tach 1 and Tach 4. The B-unit Speed Signal Processing board powers Tach 5 and Tach 10. See Figure 3-16 for the axle locations of each of these speed sensors.

The 12 Vdc supply to the speed sensors is monitored from the Serial Communications board IFB137B1.

The speed sensor input signals and output voltages go through equipment case connector CN6 as seen in Section 8.4 Connection Drawing B3018036. Power supply designations are VSP11, VSP12 and VSP4 as seen in drawing B519943 Zone D1 and D2.

The speed processing board signals are used for the following:

- No-Motion driving relays control
- Wheel diameter compensation
- Odometer signal output
- Overspeed detection
- Wheel lock detection
- Car Wash mode
- Speedometer signal used if ATP is cutout

For the A-unit of the vehicle, both channels of TACH1 are required to detect Forward / Reverse.

For the B-unit of the vehicle, both channels of TACH10 are required to detect Forward / Reverse.

The following speed sensor signals are input to and powered from the Speed Signal Processing board:

From the A-unit PLU board:

TACH11	Speed sensor signal TACH1 (Axle 1) Channel A (or 1)
TACH12	Speed sensor signal TACH1 (Axle 1) Channel B (or 2)
TACH4	Speed sensor signal TACH4 (Axle 3)

From the B-unit PLU board:

TACH101	Speed sensor signal TACH10 (Axle 6) Channel A (or 1)
TACH102	Speed sensor signal TACH10 (Axle 6) Channel B (or 2)
TACH5	Speed sensor signal TACH5 (Axle 3)

See Section 8.4 drawing B3018028 PLU IFB138B1Connection Diagram for the interface connections to this circuit board.

3.12.1.3 Digital Output Board OBA54A1

This board contains 16 digital output circuits. The output signals are sent from the Inverter System Control Board MCB107B1 containing the System CPU over the 16 bit data bus. The 5 volt signals are isolated with a photo-MOS relay and converted into a battery level output voltage. The following signals are output from this board:

FAN1K	Fan Motor Rotation Command
LCCRC	Line Charging Contactor Operating Command
LSRC	Line Switch Relay Command
HBCC	HSCBCK Command to drive the High Speed Circuit Breaker
NMRC	No-Motion Relay Command
PDF	Propulsion Dynamic Fault
CBTF1	High Speed Circuit Breaker Fault (PLU-A)
CBTF2	High Speed Circuit Breaker Fault (PLU-B)
ODP	Odometer Pulse Output (PLU-B only)
SGR	Speed Governor Relay (Overspeed Detect)
SND	Sand Command Relay

The above signals are explained in detail in the Propulsion Input / Output List in Section 6.3.

All of the above digital outputs are driven from vehicle batteries. With a short circuit load or ground on the supply side, the current surge will trip a vehicle circuit breaker in the cab.

See Section 8.4 drawing B3018027 PLU OBA54A1 Connection Diagram for the interface connections to this circuit board.

3.12.1.4 Digital Input Board 2 IBA130A2

This board is capable of 24 digital input circuits. Each input signal is isolated with a photo-coupler which converts the vehicle 28.5 Vdc battery voltage into 5 volts which is then processed by the logic. Each digital input signal is sent to the Inverter System Control Board MCB107B1 containing the System CPU over the 16 bit data bus.

The following signals are input to this board:

EB	Emergency Brake Trainline
SCEB	Slide Controlled Emergency Brake Trainline
PCO	Propulsion Cutout
IDIN	PLU ID input A-unit (IDIN2 for the B-unit)
ATPBP	Automatic Train Protection Bypass
PWC	Power Cut
M	Motor Trainline
CM	Coast / Motor Trainline
TRBR	Track Brake Status
IDIN2	PLU ID input 2 (B-unit)
NMRS	No Motion Relay NMRK Contact Status
VNMRS	Vehicle No-motion Relay Status
AC208	Detection of vehicle APS 3-phase output

The above signals are explained in detail in the Propulsion Input / Output List in Section 6.3.

See Section 8.4 drawing B3018025 PLU IBA130A1 Connection Diagram for the interface connections to this circuit board.

3.12.1.5 Digital Input Board 1 IBA130A1

This board contains 24 digital input circuits. Each input signal is isolated with a photo-coupler which converts the vehicle 28.5 Vdc battery voltage into 5 volts which is then processed by the logic. Each digital signal is sent to the Inverter System Control Board MCB107B1 containing the System CPU over the 16 bit data bus.

The following signals are input to this board:

FAN1F	Inverter Unit Cooling Fan No.1 Status
FAN2F	Inverter Unit Cooling Fan No.2 Status
FAN3F	Inverter Unit Cooling Fan No.3 Status
FAN4F	Inverter Unit Cooling Fan No.4 Status
FWD	Forward Trainline
REV	Reverse Trainline
MCKSR	Master Controller Key Switch Relay
FBREL	Friction Brake Released
LCC	Line Charging Contactor status
LS	Line Switch Contactor status
HB24	High Speed Circuit Breaker control power supply status
HSCBS	High Speed Circuit Breaker Status
OCBT	High Speed Circuit Breaker Lockout
PS	Pantograph Status
SPRUN	Limp Home Mode

The above signals are explained in detail in the Propulsion Input / Output List in Section 6.3.

See Section 8.4 drawing B3018025 PLU IBA130A1 Connection Diagram for the interface connections to this circuit board.

3.12.1.6 Serial Communications Board IFB137B1

This board contains the Remote CPU and communicates with the Gateway Unit RS485 serial communication link and does the Brake Chopper circuit control. This circuit board is also responsible for software updates to the other CPU's in the PLU.

The Remote CPU software performs the following functions:

- Brake Chopper Control
- Communication with the MVB
- Communication with the MDS

The **R** LED on the front plate is a software watchdog indicator and should be blinking.

The additional 16 LED's on the front of this board are not being used on this project.

The Software update process is as follows.

This board makes changes to the System CPU program on the Inverter System Control Board. The software is downloaded via the MDS (Ethernet). The Control, Remote, Speed, Memory and Chart CPU's are updated as required from the System CPU.

Software changes will be conducted in the following order:

1. The Serial Communications board Remote CPU receives the software from the transmission equipment external of the Propulsion Inverter equipment.

2. The Remote CPU saves the software received in an external memory.

3. The Remote CPU changes the operation mode of the System CPU from the boot mode to software upgrade mode.

4. The Remote CPU provides a reset signal to the System CPU. The Reset start is executed by boot mode.

5. The Remote CPU writes the software saved in the external memory to the Flash ROM in the System CPU.

6. The Remote CPU holds in memory the most current software versions.

The serial communications board circuit structure is as follows.

RS485 Interface

The interface required for serial communication is the RS485 interface. There are 2 channels of RS485 interface.

Analog Input circuits - There are 4 channels of analog input circuits. The range of the input voltage is -10V-+10V. The analog signal is converted into the digital signal with an A/D converter through the differential input amplifier. The digital signal is sent to the Remote CPU by a 16 bit data bus. Filter capacitor voltage is read as an analog signal through a transducer. The analog input circuit uses 1 channel of the 4 available channels.

Brake Chopper Gate Driver I/O Circuit

There is a 1 channel gate driver I/O circuit for the brake chopper. This brake chopper Gate Driver I/O is an interface that provides the IGBT drive signal to the gate driver circuit board (located inside the Inverter Unit). The output signal is isolated with a photo-coupler, and transmitted by a 20mA current loop. The state of the gate driver circuit board drive signal is fed back by a current loop, isolated with a photo-coupler, and converted into 5 volts.

Gate Drive Error Detect

The gate drive output signal is compared with the status of the feedback signal. With an error detected between the output and the status signals, the propulsion system will be disabled.

External RAM

The Dual port Random Access Memory is required to share the data between the System CPU and the Remote CPU.

Serial Channel Select

Serial Channel Select circuit selects the target CPU by the position of the Inverter System Control board MCB107B1 rotary switch for updating the software. While the software update is executed, the USB interface cannot be used.

Chrystal Oscillator

The Serial Communications board has a crystal oscillator. The crystal is used to regulate the operating frequency of the brake chopper circuit (at 300 Hz.). The purpose of the Crystal Oscillator Frequency Fault Detection function is to confirm if the output frequency of the crystal oscillator on the Remote CPU is changed so that the operation of brake chopper does not have EMI issues.

The System CPU calculates the time period between the interrupt signals and when there is no change of the frequency of the crystal oscillator, the System CPU calculates the time period as 1 second. If the System CPU reads a different count value than 1 second, it means that the crystal oscillator output frequency on the Remote CPU and/or the System CPU has changed and should be considered as incorrect.

The following Analog signals are input to the Serial Communications board Remote CPU:

VC2 - Filter Capacitor Voltage for Brake Chopper Control 1250 V = 10 V to logic

PBED - Power and Brake Effort Demand which is a PWM signal from the Master Controller.

The 12 Vdc speed sensor power supply voltage from the Speed Signal Processing board IFB138B1 is monitored from this board. If the voltage level falls to 7 Vdc, the propulsion system will be disabled and a fault will be added to the PTU Fault Protection screen.

The Filter Capacitor Fault detection calculations are done on this board.

See Section 8.4 drawing B3018023 PLU IFB137B1 Connection Diagram for the interface connections to this circuit board.

3.12.1.7 Inverter System Control Board MCB107B1

This is the main circuit board of the Propulsion Logic Unit containing the System CPU.

The System CPU has the following functions:

- To execute the drive / stop sequences of the inverter
- To calculate motor torque patterns (Tractive Effort Request)
- Overtemperature Detection
- No Motion Detection
- Logic Control (monitoring the CPU watchdogs)
- Fault and Data Logger
- Interface with the PTU
- Analog Data Input (see below)
- Phase Current Imbalance
- Traction motor misconnection
- Return Current Monitoring
- Brake Resistor Current and Temperature Monitoring

The **S** LED on the front plate is a software watchdog indicator and should be blinking.

The following analog signals are input to the Inverter System Control Board System CPU:

TH11	Heatsink temperature IGBT Phase U/V	0 to 10 Vdc to logic
TH12	Heatsink temperature IGBT Phase V/W	0 to 10 Vdc to logic
TH13	Heatsink temperature Phase W/Brake Chopper IGBT	0 to 10 Vdc

The Inverter System CPU communicates with all other CPUs in the Propulsion Logic Unit. The circuit structure is as follows.

Analog Input Circuits

There are 3 channels of analog inputs. The range of the input voltage is 0 to 10 volts. The analog signal changes the voltage to half through the differential input amplifier. The signal is converted into the digital signal using an A/D converter built in the System CPU. The differential input amplifier is effective to reduce any common mode noise.

USB Interface and Serial Channel Select Circuit

The Universal Serial Bus interface is required for connecting with the PTU computer. The program for the System CPU can be downloaded in Flash ROM by using the PTU computer. The program for the Control CPU (Inverter Control Board), the program for the Remote CPU (Serial Communications Board), and the program for Speed CPU (Speed Signal Processing Board) can be also downloaded in Flash ROM by using the PTU computer.

USB interface

The selection of any of the four CPUs can be switched with the Rotary Switch on the front panel. The position of the rotary switch selects which CPU is targeted. The serial Channel Select circuit selects the target CPU by the position of the rotary switch. When the software update is begun preformed, the Universal Serial Bus interface cannot be used.

Real Time Clock (RTC)

The Real Time Clock data is required to record the date and time that the failure event and the protection event occurrence from the PTU. The RTC is synchronized with the vehicle GPS time. The real time data is transmitted by the MDS.

Reset Circuit

When the power supply is turned on, the CPUs on each circuit board are reset.

See Section 8.4 drawing B3018022 PLU MCB107B1 Connection Diagram for the interface connections to this circuit board.

3.12.1.8 Inverter Control Board MCB108B1

This circuit board controls the operation of the inverter and has a CPU called the Control CPU. The motor torque command (Tractive Effort) for Power and Brake is provided from the Inverter System Control Board System CPU. According to the command from the System CPU, the Control CPU performs the calculations of the three-phase gate drive signals.

The **C** LED on the front plate is a software watchdog indicator and should be blinking.

The Control CPU software performs the following functions:

- Inverter Control
- Wheel Spin / Slide Control
- Protective Operations -
  - Filter Capacitor Fault Detection calculations
  - Gate Driver signals
  - Traction Motor Current Fault Detection
  - Line Current Fault Detection

The following analog signals are input to the Inverter Control board:

VC1	Filter Capacitor Voltage from DCVD2	1250 V = 10 Vdc to logic
VL	Line Voltage from DCVD1	1250 V = 10 Vdc to logic
IB	Brake Resistor Current from CTB	+/- 1000 A = +/- 10 Vdc to logic
IU	Motor Current (phase U) from CTU	+/- 2000 A = +/- 10 Vdc to logic
IV	Motor Current (phase V) from CTV	+/- 2000 A = +/- 10 Vdc to logic
IW	Motor Current (phase W) from CTW	+/- 2000 A = +/- 10 Vdc to logic
IL	Line Current from CTL	+/- 2000 A = +/- 10 Vdc to logic
IG	Ground Current from CTG	+/- 2000 A = +/- 10 Vdc to logic
IU2	Single Motor Current (Phase U) from CTU2	2000 A = 10 Vdc to logic

The following circuits are used to control the inverter:

Analog Input circuits

There are 11 channels of analog input. The range of the input voltage is -10 volts to +10 volts. The analog signals are converted into a digital format with an A/D converter through a differential input amplifier. The digital signal is then sent to the Control CPU by a 16 bit data bus. The differential input amplifier is effective to reduce any common mode noise.

Gate Driver I/O Circuit

There are 6 channels for Gate Driver I/O. Gate Driver I/O is an interface that provides the IGBT drive signal to the three-phase gate driver PCB's (located inside the Inverter Unit). The output signal is isolated with a photo-coupler, and transmitted by a 20 milliamp current loop. The state of the three-phase gate driver boards drive signal is fed back by a current loop, isolated with the photo-coupler, and converted into 5 volts.

Gate Drive Error Detect circuit

The logic of the gate drive output signal is compared with the logic of the feedback signal. The state of the drive signal and feedback signal in the three-phase gate driver boards is monitored.

External RAM

Dual port Random Access Memory is required to share the data between the System CPU and the Control CPU.

See Section 8.4 drawing B3018021 PLU MCB108B1 Connection Diagram for the interface connections to this circuit board.

3.12.1.9 Power Supply Board AVR39B1

The input voltage to this board is 38 Vac (Square-wave, 25 kHz, duty cycle 50%) from the Power Supply Unit. The Power Supply board converts the 38 volts square wave to 24 Vdc. From the 24 volt internal supply, the Power Supply Board power creates 5 Vdc to each circuit board in the PLU, +15 Vdc to the power circuit voltage detectors DCVD1 and DCVD2 and +/- 15 Vdc to each of the current transducers. 12 Vdc is supplied to the temperature detection thermistors in the Inverter Unit.

The outputs are current limited. If an overcurrent condition occurs, the 15 volt, 12 volt or P5 LED will go out. When the short circuit load is removed, the power supply will recover.

The following LED indicators are located on this board:

P5 (Green) On when 5 Vac power input from the PLU is within limits. Powered from the 38 Vac from the Power Supply Unit is current limited. There are two separate 30 Watt, 5 Vdc power supplies in parallel powering the PLU (DC1 and DC2). With either of these failed, the DC1 NG or DC2 NG LED will be turned on as explained below.

12 (Green) On when the 12 volt output to the Inverter Unit thermistors is within limits. This power supply is powered from the 24 Vdc internal power supply and is current limited.

15 (Green) On when the + and - 15 volt outputs to the voltage detectors and current transducers are within limits. This power supply is powered from the 24 Vdc internal power supply and is current limited.

P24OK (Green) On when the 24 Vdc reference voltage internal to the Power Supply board is within limits. This power supply is powered from the 38 Vac from the Power Supply Unit and is current limited.

DC1 NG (Red) Normally Off – On with a fault in one 5 Vdc output to the PLU.

DC2 NG (Red) Normally Off – On with a fault in one 5 Vdc output to the PLU.

NOTE: The PLU Power Supply board P24OK LED will be Off with no input power from the vehicle battery supply to the Power Supply Unit, a short circuit load from the PLU Power Supply board or a short circuit load from any of the gate driver boards.

See Section 8.4 drawing B3018020 PLU AVR39B1 Connection Diagram for the interface connections to this circuit board.

3.12.1.10 Chart Output Board IFB139B1

This board is for chart recorder and serial communication interface. This board is used to output selected signals to a chart recorder for monitoring and troubleshooting. This board contains the Chart CPU for Chart and Serial communications.

This board is not normally installed in the Propulsion Logic Unit, because it is only for monitoring, diagnostic, and testing with the PTU interface to a chart recorder. It is installed into the PLU only when needed.

The blank cover that is removed to fit this circuit board has a blank socket to hold the connector that will interface with the circuit board when installed.

Chart Recorder Output

There are 8 channels of analog and digital outputs which can be used for the chart recorder. Each analog output signal starts as a digital signal from the CPU and is sent to the D/A converter from the chart recorder output. The range of the digital output signals is 0V to +10V. The range of the analog output signals is -10V to +10V.

RS485 Interface

RS485 interface is required for Serial Communication. The serial communication is for TOYO's factory facility testing purposes.

USB Interface

A Universal Serial Bus interface is required for connecting with a computer. The program for the Chart CPU can be downloaded in Flash ROM by using this interface.

Necessary data to operate each function is transmitted between each CPU through an internal bus.

See Section 8.4 drawing B3018024 PLU IFB139B1 Connection Diagram for the interface connections to this circuit board.

3.12.2 Gate Driver Boards

The Gate Driver boards are attached to the Inverter Unit and accessed from the propulsion equipment case bottom cover. The function of the gate driver boards is to turn On and turn Off the power circuit IGBT's as commanded from the PLU. Each gate driver board controls 2 IGBT's. The 3-phase inverter gate driver boards are controlled by the Inverter Control board. The brake chopper gate driver board is controlled from the Serial Communications board.

The Power Supply Unit supplies 38 Vac (square-wave, 25 kHz, duty cycle of 50%) to the gate drivers. Refer to Section 8.4, Drawing B519943 on Zone F7. The IGBT is turned On with a 20mA current loop through the IGBT gate - emitter junction from the gate driver board. The emitter - collector junction carries the load current. Current flow is always from the Collector to the Emitter.

A positive signal from the gate driver to the IGBT gate-to-cathode will cause the IGBT to conduct. A negative voltage from the gate driver (gate-to-cathode) will cause the IGBT to be turned off. When the inverter is not operating, a negative bias is impressed on the IGBT gate-to-cathode. This negative voltage is used to ensure that a transient or spike voltages will not turn on the device when it is not intended. For an IGBT to conduct, a positive voltage must be on the anode and a negative voltage on the cathode.

The gate driver board has a Status output back to the PLU indicating that the command has been received and that the IGBT has been turned On or Off as commanded. If the gate driver command signal disagrees with the status signal it is considered a fault condition. When a Gate Driver Fault is detected, the PLU shuts down the propulsion system and opens the Line Switch contactor.

A short circuit control voltage load from any of the gate driver boards will cause the 38 Vac output from the Power Supply Unit to shut down. This will be indicated with the loss of the P24OK LED located on the PLU Power Supply board AVR39B1.

See Section 8.4 drawing B3018047 Gate Drive PCB Connection Diagram for the interface connections to this circuit board.

3.12.3 Power Supply Unit (PSU)

As seen in Figure 3-21, the Power Supply Unit is located adjacent to the PLU and Gateway Unit in the propulsion equipment case. A block diagram of the Power Supply Unit is shown in Figure 3-28. The Power Supply Unit is a DC-AC converter. The Input voltage is vehicle batteries. The range of the input potential is 17 Vdc to 30 Vdc.

The Power Supply Unit output is 38 Vac (square-wave, 25 kHz, duty cycle of 50%) to the PLU Power Supply Board AVR39B1 and gate drivers in the Inverter Unit. The input is vehicle battery voltage (28.5 vdc) connected on the front panel. A capacitor in the PSU is charged when vehicle battery voltage is applied. The input circuit is controlled by a current limiting resistor while the capacitor is being charged. When the capacitor is fully charged, the thyristor then turns on and bypasses the charging resistor in the PSU.

NOTE: The PLU Power Supply board P24OK LED will be Off with no input power from the vehicle battery supply to the Power Supply Unit, a short circuit load from the PLU Power Supply board or a short circuit load from any of the gate driver boards.

There are two banana jacks at the front of the unit which are used for testing only and have no revenue service application.

[redacted]

See Section 8.4 drawing B3018029 Power Supply Unit Connection Diagram for the interface connections to this circuit board.

3.12.4 Gateway Unit

As seen in Figure 3-21, the propulsion Gateway Unit is located adjacent to the PLU and Power Supply Unit in the propulsion equipment case. The Gateway Unit outline can be seen in Figure 3-29. A block diagram of the Gateway Unit functions is seen in Figure 3-30.

NOTE: The vehicle MVB network also has an Ethernet Gateway Unit located in the TCN rack of the equipment locker and used for MDS communications. This other Gateway is different from the propulsion Gateway Unit.

The propulsion Gateway Unit has all of the external communications paths to the PLU except for the hardware signals at the CN connectors on the propulsion equipment case.

The PLU communicates with the Gateway Unit from the Serial Communications board IFB137B1. The Gateway Unit is connected to the propulsion equipment case connectors CN3 and CN4 to the vehicle and the Train Network.

The RS485 signals from the PLU are converted to Ethernet and MVB signals in the Gateway Unit which provides mutual translation of the MVB signals and RS-485 signals.

The Train Control Network (TCN) has 2 redundant busses, the Multi-function Vehicle Bus (MVB) and the Wire Train Bus (WTB) for communication to additional trains. Each bus has a Network A and a Network B. In all cases, the propulsion control TCN (MVB) signals are generated by an RS485 to MVB conversion circuit board on the Gateway Unit. The maximum transmission rate is 500 kbps.

If only one Channel is not operating, that does not disable the propulsion system. This condition is defined as a Disturbance and not a Fault condition. When both channels are in failure, the propulsion systems on that car are disabled and the line switch contactors are opened. This condition is defined as a Protection.

With Limp Home selected, the propulsion line switches close and the inverter operates at reduced performance with no dynamic braking and a speed limit of 35 mph. Once the communications comes back on either channel, the PLU automatically resets the Protection condition.

The Gateway Unit has the following status LED indicators:

RUN – A Watchdog LED that should always be blinking. If either Off or continually On, cycle control power to the Gateway Unit.

PWR – This LED is On when the Gateway Unit is powered up. If Off, the Gateway Unit has failed or the vehicle battery voltage control power is missing.

FAULT – Not used

ALARM – When Off, the Gateway software has not detected a failure. When steady On, a communications timeout has occurred with either the MVB or RS485 lines.

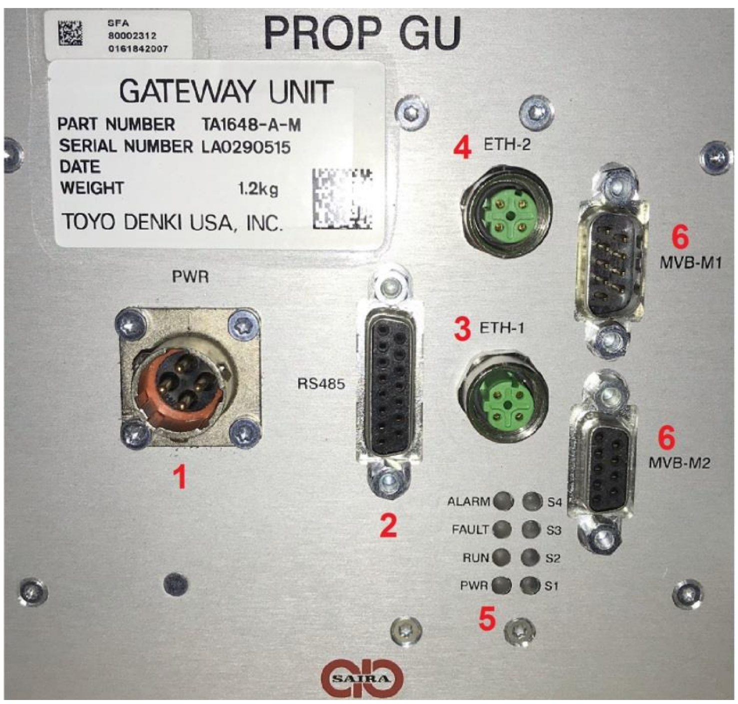
If the ALARM LED is blinking, that means that the device is waiting for a role assignment. This means that the vehicle Ethernet server is attempting to assign a dynamic IP address. The default settings use static IP addressing for secure communications. So, if this LED is blinking, refer to the vehicle Ethernet set up instructions. This is not a fault of the Gateway Unit but something going on with the vehicle.

S1 – When Off, communications with RS485/ HDLC Line 1 OK. When steady On, communications timeout.

S2 – When Off, communications with RS485/ HDLC Line 2 OK. When steady On, communications timeout.

S3 – When Off, MVB status is OK. When steady On, MVB communications fault. When blinking, the MVB line is disturbed or another device on the MVB is not connected.

There are six connectors on the front panel: Power, RS485, (2) Ethernet, and (2) MVB. The MVB connections are both 9-pin sub-D, shielded connectors. The Ethernet connectors are M12 style. Only one is used for the vehicle circuit. The single RS485 connection is a 15-pin, D-sub, shielded connector.



1. PWR: Power Supply Connector
2. RS485: DB15 connector for RS485 line 1 and RS485 line 2
3. ETH1: M12 connector for Ethernet 10/100 base T (for service)
4. ETH2: M12 for Ethernet 10/100 base T (for train network)
5. CPU Diagnostic LEDs
6. MVB connectors

Figure 3-29: Gateway Unit Outline

As seen in Figure 3-30, the Gateway Unit interfaces with the Multi-functional Vehicle Bus (MVB) as well as the vehicle Ethernet system MVB from the carbuilder car control circuits. The input circuits are redundant.

[redacted]

Data enters and leaves the gateway through the MVB. From the MVB, the data goes into the PLU through the RS-485 circuits Line 1 and Line 2 which are redundant.

Ethernet – from the carbuilder MDS and TOD circuits data enters and leaves the gateway through the Ethernet connection. From the Ethernet, the data goes into the PLU through the RS-485 circuits Line 1 and Line 2 which are redundant.

The MVB output signal Propulsion Health Status goes to vehicle controls. Indicates if any of the propulsion Disturbance / Protection / Fault conditions are detected.

RS-485 Line 1 is used for MVB signals and Line 2 is used for Ethernet signals.

The PLU continuously checks the Ethernet communication condition via the Gateway Unit. If communication error condition continues for longer than 1 second, the PLU will detect an Ethernet signal fault. In addition to this, the HEALTH command is sent from the PLU to the MDS every 10 seconds. The MDS uses this HEALTH message to recognize if the Ethernet communication system is operating normally.

The Gateway interface circuits are found Section 8.4 on Connection Drawing B519943 at Zone E/ F1.

See Section 8.4 drawing B3018030 Gateway Unit Connection Diagram for the interface connections to this device.

3.12.4.1 Gateway Unit Signals

MVB Signal 1 and MVB Signal 2 are connected to the Train Control Network.

- MVB Signal1: MVB Line A connection to/from TCN.
- MVB Signal2: MVB Line B connection to/from TCN.

When transmitting data, every node sends out data on both Line A and Line B. When receiving data, every node is able to receive data either on Line A or Line B. Line A or Line B may be inoperable. If one line fails, the other line is still able to carry the full amount of communication over the MVB.

- MDS Signal: Ethernet connection to/from MDS.
- MVB Signal PLU: RS485 communication to/from the PLU.
- MDS Signal PLU: RS485 communication to/from the PLU.

The Gateway Unit is required to connect the PLU to the vehicle circuits over the MVB. This unit has 2 redundant channels for the MVB interface.

The DC to DC Converter receives vehicle battery input power and provides isolated 5 Vdc power to the device.

The processor module is devoted to run the application software and manages the network interfaces. The operational features of the CPU module are:

- Ethernet M12 interfaces for the connection to the train network
- Management of the MVB and Expansion boards

The main features are as follows:

- Freescale PowerPC™ CPU Core @400MHz
- 16 MB memory (3MB for the application)
- 256 MB Random Access Memory DDR2 (Double Data Rate 2)
- Option: 2GB Flash Memory
- Two SMSC LAN8700iC-AEZG Ethernet controllers
- DS1302 real time clock

Serial communication interface

The Gateway Unit provides 2 insulated RS485 interfaces by means of dedicated transceivers and isolators. The Serial interfaces are available on an expansion board: the communication is controlled by the CPU Board. The two RS485 signals are reported in a single D-sub15 pin connector.

Ethernet communication interface

Two independent Ethernet interfaces are available on the ETH-1 and ETH-2 connectors and can be used for the connection to the train Ethernet network or as service and diagnostic interface. For this purpose, the ETH communication is able to support different protocols for data communication and services. The two Ethernet interfaces are completely independent thanks to the two controllers of the main CPU.

MVB communications

The MVB board handles the communications with the MVB bus. The board includes all the circuitry required for interfacing with the MVB bus.

Table 3-11 below calls out each of the Gateway LEDs by the title as seen on the device.

Table 3-11. Gateway Unit Troubleshooting

Symptom	Probable cause(s)	Corrective action(s)
LED **PWR** is Off	Device failure Or Lack of power	1. Verify battery connection 2. If not resolved replace device
LED **RUN** is Off	Application software not running and/or blocked Or Device failure	1. Replace device
LED **ALARM** doesn't stop blinking	Ethernet connection absent	
LED **ALARM** is fixed On	Communication problem on RS485 lines or MVB has been detected.	
LED **S3** is blinking	A line has detected problems by comparing the frames received on the two lines (Line A and Line B). Or A input port is in timeout	1. Verify MVB network connection integrity. 2. If not resolved replace device.
LED **S3** is fixed On	MVB interface of the device is connected but the device does not communicate on MVB.	1. Verify MVB network integrity. 2. If not resolved replace device.
LED **S1** is fixed On	Problems on RS485 line 1: timeout on the reception of the data is reached.	1. Verify RS485 line 1 network integrity. 2. If not resolved Replace device.
LED **S2** is fixed On	Problems on RS485 line 2: timeout on the reception of the data is reached.	1. Verify RS485 line 2 network integrity. 2. If not resolved replace device.

3.12.5 PLU Circuit Board Damage

To prevent damage to any PLU circuit board, the following steps must be followed:

Do not disconnect any PCB connector with control power active. Ensure that battery power has been removed from the vehicle before removing any logic circuit board front connectors.

Do not remove or replace any circuit board from the logic cradle with control power active. Ensure that battery power has been removed from the logic rack before removing or replacing any circuit board.

Discharge yourself at a well grounded point immediately before you touch the circuit board.

Use wrist strap connected to vehicle ground whenever holding a circuit board.

Never touch connection pins and conductive paths.

Do not remove the new circuit board from the static-free bag until needed.

Do not force a circuit board into the backplane assemblies. The backplane assembly allows only one type of board to be accepted in any particular slot.

Place any circuit board removed from the logic rack into a static-free bag immediately.

3.13 Propulsion Related Controls

The following is a listing of the propulsion related controls found in each cab.

3.13.1 Master Controller

Each of the two Master Controllers generates a tractive effort reference and controls the trainlines per the graph below. Only the Master Controller in the active cab will provide this control, although the Emergency Pushbutton in any cab can initiate an Emergency Brake application.

The PBED signal is the vehicle tractive effort reference. It is converted to a digital signal and transmitted to all friction brake and propulsion controllers. The signal is represented by a PWM Signal at 432 Hz. +/- 0.01 Hz, and is proportional to tractive effort command. The amplitude of this signal is not regulated, therefore it depends on the low voltage supply level. The valid Low level for this signal is 0 to 5 Vdc, and the valid High level for this signal is from 14 to 31 Vdc. This signal and the range at each detent are defined as seen in Figure 3-31.

The Master Controller contains several cams and micro switches. Some micro switches will directly control the trainlines per the figure below:

[redacted]

3.13.2 Master Controller Deadman

The Master Controller handle has a Deadman function. When the handle is released, a Full Service Brake application will be initiated. If the operator releases the handle, the following actions will occur:

a. The Deadman relay will be de-energized.

b. The Cab Propulsion Inhibit relay will be de-energized.

c. The power to the Motor and Coast / Motor trainlines is disabled.

d. The power to the Master Controller signal generator is disabled.

The PLUs and ECUs will read these signals to affect a Full Service Brake application.

3.13.3 Tractive Effort Command

For the logic to create firing commands for the power circuit IGBT’s, a Tractive Effort Command must be calculated. This command is based on the Power and Brake Effort Demand (PBED) command and passenger load weight from the friction braking system.

The Load Weight signal from the friction brake controller indicates passenger load of each section of the car. The A-unit PLU monitors the A-section load weight (Wa) and one half of the center truck (Wc). The B-unit PLU monitors the B-section load weight (Wb) and one half of Wc. This signal is input to the PLU over the MVB.

For motoring, the load weight compensation is between AW0 and AW2. The propulsion system will adjust tractive effort to compensate for varying passenger loads. Compensation will be calculated from measured value of passenger loading provided from the friction brake unit.

For dynamic braking, the load weight compensation is between AW0 and AW2. With a failure of either the A-unit or B-unit pressure transducers, the logic will monitor the load weight from the other section of the vehicle (over the MVB) presuming the same load weight for both sections of the vehicle. Failure of all of the load weight signals causes minimum weight (AW0) in Power and maximum weight (AW3) in Brake.

The PBED signal is a PWM signal from the Master Controller or the ATO system which is input to the PLU at the Serial Communications board IFB137B1 over the MVB. This signal indicates the operation command of the Master Controller or the ATO system.

If there is more than 5% difference between the Tractive Effort target value and achieved value of tractive effort calculated in the vector control sequence for 1 second, the PLU will detect a Tractive Effort Feedback Failure condition. While the propulsion inverter is detecting a wheel Spin/Slide condition, this function will be nullified.

There is a Propulsion Inhibit Relay (supplied by the carbuilder) and a Propulsion Inhibit Trainline. This trainline is a summary of the friction brake faults and door open status. If either of these happen the power to the Master Controller is removed so the M & CM trainlines go to zero and the PBED = 0 (Full Service brake) and disables the propulsion system.

Refer to Section 6.4 Trainline Functions for more detailed information.

3.13.4 PROP / HSCB Reset

This function is part of the cab TOD. When selected, a signal is sent to the PLU over the MVB requesting a propulsion reset and to close the HSCB. The purpose of the propulsion reset operation is to reset Protection/Fault conditions detected by the PLU. The PROP / HSCB TOD button is a soft reset. A hard reset is done by cycling the Propulsion Logic low voltage circuit breaker or pressing the Reset push button on the Upper Control Panel, and then restarting. The hard reset reboots the propulsion system logic. The PLU boot process takes about 15 to 30 seconds. The hard reset or shut down of the PLU should not be done within 1 minute after startup so that the PLU can complete the boot up process.

With the A-unit cab controlling, it is the TOD-A which will send the Reset signal to the MVB. With the B-unit cab controlling, it is the TOD-B which will send the Reset signal to the MVB.

The propulsion inverter will reset fault conditions when the propulsion system is disabled and the Line Switch contactor is opened. A soft reset will be commanded with a propulsion reset command on the MVB during a service brake application at zero speed. All of the propulsion faults are reset by this operation. Any propulsion system with the Line Switch contactor closed will ignore the reset signal.

The following must be true for the logic to close the HSCB:

- Direction selected (cab selected)
- HSCB Status open
- Line Switch contactor open
- Line Charging Contactor open
- HSCB Not Locked Out

3.13.5 Propulsion Cutout

The purpose of the Propulsion Cutout operation is to independently isolate the A-unit inverter or B-unit inverter from the catenary supply by opening the appropriate Line Switch contactor.

The propulsion cutout MVB input is high when none of the vehicle propulsion systems are cut out and low when any propulsion system in the train is cut out. This MVB signal indicates to the vehicle TOD when either PLU is cut out.

From the vehicle Propulsion Cutout switch, when the switch is thrown to the Cutout position, the input signal goes low and is detected at the PLU Digital Input board 2 which will cause the propulsion system to be disabled and the Line Switch contactor to open. The cutout status of both propulsion systems on the vehicle is output to the MVB.

Some re-occurring fault conditions that open the HSCB or line switches may require a propulsion system to be cut out to allow the High Speed Circuit Breaker to close and the vehicle to remain in operation. These conditions include:

- Line Overcurrent
- Ground Fault
- Filter Capacitance Charging Fault
- LCC or LS Command / Status Fault

3.13.6 Dynamic Brake Cutout

Dynamic Brake Cutout can be selected from the TOD after using a password. The purpose of the Dynamic Brake Cutout operation is to cutout the dynamic brake on the entire train. The Dynamic Brake Cutout condition prohibits gate firing of the propulsion IGBT's and brake chopper IGBTs to apply dynamic brake. With dynamic brake cutout, the propulsion system will be disabled with a brake request and the brake application at the effected truck will be full friction braking.

3.13.7 Regenerative Brake Cutout

Regenerative Brake Cutout can be selected from the TOD after using a password. The purpose of the Regenerative Brake Cutout operation is to cutout the regenerative brake of the LRV. In the Regenerative Brake Cutout condition, the Line Switch is opened and the braking effort will continue as rheostatic braking.

The Dynamic Brake Cutout signal will have a priority over the Regenerative Brake Cutout signal. When both Dynamic Brake Cutout and Regen Brake Cutout are active at the same time, there will be no electric braking.

3.13.8 Tow Mode

This function allows a higher torque during a power application when towing the vehicle(s) with malfunction and is intended to be a temporary, operator-controlled function. Tow Mode is activated from the TOD in the controlling cab. The tow mode torque is determined by using the PBED signal. The maximum tractive effort in Tow mode is set to 22.4 kN which is higher than the maximum powering torque with AW2 load in normal operation to allow towing of another AW3 car. Vehicle speed is limited to 32 kph (20 mph) while in Tow Mode.

The leading PLU will initiate the Tow Mode when the Tow Mode switch is active, the vehicle is zero speed and Full Service Brake is commanded. The vehicle system activates the Tow Mode Trainline when the Tow Mode signal of the leading PLU is active.

The other PLUs will initiate the Tow Mode when the Tow Mode Trainline is active, Exit from Tow Mode when the Tow Mode Trainline signal is deactivated.

There is no time limit for Tow Mode, but the calculated traction motor temperatures will rise and this could limit continual use.

3.13.9 Car Wash Mode

The purpose of the car wash mode is to limit the vehicle speed to 3.2 kph (2.0 mph) for car washing. In Car Wash mode, the four Inverter Unit cooling fans are disabled.

The leading PLU will initiate the Carwash MVB signal when the Carwash Button is depressed with No-motion detected and Full Service Brake is commanded. The MVB Carwash_TL is activated when the Carwash Mode signal of the leading PLU is active. The other PLU's will initiate the Carwash Mode when the Carwash Mode is active. Exit the Carwash Mode when the Carwash button is depressed again at zero speed and Full Service Brake.

3.13.10 Limp Home Mode

The purpose of the Limp Home Mode is to move a vehicle or train with a Train Control Network failure condition. The Limp Home function is controlled from a sealed switch on the Cab Bypass / Cutout Switch Panel and indicated from the TOD Operating Screen when active. With the Limp Home Mode switch thrown, the Limp Home signal goes trainline and is input to each PLU Digital Input board #1. The vehicle can now be moved with limited operation.

The tractive effort is limited to an acceleration rate of 0.67 m/s^2 (1.5 mph/ps) and speed is limited to 56 kph (35 mph). The load weight is fixed at AW2. Dynamic braking is disabled and only friction brakes are used.

3.14 Propulsion Related Trainlines

The following vehicle trainlines are integral to the propulsion system. See Section 6.4 of this manual for a more detailed relationship of the trainlines.

3.14.1 Emergency Brake Trainline

The EB Trainline input must be energized to allow the Line Switch contactor to be closed. The Master Controller provides the EB supply and return circuits to the trainline through the ATP logic and the console EB pushbutton switch. The Emergency Brake trainline active is a requirement to energize the Line Switch Relay controlling the Line Switch contactor. High is EB not applied (normal). Low is EB applied. With the loss of the EB Trainline, propulsion and dynamic braking are disabled.

3.14.2 Friction Brake Released Trainline

The Friction Brake Released Trainline input is activated by the friction brake ECU's when friction braking has been released on the train. High is Friction Brakes are released. Low is friction brakes are not released. The PLU will cut traction power if the brakes are not released within 5 seconds after power is applied.

3.14.3 CM Trainline

Coast / Motor Command Trainline from a micro switch in the Master Controller.
High is Motoring or Coast. Low is Braking mode.

3.14.4 M Trainline

Motor Command trainline from a micro switch in the Master Controller.
High is Motoring. Low is Coast or Braking mode.

3.14.5 Forward and Reverse Trainlines

The propulsion Line Switch contactor will not be closed until a direction has been selected from the Master Controller. The detection of the Forward or Reverse trainlines are used to determine the IGBT firing patterns to control the direction of movement of the car. FWD and REV cannot both be high at the same time. Depending on which cab is active, only one will be high for that direction.

3.14.6 Slide Control Emergency Brake Trainline

The Slide Control Emergency Brake Trainline is monitored from the Digital Input board 2 IBA130A2. This trainline is normally active and is controlled from a micro switch in the Master Controller. Slide Controlled Emergency Brake utilizes the last detent of the main handle position. When the Slide Control Emergency Brake trainline is disabled, the propulsion system remains enabled producing rheostatic braking. This function has precedence over all other functions except Emergency Braking. The purpose is to have EB type brake rate with slide controlled dynamic braking.

Slide Controlled Emergency Brake –

High: Normal

Low: Slide Controlled Emergency Brake has been applied.

This trainline is disabled (Low) from a switch on the Master Controller in the SCEB position which results in a 5% PBED from the Master Controller.

3.14.7 Sanding Trainline

The Master Controller applies sanding during EB and SCEB by energizing this trainline. The brake system ECUs and propulsion PLUs can also request sanding. Any PLU can request sanding and outputs a digital signal to activate the sanding magnet valve. Each PLU also receives a Sanding Control TL Status signal from the MVB. The operator can apply sanding by pressing the Sanding button on the console.

3.14.8 Propulsion Fault and Cutout Trainline

The Propulsion Fault and Cutout trainline is made up of interlocks from the Propulsion Dynamic Fault Relay (PDFR) and the PLU Cutout relays (PCORA or PCORB). See KI drawing UD01450 Sheet 306.

The PDFRs are controlled from the Propulsion Dynamic Brake (PDF) output signal from each PLU from the Digital Output board OBA54A1. The output signal is high with no fault conditions and low with a fault condition detected. The Propulsion Cut Out Relay (PCOR) is controlled by the Cutout switches located on each Bypass Panel. The lead vehicle Gateway reads the Propulsion Fault and Cutout trainline and puts the status of the trainline on the train MVB.

The vehicle Gateway Unit (which is different from the propulsion Gateway Unit) monitors the PDFR relay. With no protection, fault of cutout conditions detected, this trainline is at vehicle battery potential and the PDFR relay is energized and the Propulsion Fault indicator on the TOD will be displayed in green.

3.14.8.1 Propulsion Faults Deenergizing the PDFR Relay

The following conditions will indicate a propulsion fault and de-energize the PDFR relay immediately:

Truck (Propulsion Logic Unit) ID Abnormality

HSCB Fault Detection

Line Charging Contactor Fault Detection

Line Switch contactor Fault Detection

Motor Axle Speed Sensor Fault

Inverter Gate Fault

Brake Chopper Gate Fault

Phase current imbalance

Frequent Output Overcurrent

Input Command Abnormality (Forward/Reverse)

IGBT Overheat Protection (Inverter)

Gate Voltage source fault

Control Voltage fault

Current Transducer Power Source fault

Analog Signal Power Low Voltage

CPU Watch Dog Fault

Propulsion Power Effort Fault

Propulsion Ground Fault

Brake Chopper Fault

Input Overcurrent

Traction Motor Over Heat

Inverter Unit Thermistor Fault (THUV, THVW and THBch)

Illegal Torque Detection

Filter Capacitor Capacitance fault

Motor Lead Miss Connection

The following conditions will de-energize the Propulsion Fault Trainline and the PDFR relay with continuing frequently (3 times in 1 minute) or if the fault condition lasts longer than 30 seconds:

Adhesion failure – Powering (for 30 seconds)

Adhesion failure – Braking (for 30 seconds)

Brake Resistor Overheat

Filter Capacitor Low Voltage

Filter Capacitor Overvoltage

Filter Capacitor Voltage Rising

Friction Brakes Not Released

IGBT Overheat Protection, Brake Chopper

IGBT Temperature Rising

HSCB Lockout (3 overcurrent trips)

HSCB Power Source (vehicle batteries) Abnormality

HSCB Tripped

Line Voltage Low

MVB Fault

Output Overcurrent

Rollback Detection

Charging resistor protection (resistor used 3 times within 1 minute)

The following conditions will not de-energize the Propulsion Fault Trainline or effect PDFR relay operation:

Trailer Axle Speed Sensor Fault

OCS Gap Detected

Cooling Fan Motor Speed fault

Ethernet Fault

Load Weight Fault, A, B or C Truck

Multi-functional Vehicle Bus No.1 Fault

Multi-functional Vehicle Bus No.2 Fault

Relay Abnormality (NMRK No-motion Relay)

Trainline and PBED Fault (Full Service Brake applied)

SCEB Fault (Full Service Brake applied)

With the loss of the Propulsion Fault Trainline (to 0 volts), there will be a 35 mph speed limit imposed on the vehicle (or train).

3.14.9 Reset Trainline

NOTE: This circuit is not controlled or monitored by the Propulsion Logic Unit and not directly related to the propulsion system.

The Reset Pushbutton on the Upper Control Panel in each cab is enabled when the train is stopped and the No-motion Relay is energized (see KI drawings UD01450 Sheet 304). The Reset pushbutton will also be enabled if the No-motion Bypass Relay (NMBPR1B) is energized.

If the operator depresses the Reset pushbutton the Master Reset Timer Relay (MRSTR) will energize the output for 20 seconds to energize the Master Reset Relay (MRSR). This will de-energize the Local Bus Contactors for 20 seconds which will remove control power to all electronic units on the train causing these devices to reboot and reset. This is what is called a hard reset.

CHAPTER 4.0

SCHEDULED MAINTENANCE

4.1 Introduction

This section of the manual deals with the preventive maintenance requirements for the P3010 LRV propulsion equipment to keep the vehicles in service.

Accurate maintenance records should be maintained that reflect the inspections and preventive maintenance operations performed. These records will be invaluable in detecting, analyzing, and correcting negative operation trends and may also reveal situations where it might be advantageous to adjust the period specified in the tables.

Maintenance personnel must be familiar with the methods associated with operating, testing, and repairing the propulsion system equipment.

Preventive Maintenance is classified into the following three types:

A. Visual Inspection — Equipment is visually inspected by maintenance personnel. Required actions such as cleaning, tightening fasteners or repairing are performed.

B. Parts Inspection — Equipment is removed from car body, and inspected in detail. When worn components are found on the inspection, they are replaced.

C. General Inspection — Equipment is removed from car body and, if required, disassembled to units, components, or parts. Some units, components, or parts are preventively replaced on the inspection as overhaul. Additionally, some units and components are refurbished.

4.2 Scheduled Maintenance Objectives

Two objectives of any maintenance program are to keep all equipment in good running order and to restore faulty equipment as quickly as possible after a failure to maximize vehicle availability.

Meeting these objectives requires properly trained personnel using the proper tools, test equipment, and repair facilities. These maintenance instructions explain how to inspect the specific characteristics and to perform the maintenance to replace wear items. Instructions are included for corrective maintenance that can be done without taking the vehicle out of service.

4.3 Safety Information

Maintenance is not to be performed on the propulsion inverter until the following safety warnings are read and fully understood. If any portion is not understood, contact a supervisor.

There are three (3) areas of potential hazards when maintaining the propulsion inverter: electric shock, rotating machinery, and hot surfaces. They are described below:

4.3.1 Rotating Equipment

The rotating cooling fans may cause injury. Do not touch the cooling fans while they are rotating.

4.3.2 Hot Surfaces

There are two kinds of resistors inside the propulsion equipment case, Charging Resistor (CHR) and Filter Capacitor Discharge Resistor (DCHR). These resistors can be hot even if current is not flowing in them. Do not touch the surface of the resistors until they have cooled to room temperature.

4.3.3 Electric Shock Hazard

The filter capacitors in the propulsion inverter may be at high voltage for up to three minutes after the propulsion inverter is separated from the catenary supply. Touching any main circuit constituents before the electric charge in the capacitors is completely discharged may cause electric shock to the personnel. Make sure not to handle the component of the propulsion inverter for five (5) minutes after separated from the catenary supply.

4.3.4 Preparing Propulsion Inverter for Inspection

WARNING

HIGH VOLTAGE

THE PROPULSION SYSTEM MAY POTENTIALLY BE AT A HIGH VOLTAGE. CHECK THAT THE STEPS LISTED BELOW ARE FOLLOWED TO AVOID CONTACT WITH HIGH VOLTAGE.

1. Lower the pantograph.
2. Wait five minutes before opening the equipment case bottom cover.
3. Loosen the 8 captive bolts securing the bottom cover. Slide the cover to clear the 4 safety hangers allowing the cover to be dropped. When done, torque cover bolts to 14 Nm (10.3 ft-lbs.).

   Filter capacitor voltage must be checked from either capacitor in the Inverter Unit accessed from the equipment case bottom cover.

   Place the negative meter probe on the 500D cable on the filter capacitor.

   Place the positive meter probe on the 507 cable on the filter capacitor.

   Ensure the voltage is less than 20 volts before working on the equipment.
4. Place the Knife Switch in the OFF position or the Shop Power position.

Shop power can now be used. The Knife Switch blade must not be touched or moved as long as there is high voltage on the vehicle from any source.

4.4 Maintenance Schedule

Table 4-1 explains the maintenance requirements to keep the propulsion equipment operating in a safe and reliable condition and to detect early signs of equipment degradation which, if left unattended, may eventually result in failure of the propulsion system.

Shown below is the scheduled maintenance index which lists frequency and each maintenance task. The reference column indicates the section that details the procedures.

Table 4-1. Preventive Maintenance Tasks

Maintenance Interval	Part Description	Scheduled Maintenance Task	Section 0700 Propulsion Running Maintenance & Servicing Manual Section Reference
10,000 mile inspection interval			
Initial 10,000 miles	Gear Unit	Replace gear unit lubrication. The gear unit oil can be refilled again after being filtered. For this purpose, using a filter element with a retention rate of 6 μm (β x ≥ 200, according to ISO 16889 is recommended. If the gear unit oil level is down, fill up with fresh oil to the required level.	4.9.1
		Inspect gear unit and coupling for leaks and external damage	
		Examine fill plug magnet	
10,000 Miles	Brake Resistor	Remove debris from the exterior	4.7.1
		Inspect for loose hardware and signs of overheating	
10,000 Miles	Gear Unit	Inspect gear unit and coupling for leaks and external damage	4.9.1
		Visual check of oil level at oil level gage glass	
		Check the rubber bushings of the transmission/motor connection.	
		Check the rubber bushings in the torque support.	
		Examine fill plug magnet	
10,000 Miles	HSCB Control Panel	Inspect and clean the control panel. Check for loose connections.	4.14.1
10,000 Miles	Traction Motors	Clean traction motor filters	4.8.1
		Inspect cables, connectors of traction motor, speed sensors and cables, bearing covers and painted surfaces for damage.	
		Inspect motor mounts, air filter housing, coupling flange, cover and housing bolts for tightness. Inspect traction motor bearing caps and High Speed Coupling for leaks.	

Table 4-1. Preventive Maintenance Tasks (cont'd.)

Maintenance Interval	Part Description	Scheduled Maintenance Task	Section 0700 Propulsion Running Maintenance & Servicing Manual Section Reference
At the 30,000 Mile interval, the 10,000 mile inspections listed above are also done.			
30,000 Miles	Line Reactor	Remove debris from protective cage	4.6.2
		Inspect for loose hardware and signs or overheating.	
30,000 Miles	Traction Motor	Clean Filter	4.8.2
		Blow out light debris from inside motor	
30,000 Miles	Lightning Arrestor	Clean debris from the lightning arrestor.	4.12.2
		Check for chips or cracks, and verify that cables are secure	
30,000 Miles	Inverter Air Filter	Clean propulsion inverter air filter mesh screen	4.5.2
		Blow out the collected debris in the self-cleaning filter located behind the mesh screen and clean heat sink fins	
		Inspect fan blades	
		Inspect for loose hardware	
30,000 Miles	Inverter Unit Heatsink	Blow out heat sink fins	4.5.2
At the 60,000 Mile interval, the 10,000 mile and 30,000 mile inspections listed above are also done.			
60,000 Miles	Ground Brushes	Measure the wear of brushes and replace if necessary	4.10.3
		Inspect shunts for loose connections and broken strands	
		Inspect slip rings and connector lug contact areas for wear	
60,000 Miles	Knife Switch	Clean contacts using shop towels	4.13.3
		Lubricate contact interfaces with SHELL ALVANIA #2	
		Inspect contacts for corrosion and wear	
		Inspect for loose hardware	
		Check secondary blade springs	
		Check jaw adjustments	

Table 4-1. Preventive Maintenance Tasks (cont'd.)

Maintenance Interval	Part Description	Scheduled Maintenance Task	Section 0700 Propulsion Running Maintenance & Servicing Manual Section Reference
60,000 Miles	Propulsion Inverter Equipment Case	Check that discharge resistor cover is clear of debris	4.5.3
		Check the operation of the EBRT.	
		Check access door gaskets for wear and proper sealing	
		Check all interior electrical connections for tightness. This includes the cable lugs, bus bars, control cables at voltage detectors and transducers, and resistor connections.	
		Inspect the resistors and contactors in the propulsion equipment case for tight connects and any signs of overheating	
		Check that the PLU, Power Supply, and Gateway Unit connections and circuit boards are secure.	
		Inspect insulators for cracks or other damage and clean with an approved MTA cleaning agent.	
		Examine the door gaskets ensure the gaskets are not worn, ripped, compressed or missing.	
60,000 Miles	Line Switch Contactor	Measure wear of Line Switch contactor contacts and verify that the movable contacts moved freely.	4.5.3
		Inspect Line Switch contactor for loose hardware.	
60,000 Miles	Line Charging Contactor	Inspect Line Charging Contactor for loose hardware.	4.5.3
60,000 Miles	High Speed Circuit Breaker	Inspect arc chute	4.11.3
		Inspect for loose hardware	
		Inspect mechanical components.	
60,000 Miles	Gear Unit	Start of taking oil sample for extended oil change ntervals.	4.9.3
		Additional oil samples and analyses after every 30 000 miles, until a maximum mileage of 180,000 miles.	
		Replace gear unit lubrication (if extended oil change is not permitted). Clean gear unit housing and replace the corrosion protection.	
		Check screw connections.	
		Repair paint and corrosion damage.	
		Check press fit of flange connections on the drive coupling.	

Table 4-1. Preventive Maintenance Tasks (cont'd.)

Maintenance Interval	Part Description	Scheduled Maintenance Task	Section 0700 Propulsion Running Maintenance & Servicing Manual Section Reference
At the 120,000 Mile interval, the 10,000, 30,000 and 60,000 Mile inspections listed above are also done.			
120,000 Miles	Gear Unit	Change Gear Unit lubricant (If extended oil change is permitted). Examine fill plug magnet	4.9.4
120,000 Miles	High Speed Circuit Breaker	Clean and inspect arc guides Check contacts for wear	4.11.4
3 years or 360,000 miles	Traction Motor	Add grease to traction motor bearings	4.15
5 years or 600,000 miles	Traction Motor	Overhaul	4.16.1
5 years or 600,000 miles	Gear Unit	Inspection and Maintenance	Refer to HRMM Table: 3-1
10 years or 1,200,000 miles	Gear Unit	Overhaul	4.16.2
5 Years or 600,000 miles	High Speed Circuit Breaker	Replace shock absorbers	Refer to HRMM Table: 3-1
10 Years or 1,200,000 miles	High Speed Circuit Breaker	Overhaul	Refer to HRMM Table: 3-1
15 Years or 1,800,000 miles	Propulsion Inverter Equipment Case	Replace filter capacitors	Refer to HRMM Table: 3-1
5 years or 600,000 miles	High Speed Coupling	Replace grease	4.16.3 or Refer to HRMM Table: 3-1
10 years or 1,200,000 miles	Line Charging Contactor	Replace Contactor	RMSM Section 5.7.11

The Knife Switch is the only component in the propulsion system that requires lubrication during each maintenance interval (10K, 30K, 60K and 120K).

4.5 Propulsion Equipment Case

4.5.1 10,000 Mile Inspections

1. Inspect the EBRT.

a. Follow all Metro shop safety practices.

b. With High Voltage removed from the vehicle (pantograph down), confirm operation of the EBRT on an Emergency Brake application.

c. At each Inverter Unit within the control (low power) side at the top of the unit is a relay rack assembly. Identify the EBRT. See Figure 2-16 for reference.

d. The EBRT has indicator lights that indicate its function.

e. Verify that both the red and green indicators on the relay are lit.

f. With a technician in the cab, key up the LRV to the ON position and select the FORWARD direction and verify that the brakes are in Full Service Brake and that Emergency Braking is not applied.

g. The technician in the cab should then move the master controller to an approximately ¾ brake position (out of full service).

h. The technician in the Cab, at the command of the observer should depress the emergency push button.

i. Verify that the green indicator goes dark in approximately 3 seconds.

j. Restore the inverter under test and repeat this procedure on the remaining inverter on the vehicle under test.

4.5.2 30,000 Mile Inspections

1. Propulsion Inverter Unit Air Filter and Heatsink Inspection and cleaning

a. Open the fan door by unlatching the three clasps at the bottom and then remove door.

b. Put the cover on the floor with the exterior facing up. Using compressed air, with the nozzle approximately 1 meter (3 feet) from the filter, clean the filter (use a face mask and goggles).

c. Confirm that the cooling fan blades are not damaged.

d. Remove the fan unit from the Inverter Unit.

e. Clean the fins of the heat sink. Blow the dust down to the floor, and wipe down the surface of the fins with a dry, clean cloth.

f. Re-install the fan unit, being sure to connect the electrical connectors at each end.

g. Close the door and lock the three clasps.

4.5.3 60,000 Mile Inspections

Propulsion Inverter Unit Inspection

1. Check from the exterior that the discharge resistor vent is free of debris.

2. Open all equipment case doors. Replace gaskets or adjust door latches if dirt or moisture enters the interior.

3. Check that electrical connections inside the equipment case are secure. This includes the exterior cable lugs, resistor connections, transducer connections, PLU/PSU/Gateway Unit connectors, and all other control wiring.

4. Check that relays and PLU circuit boards are secure.

5. Inspect insulators for cracks or other damage.

6. Inspect the Line Switch contactor

a. Remove the arc chute.

(1) Remove the four M8 bolts and washers (two on top and two at the bottom) at the left side of the contactor securing the connection to the bus bars at the top and bottom of the arc chute.

(2) Squeeze together the black plastic release buttons on the front of the arc chute and turn down the four locking levers one by one. The locking bars will pop up at the release button. Remove the arc chute.

b. Do not clean the arc chutes or de-ionizing plates, but replace when they are damaged due to arcing. Replace the Arc Chute if cracks or chipping is found or the wall thickness is less than 50% or original 6 mm thickness.

c. As seen in Figure 4-1, check the stationary and movable contacts for wear. The thickness of the new contacts is 1.5 mm (0.059 inch). When any of the contacts wear down to 0.45 mm (0.018 inch), all of the contacts need to be replaced (replace the bridge and both stationary contacts in the arc chute).

d. If there is a carbon film on the contacts, clean the carbon film from the contactor tips using a lint free cloth soaked in an alcohol based solution. Dressing of the contact tips is not recommended or necessary.

e. All of the contacts should be replaced if any of the contacts are severely burnt or pitted.

f. Ensure that the contacts are not canted. One indication of canting is an off-center burn pattern on the contact surface.

g. The movable contacts (bridge) must move freely in and out. On either side of the contactor there are handles that allow the bridge (and auxiliary switches) to be operated manually.

h. If there is a carbon film caused by the contactor opening under load, clean the carbon film from the contactor tips using a lint free cloth in an alcohol based solution. Dressing of the contact tips is not necessary.

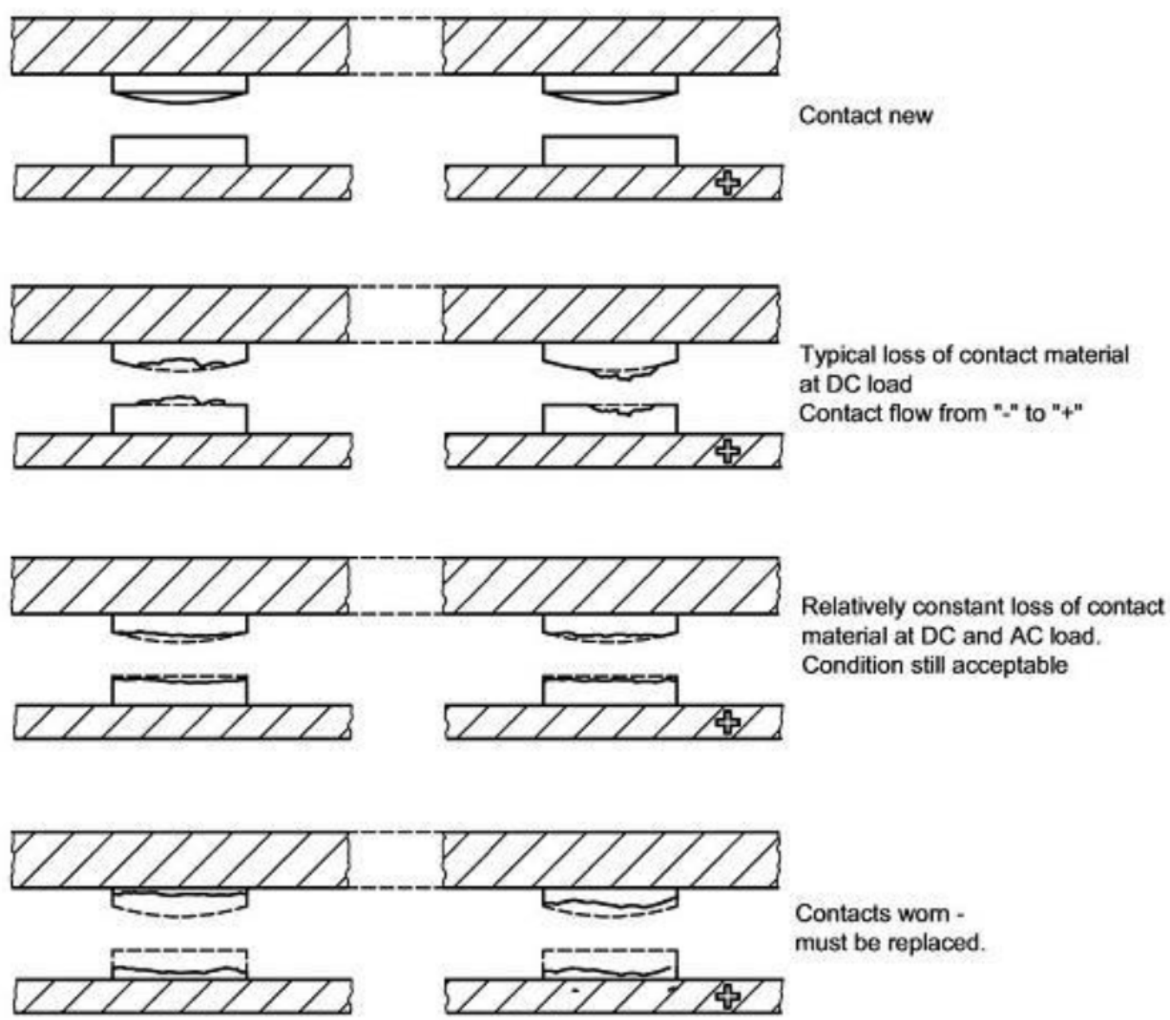


Figure 4-1: Line Contactor Wear

i. Reinstall the arc chute.

(1) Place the Arc Chute into the contactor base.

(2) Return the four locking levers one by one to the Locked position.

(3) Secure the arc chute to the bus bars and torque the four M4 bolts to 14 Nm (10.3 ft.-lbs.).

j. Verify that bus bars and control wiring are secure.

7. Inspect the Line Charging Contactor. When the Line Charging Contactor requires maintenance, do the following:

a. The LCC contactor does not come apart to check the contact tips. There are no serviceable items that are part of the Line Charging Contactor.

b. Verify that all hardware and control wiring is secure.

Because the contact thickness cannot be checked, the Line Charging Contactor must be replaced with a new contactor every 10 years.

8. Ensure that door gaskets are not worn, ripped, compressed or missing. The gaskets are important to keep rain and car wash water out of the equipment case and away from the high voltage components. When latching the doors closed there should be some compression of the gasket as the latch is engaged. If there is not a tight fit either the gasket is compressed and should be replaced or the latching hardware needs adjustment.

9. Latching Hardware Adjustment. See Figure 4-2.

a. Unlatch the latching hardware.

b. Loosen the locking nut on the hook.

c. Turn the latch hook clockwise to apply more pressure on the cover gasket.

d. Latch the latching hardware and check the fit of the cover. The cover should require pressure to close.

e Unlatch the latching hardware and turn the latch hook two to three turns counterclockwise. Apply Loctite #242 to the nut loosened in step 2 and re-tighten.

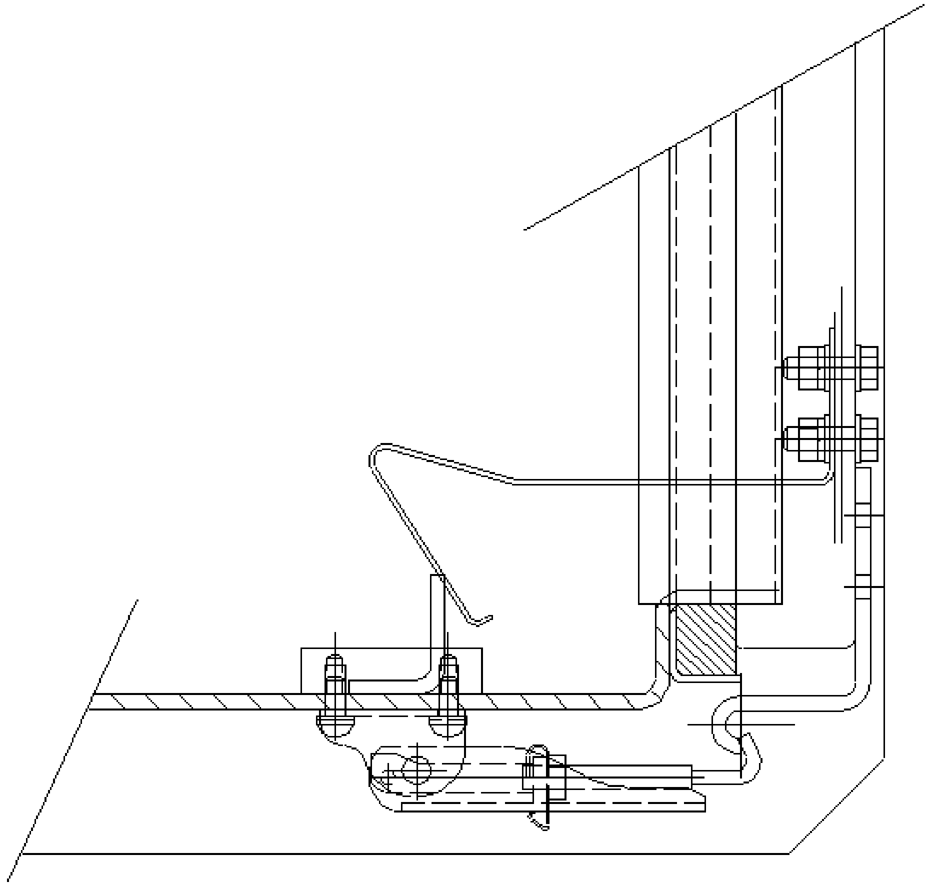


Figure 4-2: Latch Adjustment

10. Cover Gasket Replacement

a. Remove the damaged cover gasket and clean the surface area of all gasket material and sealant.

b. Cut gasket material to the proper lengths, apply a thin coat of Three Bond 5211 adhesive, and install gasket.

c. With a new gasket, the latch may need to be adjusted.

4.5.4 120,000 Mile Inspections

No maintenance required.

4.6 Line Reactors

4.6.1 10,000 Mile Inspections

No maintenance required.

4.6.2 30,000 Mile Inspections

1. Remove debris from the equipment case exterior. Carefully remove any large debris that has accumulated on the unit or inside the windings.

2. Inspect the cables and cable lugs for security and integrity. Replace if cracked or burned.

3. Look for signs of damage to the winding, insulation, terminals or mechanical structure.

4. Look for signs of overheating on the coils and terminals. Overheating appears as burn marks in the insulation or deformed or sagging covers. If overheating conditions have occurred, remove the line reactor and check on the bench tester. If the insulation resistance or dielectric isolation to ground fails, replace the line reactor. See Note below.

As necessary, spray the unit with low pressure water to remove any small debris or loose buildup from the unit exterior and between winding layers.

CAUTION

DO NOT USE HIGH PRESSURE WASHERS DURING THE CLEANING PROCESS. IT MAY CAUSE DAMAGE TO THE UNIT.

4.6.3 60,000 Mile Inspections

No maintenance required.

4.6.4 120,000 Mile Inspections

No maintenance required.

NOTE: If Line Reactor shows signs of physical impact damage or overheating, check the inductance value of both line reactor coils. The required inductance values are 1.25 mH (1.375 to 1.125) for the coil between terminals 506 and 507, and 0.5 mH (0.55 to 0.45) for the coil between terminals 507 and 508 at 360 Hz. Inductance values in parenthesis, reflect the tolerance of ±10 %. Refer to Table 4-2 for expected inductance reading at frequencies higher than 360 Hz.

These measurements are made from inside the Inverter equipment case (no need to remove the shrink insulation at the Line Reactor connections) as long as the cables to the line reactor are removed from the equipment case internal connections. These cables are 3 meters in length and are 2000V EXANE FLXE, 4/0.

506 is the input cable from Line Reactor 1

507 is the input / output cable from / to Line Reactor 1 and 2

508 is the input cable from Line Reactor 2

From the propulsion equipment case, find and disconnect each of the three power circuit cables noted above.

Refer to table 4-2 for the expected inductance reading if the Test meter operating frequency is not 360 hertz. These values can be considered typical and the cables should not affect the measurement of the inductance.

Table 4-2. Expected Inductance at Different Test Frequencies

Inductance (mH)	Frequency				
	500 Hz	1000 Hz	3000 Hz	5000 Hz	10000 Hz
Reactor L1 1.25 mH terminals 506 - 507	1.246	1.190	0.916	0.875	0.772
Reactor L2 0.50 mH terminals 507 - 508	0.496	0.445	0.366	0.339	0.317
Inductance L1 / L2 terminals 506 - 508	1.743	1.566	1.280	1.180	1.078

4.7 Brake Resistor Assembly

4.7.1 10,000 Mile Inspections

1. Check that ceramic spacers between the grids do not show cracks (visible by eye) or damages that could reduce the insulation level. If a suspect crack exists, check the insulation resistance by means of a 1000V Megger between resistor terminals connections and external brake resistor box (ground connection) and verify if the insulation is greater than 50 MΩ in dry condition. Clean the support insulators and the ceramic spacers between the resistor elements especially on the bottom part of the resistor assembly. Clean the resistor element grids as well by using a brush. After cleaning, measure the insulation resistance again. If the resistance is still lower than 50 MΩ in dry condition, replace the damaged components.
2. Inspect components for obvious signs of physical damage and overheating. A blue color on the top cover or deformed / sagging covers indicates that the brake resistors have been subject to overheating. Replace as needed.
3. Remove debris.
4. Inspect the grillwork around each resistor assembly and remove any objects (paper, plastic bags etc.) that may cause a restriction to cooling air flow or may start a fire.

4.7.2 30,000 Mile Inspections

No maintenance required.

4.7.3 60,000 Mile Inspections

No maintenance required.

4.7.4 120,000 Mile Inspections

No maintenance required.

4.8 Traction Motors

4.8.1 10,000 Mile Inspections

1. Remove, clean, and reinstall the air filter as shown in Figure 4-3.

a. Unhook the latch on the air filter cover.

b. Open the cover by pushing it slightly as seen in the figure below and then pull out.

c. Remove the filter from its frame.

d. Clean the filter by blowing it with shop air (use face mask) or vacuum cleaner. If the dirt cannot be completely removed, loosen it using hot water and a brush followed by another application of air pressure. Wash it with a finish safe solvent like CRC brake clean, if necessary.

e. Replace the filter if it has been damaged beyond repair.

f. Insert the cleaned and dry filter into its frame. Close the cover and be certain that it seats correctly and is retained in place by the clasp.

2. Clean the traction motor of dirt and grease.

3. Inspect all cables for damaged insulation. Replace any cable that is chafed, cut, or has cracked insulation. Check both the three power cables from the inverter, the ground wire attached to the side of the motor, and the speed sensor cables.

4. Inspect connectors, wiring and speed sensor for damage. Replace any damaged parts.

5. Remove from the housing and check the face of the speed sensor for wear marks from rubbing of the toothed wheel. Remove any debris. Reinstall in the housing.

6. Inspect motor mount rubber bushings, air filter housing, coupling flange, cover, and housing bolts for tightness. No crack can be acceptable for rubber bushings. Replace if found. Regarding housing bolts, check if the torque marks are aligned.

7. Inspect bearing caps for grease leaks.

8. Inspect the High Speed Coupling / traction motor interface for grease leaks.

NOTE: The “Shop Air” that is referenced should be the normal “Shop Air” at (90) psi. “Shop Air” lower than (100) psi will be adequate for performing the cleaning interval.

4.8.2 30,000 Mile Inspections

1. Remove, clean, and reinstall the air filter as shown in Figure 4-3.

a. Unhook the latch on the air filter cover.

b. Open the cover by pushing it slightly as seen in the figure below and then pull out.

c. Remove the filter from its frame.

d. Clean the filter by blowing it with shop air (use face mask) or vacuum cleaner. If the dirt cannot be completely removed, loosen it using hot water and a brush followed by another application of air pressure. Wash it with a finish safe solvent like CRC brake clean, if necessary.

e. Replace the filter if it has been damaged beyond repair.

2. Clean the traction motor cooling vents by blowing it with shop air (use face mask, hearing protection, and safety glasses). The shop air should be blown through the airinlet with the traction motor air filter removed. Shop Air must beblown through the motor cooling vents for (5) minutes each motor.

3. Insert the cleaned and dry filter into its frame. Close the cover and be certain that it seats correctly and is retained in place by the clasp.

NOTE: The “Shop Air” that is referenced should be the normal “Shop Air” at (90) psi. “Shop Air” lower than (100) psi will be adequate for performing the cleaning interval.

4.8.3 60,000 Mile Inspections

No maintenance required.

4.8.4 120,000 Mile Inspections

No maintenance required.

See Section 4-15 for the lubrication of the traction motor bearings.

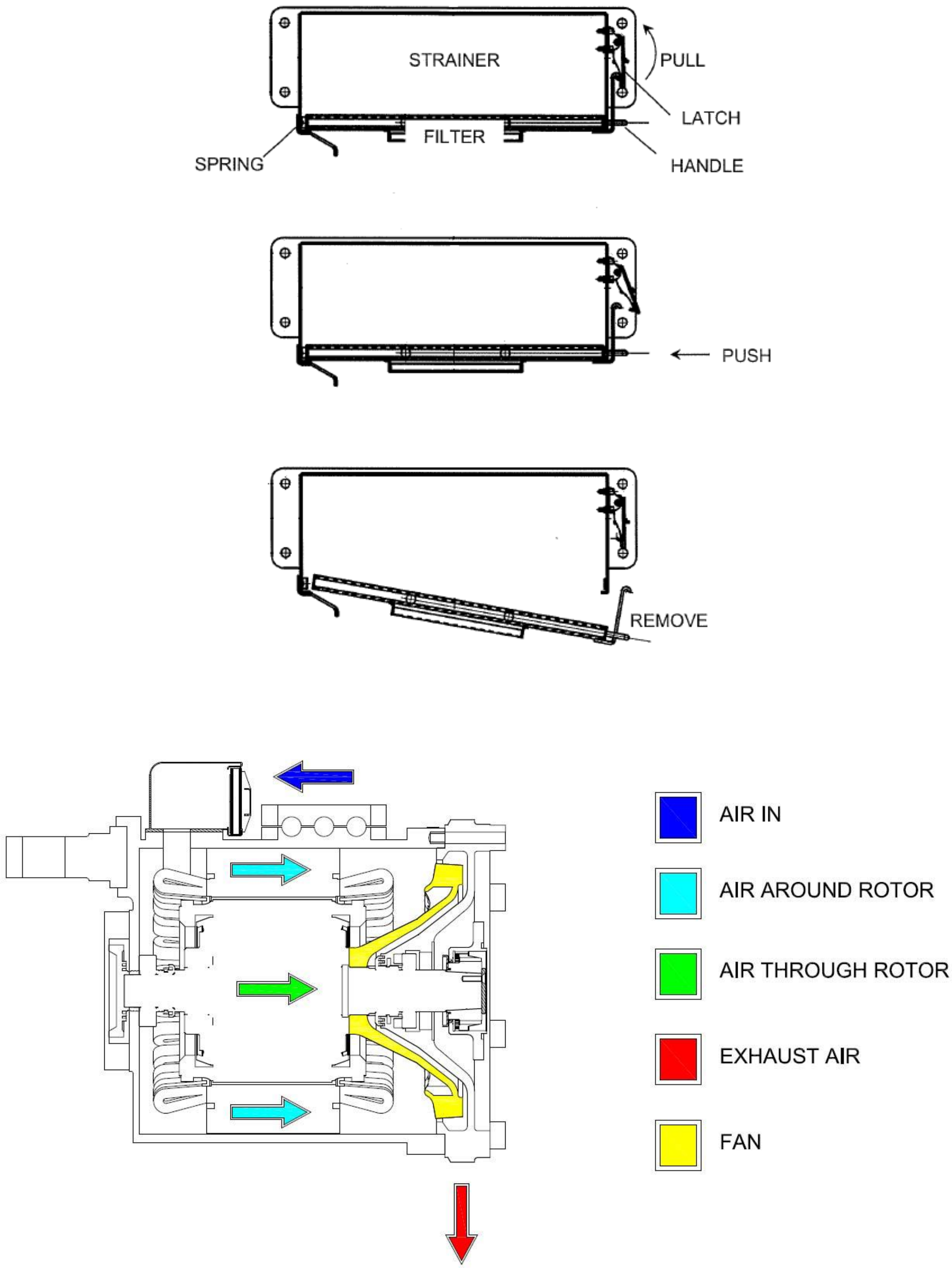


Figure 4-3: Air Filter Removal and Installation

4.9 Gear Unit

CAUTION

DO NOT AIM WATER JETS, STEAM JETS OR COMPRESSED AIR DIRECTLY AT THE LABYRINTH SEALS, GEAR UNIT, OR TRACTION MOTOR OPENINGS. IF NECESSARY, USE A PROTECTIVE COVER. WHEN USING A HIGH PRESSURE CLEANER, KEEP A DISTANCE OF 0.5 TO APPROX. 1 METER FROM THE GEAR UNIT.

GRINDING SWARF, CLEANING AGENTS, AND PAINT CAN PENETRATE INTO THE LABYRINTH SEALS AND CAUSE GEAR UNIT DAMAGE. BEFORE ANY GRINDING OR PAINTING WORK CLOSE TO THE LABYRINTH SEALS, THE LABYRINTH SEALS SHOULD BE COVERED WITH ADHESIVE TAPE.

4.9.1 10,000 Mile Inspections

Visual inspect for external damage (points of impact, corrosion).

Visual inspect for lubricant leakage.

Check for oil leaks or seepage from the gear unit. Due to dust build up and oil and the small amount of oil leaked into the air as vapor, it is not easy to discern if the gear unit is leaking. Dry oil dust is acceptable. Leakage of oil condensate mixed with brake dust that is not shiny is acceptable.

Oil-tightness is defined as an oil leakage with droplet formation being inadmissible.

- Dry oil dust – slight leakage of oil condensate mixed with brake dust and other dust, not shiny.
- Dusty moist gearbox housing - leakage of oil condensate mixed with brake dust and other dust, not shiny.
- Moist oil/dust mixture - heavier leakage of oil condensate mixed with brake dust and other dust, partly shiny areas, matt shine, no droplet formation.
- Oil leakage with droplet formation – heavy oil leakage from the labyrinth seal with droplet formation. Oil carried to gearbox housing and to locomotive/vehicle case.

Inspect the High Speed Coupling / Gear Unit interface for grease leaks.

Check Oil Level

CAUTION

CARRY OUT OIL LEVEL CHECKS ONCE THE GEAR UNIT (AND OIL) IS AT ROOM TEMPERATURE. OIL LEVEL CHECKS PERFORMED WHILE THE GEAR UNIT OIL IS HOT WILL INDICATE A HIGH OIL LEVEL.

1. Remove locking wire at oil filler plug (1) as shown in Figure 4-4.

2. Clean the area around the oil filler plug.

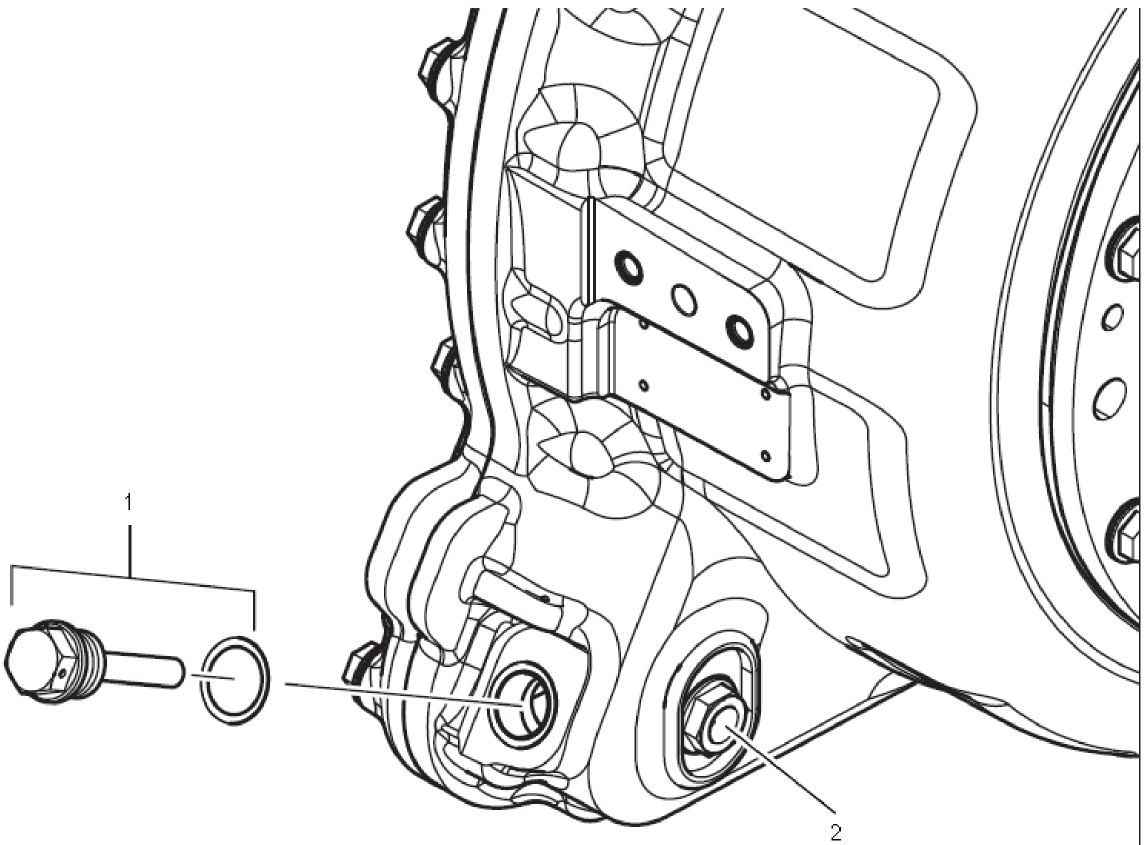


Figure 4-4: Oil Filler Plug

3. Unscrew oil filler plug (1) with sealing ring (SW 24 mm).

Examine the Fill Plug magnet. Figure 4-5 shows oil filler plugs with metallic abrasion on the magnet as can be detected during the run-in phase before the 2nd oil change. After that, the quantity of abrasion should become less. This wear is not critical provided that it takes the form of fine, dust-like wear or abrasive sludge. If coarse metal particles are found on the magnet and these are easy to feel, then contact ZF Friedrichshafen AG.

Figure 4-5: Oil Filler Plugs With Metallic Abrasion

4. Check Fill Plug Magnet
   Attempt to rotate the magnet bar by hand at approximately 1.5 NM (1.10 foot pounds) to see if it is loose from the plug.
   Pull the magnet bar from the plug by hand at approximately 100 N (22 pounds of force) to see if there is axial movement. If the magnet is loose, replace the plug.

5. Check oil level.
   Maximum oil level – Half way up sight glass (lower edge of oil filler hole)
   Minimum oil level - at maximum 5 mm below lower edge (oil not seen in sight glass)

6. Top up with gear unit oil until full. The lower edge of the oil filler hole (oil overflow) defines the oil fill quantity.

7. Clean the oil filler plug (1) and screw in again with a new sealing ring. Tightening torque MA: 70 Nm, SW 24.

8. Install safety wire as seen in Figure 4-6 and 4-7.

a. Insert wire through the bore in the screw plug.

b. Wrap one end of the wire in a clockwise direction around the hexagon.

c. Take hold of both ends of the wire with the lock wire pliers. Twist along the full length of the wires (distance between screw plug and housing bore).

d. Insert one end of the wire through the housing bore.

e. Take hold of both ends of the wire with the lock wire pliers. Tighten and twist wire.

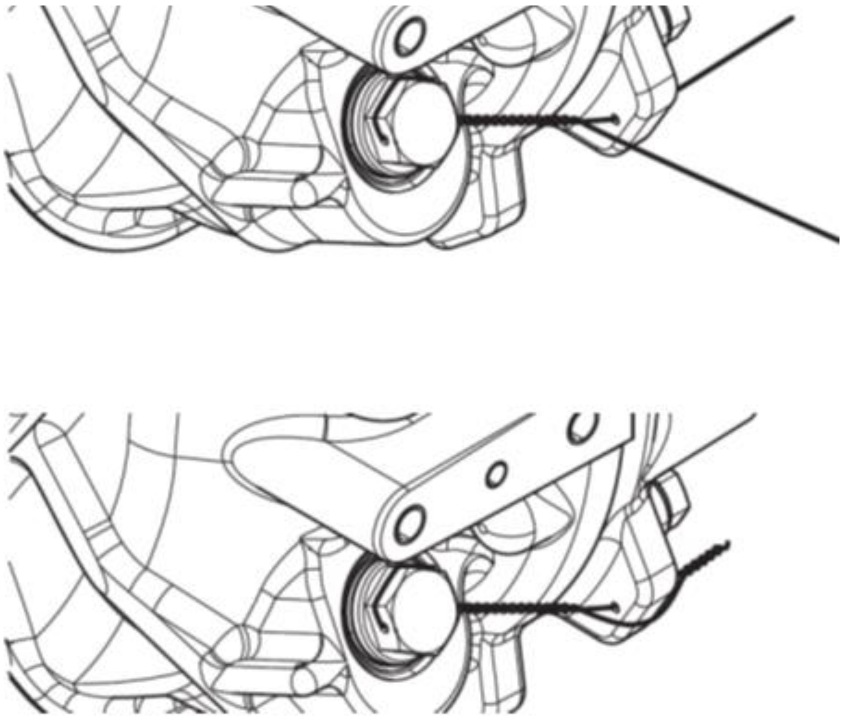


Figure 4-6: Lock Wire Installation (1)

f. Cut both ends of the wire and bend against the housing.

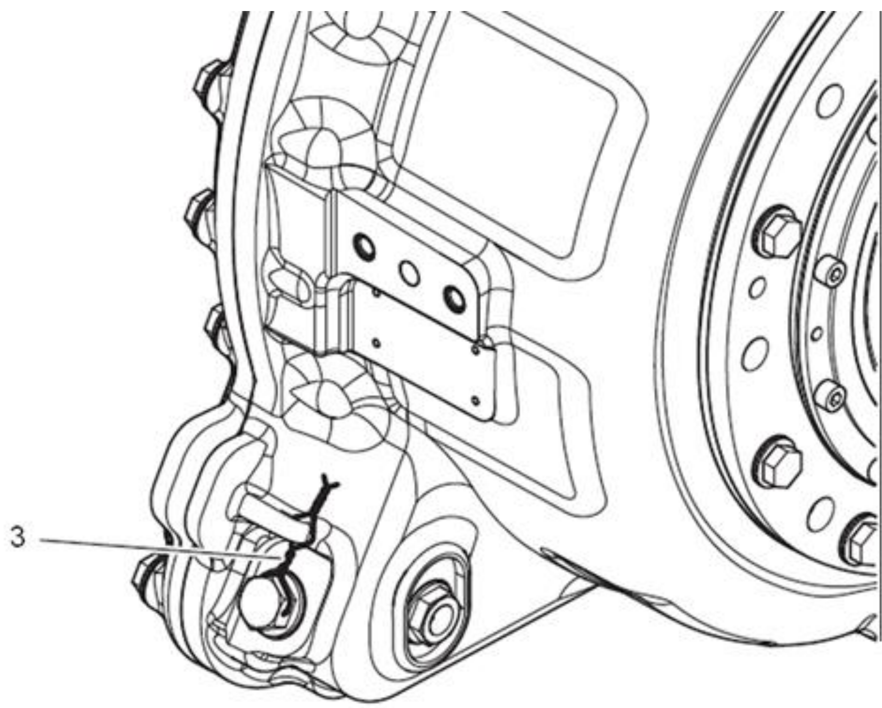


Figure 4-7: Lock Wire Installation (2)

Check Rubber Bushings

Inspect all rubber bushings for any abnormal wear. Thin, small cracks are acceptable if they do not encircle the bushing and are 10% or less deep. See Figure 4-8. These rubber bushings are serviceable and can continue to be used. Smaller cracks are generally of no significance.

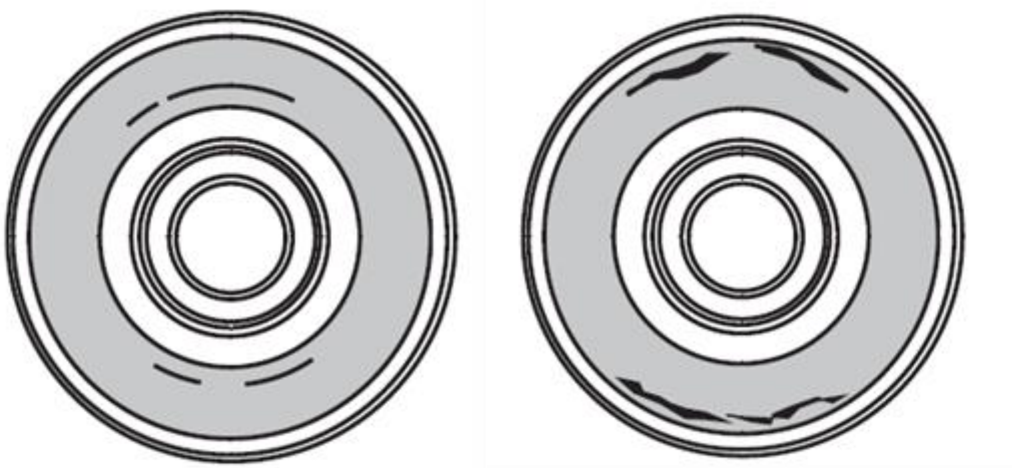


Figure 4-8: Example of Acceptable Cracks on Rubber Bushings

The rubber bushing in Figure 4-9 can still be used however the inspection intervals need to be shortened.

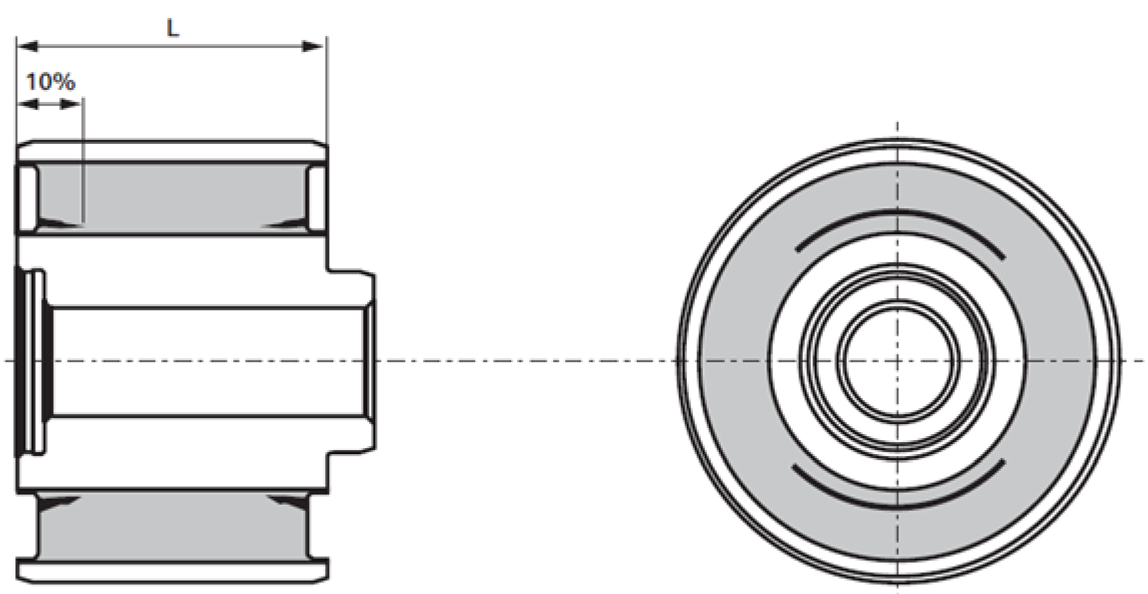


Figure 4-9: Example of Cracks that Require Shorter Inspection Intervals

Cracks that join together to form a circle around the bushing and are deeper than 10% of the total depth are not acceptable. Replace the bushing or support arm as soon as possible. Replace the rubber bushing/torque support shown in Figure 4-10 as soon as possible.

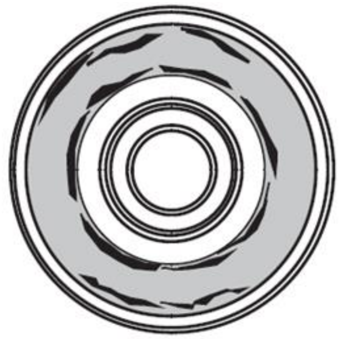


Figure 4-10: Example of Not Acceptable Cracks in Rubber Bushings

4.9.2 30,000 Mile Inspection

No maintenance required.

4.9.3 60,000 Mile Inspections

The initial oil change will be done at the 60K mile interval. All remaining oil changes will be done at the 120K mile interval. See the explanation in Section 4.9.4 to replace the gear unit oil.

At the initial 60,000 Mile Inspection, conduct following oil sampling as needed.

Oil change intervals can be extended if:

- This process has been harmonized and agreed beforehand with ZF Friedrichshafen AG. Contact ZF Customer Service.
- Oil analyses were conducted.
- The oil analyses results have been positive.

1. Take oil samples from the reference gear units. The procedure for taking oil samples is described in Service Information No. 025 in the next page.
   - With respectively four gear units at two different vehicles.
   - Sampling interval of oil samples: Every 120,000 km; subsequently, every 50,000 km up to a mileage [km] of 320,000 km (4 intervals / 32 oil samples).
2. The results of the oil analyses conducted must be presented to ZF Friedrichshafen AG for evaluation purposes. Depending on the oil analysis result, release is granted up to the next sampling interval.
   - If no release is granted, the oil change intervals stipulated in the maintenance schedule have to be complied with.
   - If the application conditions of the train change significantly, approved and extended oil change intervals need to be approved again as seen in Figure 4-11.

SERVICE INFORMATION

2012.05 - **025**

Extended oil change intervals

The oil change intervals can be extended about in common agreement with ZF.
In order to ensure the necessary oil quality, it is required to take oil samples / oil analyses of gearboxes.
The results have to be forwarded to ZF for evaluation.

1 Measures to be taken prior to sampling

This information regarding oil sampling should ensure that the representative oil samplings oil analysis is available. Clean the sampling spot on the gearbox before starting with sampling in order to prevent impurities from outside to get into the sampling.
LOCTITE Cleaner No. 7070 together with non fluffy paper cleaner has proved to be a satisfactory.

2 Sample bottles

The new PE sample bottles with screwed plug should be adapted for the sampling of at least 0.2 up to 0.5 l oil. Each sample bottle must receive a label after oil sampling has been performed. This label must include the required information according to the sample.

3 Oil sampling

The sampling must be carried out in warm state just after the gearbox has been stopped (maximum 10 minutes after).
Prior to filling up the sample bottle, about 1 litre of oil must be drained into a vessel.

4 Magnet at the screw plug

Clean the magnetic plug with a new and clean paper cloth and send this cloth in a plastic bag or something similar together with the oil sampling. Do not forget to mention the sampling number.

5 Re-filling of the gearbox

Top up with fresh oil (missing quantity) and note quantity of topping up oil. Extreme cleaness must be ensured.

6 Inspections to be carried out

The following inspections are to be implemented:
- Determination of ppm content of the following elements to assess the additivation: Na, Ca, Mg, Ba, ZN, S, P, Cl
- Determination of ppm content of the following elements to assess the wear: Al, Fe, Cu, Si
- Implementation of an IR analysis (DIN 51451)
- Determination of kinematical viscosity at: 40 and 100 °C
- Determination of water content

In order to be able to assess the results of the analysis, an analysis of the fresh oil is to be carried out as well as a basis for comparison.
The parameters of the analysis are to be evaluated according to mileage.
The limit value for water is determined as stated below.
The Fe limit values is to be determined individually for the corresponding gearbox.

	Dimension	Fresh / New oil	Used / Old oil
H_2O	Ppm	500	< 1000
Fe	Ppm	Dependent on gearbox	

Label for sample bottles

Date:	Sample no.:	
Sampler:		
Transportation Authority:		
Vehicle no.:		
Gearbox type:	Serial no.:	
Oil manufacturer		
Oil type:		
Running since last oil change:		km
Total run km:		km

Figure 4-11: Survey for Extended Oil Change Intervals

4.9.4 120,000 Mile Inspections

Change the Gear Unit oil

1. Remove safety wire from the Fill plug and Drain plug.
2. Clean area around Fill and Drain plugs.
3. Remove the Fill plug. Check the Fill Plug Magnet as described in 4.9.2 step 4.
4. Remove the Drain plug and drain the oil into a suitable container.
5. The Fill plug has a magnet to catch metal chips in the gear unit. Check and remove metallic particles from the Fill plug magnet.
6. If large or rough metal particles are found on the magnet, remove the truck from the vehicle. Clean the area around the gear unit inspection plug on the top of the gear unit and remove the inspection plug. Examine the gears that can be seen from the opening. If the gears appear to be worn down or course metal chips are found, contact the manufacturer.
7. Add approximately 1 liter (1 quart) of oil and let drain to remove any residue from the bottom of the gear unit reservoir.
8. Install new sealing ring on Drain Plug and install Drain plug. Torque to 70 Nm (52 ft-lb) and safety wire plug.
9. Install new Exxon Mobil Delvac Synthetic Gear Oil 75W-90 to Fill plug (3.5 liters). Check that the oil level is half way up the gear unit sight glass.
10. Measure the length of the fill plug magnet with a micrometer or ruler. If the exposed length of the magnet is less than 60 mm (2.36 inches), it is good.
11. Install new sealing ring on Fill plug and install Fill plug. Torque to 70 Nm (52 ft-lb) and safety wire.

- Clean the gear unit housing and renewing the corrosion protection as follows

1. Clean gear unit housing with warm or cold water jet, hot steam. The critical cleaning spots are outlined in Figure 4-12.

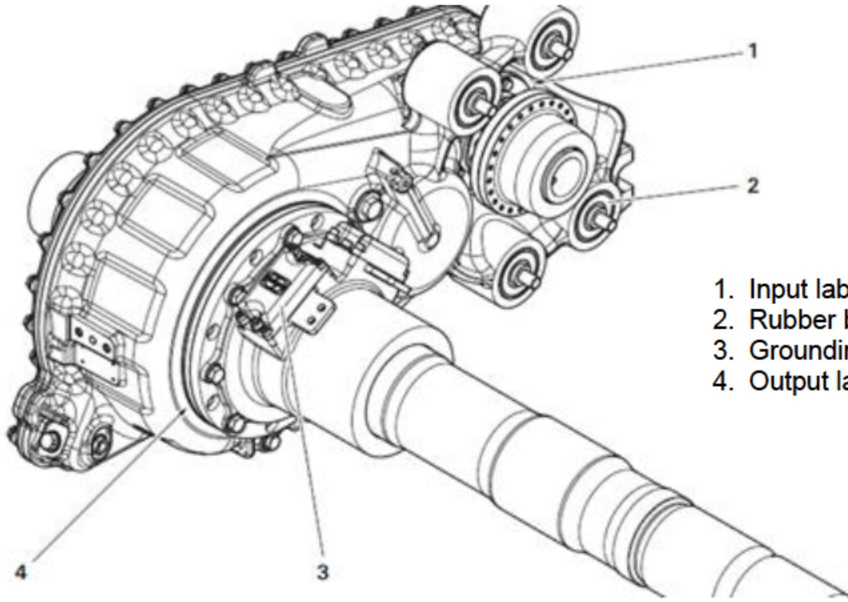
CAUTION

INCREASED RISK OF INJURY AT CONTACT WITH AGGRESSIVE CLEANING AGENTS.

Do not allow aggressive cleaning agents to come into contact with your skin, do not drink them, or inhale their vapors! Wear protective gloves and goggles! Keep away from ignition sources! If cleaning agents come into contact with your skin, wash off immediately with plenty of water! Seek medical assistance immediately if cleaning agents are swallowed unintentionally! Pay attention to accident prevention regulations!

2. Treat stubborn dirt on the gear unit housing with a suitable cleaning agent and then use a scrubber, cleaning cloths, and/or cleaning brush to remove it.

3. Treat metallic bright surfaces with corrosion protection agent.



1. Input labyrinth
2. Rubber bearing
3. Grounding contact
4. Output labyrinth

Figure 4-12: Critical Cleaning Spots

- Check the screw connections as follows

Only retighten listed screw connections. All other screw connections are mounted with thread lockers (LOCTITE) and may not be re-tightened. Only use checked torque wrenches. Preciseness tolerance ±10% of stipulated value. Comply with the tightening torques.

Table 4-3. Screw Connection Torque Table for the Gear Unit

Screw connection	Tightening torque
Gear Unit	
Oil filler plug	70 Nm
Oil drain plug	70 Nm
M42 inspection screw plug at the input	120 Nm
M42 inspection screw plug at the output	120 Nm
All plastic screw plugs	Hand-tightened
Torque support	
Torque support at Gear Unit	440 Nm ±10%
Torque support at bogie	According to the bogie manufacturer's provisions
Drive coupling	
Connect coupling halves	68Nm
Motor with Gear Unit	
Motor/Gear Unit screw connection	440 Nm ±10%

Repair paint and corrosion damage as follows

1. Clean any corroded areas on the Gear Unit housing with a wire brush and/or grinding fabric tape.

2. Remove grease from damaged paint areas using a suitable cleaning agent.

3. Paint cleaned area(s).

4. Maintenance elements such as the oil filler and oil drain plugs have to be painted on the front surface.

5. Treat all uncoated outer parts with a rust inhibitor.

4.10 Ground System Brushes

4.10.1 10,000 Mile Inspections

No maintenance required.

4.10.2 30,000 Mile Inspections

No maintenance required.

4.10.3 60,000 Mile Inspections

1. Clean the dirt and debris from the ground brush housings and cables.

2. Verify that the cables are tight and do not have excessive wear, deterioration or signs of electrical arcing. Check the cables to the ground brush and also the cables to the speed sensors.

3. Open the housing and remove the ground brushes. Remove the brush pressure devices by pressing the outer leg (facing away from the brush) towards the brush and lift the pressure device. The brush should now slide out. See Figure 4-13 and Figure 4-14.

   Check the brush for wear and replace if required. Each brush has a wear line on the side of the brush indicating when the brush must be replaced. Replace brush as brush length gets within 1/8 inch of line. If the wear line cannot be seen on the side of the brush, the brush has worn down beyond the wear line and the brush must be replaced.

   If the carbon brush is stuck in the housing or if the brush shows uneven wear, then moisture, grease, or oil in conjunction with the abrasive wear debris is restricting the brush movement. Clean out the brush guide slot.

4. Inspect the brush shunts inside the housing for loose connections and broken shunts. If more than 10% of the strands are broken on any given shunt, replace the brush.

5. With the brushes removed, clean out the axle ground brush housing to remove dust and dirt as needed. Liquid cleansing agents or compressed air must never be used to remove the debris under any circumstances. Use a vacuum to collect the debris.

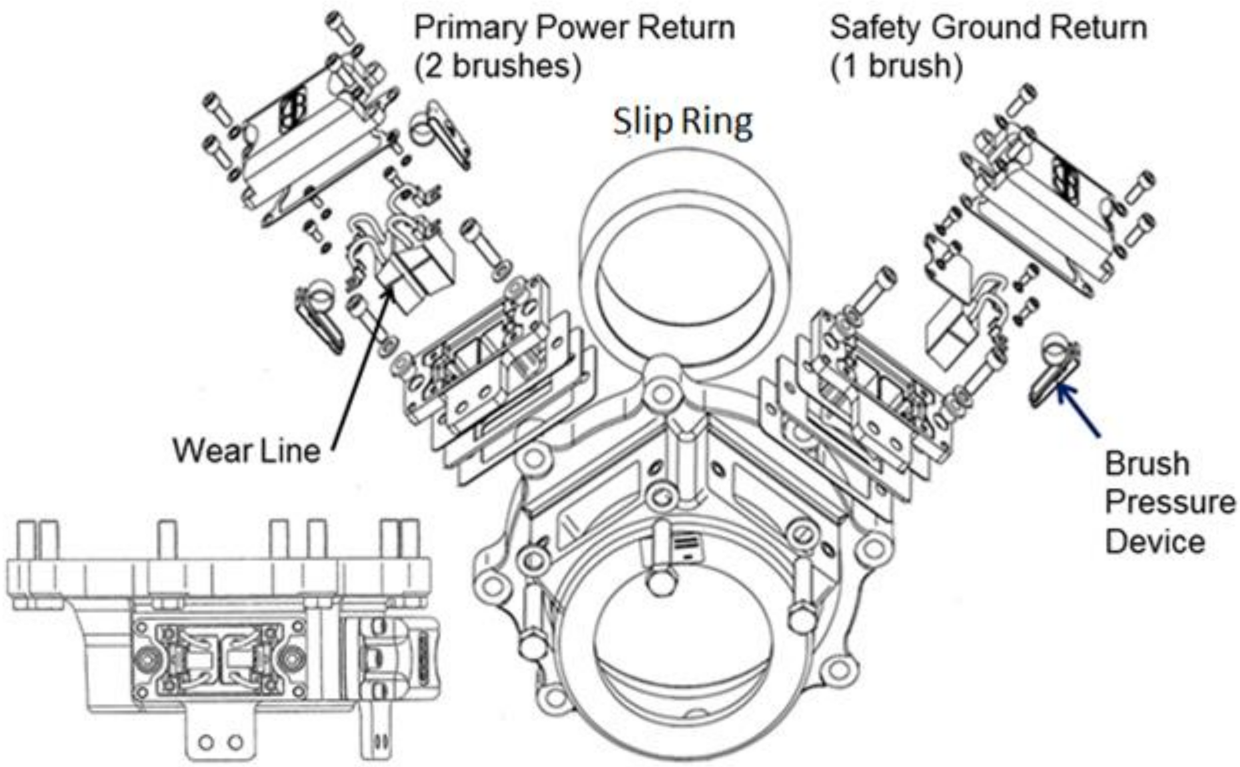


Figure 4-13: Ground Brushes, Motor Axles

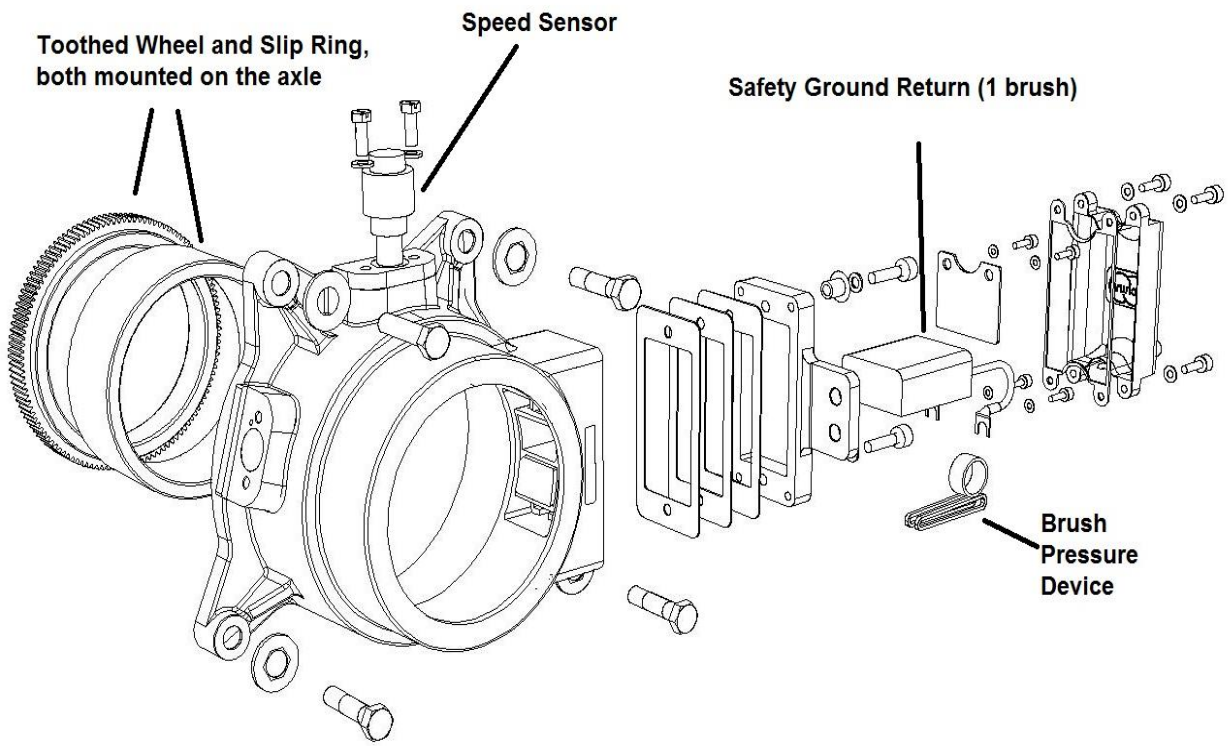


Figure 4-14: Ground Brushes, Trailer Axles

6. Looking through brush holder, visually check the slip ring for grease, pitting, and scoring on the surface. Some wear marks are expected. Deep grooves or burn marks on the slip ring are not acceptable.

7. Replace the brush, brush pressure device and housing cover. Torque cover bolts to 16.5 Nm (12.2 Ft-lbs.).

8. For the Trailer Ground Brushes only, inspect the speed sensor. Remove from the housing and check the face of the sensor for wear marks from rubbing of the toothed wheel. Remove any debris. Check the connector and wiring for damage. Reinstall in the housing. Replace any damaged parts.

4.10.4 120,000 Mile Inspections

No maintenance required.

4.11 High Speed Circuit Breaker

4.11.1 10,000 Mile Inspections

No maintenance required.

4.11.2 30,000 Mile Inspections

No maintenance required.

4.11.3 60,000 Mile Inspections

CAUTION

WHEN REMOVING THE COVER, LIFT FROM THE BOTTOM OF THE COVER. DO NOT LIFT THE COVER FROM THE VENTELATION LOUVERS. THE VENTS ARE NOT STRONG ENOUGH TO HOLD THE WEIGHT AND THE VENTS MAY BE DAMAGED IF USED AS HANDLES.

Remove the cover (1) as shown in Figure 4-15 by removing the eight M8 bolts (2). Lift the cover from the bottom flange. Do not lift the cover from the vent louvers. Clean the dirt and debris from the cover and from inside the unit. Check for evidence of water entry. Check the gasket attached to the cover.

1. Verify that the cables and cable glands are tight and that the cables do not have excessive wear or deterioration.

2. Using the PTU program, close and open the HSCB to observe the normal operation of the device.

3. Inspect the gasket on the cover to ensure that it is not damaged or compressed.

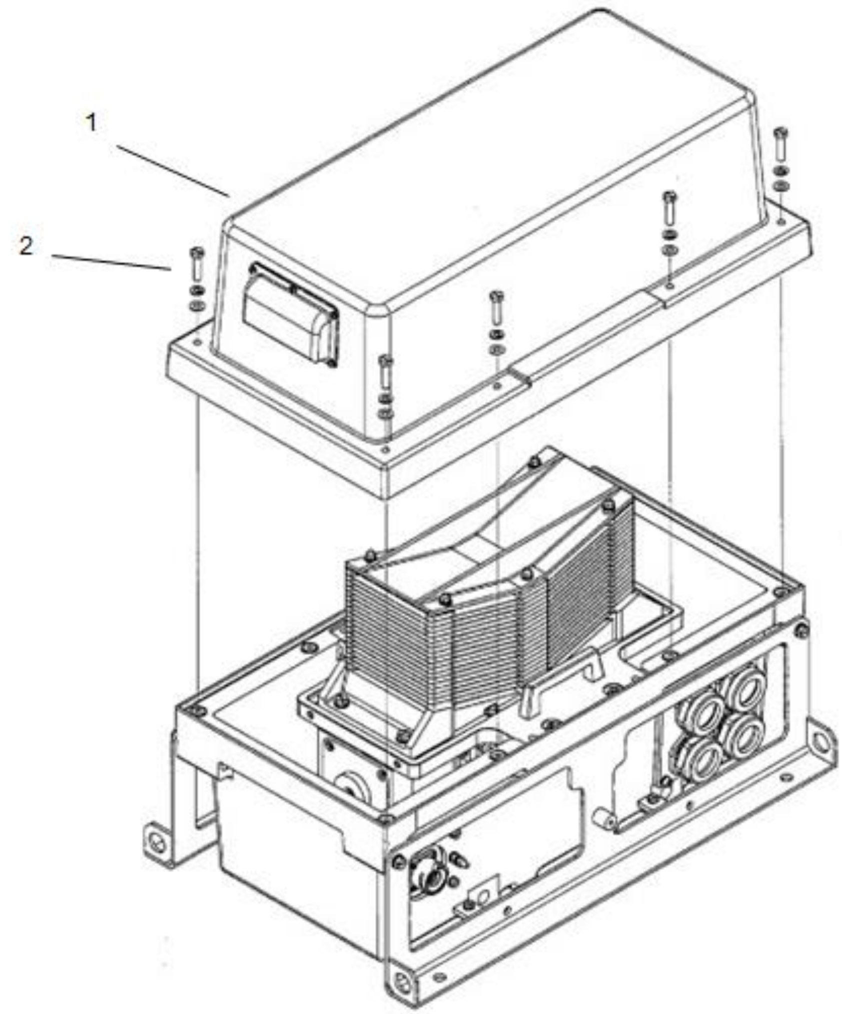


Figure 4-15: HSCB Cover Removal

4.11.4 120,000 Mile Inspections

1. Remove the cover (1) as shown in Figure 4-15 by removing the eight M8 bolts (2). Lift the cover from the bottom flange. Do not lift the cover from the vent louvers.

2. Remove four bolts (2) securing the arc chute / de-ionizing plates (1) for inspection as shown in Figure 4-16. Remove any material deposits greater than 0.5 mm. The de-ionizing plate grid thickness is nominally 2.3 mm. Replace the arc chute and de-ionizing plates assembly if any de-ionizing plate (using a micrometer) has a thickness of 1.3 mm or less.

3. Inspect the surface of the stationary and movable contacts for damage. Wipe off any dust. Avoid skin contact with the contact tips (oils in the skin). If necessary, clean the contacts with Scotch Brite. If there is any transfer of material between the contact tips, the HSCB is opening slowly and must be replaced.

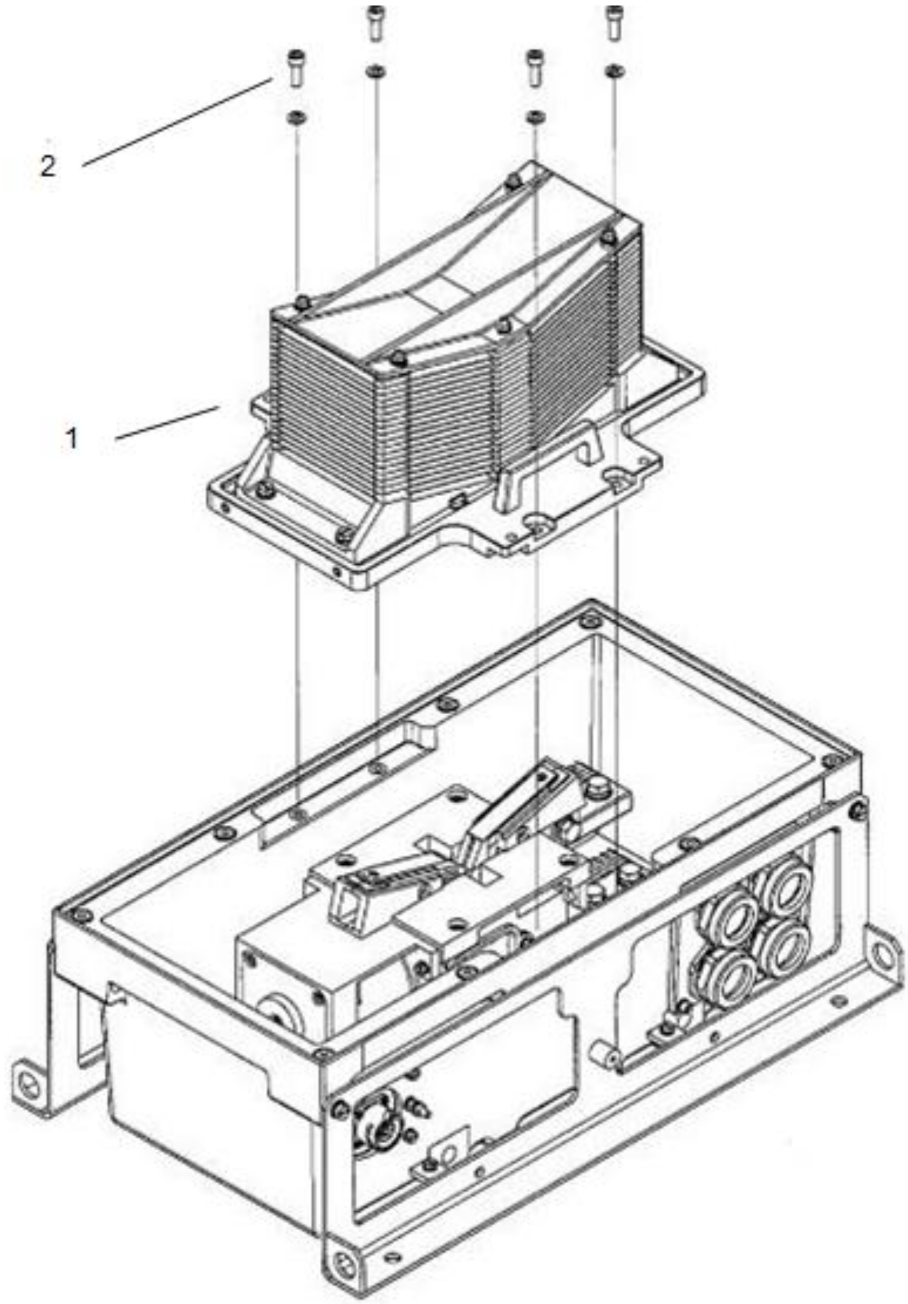
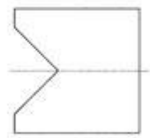
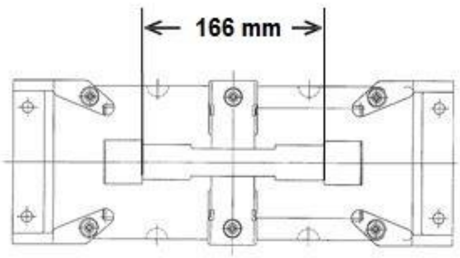


Figure 4-16: HSCB Arc Chute Removal

Deion grid		If the thickness reaches 1.3 mm or any hole is found, replace the arc chute.
Base plate		186 mm Replace the arc chute.

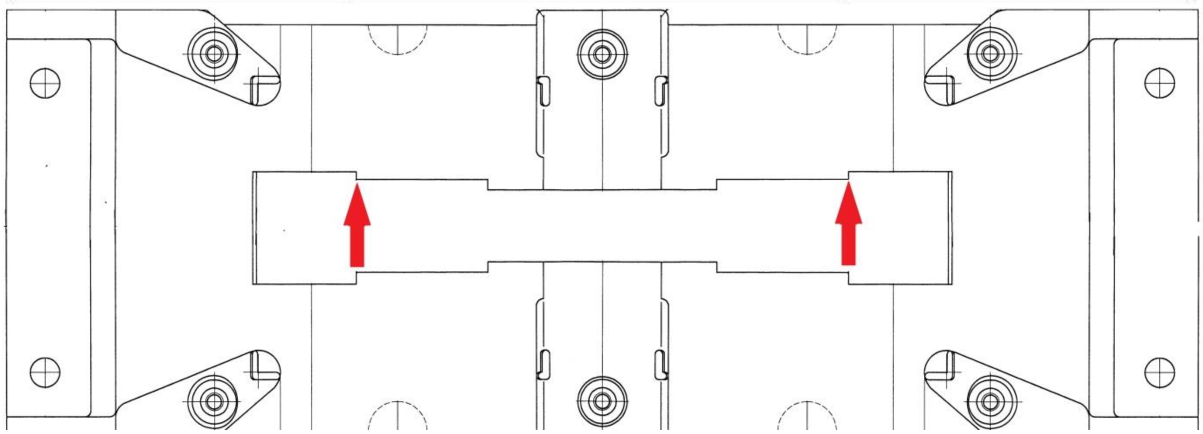


Figure 4-17: HSCB Arc Chute Inspection

4. Measure the thickness of the stationary contact and moving contact. See Figure 4-18 for reference. Measure the height of the areas indicated in black, with respect to the main surface of the contacts. These raised areas will wear during use. The surfaces will be black and pitted due to the burn marks created as the HSCB is used. This is normal for an HSCB. Each contact is 3 mm (0.118”) when new. If the thickness is 1.5 mm (0.059”) or less on either of the contacts, remove the HSCB and replace with a spare. Have the contact tips replaced, the HSCB cleaned, lubricated and then tested on a bench.

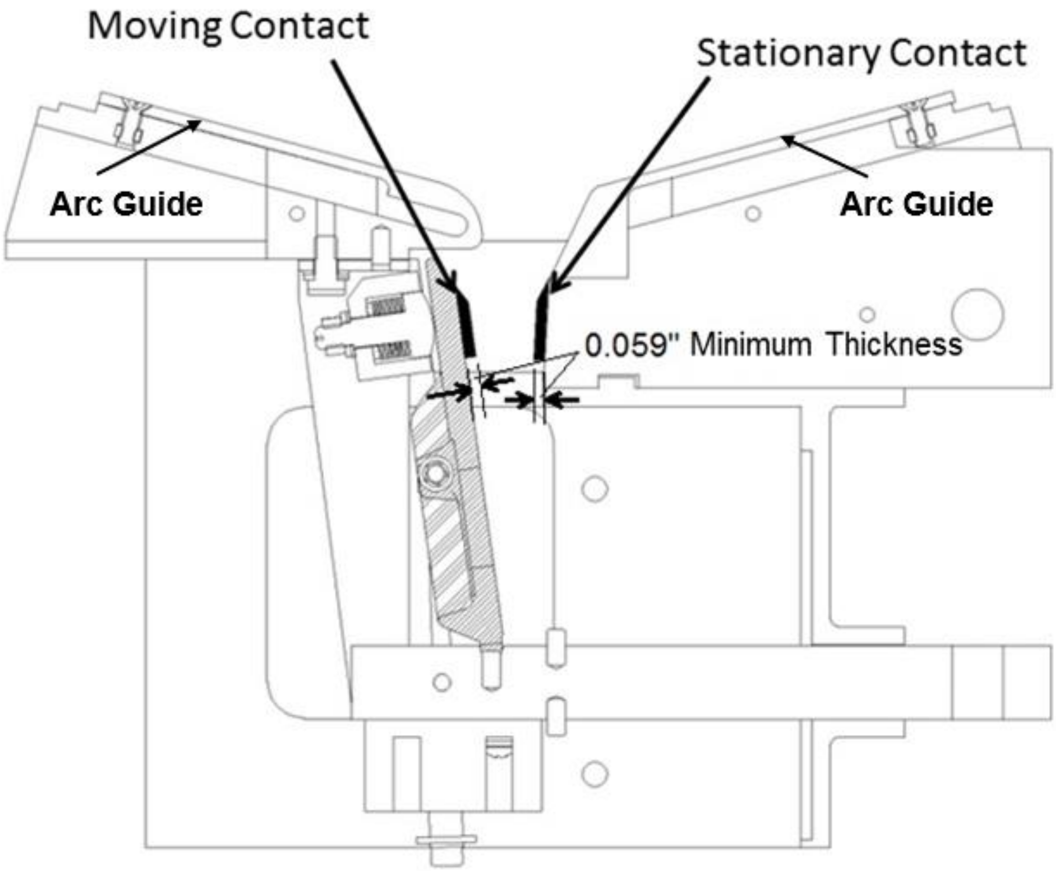


Figure 4-18: HSCB Contact Measurement, New

5. As seen in Figure 4-18, check the arc guides for any burn marks or pitting. The arc guides can be cleaned with a clean dry lint free cloth. Wipe the arc guides starting at the contact tips and wipe outwards away from the contacts. With sever burning or pitting on either of the arc guides, the minimum acceptable width for either guide is 14 mm and minimal acceptable thickness for either guide is 1.3 mm.

CAUTION

THE ARC GUIDES ARE CLEANED STARTING AT THE CONTACT TIPS AND WIPE OUTWARDS AWAY FROM THE CONTACTS SO THAT THE RESIDUE FROM THE CLEANING DOES NOT FALL BETWEEN THE CONTACT TIPS AND CONTAMINATE THE LUBRICANT ON THE MOVABLE CONTACT HINGE POINT.

6. With the De-ionizing Plate / Arc Chute Assembly removed from the HSCB as seen in Figure 4-16, examine the plates as seen in Figure 4-17, If any plate has a thickness of 1.3 mm (0.05 inch) or less (because of burning), replace the assembly. Check for excessive wear at arc chute base plate opening. Replace De-ionizing plate/Arc Chute Assembly if opening is more than 186 mm (7.3 inches) long. Nominal distance is 166 mm (6.5 inches). With a defective De-ionizing Plate / Arc Chute Assembly, please return it to Toyo Denki for repair.

7. Mount the arc chute / de-ionizing plates (1) as seen in Figure 4-1516. Tighten the M8 x 4 bolts, washers, and lock washers (2) to 14 Nm (10.3 ft-lbs.).

8. Install the eight M8 bolts that secure the HSCB cover with a 13 mm socket as seen in Figure 4-15. Tighten to 14 Nm (10.3 ft-lbs.).

4.12 Lightning Arrestor

4.12.1 10,000 Mile Inspections

No maintenance required.

4.12.2 30,000 Mile Inspections

1. Clean the lightening arrestor housing.

2. Inspect the insulation for chips and cracks and clean the housing with an MTA approved cleaning agent.

3. Inspect cable connections.

4.12.3 60,000 Mile Inspections

No maintenance required.

4.12.4 120,000 Mile Inspections

No maintenance required.

4.13 Knife Switch

WARNING

HIGH VOLTAGE!

CONFIRM THAT THE PANTOGRAPH IS LOWERED AND SHOP POWER CABLE DISCONNECTED BEFORE WORKING ON THE KNIFE SWITCH.

4.13.1 10,000 Mile Inspections

No maintenance required.

4.13.2 30,000 Mile Inspections

No maintenance required.

4.13.3 60,000 Mile Inspections

1. Clean the Knife Switch contact points with a dry, clean lint free cloth to remove any dust, debris, and old lubricant.

2. Check the blades and jaws for discoloration to assure that the contact pressure is good.

3. Check the secondary blade springs. Ensure the secondary blade snaps back to the primary blade when the spring is engaged.

4. Engage the secondary blades to the jaws. With a piece of paper, ensure that the blade has a solid connection to either side of the jaw. The paper should not be able to slide down the jaw on either side.

5. Apply a thin coat of Shell Alvania #2 lubricant to the contact surface of the blades. It should be just enough to create a thin film on the surface.

6. Push the blade into position and repeat a few times. Apply additional lubricant if it seems that the initial application was pushed off.

7. The blades may feel that they are easier to mate, but this may not be entirely due to the lubricant. The memory of the metal causes a high pull force if the Knife Switch has not been recently exercised. It loosens to the normal pull force after one complete cycle.

8. Return handle to the NORMAL position and latch the lid of the Knife Switch box.

4.13.4 120,000 Mile Inspections

No maintenance required.

4.14 HSCB Control Panel

Located in vehicle passenger compartment.

4.14.1 10,000 Mile Inspections

Check that cables and connections remain secure and are not damaged.

4.14.2 30,000 Mile Inspections

No maintenance required.

4.14.3 60,000 Mile Inspections

No maintenance required.

4.14.4 120,000 Mile Inspections

No maintenance required.

4.15 Add Traction Motor Lubricant (360,000 miles interval)

The expected interval for adding grease to the traction motor bearings is approximately every three years (every 360,000 miles). Grease is added to the fittings as shown in Figure 4-19.

1. Thoroughly clean the area around each 1/8-27 NPT pipe plug with a clean, lint-free cloth.

2. Remove each pipe plug on either side of the motor.

3. Install clean 1/8-27 NPT grease fitting into the threaded opening.

4. Expel a small amount of grease and clean the grease gun nozzle.

   For the first application of lubricant (year 3), sufficient lube must be added to fill the lube fill pipe and then the bearing cap.

   Using the grease gun, inject 58 grams (2 ounces) of Exxon Unirex N2 or equivalent grease into the fitting on the speed sensor (ball bearing) side and 65 grams (2.3 ounce) of Exxon Unirex N2 or equivalent grease into the fitting on the drive (roller bearing) side of the traction motor.

   For all of the remaining lube applications (year 6 and after) sufficient lube must be added to only fill the bearing cap (the fill pipe is now full of lubricant).

   Using the grease gun, inject 20 grams (0.70 ounce) of Exxon Unirex N2 or equivalent grease into the fitting on the speed sensor side and 25 grams (0.88 ounce) of Exxon Unirex N2 or equivalent grease into the fitting on the drive side of the traction motor.

Table 4-4. Specified Quantities of Grease (year 6 and after)

Bearing	Part	Quantity	When to Add Grease	Where to Apply Grease
Roller Bearing (Gear Unit End)	Bearing	25g (0.9 ounces)	3 years or 360,000 miles	Port on frame, gear end
	Bracket	40g (1.4 ounces)	Only when covers removed	Under the bearing cover
	Cover	45g (1.6 ounces)	Only when covers removed	Under the bearing cover
Ball Bearing (Speed Sensor End)	Bearing	20g (0.7 ounces)	Only when covers removed	Port on frame, speed sensor end
	Bearing Box	38g (1.3 ounces)	Only when covers removed	Under the bearing cover
	Cover	32g (1.1 ounces)	Only when covers removed	Under the bearing cover

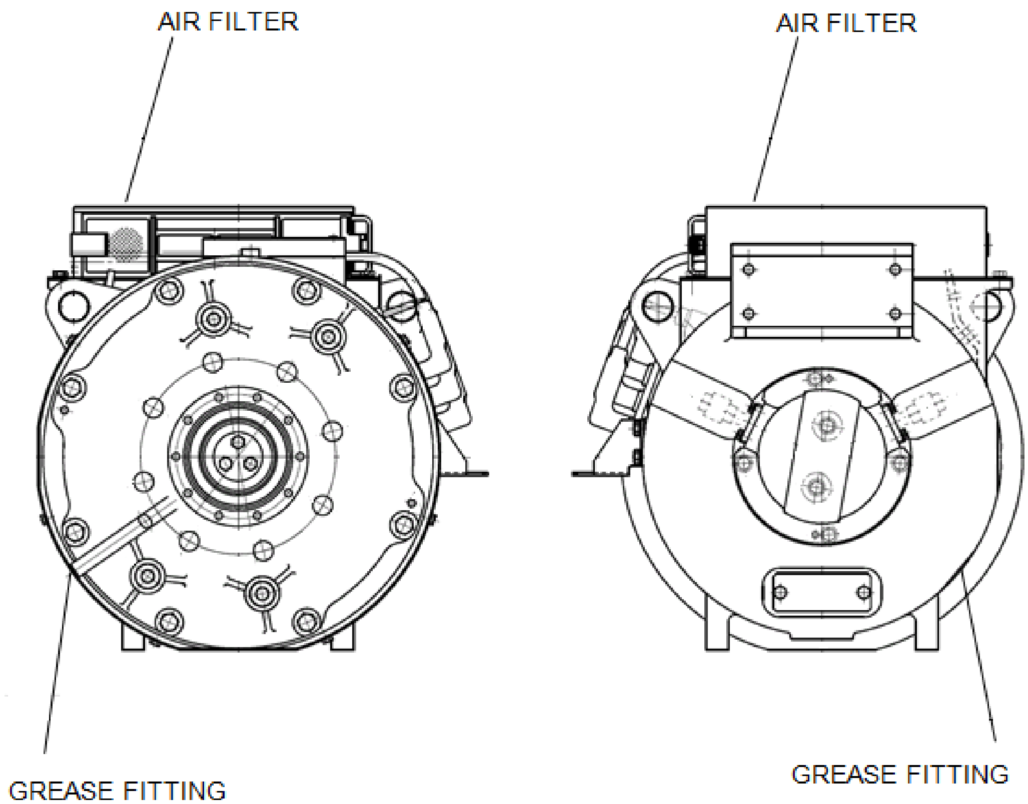


Figure 4-19: Traction Motor Grease Fittings

5. Remove the grease fitting.
6. Thoroughly clean the threads on the pipe plug.
7. Coat the pipe plug threads with Teflon thread sealant.
8. Install the pipe plugs and tighten firmly.

4.16 Equipment Overhaul

4.16.1 Traction Motor Overhaul

Overhaul of the traction motors is recommended by the equipment manufacturer at 600,000 mile intervals (5 years). This overhaul is to examine the bearings and to replace the bearings only if they are damaged.

The insulation material of the stator, rotor, and leads may deteriorate over time. During initial fleet operation, a sampling program should also be performed to overhaul and perform a detailed inspection of the traction motor parts. This program should be performed on one motor after approximately one year of operation and then repeated with a second motor at approximately two years of operation. The inspections should include the bearings and grease conditions. There should not be any degradation noted.

The intent of this sampling program is to verify that the maintenance intervals are correct and that the 600,000 mile overhaul interval will be achieved based on local running and operating conditions. The traction motor overhaul is explained in the Heavy Repair Manual.

4.16.2 Gear Unit Overhaul

At this 10 year interval (1,600,000 miles), it is recommended by the equipment manufacturer that the gear unit be removed and overhauled.

4.16.3 High Speed Coupling Lubricant

At this 5 year interval (600,000 miles), it is recommended by the equipment manufacturer that the High Speed Coupling be removed, the old lubricant removed and new lubricant installed. Refer to HRMM Table: 3-1.

4.16.4 High Speed Circuit Breaker Overhaul

There are two overhaul processes for the HSCB. Every 6 years the HSCB must be disassembled to replace the two shock absorbers. Every 12 years, or when the contact tip thickness is worn to minimum thickness (whichever comes first) is the complete overhaul of the HSCB. This is the internal component replacement, cleaning, lubrication and testing.

The HSCB Close / Open cycling under no load conditions is expected to be approximately 200,000 operations before overhaul.

The overhaul and testing procedures for the HSCB are explained in the Heavy Repair Manual.

The trip setting of the HSCB is 3200 amps. This trip setting is not to be tampered with on the vehicle or during the overhaul. If the trip setting of the HSCB is suspect, replace the HSCB.

CHAPTER 5.0

CORRECTIVE MAINTENANCE

This chapter of the manual explains the removal and replacement of the various components and line replaceable units. During the inspection processes, the visual inspection of the hardware torque marks needs to be done to ensure that the hardware is properly torqued. For each of the following procedures, remove the old torque marks from the hardware as part of the removal process and install torque marks to the hardware after the hardware is torqued.

Refer to Tables 5-1 and 5-2 for torque values as needed throughout this chapter.

Table 5-1. Metric Torque Table

Strength (Material) / Nominal diameter	Class 4.8 (Included SUS)		Class 8.8		Brass bolt, screw	
	Standard Torque	Range	Standard Torque	Range	Standard Torque	Range
M2	0.2	0.19-0.24	0.3	0.25-0.34	0.1	0.10-0.15
M3	0.7	0.59-0.78	1.2	0.88-1.27	0.4	0.29-0.49
M3.5 M3.6	1.1	0.98-1.27	1.7	1.37-1.76	0.7	0.59-0.88
M4	1.7	1.47-1.86	2.3	1.96-2.45	1.1	0.98-1.27
M5	3.4	2.94-3.63	4.4	3.92-4.70	2.3	1.96-2.55
M6	5.8	5.39-6.66	8.0	6.86-8.62	4.7	3.92-5.19
M8	14	12.7-15.7	19	16.7-20.6	10	8.43-11.1
M10	28	26.5-32.3	39	34.3-42.1	16	14.3-18.2
M12	49	45.1-55.9	68	58.8-73.5	38	33.3-42.4
M16	120	108-137	160	137-176	83	71.8-91.4
M18			225	196-245		
M20	235	216-265	320	284-343	143	124-157
M22	320	294-363	440	382-470		
M24	410	372-461	550	480-598		
M30	810	745-941	1120	970-1225		
M36	1410	1274-1666	2000	1666-2156		

Table 5-2. Imperial Torque Table

		Stainless Steel Group 1, 2, 3 Condition CW		Steel Fastener			
				Grade 5		Grade 8	
		A	B	A	B	A	B
1/4 - 20	ft-lbs. Nm kg cm	6 8 80	5 6 60	8 11 110	6 8 80	12 16 165	9 12 120
5/16 - 18	ft-lbs. Nm kg cm	13 18 180	10 14 140	17 23 230	13 18 180	25 34 350	18 24 250
3/8 - 16	ft-lbs. Nm kg cm	24 33 330	18 24 250	31 42 430	23 31 320	44 60 610	33 45 460
7/16 - 14	ft-lbs. Nm kg cm	38 52 530	28 38 390	49 67 680	37 50 510	70 95 970	53 72 730
1/2 - 13	ft-lbs. Nm kg cm	58 78 800	43 58 590	76 103 1050	57 77 790	105 142 1450	80 108 1100
5/8 - 11	ft-lbs. Nm kg cm	115 155 1590	85 115 1190	150 205 2070	125 170 1730	210 285 2900	160 215 2200
3/4 - 10	ft-lbs. Nm kg cm	140 190 1940	105 145 1500	265 360 3660	200 270 2770	370 500 5120	280 380 3870
7/8 - 9	ft-lbs. Nm kg cm	225 305 3110	170 230 2350	430 585 5940	320 435 4430	600 815 8300	450 610 6220
1- 8	ft-lbs. Nm kg cm	340 460 4700	255 345 3530	640 870 8850	480 650 6640	910 1230 12500	580 925 9400
NOTE A: DO NOT USE LUBRICANT FOR FASTENERS - DRY NOTE B: TO BE OILED OR WAXED ON THREADS OF FASTENERS - LUBRICATED							

WARNING

HIGH VOLTAGE

THE PROPULSION SYSTEM MAY POTENTIALLY BE AT A HIGH VOLTAGE. CHECK THAT THE STEPS LISTED BELOW ARE FOLLOWED TO AVOID CONTACT WITH HIGH VOLTAGE.

1. Lower pantograph.
2. Wait for five (5) minutes before opening the equipment case bottom cover.
3. Loosen the 8 captive bolts securing the bottom cover. Slide the cover to clear the 4 safety hangers allowing the cover to be dropped. When done, torque cover bolts to 14 Nm (10.3 ft-lbs.).

   Filter capacitor voltage must be checked from either capacitor in the inverter equipment case accessed from the bottom cover.

   Place the negative meter probe on the 500D cable on the filter capacitor.

   Place the positive meter probe on the 507 cable on the filter capacitor.

   Ensure the voltage is less than 20 volts before working on the equipment.

4. Place the Knife Switch in the OFF position or the Shop Power position.

Shop power can now be used. The Knife Switch blade must not be touched or moved as long as there is high voltage on the vehicle from any source.

Vehicle battery voltage must be isolated from any component before any control wiring is removed.

The following lists the component removal and installation procedures as called out in Chapter 5:

5.1 Propulsion Inverter Air Filter

5.2 Ground Brush

5.3 Lightning Arrestor

5.4 Auxiliary Fuse

5.5 High Speed Circuit Breaker

5.6 Speed Sensors

5.7 Components in the Propulsion Equipment Case

5.7.1 Replace Inverter Unit

5.7.2 Replace PLU Circuit Boards

5.7.3 Replace Power Supply Unit

5.7.4 Replace Gateway Unit

5.7.5 Replace Fan Unit

5.7.6 Replace Relay Unit

5.7.7 Replace Current Transducer Unit Number 1

5.7.8 Replace Current Transducer Unit Number 2

5.7.9 Line Switch Contacts Inspection and Replacement

5.7.10 Replace Line Switch Contactor

5.7.11 Replace Line Charging Contactor

5.7.12 Replace Discharge Resistor Unit

5.7.13 Replace Charging Resistor Unit

5.7.14 Replace DC Voltage Detector Unit

5.7.15 Replace Battery Voltage Noise Filter

5.7.16 Replace High Speed Circuit Breaker Control Panel

5.7.17 Replace Filter Capacitor Unit 1 and 2

5.1 Propulsion Inverter Air Filter

5.1.1 Tools Required

- Standard metric tool set

5.1.2 Removal and Replacement Process

1. Use a 10 mm socket to remove the 6 M6 bolts (1) holding the filter (2) to the housing (3) as shown in Figure 5-1. The screw, flat washer (4), and lock washer (5) are captive hardware and should remain attached to the air filter.

2. Lift the air filter from the lip.

3. To replace, place air filter in position and secure with hardware as listed above. Tighten to 5.8 Nm (4.3 ft-lbs).

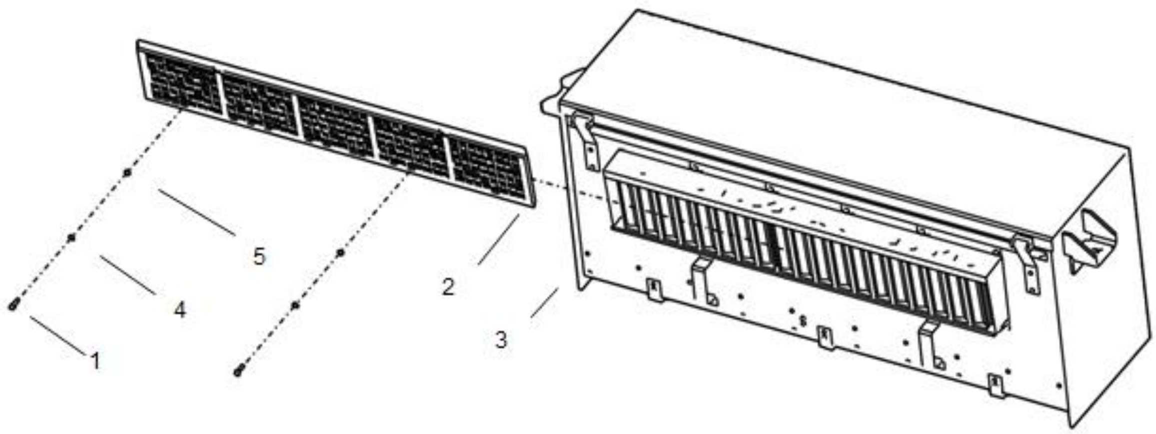


Figure 5-1: Propulsion Inverter Air Filter Removal

5.2 Ground Brush

5.2.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.2.2 Removal and Replacement Process, Motor Axle Ground Brush

1. Remove high voltage from the vehicle and the wires connected to the ground brush.
2. See Figure 5-2. Unscrew and remove the socket head cap screws (1) with a 6 mm hex key. Remove all four screws.

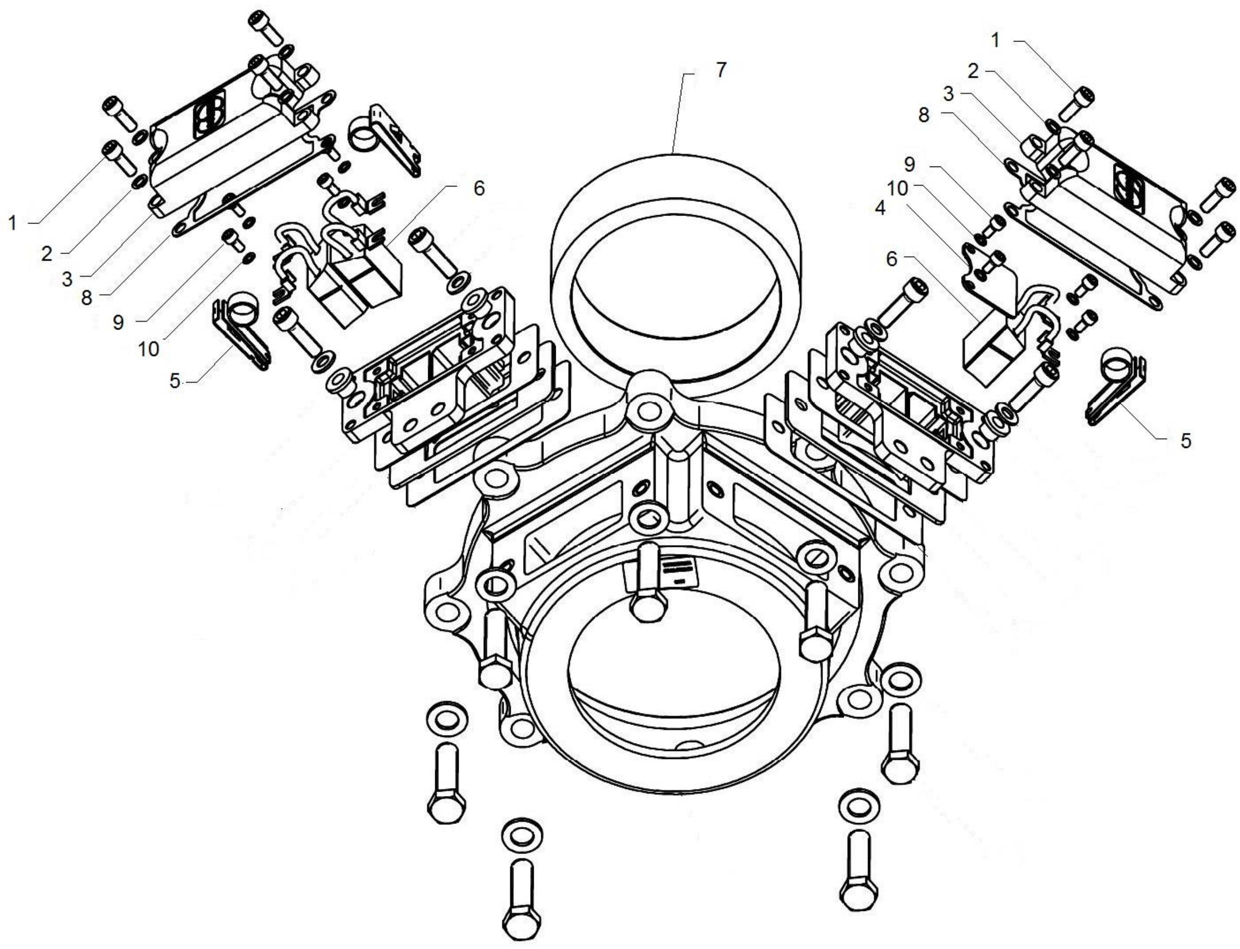


Figure 5-2: Motor Axle Ground Brush Components

3. Remove the lock washers (2), cover (3) and gasket (8) from the brush guide.

4. Using a 5 mm hex key, remove four screws (9), lock washers (10) and the cover plate (4) if this side only has one brush.

5. Remove the brush pressure device (5) by pressing the outer leg (facing away from the brush) towards the brush and lift the pressure device. Replace brush (6) if the wires are frayed or damaged, or if worn down to within 1/8 of an inch of the wear mark line. Check that the wear mark is visible. The wear must be evenly distributed. No chips, scoring, or traces of oil are allowed.

6. Look into the housing and inspect the slip ring (7). The ring must be free of grooves, nicks, or grease.

7. To reassemble the system, insert the ground brush and pressure device into the housing, making sure that the pressure device sits evenly on the brush. Place cover plate (4) into position. Reinstall screws (9) and lock washers (10) with a 5 mm hex key. Torque to 7 Nm (5.2 ft-lbs).

8. Replace gasket (8) if needed. Reinstall the cover (3) with screws (1) and lock washers (2). Use a 6 mm hex key and install all four screws. Torque to 16.5 Nm (12.2 ft-lbs.).

9. Attach the ground wire connection (not shown) and torque to 27 Nm (20 ft-lbs.).

5.2.3 Removal and Replacement Process, Trailer Axle Ground Brush

1. Remove high voltage from the vehicle and the wires connected to the ground brush.

2. See Figure 5-3. Unscrew and remove the socket head cap screws (1) with a 6 mm hex key. Remove all four screws.

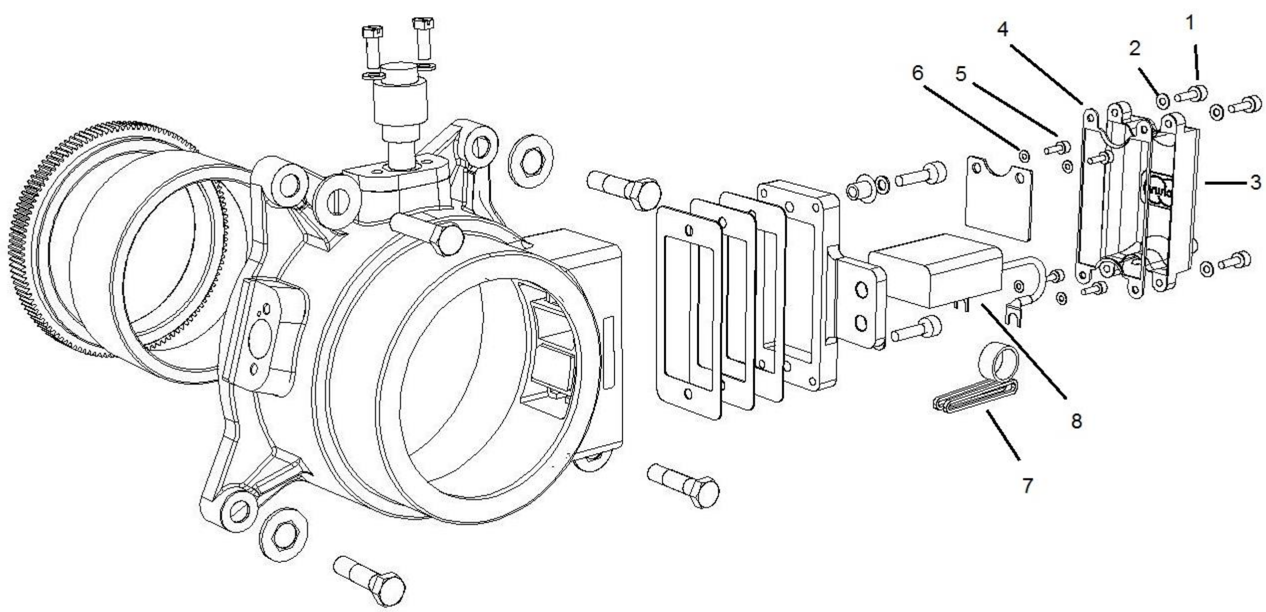


Figure 5-3: Trailer Axle Ground Brush Components

3. Remove the lock washers (2), cover (3) and gasket (4) from the brush guide.

4. Remove the socket head cap screws (5) and lock washers (6) with a 5 mm hex key. Remove all four screws and the cover plate.

5. Remove the brush pressure device (7) by pressing the outer leg (facing away from the brush) towards the brush and lift the pressure device. Remove the brush (8) for inspection or replacement Ensure that the wires are not frayed or damaged. Replace the brush if it is worn down to within 1/8 of an inch of the wear mark line. Check that the wear mark is visible. The wear must be evenly distributed. No chips, scoring, or traces of oil are allowed.

6. Look into the housing and inspect the slip ring. The ring must be free of dirt, grooves, nicks, or grease.

7. To reassemble the system, insert the ground brush and pressure device into the housing, making sure that the pressure device sits evenly on the brush. Reinstall the cover plate, four screws (5) and lock washer (6). Use a 5 mm hex key. Torque to 7 Nm (5.2 ft-lbs.).

8. Replace the gasket if needed. Reinstall the cover (3) with screws (1) and lock washers (2). Use a 6 mm hex key and install all four screws. Torque to 16.5 Nm (12.2 ft-lbs.).

9. Attach the ground wire connection (not shown).

5.3 Lightning Arrestor

5.3.1 Tools and Equipment

- Standard tool set
- Torque wrench

5.3.2 Removal

1. Remove high voltage from the vehicle. Ensure that the catenary supply above the vehicle is dead.

2. Remove the electrical connections from the terminal studs shown in Figure 5-4.

3. Remove the two mounting bolts that secure the lightning arrestor to the bracket.

5.3.3 Installation Process

1. Reinstall the new lighting arrestor. Tighten the 5/16” screws to 18 Nm (13 ft-lbs.).

2. Tighten the terminal stud connections to 33 Nm (24.3 ft-lbs.).

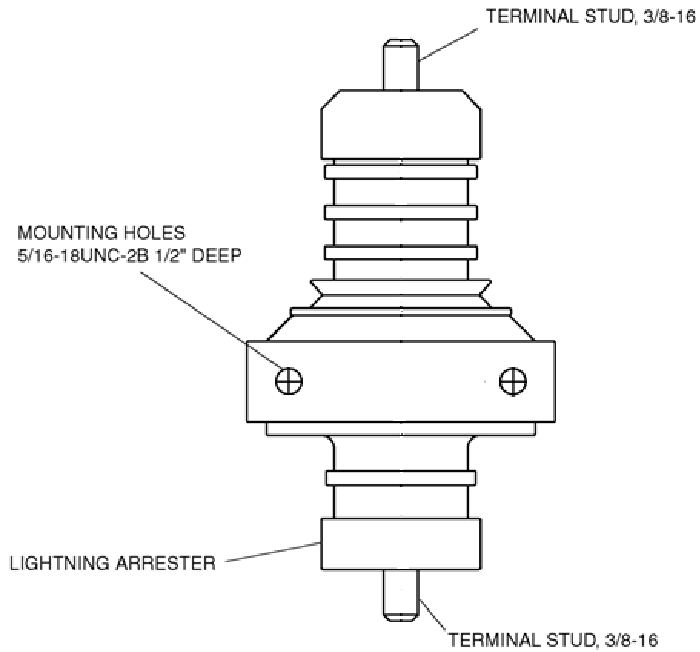


Figure 5-4: Lightning Arrestor

5.4 Auxiliary Fuse

5.4.1 Tools and Equipment

- Standard tool set
- Torque wrench

5.4.2 Removal Process

1. Remove high voltage from the vehicle. Ensure that the catenary supply above the vehicle is dead.
2. Open the auxiliary fuse box door by unlatching both latches.
3. Use a 9/16” socket to remove the nuts and washers holding the fuse and cables to the 3/8-16 studs as shown in Figure 5-5.
4. Remove fuse.

5.4.3 Installation Process

1. Install replacement fuse and cables and secure with nuts and washers holding the fuse.
2. Tighten nuts to 24.4 Nm (18 ft-lbs.).
3. Close and latch the cover.

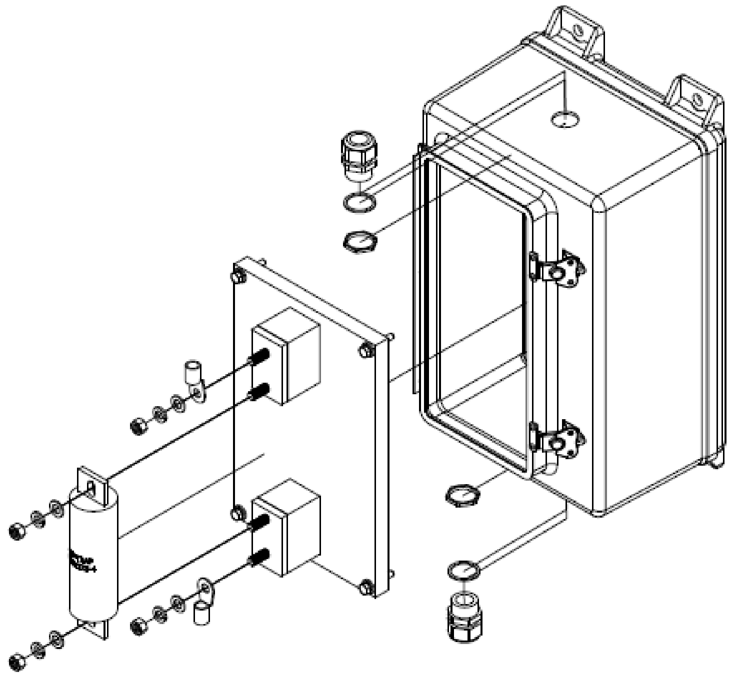


Figure 5-5: Auxiliary Fuse Box

5.5 High Speed Circuit Breaker

5.5.1 Tools and Equipment

- Flat blade screwdriver
- Standard metric tool set
- Torque wrench
- Silicone adhesive sealant

5.5.2 Removal Process

1. Remove high voltage from the vehicle. Ensure that the catenary supply above the vehicle is dead.

2. Remove the auxiliary circuit cable connector. Rotate the circular connector counter-clockwise until it releases.

3. Remove the cover (1) as shown in Figure 5-6 by removing the eight M8 x 8 bolts (2). The bolt heads are 13 mm.

NOTE: Lift the cover from the bottom flange. Do not lift the cover from the exhaust vent louvers. The vent louvers are not strong enough to use as leverage to remove the cover and the louvers may be damaged if used as a handle.

4. Remove the arc chute / de-ionizing plates (1) as shown in Figure 5-7 by removing the four mounting bolts (2) along with the flat washers and lock washers.

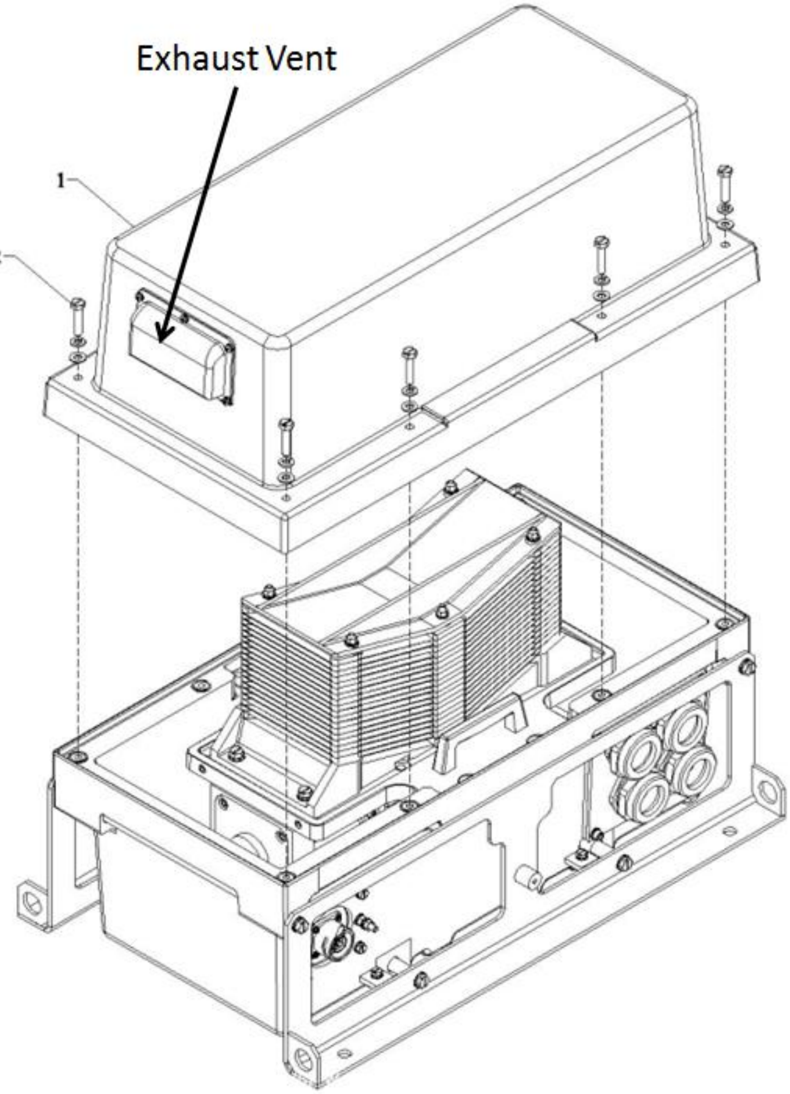


Figure 5-6: HSCB Cover Removal

5. Loosen the cable grips and disconnect the four M12 x 2 bolts for each power cables. Use a 19 mm socket. The crimp terminals attach to the terminals of the HSCB. The cable glands panel is next removed by loosening the screws in each corner. The cable glands do not need to be loosened if the entire panel is removed.

6. Remove the M8 bolt for the ground wire connection and the ground wire with a 13 mm socket.

7. Remove the M12 bolts with a 19 mm socket. These bolts secure the HSCB frame to the vehicle. Remove the frame containing the HSCB.

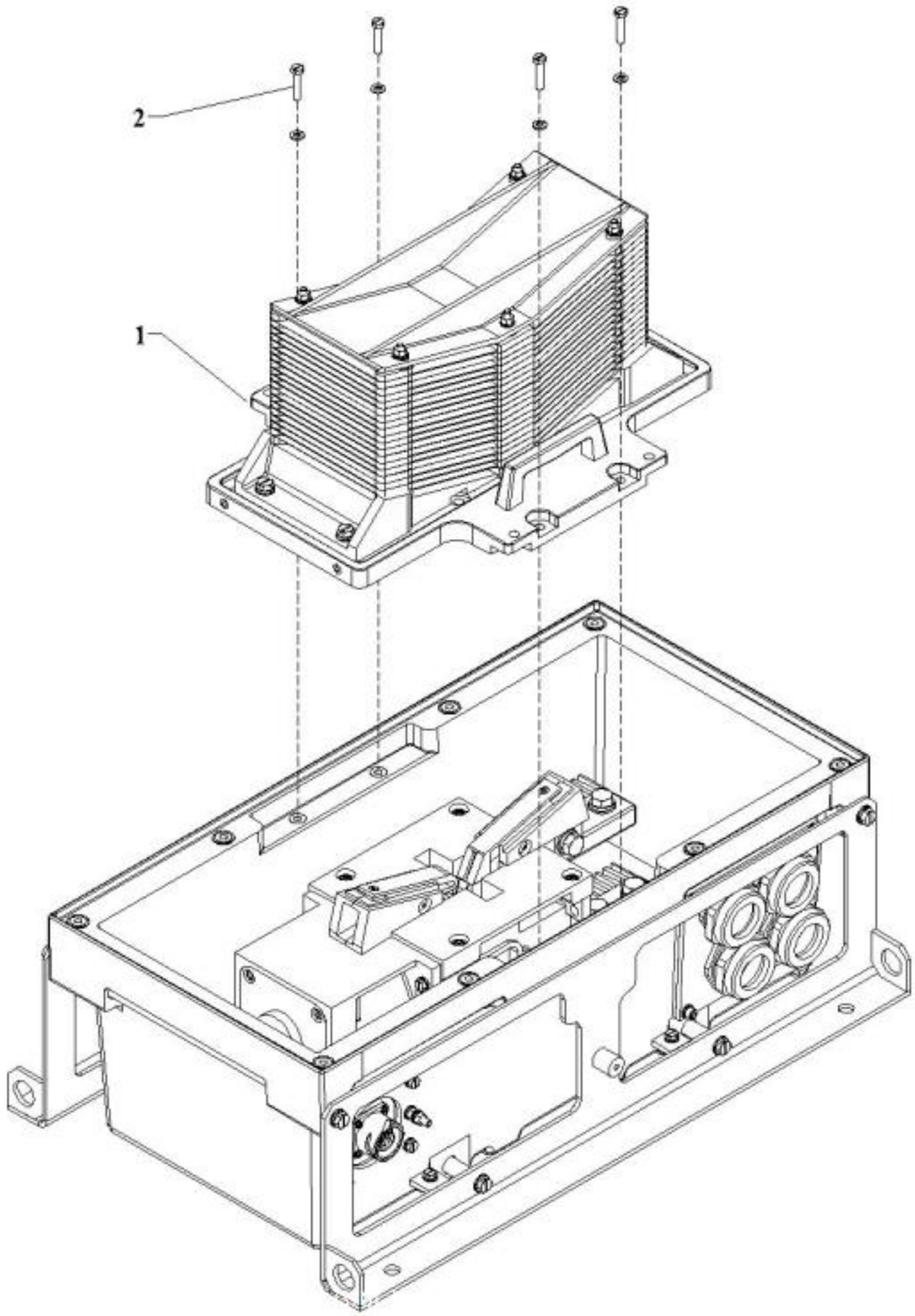


Figure 5-7: HSCB Arc Chute Removal

5.5.3 Installation Process

1. If not already done, remove the cover (1) as shown in Figure 5-6 by removing the eight M8 x 8 bolts (2). The bolt heads are 13 mm.

2. If not already done, remove the arc chute / de-ionizing plates (1) as shown in Figure 5-7 by removing the four mounting bolts (2) along with the flat washers and lock washers.

3. Position HSCB and frame onto the vehicle roof and use a 19 mm socket to tighten the M12 bolts that secure the HSCB frame to the roof. Torque to 49 Nm (36 ft-lbs.).

4. Re-install the cable gland plate that contains the four power cables. Use silicone adhesive sealant to make a water-tight seal. Tighten the screws in each corner (not shown). The lower left corner screw also holds the ring terminal ground wire. Secure the power cables into the designated positions with the M12 x 2 bolts, flat washers and lock washers. Torque to 49 Nm (36 ft-lbs.).

5. Mount the arc chute / de-ionizing plates (1) as seen in Figure 5-7. Tighten the M8 x 4 bolts, washers, and lock washers (2) to 14 Nm (10.3 ft-lbs.).

6. Connect the ground terminal to the exterior. This is an M8 x 1 bolt with a flat washer and lock washer. Use a 13 mm socket. Tighten to 14 Nm (10.3 ft-lbs.).

7. Connect the M12 bolts to the main power wiring terminals with a 19 mm socket and torque to 49 Nm (36 ft-lbs.). Tighten the cable glands.

8. Attach the auxiliary circuit cable connector. Rotate the circular connector clockwise until it clicks into place. The circle mark on the connector body must align with the straight line on the bulkhead connector.

9. Install the eight M8 bolts that secure the HSCB cover with a 13 mm socket as seen in Figure 5-6. Tighten to 14 Nm (10.3 ft-lbs.).

5.6 Speed Sensors

The speed sensors are located at the non-drive end of the traction motor and the trailer axle ground brush housings. Traction motors 1 and 4 have two speed sensors and traction motors 2 and 3 have one speed sensor each. They are secured with two M8 bolts.

To remove the sensors, remove the quick disconnect connector, being careful not to damage the wires. Use a 13 mm socket to loosen the bolts.

During reinstall, torque to 19 Nm (14.1 ft-lbs.). Insert and secure the quick disconnect connector. If more detail is required, see the carbuilder documentation.

5.7 Components in the Propulsion Equipment Case

5.7.1 Replace Inverter Unit

The Removal and installation of the Inverter Unit, as well as all of the components that make up the Inverter Unit is found in the Heavy Repair Manual Section 3.2.4.

5.7.2 Replace PLU Circuit Boards

5.7.2.1 Tools and Equipment

- Flat blade screwdriver

5.7.2.2 Removal Process

CAUTION

DO NOT REMOVE OR REPLACE ANY CIRCUIT BOARD FROM THE LOGIC CRADLE WITH CONTROL POWER ACTIVE. ENSURE THAT BATTERY POWER HAS BEEN REMOVED FROM THE LOGIC RACK BEFORE REMOVING OR REPLACING ANY CIRCUIT BOARD.

CAUTION

WHEN WORKING WITH PRINTED CIRCUIT BOARDS, PUT A GROUNDED WRIST STRAP ON ONE WRIST. DISCHARGE YOURSELF AT A WELL GROUNDED POINT IMMEDIATELY BEFORE YOU TOUCH THE CIRCUIT BOARD. AVOID TOUCHING CONTACT PINS AND CONDUCTIVE PATHS.

1. Remove the connectors from the front panel of the circuit board. The PLU circuit board locations are shown in Figure 5-8. With the connector latch in the upper position, the connector is locked in place. With the latch pulled down, the connector can be removed and installed.

2. Loosen the screws at the top and bottom of the circuit board and disengage the board by using the upper and lower handles.

5.7.2.3 Installation Process

1. To install a circuit board, push it in position until it fully seats into the backplane. Tighten screws and re-attach cables.

2. After installation power up the PLU and check the revision level of software for all circuit boards of the PLU. If not current, update the software.

3. If circuit boards MCB108B1 is replaced, re-enter the wheel diameter as described in Section 3.9.3.

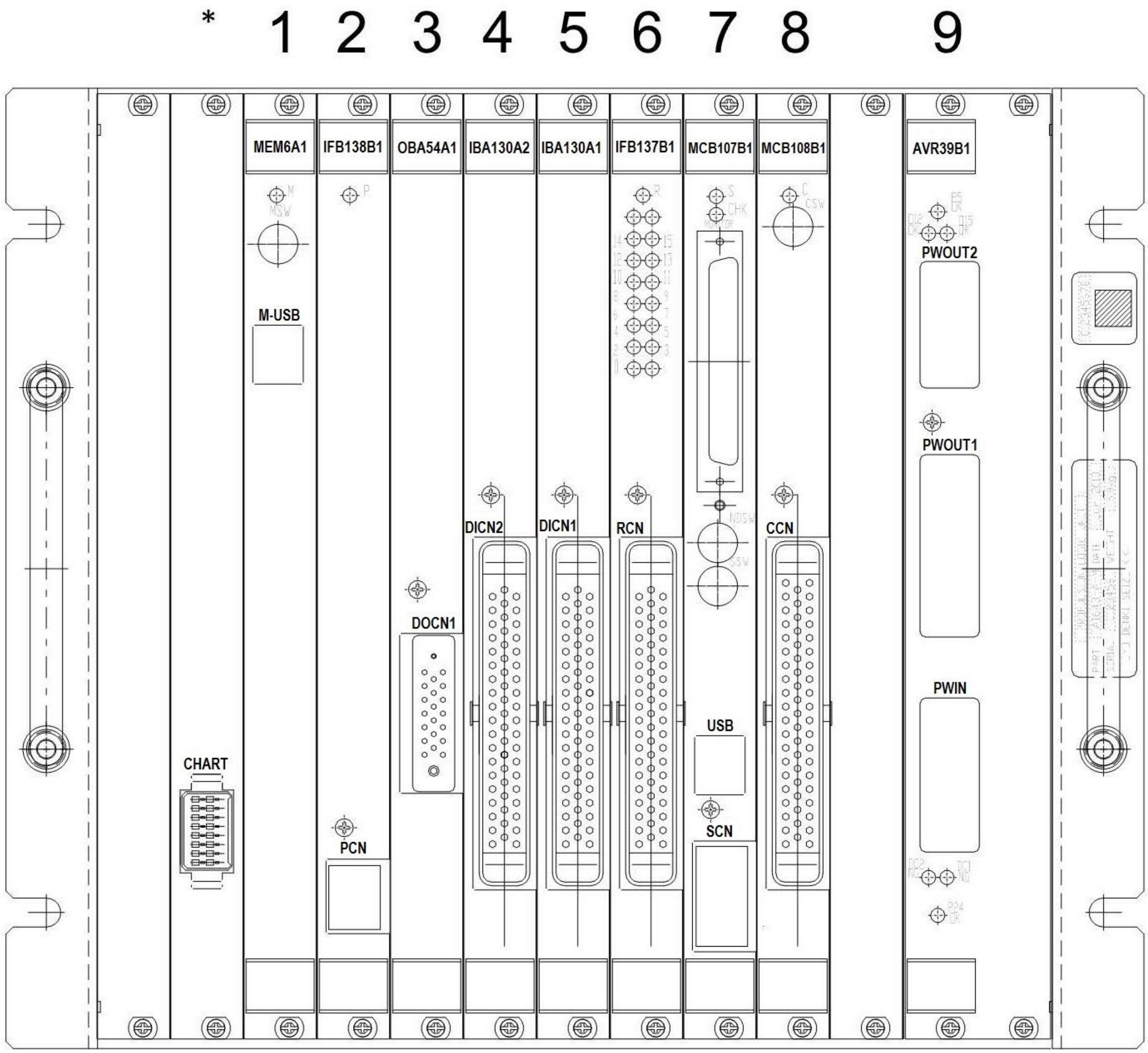


Figure 5-8: Propulsion Logic Unit Circuit Boards

* When needed, the Chart Output board IFB139B1 is fitted into this position:

1 – Memory, MEM6A1
2 – Speed Signal Processing, IFB138B1
3 – Digital Output, OBA54A1
4 – Digital Input 2, IBA130A2
5 – Digital Input 1, IBA130A1
6 – Serial Communications, IFB137B1
7 – Inverter System Control, MCB107B1
8 – Inverter Control, MCB108B1
9 – Power Supply, AVR39B1

5.7.3 Replace Power Supply Unit

5.7.3.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.3.2 Removal Process

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. Disconnect the cables from the front of the PSU.
2. Remove the four M6 screws (2) by using a 10 mm socket as shown in Figure 5-9.

5.7.3.3 Installation Process

Reinstall the new PSU (1) and tighten the hex screws (4) to 5.8 Nm (51 in-lbs.) as shown in Figure 5-9. Use flat washers (3) and lock washers (2). Plug in the harness connectors (not shown).

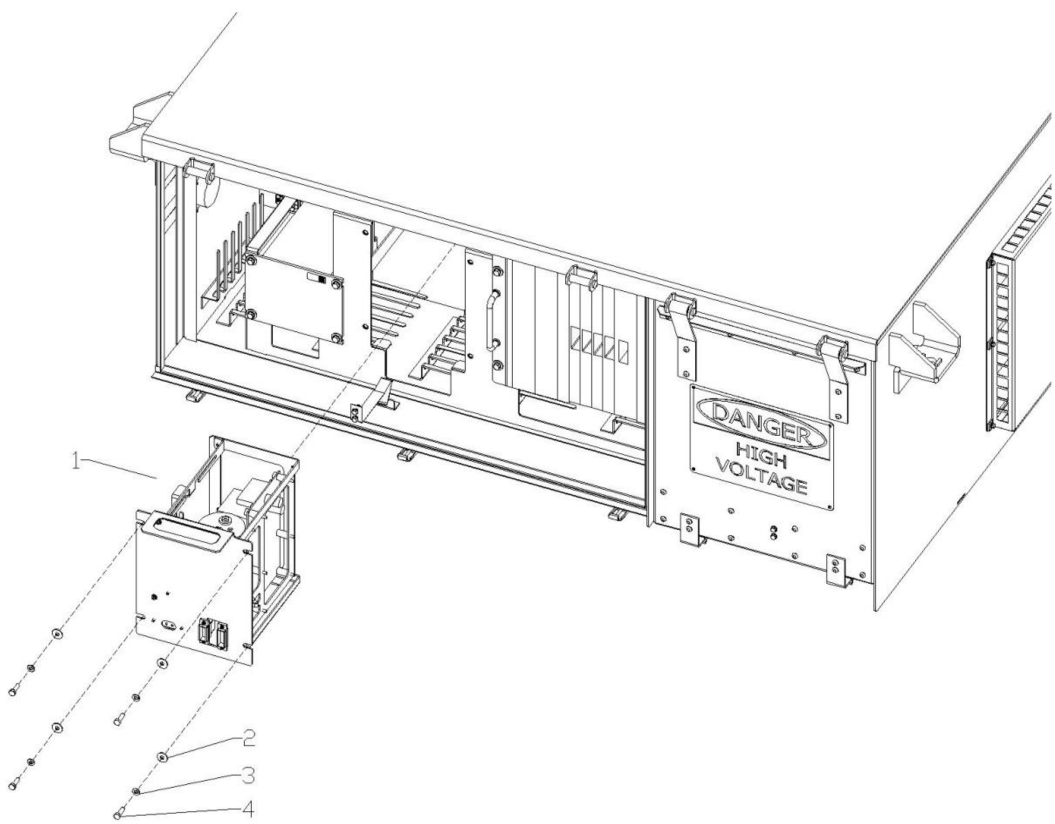


Figure 5-9: Power Supply Unit Installation

5.7.4 Replace Gateway Unit

5.7.4.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.4.2 Removal Process

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. Remove the various electrical connections from the front of the Gateway Unit (2).

2. Remove the four M6 screws (1) by using a 10 mm socket and remove Gateway Unit (2) as shown in Figure 5-10.

5.7.4.3 Installation Process

1. Reinstall the new Gateway Unit (2) and tighten the hex screws (1) to 5.8 Nm (51 in-lbs.) as shown in Figure 5-10. Use flat washers (3) and lock washers (4).

2. Install the electrical connections.

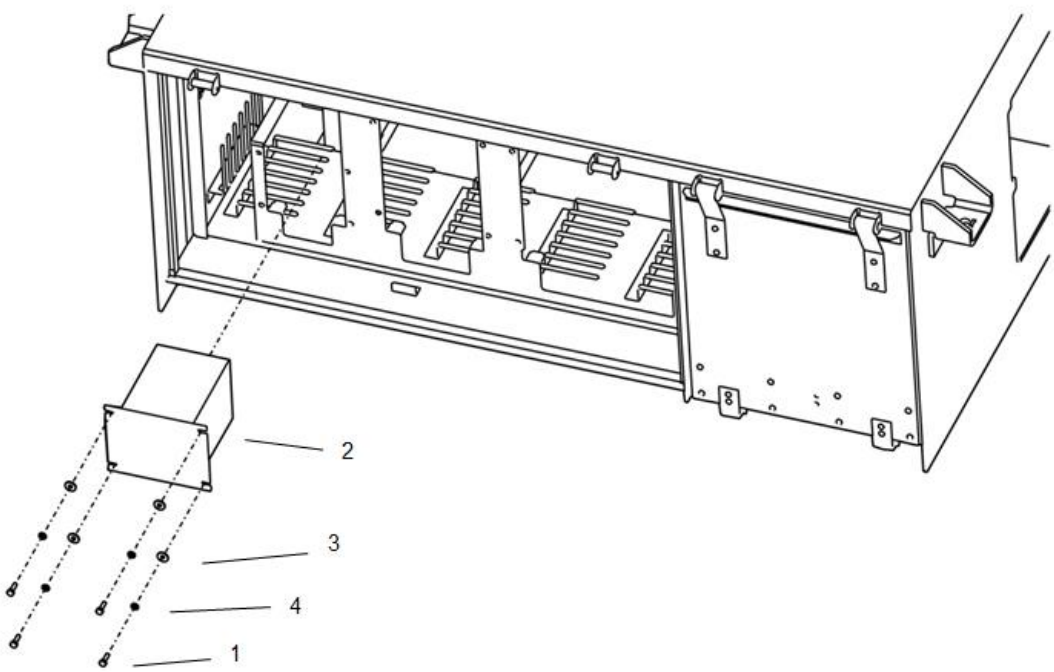


Figure 5-10: Gateway Unit Installation

5.7.5 Replace Fan Unit

5.7.5.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.5.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND THE VEHICLE APS DISABLED.

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. The fan unit (1) can be removed from the Inverter Unit (2) while the Inverter Unit remains in the propulsion equipment case, Figure 5-12. First, remove the equipment case door that contains the air filter.

2. Disconnect the FANCN1 and FANCN2 connectors at the sides of the fan unit.

3. Loosen the eight (8) hex head bolts (3), flat washers (5) and lock washers (4) that secure the fan unit to the inverter frame as shown in Figure 5-12. Use a 10 mm socket. These are M6 threads. The fan assembly can then be removed.

To remove only a single fan - Figure 5-11.

1. Release the tab securing each connector and disconnect each connector FANACN and FANPCN at the base of the fan.

2. Loosen the four (4) hex head bolts, flat washers and lock washers that secure the fan to the fan unit frame. Use an 8 mm socket. These are M5 threads. The fan can then be removed.

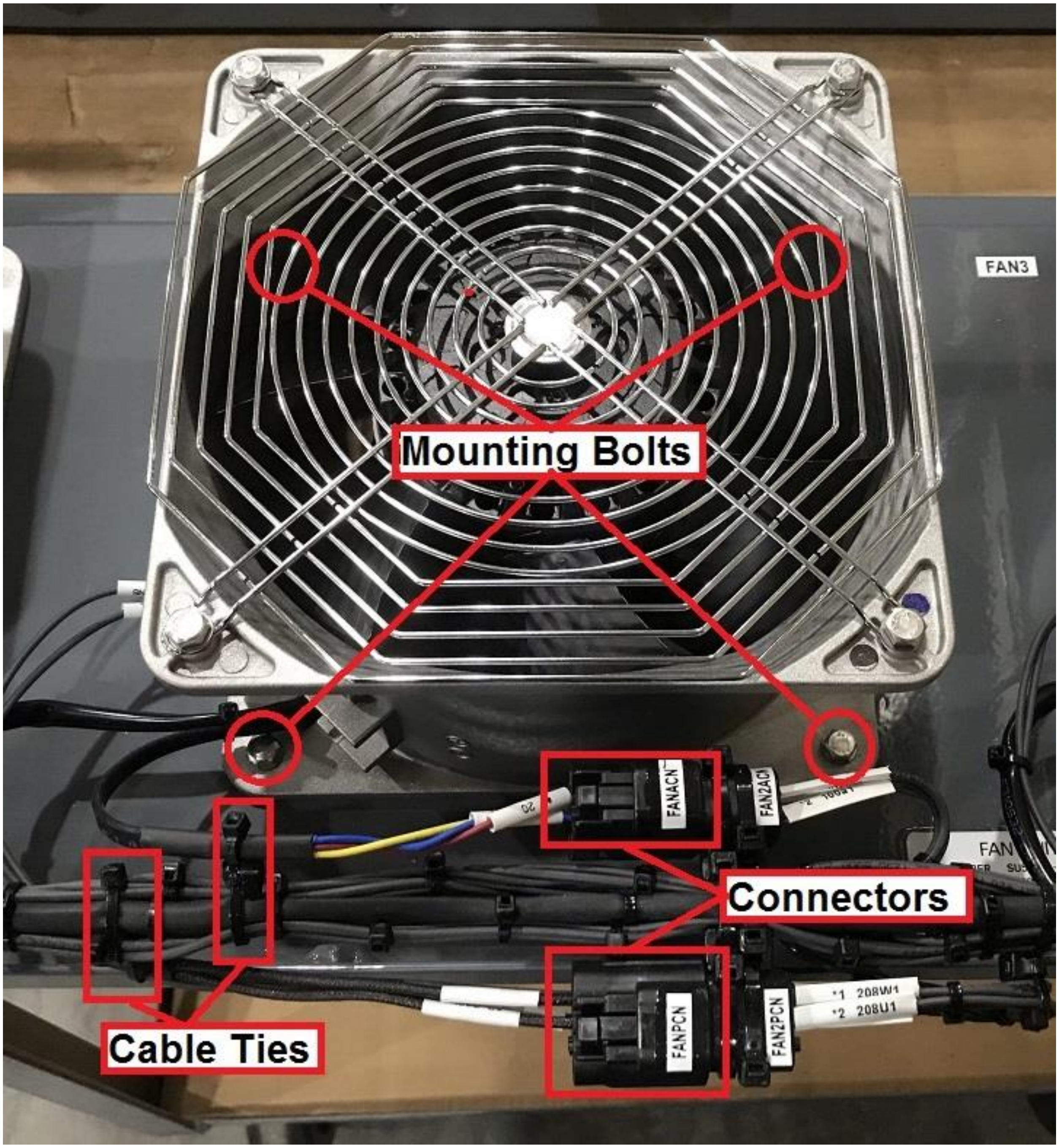


Figure 5-11: Single Fan Unit Replacement

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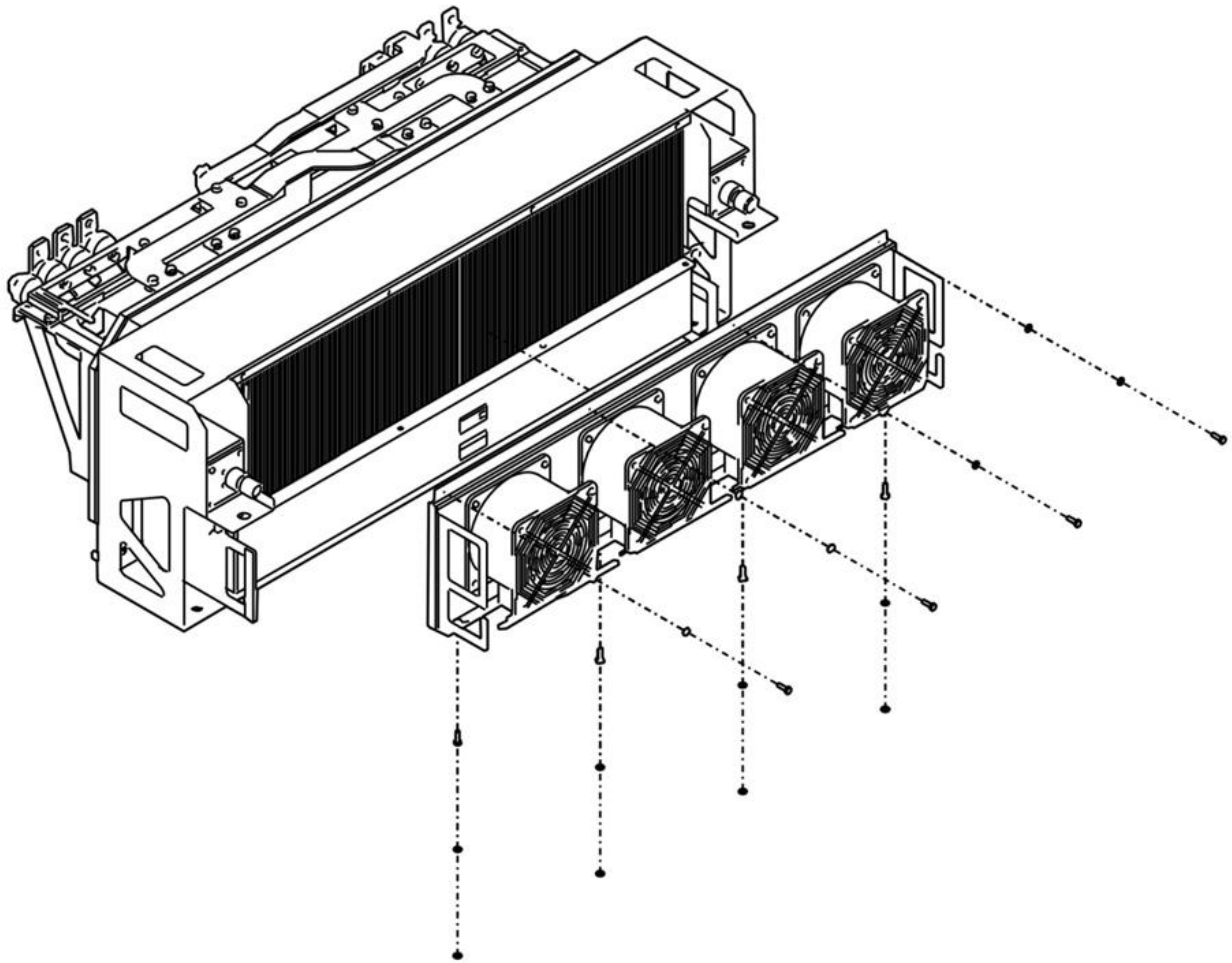

Figure 5-12: Fan Unit Installation

5.7.5.3 Installation Process

1. Install the fan unit and secure with eight bolts (3), lock washers (4), and flat washers (5). These are M6 bolts. Use a 10 mm socket.

2. Torque the bolts to 5.8 Nm (51 in-lbs.).

3. Connect the FANCN1 and FANCN2 connectors at the sides of the fan unit.

To install a single fan to the fan unit - Figure 5-11.

1. Install the fan and secure with four bolts, lock washers, and flat washers. These are M5 bolts. Use an 8 mm socket.

2. Torque the bolts to 4.4 Nm (39 in-lbs.).

3. Connect the connectors FANACN and FANPCN.

CAUTION

ENSURE FINGER GUARD IS REINSTALLED ON FAN MOTOR.

5.7.6 Replace Relay Unit

5.7.6.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.6.2 Removal Process

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. The relays are socketed for easy removal. To remove a single relay, unlatch the clamp holding it in and pull out the failed relay. Push it firmly to fully seat. Re-attach the clamp.

2. The Relay Unit (1) can be removed without disturbing any other components in the equipment case (2), Figure 5-13. First, remove the longer door on the side that has two doors.

3. Disconnect the connectors at the sides of the Relay Unit.

4. Loosen the six hex head bolts (3), flat washers (5) and lock washers (4) that secure the Relay Unit to the frame as shown in Figure 5-13. Use a 10 mm socket. These are M6 bolts. The relay assembly can then be removed.

To remove only a single relay or socket from the Relay Unit, refer to the following instructions.

For relays 208VDK, NMRK, HSCBCK, EBR and EBRT

1. Detach retaining clip(s) from the relay.

2. Pull out the relay from the relay socket.

For relays FM1R and LSR, and relay sockets of 208VDK, NMRK, HSCBCK, EBR and EBRT

1. Detach all the wires connected to each relay/socket on the Relay Unit.

2. Loosen the three hex head bolts (24), flat washers (26) and lock washers (25) that secure the DIN rail to the Relay Unit as shown in Figure 5-13. These are M5 bolts. Use an 8 mm socket. The DIN rail assembly can then be removed.

Remove end plates (9) as shown in Figure 5-14 and slide the relay/sockets out of the DIN rail.

5.7.6.3 Installation Process

1. To reinstall, tighten the six M6 bolts, lock washers (4), and flat washers (5). Use a 10 mm socket and torque to 5.8 Nm (4.3 ft-lbs.).

2. Connect the connectors at either side of the Relay Unit.

To install a relay or relay socket to the Relay Unit, refer to the following instructions.

For relays 208VDK, NMRK, HSCBCK, EBR and EBRT

1. Insert the relay to the relay socket.

2. Attach retaining clip(s) on the relay.

For relays FM1R and LSR, and relay sockets of 208VDK, NMRK, HSCBCK, EBR and EBRT.

1. Insert the relay/socket to the DIN rail (13) as shown in Figure 5-14.

2. Attach end plates (9) on the DIN rail as shown in Figure 5-14.

3. Tighten the three hex head bolts (24), flat washers (26) and lock washers (25) that secure the DIN rail to the Relay Unit as shown in Figure 5-14. These are M5 bolts. Use an 8 mm socket and torque to 4.4 Nm (39 ft-lbs.).

4. Attach all the wires to each relay/socket on the Relay Unit.

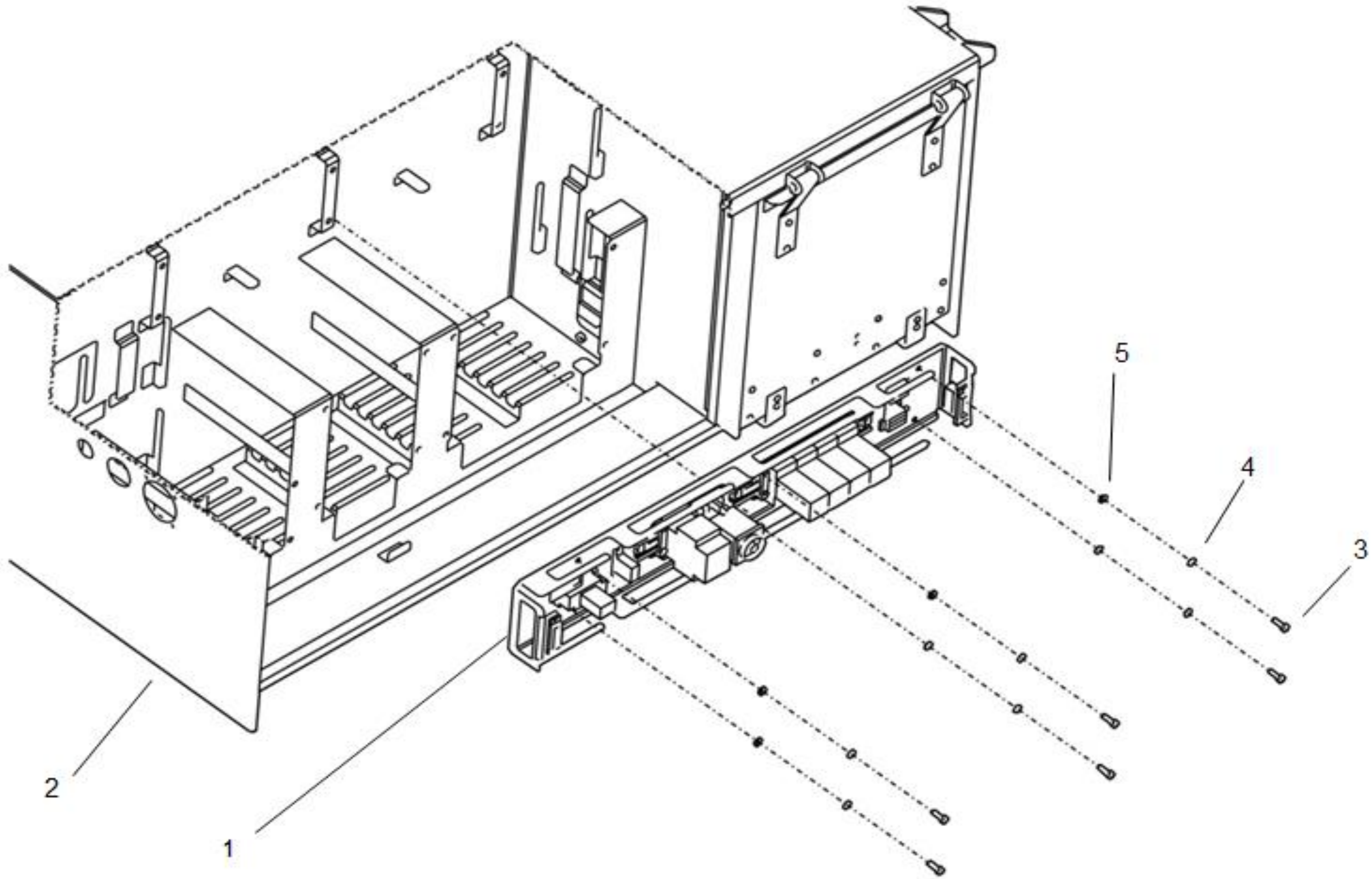

Figure 5-13: Relay Unit Installation

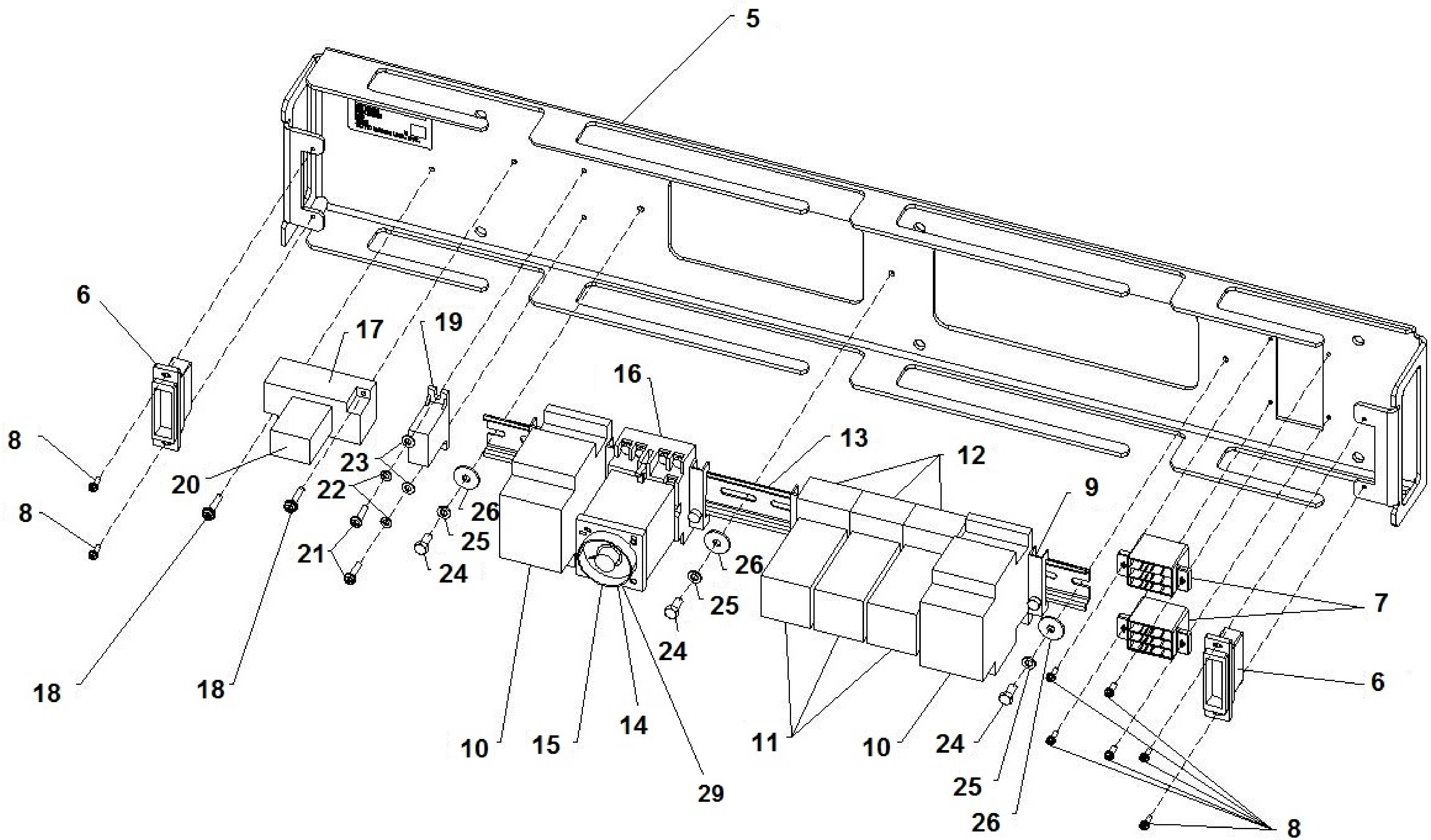

Figure 5-14: Relay Unit Configuration

5.7.7 Replace Current Transducer Unit Number 1

5.7.7.1 Tools and Equipment

- Standard metric tool set and Torque wrench

5.7.7.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DISCHARGED BEFORE WORKING ON THE CURRENT TRANSDUCERS.

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. Remove high voltage from the vehicle and wait 5 minutes.
2. Loosen the 8 captive bolts securing the bottom cover. These are M8 bolts. Use a 13 mm socket. Slide the cover to clear the 4 safety hangers allowing its removal.
3. Check the filter capacitor voltage from the compartment under the equipment case.

   Place the negative meter probe on the 500D cable on the filter capacitor.

   Place the positive meter probe on the 507 cable on the filter capacitor.

   Ensure the voltage is less than 20 volts before working on the equipment.
4. The Current Transducer Unit will need to be replaced when a transducer fails. CT1 is mounted to the inside ceiling of the propulsion inverter and contain bus bars for electrical transmission. To access the device, remove the bottom access cover in the propulsion equipment case.
5. Remove the electrical connector from each of the three current transducers.
6. Disconnect thirteen bus bars. The bolts (7) are M8 threads so use a 13 mm socket. Refer to Figure 5-15. Also remove the flat washers (8) and lock washers (9).
7. Loosen the five M8 bolts (2) that hold the CT1 (1) frame in place. Remove the bolts, flat washers (3) and lock washers (4). The CT1 can now be removed.

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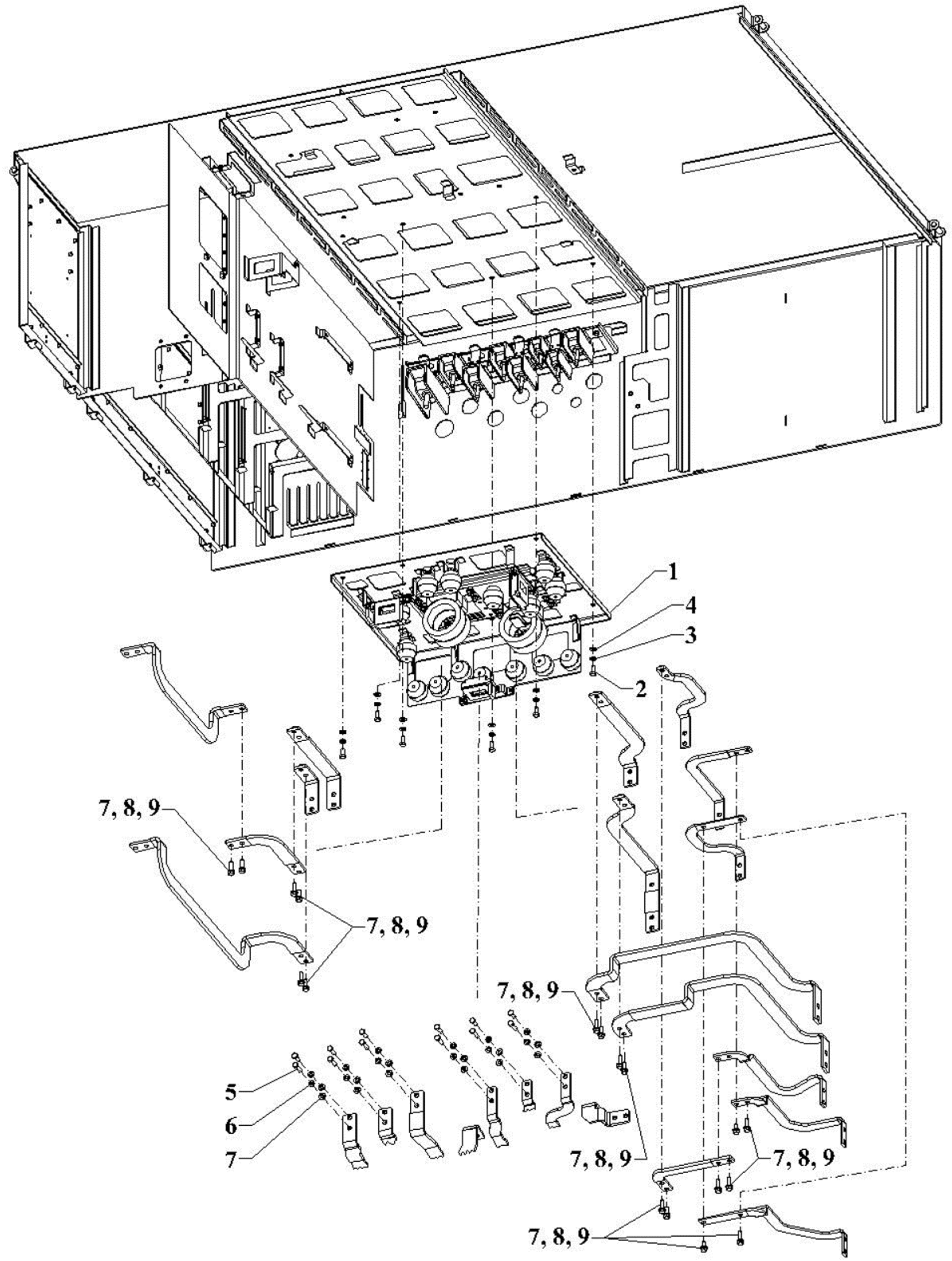

Figure 5-15: Current Transducer Unit 1 Installation

Refer to the following to remove only a current transducer or noise suppression core.

1. Remove the bus bar which penetrates the transducer or NSC. The bolts are M8 threads so use a 13 mm socket. When replacing the transducer, remove the electrical connector.

2. Loosen the bolts that hold the transducer or NSC in place. The captive bolts for the transducer are M4 threads so use a 7 mm socket. The bolts for the NSC are M6 threads so use a 10 mm socket.

5.7.7.3 Installation Process

1. To reinstall, tighten the five M8 bolts, washers, and lock washers to mount the CT1 frame to the equipment case. Tighten to 14 Nm (10.3 ft-lbs.).

2. Connect the bus bars and tighten to 14 Nm (10.3 ft-lbs.).

3. Connect the electrical connectors to each of the three current transducers.

4. Install bottom cover and torque the M8 captive bolts to 14 Nm (10.3 ft-lbs).

To install only a current transducer or noise suppression core, refer to the following instructions.

1. Tighten the bolts that hold the transducer or NSC in place. The captive bolts for the transducer are M4 threads so tighten to 2.3 Nm (1.7 ft-lbs) with a 7 mm socket. The bolts for the NSC are M6 threads so tighten to 5.8 Nm (4.3 ft-lbs.) with a 10 mm socket.

2. Attach the bus bars which penetrate the transducer or NSC. The bolts are M8 threads so use a 13 mm socket and tighten to 14 Nm (10.3 ft-lbs.). When installing the transducer, insert the electrical connector to the transducer.

5.7.8 Replace Current Transducer Unit Number 2

5.7.8.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.8.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DISCHARGED BEFORE WORKING ON THE CURRENT TRANSDUCERS.

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. Remove high voltage from the vehicle.

2. Loosen the eight M8 captive bolts securing the bottom cover. Use a 13 mm socket. Slide the cover to clear the 4 safety hangers allowing the cover to be removed.

3. Check the filter capacitor voltage from the compartment under the equipment case.

   Place the negative meter probe on the 500D cable on the filter capacitor.

   Place the positive meter probe on the 507 cable on the filter capacitor.

   Ensure the voltage is less than 20 volts before working on the equipment.

4. The Current Transducer Unit will need replaced when a transducer fails. CT2 is mounted to the inside ceiling of the propulsion inverter and contain bus bars for electrical transmission. To access, remove the bottom access cover in the propulsion equipment case.

5. CT2 has four transducers. Remove the electrical connector from each.

6. Disconnect eight bus bars. These are M8 threads so use a 13 mm socket to remove bolt (5), flat washer (7) and lock washer (6). Refer to Figure 5-16.

7. Loosen the five M8 bolts (2) that hold the CT2 frame (1) in place. Four are shown in Figure 5-15. Also remove the flat washers (3) and lock washers (4). The CT2 module can now be removed.

To remove only a current transducer or noise suppression core, refer to the following instructions.

1. Remove the bus bars which penetrates the transducer or NSC. The bolts are M8 threads so use a 13 mm socket. When replacing the transducer, remove the electrical connector.

2. Loosen the bolts that hold the transducer or NSC in place. The captive bolts for the transducer are M4 threads so use a 7 mm socket. The bolts for the NSC are M6 threads so use a 10 mm socket.

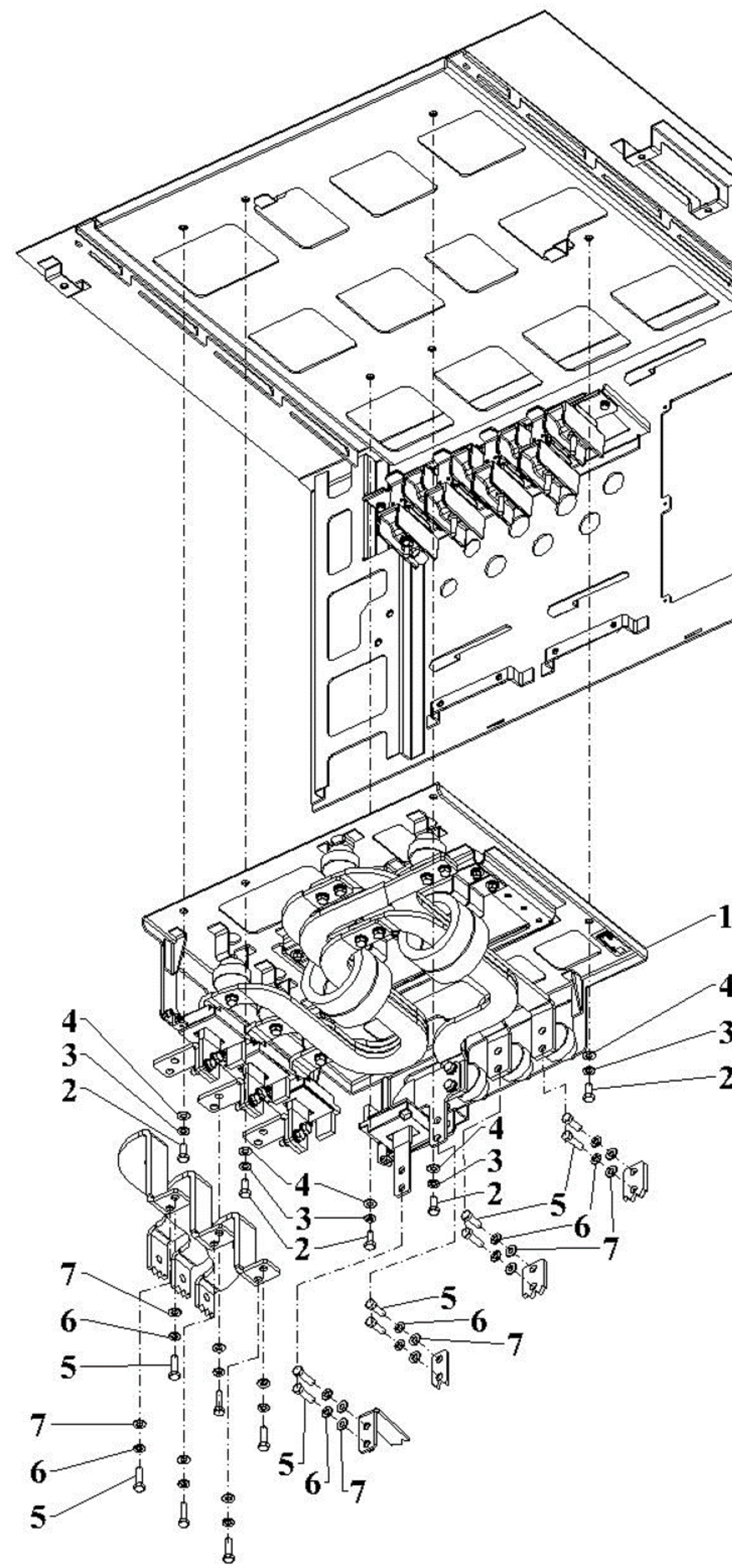

Figure 5-16: Current Transducer Unit 2 Installation

5.7.8.3 Installation Process

1. To reinstall, tighten the five M8 bolts, washers, and lock washers to mount the CT frame to the equipment case. Tighten to 14 Nm (10.3 ft-lbs.).

2. Connect the bus bars and tighten to 14 Nm (10.3 ft-lbs.).

3. Connect the electrical connectors to each of the four current transducers.

4. Install bottom cover and torque the M8 captive bolts to 14 Nm (10.3 ft-lbs.).

To install only a current transducer or noise suppression core, refer to the following instructions.

1. Tighten the bolts that hold the transducer or NSC in place. The captive bolts for the transducer are M4 threads so tighten to 2.3 Nm (1.7 ft-lbs) with a 7 mm socket. The bolts for the NSC are M6 threads so tighten to 5.8 Nm (4.3 ft-lbs.) with a 10 mm socket.

2. Attach the bus bars which penetrate the transducer or NSC. The bolts are M8 threads so use a 13 mm socket and tighten to 14 Nm (10.3 ft-lbs.). When installing the transducer, insert the electrical connector to the transducer.

5.7.9 Line Switch Contacts Inspection and Replacement

5.7.9.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.9.2 Inspection Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DISCHARGED BEFORE WORKING ON THE LINE SWITCH.

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

It requires some experience to evaluate the state of the contacts. Even after only a few cycles under load the contacts look used and “dirty” for the inexperienced eye. When any of the contacts wear down to 0.45 mm (0.018 inch), all of the contacts need to be replaced (replace the bridge and both stationary contacts in the arc chute).

1. The Line Switch contactor components are shown in Figure 5-17. The removal of the arc chute to access the contact tips is shown in Figure 5-18. Use these illustrations for reference for this section.

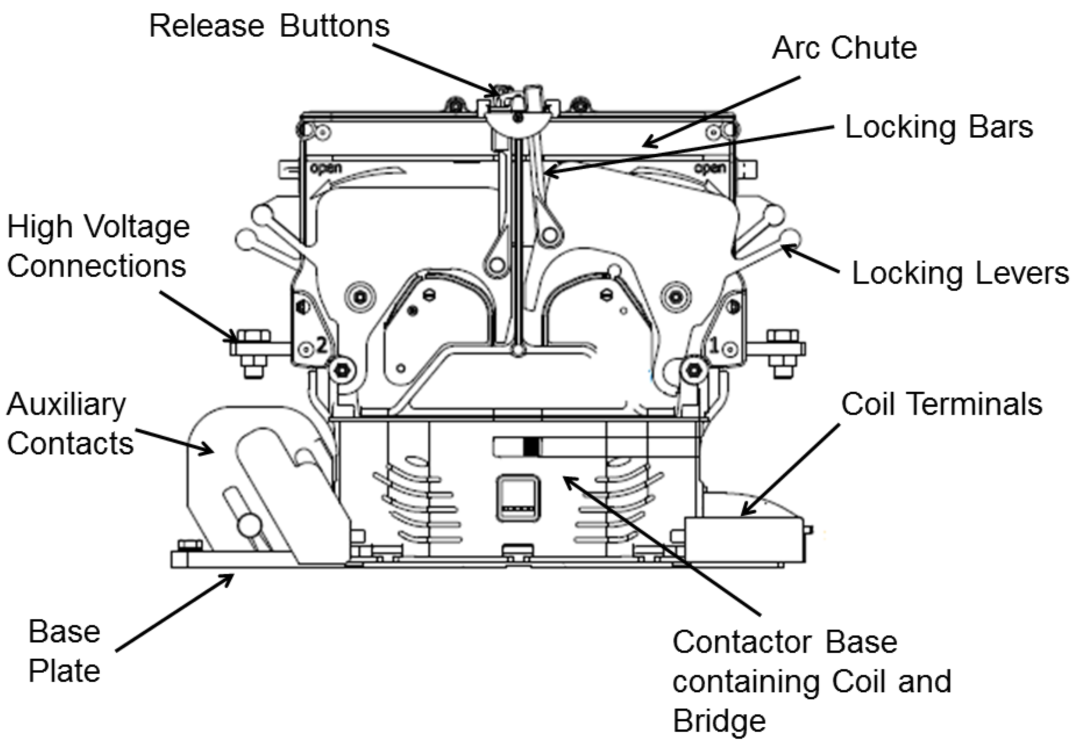

Figure 5-17: Line Switch Contactor Components

2. Isolate both high voltage and control voltage from the contactor.
3. To access the main contacts, the arc chute must be removed first. Disconnect the four M4 bolts on the bus bars from the left side of the contactor at the top and the bottom of the contactor as seen in Figure 5-18.
4. As seen in Figure 5-16, squeeze together the black plastic release buttons on the front of the Arc Chute and turn down the four locking levers one by one. The locking bars will pop up at the release button. Place the arc chute containing the stationary contacts on a flat surface in an upright position to examine the contact tips.
5. The auxiliary contacts have a life-time that exceeds the main contacts. To inspect, remove the 2 thumb screws securing the plastic cover over the Auxiliary Contacts as seen in Figure 5-16. Ensure that all of the connections are secure. The auxiliary switches must be clean and not show signs of overheating.

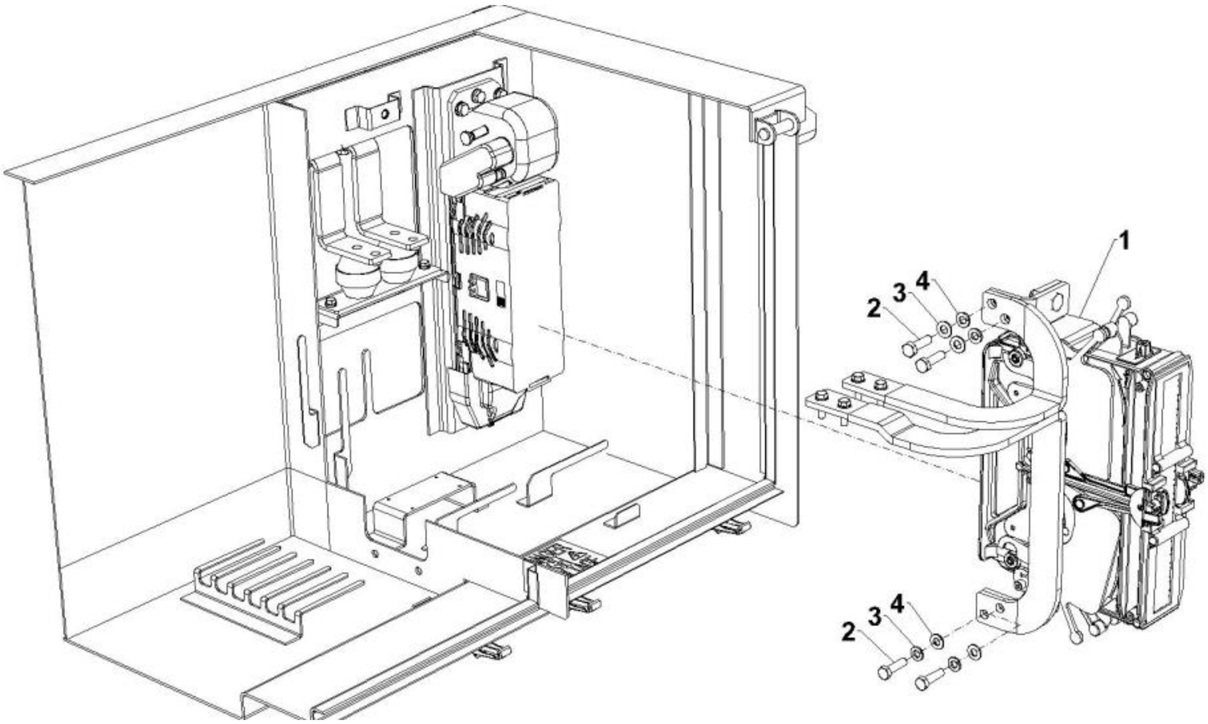

Figure 5-18: Line Switch Contactor Arc Chute Removal

5.7.9.3 Contact Removal Process

The stationary contacts are fixed to the upper and lower bus bars. To remove the stationary contacts, the latching levers must be in the closed position to avoid damage. As seen in Figure 5-19, remove all four M6 screws with a 10 mm socket and put the screws and washers aside. Two screws are secured with red locking varnish.

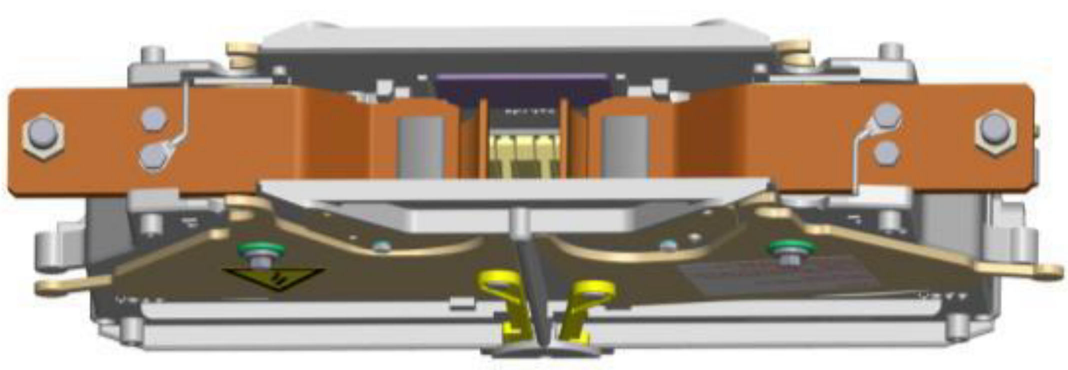

Figure 5-19: Stationary Contact Removal

To remove the movable contacts (bridge), remove the nut at the bottom of the contactor, shown in Figure 5-20, with a 10 mm socket and put the nut and the washer aside. The nut is secured with red locking varnish. The moving bridge, Figure 5-21, can be pulled out.

Figure 5-20: Movable Contact Removal

Figure 5-21: Line Contactor Moving Bridge

5.7.9.4 Contact Installation Process

Connect the replacement contact tip/bus bar bus bars to the Arc Chute connection. Torque bus bar bolts to 14 Nm (10.3 ft-lbs.).

Mount the new bridge from the top and secure it with a washer and nut. Torque to 7 Nm. Secure the nut with red locking varnish.

5.7.9.5 Install Arc Chute

Install the Arc Chute into the contactor base.

Install four M4 bolts with a 7 mm socket. Use lock washers to secure the arc chute bus bars on the left side of the arc chute to the equipment case bus bars, as seen in Figure 5-17. Do not torque at this time.

As seen in Figure 5-17, squeeze together the black plastic release buttons on the front of the arc chute and turn up the four locking levers one by one. The locking bars will pop up at the release button.

Torque the four M8 bolts to 14 Nm (10.3 ft.-lbs.) with a 13 mm socket.

5.7.10 Replace Line Switch Contactor

5.7.10.1 Tools and Equipment

- Standard metric tool set
- Torque wrench
- Cable ties
- Screwdriver, flat blade

5.7.10.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DISCHARGED BEFORE WORKING ON THE LINE SWITCH.

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. Remove power from the propulsion inverter. Follow steps 2-7 to remove the entire Line Switch contactor. Follow steps 8 and 9 to remove only the arc chute for inspection purposes.
2. Refer to Figure 5-22. Use a 13 mm socket to remove four M8 bolts (10), lock washers (11), and flat washers (12), two on the top and two at the bottom on the left side of the contactor, connected to the bus bars.
3. Squeezing together the black plastic release buttons on the front of the arc chute (15) and turn down the four locking levers one by one. The locking bars will pop up at the release button. Remove the arc chute.
4. Remove the cover (13) of the auxiliary contacts. Loosen the 2 thumb screws and disconnect the wires from the switches with a screwdriver. Cut the cable ties that hold the harness to the contactor base.
5. Remove the screw securing the cover (14) over the coil termination. The coil wires are secure to the contactor with a friction connection. Place a small screwdriver in the slot directly above the wire and press down to remove the two wires.
6. Use a 13 mm socket wrench to remove two M8 bolts (3), lock washers (4), flat washers (5), and nut (6). Remove the two bus bars on the left side of the contractor.
7. Remove the contactor frame (2) from the equipment case frame by loosening the upper and lower M8 hex head bolts (7), lock washer (8) and flat washer (9). Use a 13 mm socket.

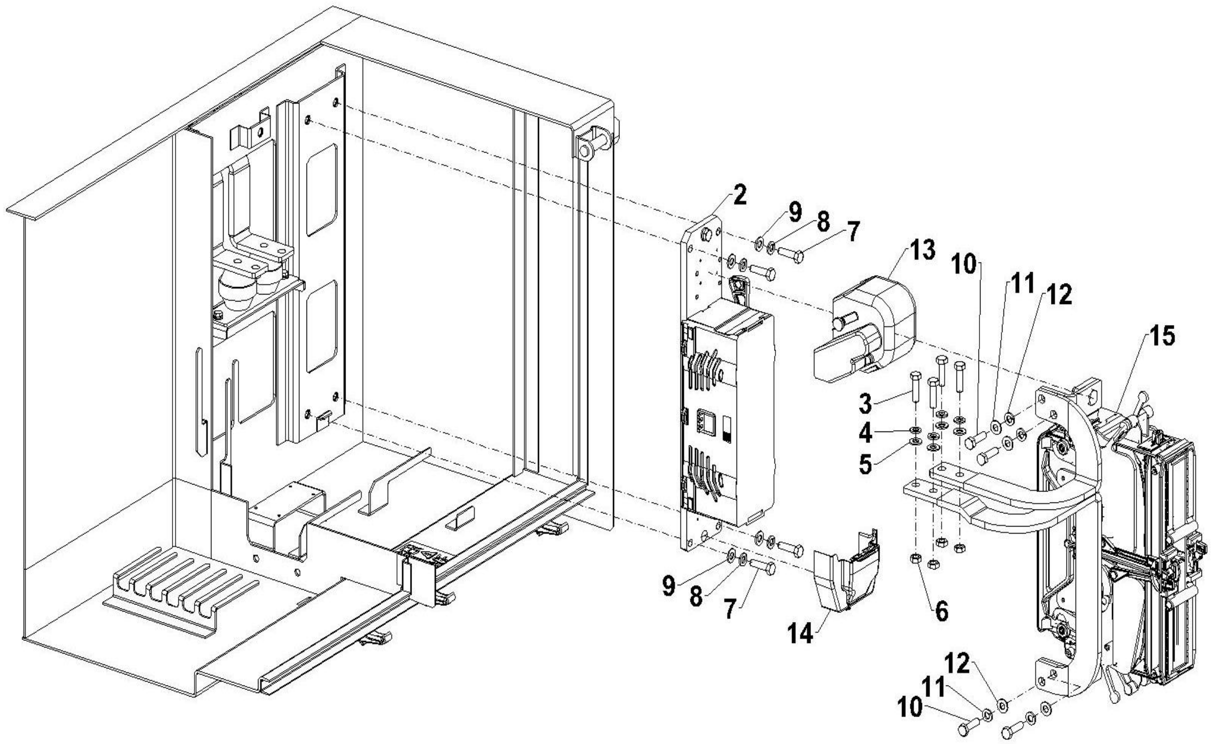

Figure 5-22: Line Switch Contactor Installation

8. Refer to Figure 5-23. Use a 13 mm socket to remove four M8 bolts (2), lock washers (3), and flat washers (4), two on the top and two at the bottom on the left side of the contactor, connected to the bus bars.

9. Squeezing together the black plastic release buttons on the front of the arc chute (1) and turn down the four locking levers one by one. The locking bars will pop up at the release button. Remove the arc chute.

10. Perform the inspection as required. To re-install, follow steps 7 through 9 of the installation process below in this section.

5.7.10.3 Installation Process

1. Attach the contactor base (2) to the equipment case frame with the four M8 hex bolts (7), lock washers (8), and flat washers (9). Use a 13 mm socket. Tighten to 14 Nm (10.3 ft-lbs.).

2. Connect the wires to each of the auxiliary switches as shown in the table below. Note the connections to each auxiliary switch from the cover over the switches.

Table 5-3. Line Switch Auxiliary Switch Terminations

Switch Number	Switch Terminal	Wire marker
1	13	13A
1	14	14 20

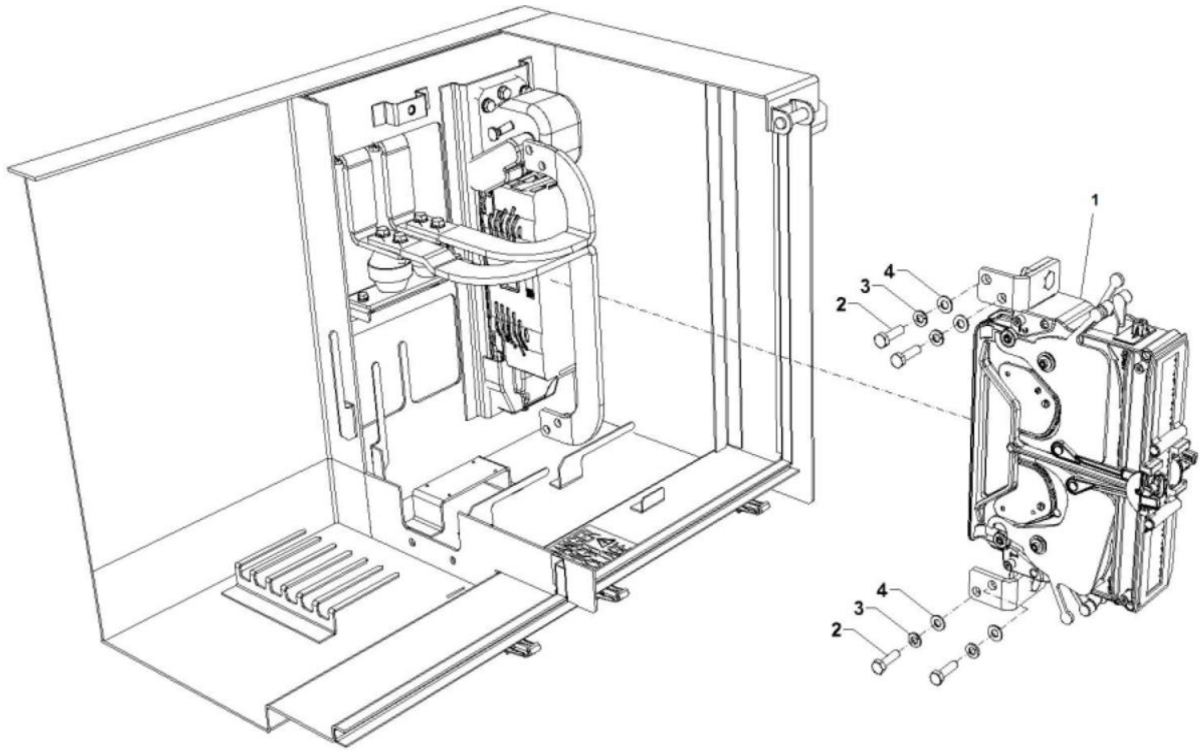

Figure 5-23: Line Switch Contactor Installation

3. Install the protective cover (13) for the auxiliary switches.

4. To install the coil cables, using a small screwdriver, release the compression fitting for each wire by pushing into the slot above where the cable is to be connected. With the compression fitting released, insert the cable and then remove the screwdriver. Connect the A1 cable to the A1 connection and the A2 cable to the A2 connection.

5. Install the protective cover (14) for the coil terminations.

6. Install the 2 bus bars taken from the old contactor and connect to the equipment case bus bars using bolt (3) lock washer (4) flat washer (5) torque and nut (6). Torque to 14 Nm (10.3 ft-lbs.).

7. Install the arc chute into the contactor base. Install the four M8 hex bolts (10), washers (11) and lock washers (12) securing the bus bars attached to the arc chute to the equipment case bus bars. Do not torque at this time.

8. Return the four contactor locking levers one by one to the Locked position.

9. Secure the arc chute to the bus bars and torque the four bolts with a 13 mm socket. Torque to 14 Nm (10.3 ft.-lbs.).

5.7.11 Replace Line Charging Contactor

5.7.11.1 Tools and Equipment

- Standard metric tool set
- Torque wrench
- Pliers, needle nose

5.7.11.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DISCHARGED BEFORE WORKING ON THE LINE CHARGING CONTACTOR.

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. Remove high voltage from the vehicle.

2. The Line Charging Contactor (1) does not contain any serviceable parts (including contact tips). If it fails, replace with a new contactor.

3. To remove from the equipment case, disconnect the power harness wires with an 8 mm socket. Then, disconnect the terminals of the secondary wires by pulling with needle nose pliers.

4. Loosen the four M4 captive screws (2) as shown in Figure 5-24. The contactor can now be removed. Use a 7 mm socket.

5.7.11.3 Installation Process

1. Secure the replacement contactor to the equipment case frame with the four captive screws, flat washers and lock washers (2) as shown in Figure 5-24. Torque to 1.7 Nm (15 in-lbs. or 1.25 ft-lbs). Use a 7 mm socket.

2. Matching the wire markers with each connection on the contactor, connect the wire terminals as seen in the Table 5-4.

3. Tighten the power connections with a 7 mm socket. Torque to 1.7 Nm (15 in-lbs.).

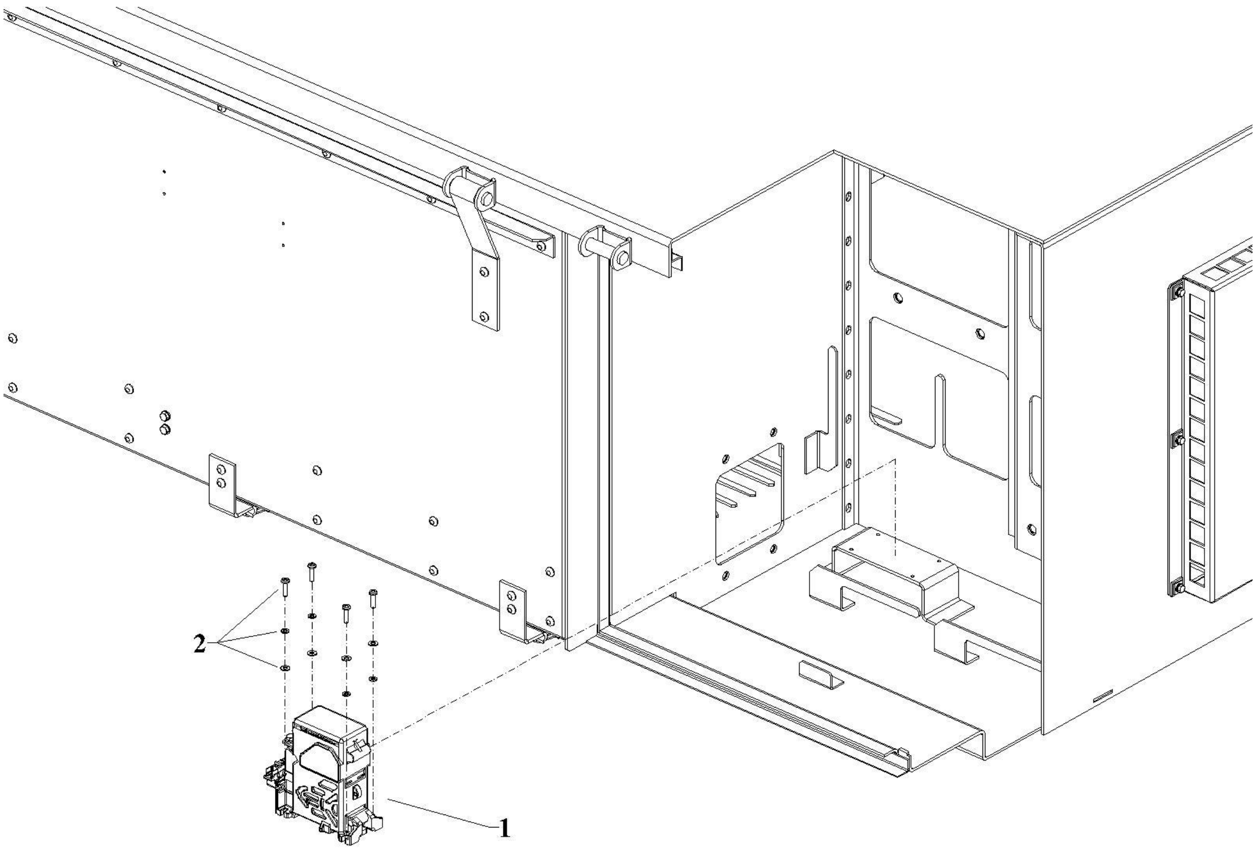

Figure 5-24: Line Charging Contactor Installation

Table 5-4. Line Charging Contactor Terminations

Wire Marker	Contactor Wire Location	Function
+1 504	+ Facing outside of equipment case	Power circuit cable input
-2 504A	- Facing inside of equipment case	Power circuit cable return
A1 LCCC	A1 Facing outside of equipment case	Control coil circuit feed
A2 LSR1	A2 Facing inside of equipment case	Control coil circuit return
11 13B	11 Facing inside of equipment case	Feedback microswitch
12 20	12 Facing outside of equipment case	Feedback microswitch

5.7.12 Replace Discharge Resistor Unit

5.7.12.1 Tools and Equipment

- Standard metric tool set
- Torque wrench
- Silicon adhesive sealant

5.7.12.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DISCHARGED BEFORE WORKING ON THE DISCHARGE RESISTORS.

1. Remove high voltage from the vehicle.
2. Loosen the 8 M8 captive bolts securing the bottom cover. Slide the cover to clear the 4 safety hangers allowing the cover to be removed. Use a 13 mm socket.
3. Check the filter capacitor voltage from the compartment under the equipment case.

   Place the negative meter probe on the 500D cable on the filter capacitor.

   Place the positive meter probe on the 507 cable on the filter capacitor.

   Ensure the voltage is less than 20 volts before working on the equipment.
4. Disconnect the high voltage wires connected to each resistor.
5. Loosen the four mounting bolts (1) with a 10 mm socket. The discharge resistor (2) can be removed. Pull to the interior of the equipment case as shown in Figure 5-25.

5.7.12.3 Installation Process

1. Apply silicon sealant around the inside edge (3) and place into position.
2. Using a 13 mm socket, secure with four M8 hex head bolts, lock washers (4), and flat washers (5) as shown in Figure 5-25. Torque to 5.8 Nm (51 in-lbs.).
3. Matching each wire marker to the placard associated with each resistor, attach the high voltage cables to each resistor. Each resistor has a placard adjacent to it as 507, 500, 500A and 500B. Match and connect each of the cable numbers to the placard on the plate next to the resistor.

   The 507 resistor has 1 cable connection

   The 500 resistor has 2 cable connections

   The 500A resistor has 1 cable connection

   The 500B resistor has 1 cable connection

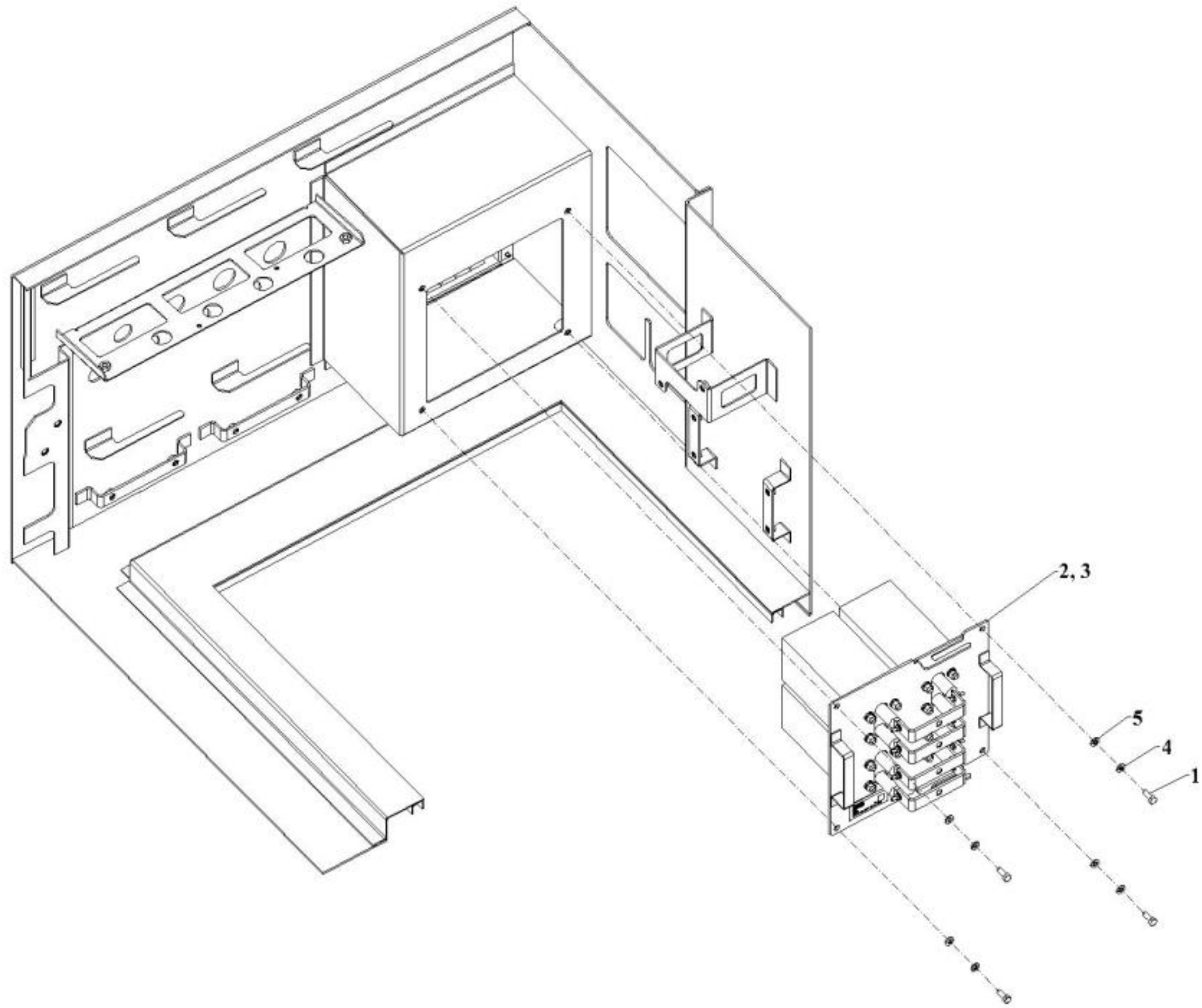

Figure 5-25: Discharge Resistor Installation

4. Torque each bolt to 5.8 Nm (4.3 ft-lbs.). Use a 13 mm socket.
5. Install bottom cover and torque the M8 captive bolts to 14 Nm (10.3 ft-lbs). Use a 13 mm socket.

5.7.12.4 Single Resistor Element Replacement Process

1. The Discharge Resistor consists of 4 resistors in the DCHR Unit. To replace any single resistor element, follow these steps and refer to Figure 5-26. First, loosen and remove M4 bolts and nuts holding the bus bar (12) to the resistor.

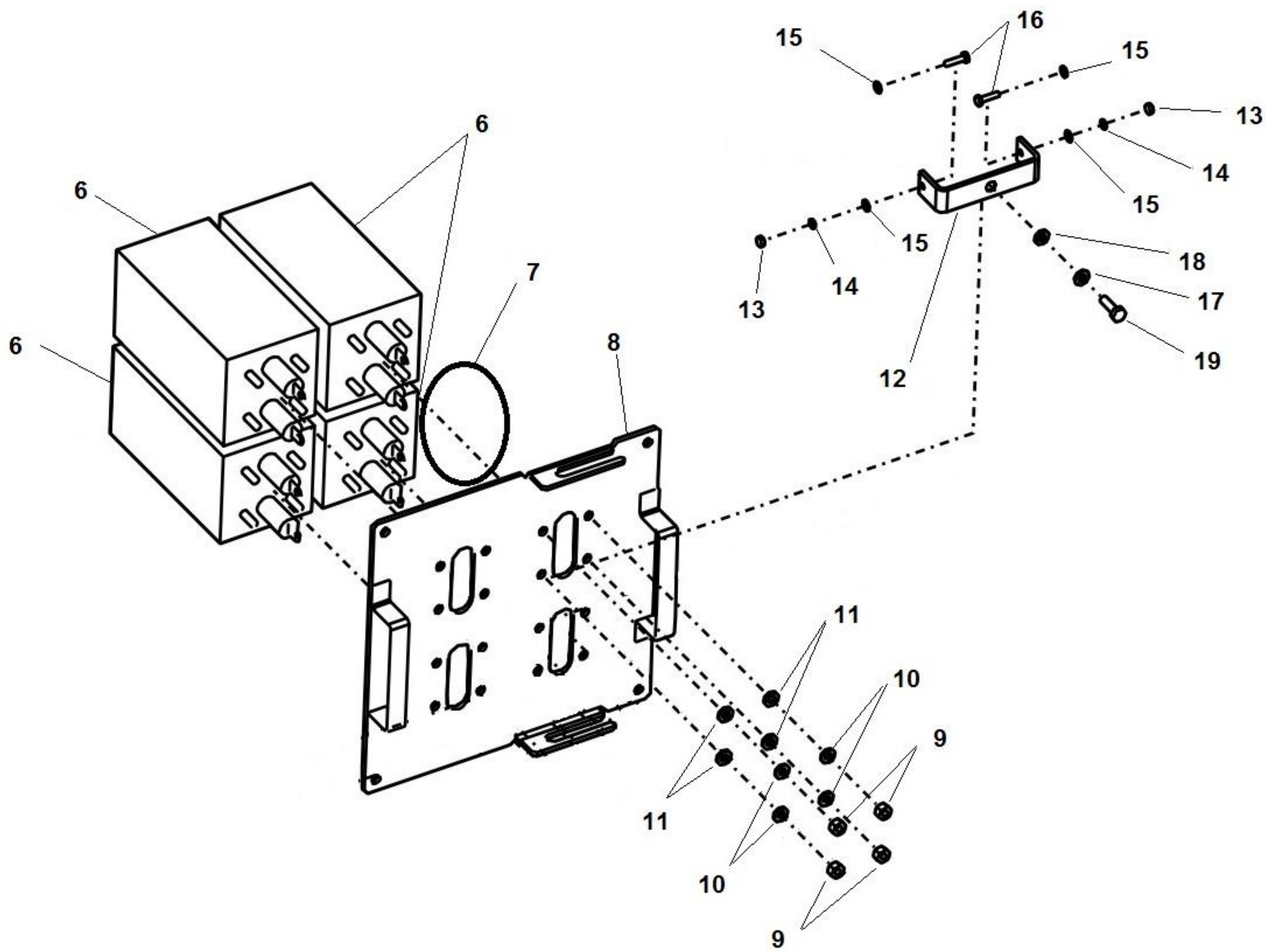

Figure 5-26: Discharge Resistor Single Resistor Replacement

2. Remove the four M5 hex nuts (9) holding the resistor element (6) to the faceplate frame (8). Use an 8 mm socket wrench for the M5 nuts. Please note that there is an O-ring gasket between the faceplate (8) and resistor element (6).

3. Place the O-ring (7) into position and insert the resistor unit into the faceplate frame. Place a flat washer (11) and lockwasher (10) on each stud. Tighten the four M5 hex nuts (9) to each stud, torqueing to 5.8 Nm (51 in-lbs).

4. Re-install the M4 x 16 bolts (16), lockwashers (14), flat washers (15) and hex nuts (13) to attach the bus bars to the resistor element loosened in step 1. Torque to 1.7 Nm (15 in-lbs).
5. Install the Discharge Resistor as directed in the previous Section 5.7.13.3.
6. Attach the cable to the resistor with the M6 x 16 hex head bolt (19), using a lockwasher (17) and flat washer (18). Use a 10 mm socket. Torque to 5.8 Nm (51 in-lbs).

5.7.13 Replace Charging Resistor Unit

5.7.13.1 Tools and Equipment

- Standard metric tool set and Torque wrench

5.7.13.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DISCHARGED BEFORE WORKING ON THE CHARGING RESISTORS.

As seen in Figure 5-27 -

1. Loosen the 8 M8 captive bolts securing the bottom cover. Slide the cover to clear the safety hangers allowing the cover to be removed. Use a 13 mm socket.
2. Check the filter capacitor voltage from the compartment under the equipment case.

   Place the negative meter probe on the 500D cable on the filter capacitor.

   Place the positive meter probe on the 507 cable on the filter capacitor.

   Ensure the voltage is less than 20 volts before working on the equipment.
3. The Charging Resistor is shown in Figure 5-27. Disconnect the electrical wiring from each end of the charging resistor (2) (wiring not shown on drawing). Use an 8 mm socket to remove the M5 hex head bolt and nut (8) from the resistor terminals.
4. Remove the resistor bracket from the equipment case (1) by loosening the four M6x25 hex head bolts (9). The discharge resistor can now be removed.

5.7.13.3 Installation Process

1. To replace only the resistor (2), remove the two M5 x 25 head bolts (5) that hold the resistor to the bracket (13). Use an 8 mm socket. Remove the resistor.
2. Install a new resistor and tighten the bolts (9) and large plain washers (6). Torque to 3.4 Nm (30.1 in-lbs).
3. Attach to the enclosure frame with four M6 hex head bolts (9), lock washers (3), and flat washers (4) as shown in Figure 5-27. Torque to 5.8 Nm (51 in-lbs.). Use a 10 mm socket.

4. Matching each wire marker to the placard attached to the resistor, attach the electrical connections (12) to each terminal. Using an 8 mm socket, attach the M5x16 bolt (10), hex nut (8), flat washer (11) on each side, and lock washer (7) next to the nut. Torque to 3.4 Nm (30.1 in-lbs.). Use an 8 mm socket.

5. Install the equipment case bottom cover and torque cover bolts to 14 Nm (10.3 ft-lbs.). Use a 13 mm socket.

5.7.14 Replace DC Voltage Detector Unit

5.7.14.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.14.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DISCHARGED BEFORE WORKING ON THE VOLTAGE DETECTORS.

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

1. Remove high voltage from the vehicle.

2. Loosen the 8 M8 captive bolts securing the bottom cover. Slide the cover to clear the four safety hangers allowing the cover to be removed. Use a 13 mm socket.

3. Check the filter capacitor voltage from the compartment under the equipment case.

   Place the negative meter probe on the 500D cable on the filter capacitor.

   Place the positive meter probe on the 507 cable on the filter capacitor.

   Ensure the voltage is less than 20 volts before working on the equipment.

4. The DC Voltage Detection Unit is shown in Figure 5-28. Disconnect the two low voltage electrical connectors (not shown) at the voltage detector unit and remove the four high voltage cables (not shown).

5. Loosen the four mounting M6 bolts (3) that hold the DCVD (1) unit to the equipment case frame. Use a 10 mm socket.

6. To remove only one voltage detector circuit board (2), loosen four mounting bolts (6).

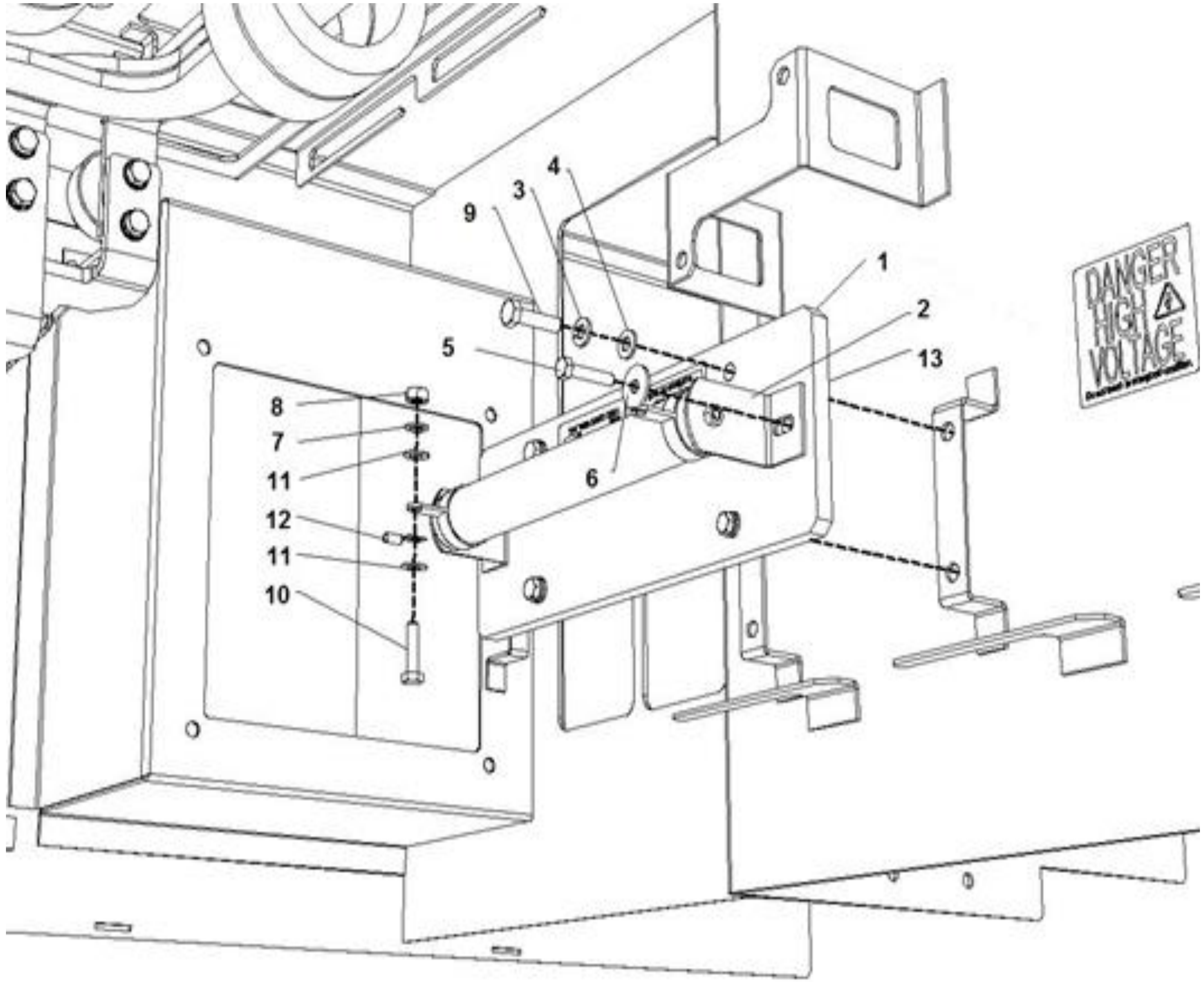

Figure 5-27: Charging Resistor Installation

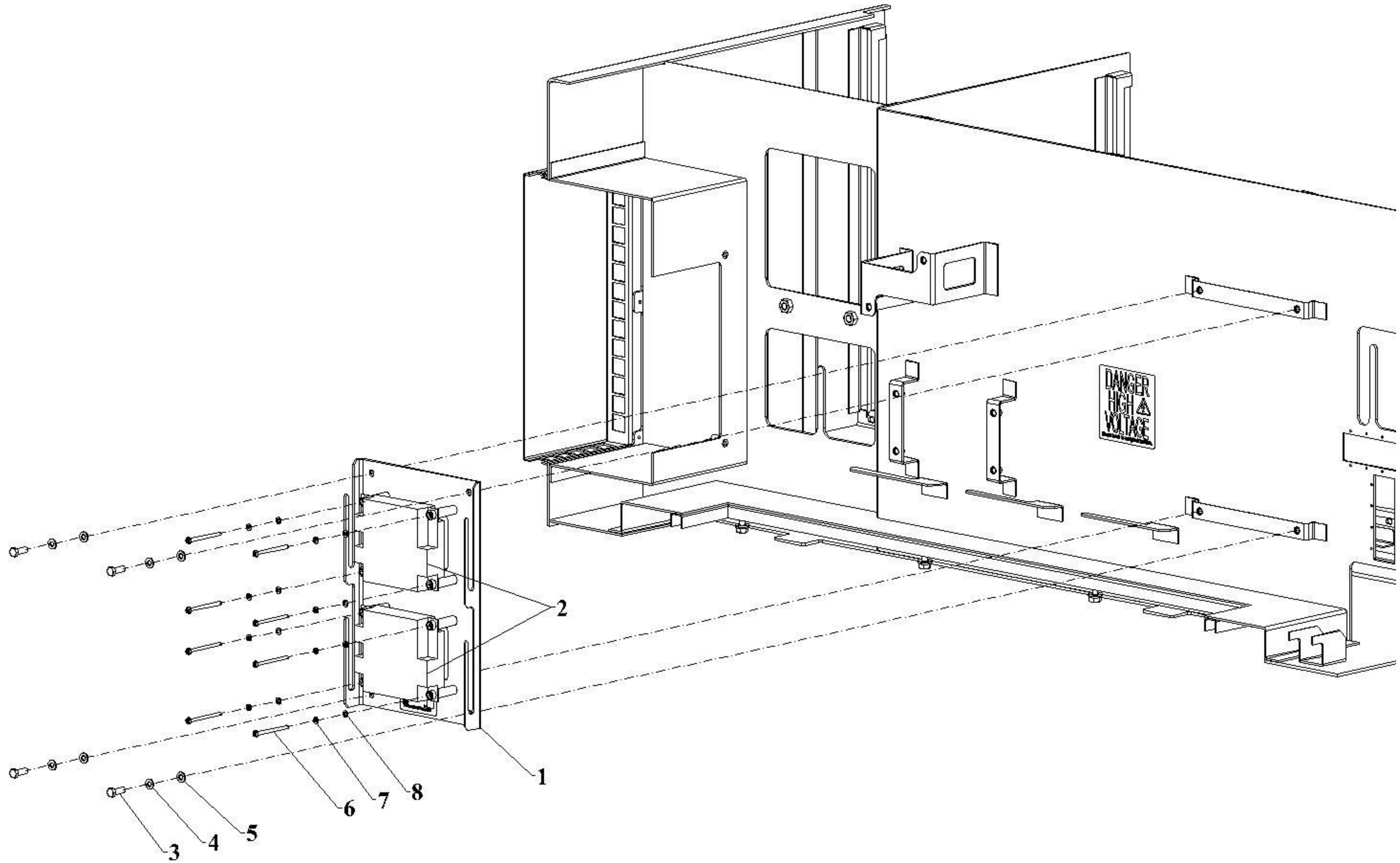

Figure 5-28: DC Voltage Detector Installation

5.7.14.3 Installation Process

1. Attach the new unit with four M6 mounting bolts (3), lock washers (4), and flat washers (5) as shown in Figure 5-28. Torque to 5.8 Nm (51 in-lbs.). Use a 10 mm socket.

2. To install only one circuit board, use four sets of mounting bolts (6), lock washer (7) and flat washer (8). Torque to 5.8 Nm (51 in-lbs).

3. Connect the two electrical connectors and then, matching each wire marker to the placard, attach the four high voltage cables at the four M4 screw terminals with a 7 mm socket. Each of the four high voltage cables is cut to a specific length so that each cable can reach the necessary connection on each circuit board. Torque to 1.7 Nm (1.25 ft-lbs. or 15 in-lbs.).

4. Install bottom cover and torque the M8 captive bolts to 14 Nm (10.3 ft-lbs.). Use a 13 mm socket.

5.7.15 Replace Battery Voltage Noise Filter

5.7.15.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.15.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DICHARGED BEFORE WORKING IN THE EQUIPMENT CASE.

CAUTION

ENSURE VEHICLE BATTERY VOLTAGE IS ISOLATED FROM THE INVERTER EQUIPMENT CASE.

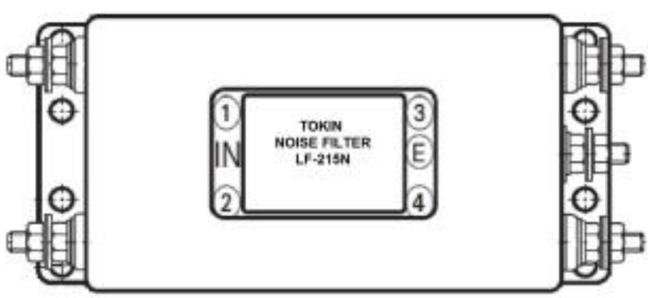

Figure 5-29: Battery Voltage Noise Filter

1. Remove high voltage from the vehicle and the vehicle battery input to the propulsion equipment case.

2. The Noise Filter is shown in Figure 5-29 and is located in the propulsion inverter behind the electronic compartment door, against the left-side wall.

3. Disconnect the cables from the five electrical connectors on the sides of the filter unit.

4. Loosen the four M4 mounting bolts (3) that hold the filter unit to the equipment case frame and remove filter. Use a 7 mm socket.

5.7.15.3 Installation Process

1. Place the Filter Unit into position with the front placard upside down. In this configuration, the two input studs are on the right side and the three output studs are on the left side. Using a 7 mm socket, attach the new unit with four M6 mounting bolts (3), lock washers (4), and flat washers (5). Torque to 1.7 Nm (15 in-lbs.).

2. Connect the five electrical connectors onto the studs on the sides of the unit using M4 nuts and washers as noted on the wire markers and the placard on the front face of the unit. Torque each nut to Torque to 1.7 Nm (15 in-lbs.).

5.7.16 Replace High Speed Circuit Breaker Control Panel

5.7.16.1 Tools and Equipment

- Standard metric tool set
- Torque wrench

5.7.16.2 Removal Process

1. Disconnect the four electrical connectors at the front of the box.

2. Remove the four M6 x 20 bolts that secure the control panel to the rack.

5.7.16.3 Installation Process

1. Use a 10 mm socket to secure the HSCB Control Panel into position with four M6 x 20 bolts along the front. Torque to 5.8 Nm (4.3 ft-lbs.).

2. Connect the four electrical connections, CN1 through CN4.

5.7.17 Filter Capacitors 1 or 2

Filter capacitors 1 and 2 are located in the propulsion equipment case. Filter capacitors 3 and 4 are located in the Inverter Unit. The overhaul process for the Inverter Unit is in the Heavy Repair Manual.

5.7.17.1 Tools and Equipment

1. Multi meter
2. Standard metric tool set
3. Torque wrench

5.7.17.2 Removal Process

WARNING

THE PANTOGRAPH MUST BE LOWERED AND FILTER CAPACITORS DICHARGED BEFORE WORKING ON THE FILTER CAPACITORS.

1. Filter capacitors 1 and 2 are identical electrically but have different mounting methods.
2. To remove, verify that high voltage has been disconnected for at least 5 minutes. Verify that the charge on the capacitor has dissipated to less than 20 Vdc.
3. Check the filter capacitor voltage from the compartment under the equipment case.
   - Place the negative meter probe on the 500D cable on the filter capacitor.
   - Place the positive meter probe on the 507 cable on the filter capacitor.
   - Ensure the voltage is less than 20 volts before working on the equipment.
4. To remove either FC1 or FC2, the frame bar (1) must be removed. Remove the M8 bolts (2) on each end with a 13 mm socket wrench. Refer to Figure 5-30 for FC1 and Figure 5-31 for FC2.
5. Loosen the four M8 bolts (5) that secure the FC1 or FC2 bracket to the enclosure frame.
6. Loosen the M8 bolts (8) that hold the bus bar to the top of the FC unit. The FC can now be removed.

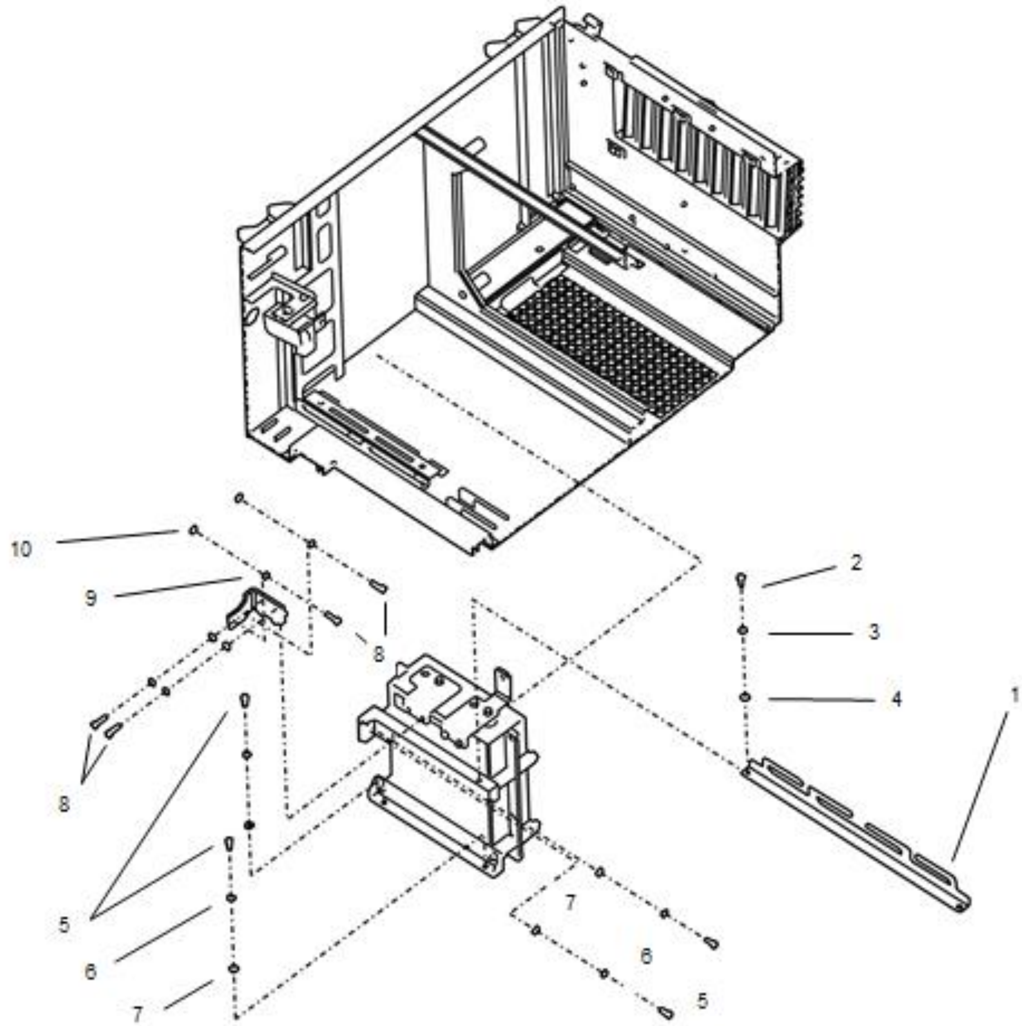

Figure 5-30: Filter Capacitor Unit 1 Installation

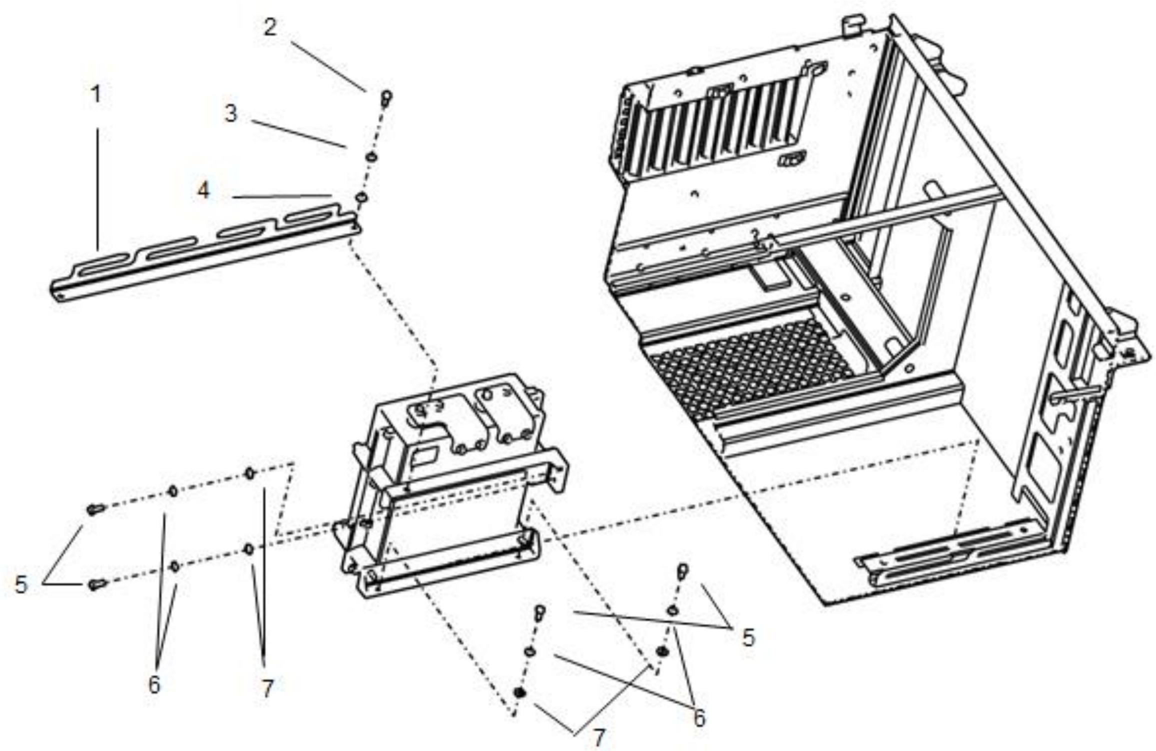

Figure 5-31: Filter Capacitor Unit 2 Installation

5.7.17.3 Installation Process

1. To install a new FC, first install the FC frame bolts (5), lock washers (6), and flat washers (7). Tighten to 14 Nm (10.3 ft-lbs.).
2. Next, attach the bus bar electrical connection to the top of the FC unit with bolts (8), lock washers (9) and flat washers (10). Tighten to 8 Nm (5.9 ft-lbs.). This should be done before reattaching the frame bar.
3. Reattach the frame bar (2), lock washers (3), and flat washers (4) removed in step 3 and tighten to 14 Nm (10.3 ft-lbs.).

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CHAPTER 6.0

TROUBLESHOOTING

This chapter contains information that is to be used as a guide for troubleshooting the propulsion inverter and the Propulsion Logic Unit. A Protection event is an abnormal condition which is caused mainly by something external of the inverter. A Fault is an abnormal condition which may be derived from a malfunction of the inverter. This information is indicated on the TOD.

Section 6.1 explains MDS propulsion fault signals as displayed on the vehicle TOD.

Section 6.2 contains the propulsion software operating parameters.

Section 6.3 is the Propulsion Logic Unit Input / Output List.

Section 6.4 contains a table explaining Trainline functions.

Section 6.5 explains how to check for a power circuit ground fault.

Section 6.6 explains how to check for a short circuit IGBT.

Section 6.7 is a troubleshooting chart describing symptom, cause and remedy.

6.1 MDS Propulsion Fault Signals

The following signals are displayed in alphabetical order from the TOD with each propulsion system fault sent to the MDS. For troubleshooting purposes, the explanations presented here may be more detailed than what is presented on the TOD screen to the operator. The _F at the end of each title designates a Fault, Protection or Disturbance. Troubleshooting flowcharts for each fault can be referred to by clicking the fault name shown on the fault indication screen of the propulsion PTU.

BROH_F Bch Resistor Overheat

The calculated temperature of the Brake Resistor Assembly has exceeded 500 degrees C (932 degrees F). This condition will shut down the inverter and open the Line Switch contactor. Recovery is automatic when the calculated temperature falls to 450 degrees C (842 degrees F).

BRRE_F Friction Brake Not Released

This fault indicates that the Friction Brakes have not been released 5 seconds after power is first initiated. When the Friction Brake Not Released Trainline is low, the propulsion system will shut down and open the Line Switch contactor. High is Friction Brakes are released. Low is friction brakes are not released.

BSLB_F Adhesion Failure (Braking)

Adhesion is detected by monitoring the magnetic flux from the traction motors and confirmed by monitoring and comparing the speed sensor output signals. This failure is caused by either a Speed Differential Condition which is detected with more than a 25% difference in speed between the powered axle and trailer (center truck) axle or a Major Slide Detection adhesion failure that exceeds the set limit of 3.94 m/s/s. When this Wheel Slide condition is detected above 3 mph, the propulsion system is disabled, PLU_Slide_Detected signal on the MVB is set to high, the Line Switch contactor is opened for 1 second and sand is applied for 2 seconds. After 1 second, the PLU will reapply torque. This sequence repeats until it gets adhesion. Automatic reset is when the Slide condition is no longer detected.

BSLP_F Adhesion Failure (Powering)

Adhesion is detected by monitoring the magnetic flux from the traction motors and confirmed by monitoring and comparing the speed sensor output signals. This failure is caused by either a Speed Differential Condition which is detected with more than a 25% difference in speed between the powered axle and trailer (center truck) axle or a Major Slip adhesion failure which is any wheel Spin condition greater than 5.49 m/s/s. When this Wheel Slip condition is detected, the propulsion system is disabled, the Line Switch contactor is opened for 1 second and sand is applied for 2 seconds. This sequence repeats until it gets adhesion. Automatically reset when the Spin condition is no longer detected.

BSM_F Rollback Detected

Either 15 inches of rollback has occurred, or the rollback speed reached 1 mph after torque initiation. This condition will set the Rollback signal to high which will apply Friction Braking, shut down the inverter and open the Line Switch contactor. Rollback detection is reset when zero speed is detected and Full Service Brake is applied.

CBTD_F HSCB or LS or LCC Fault Detection

A discrepancy has been detected with the command to and the feedback status from the High Speed Circuit Breaker, Line Switch contactor or Line Charging Contactor. This is a discrepancy between the command signal and the feedback signal for longer than 1 second. This condition will shut down the inverter, open the Line Switch contactor and open the HSCB. The opening of the HSCB causes the other propulsion system on the vehicle to be disabled and that Line Switch contactor opened.

To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. If a TOD Reset or hard reset does not work, the effected propulsion inverter must be cut out. Also refer to Table 6-2, Symptom 1 to 5 in Section 6.7.

CFD_F Inverter Gate Fault

An IGBT gate driver fault has been detected in one of the three phases. There is a discrepancy between the gate command and the feedback signal. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed with Full Service Brake. The Trace Data will identify which phase failed. Also refer to Table 6-2, Symptom 6 in Section 6.7.

CFDB_F Bch Gate Fault

A brake chopper IGBT gate driver fault (Bch1 or 2) has been detected. There is a discrepancy between the gate command and the feedback signal. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. Also refer to Table 6-2, Symptom 6 in Section 6.7.

CHIF_F BCh Fault

Power of greater than 350 kW is flowing through the brake resistor assemblies. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake.

CHR_F Charging Resistor Protection

The Line Charging Contactor has been energized 3 times within 1 minute and will not be energized again for one minute to allow cooling of the charging resistor. This fault will repeat until the effected inverter is cut out.

CN_F SCEB Fault

Incorrect combination of Slide Controlled Emergency Brake signals will cause SCEB to be applied. Reset when No-motion is detected and Full Service Brake.

ESLVD_F Line Low Voltage

Line Voltage detected at less than 475 volts in power. This condition will shut down the inverter and open the Line Switch contactor. Reset is automatic once line voltage has risen to 525 volts.

ETH_F Ethernet Fault

Ethernet Communication fault. This just a warning and does not affect the operation of the vehicle. Also refer to Table 6-2, Symptom 15 in Section 6.7.

FAN1KM Fan Motor Speed Fault

One or more of the Inverter Unit cooling fans is operating at less than 2000 RPM for longer than 20 seconds. This condition is automatically reset when the effected cooling fan runs at nominal speed for longer than 5 seconds. The operation of the propulsion system is not affected by this fault condition. Also refer to Table 6-2, Step 10-4 and 10-5 in Section 6.7.

FCC_F Filter Capacitor Capacitance Fault

The calculation of the value of the filter capacators is done with the Line Switch contactor open and the Line Charging Contactor closed. The line voltage is monitored as well as the line current and the charging and discharging time of the filter capacitors. Using these signals, the value of the four filter capacitors is calculated and must be greater than 37,800uF, which is 90% of the rated value of 42,000uF.

With this fault, the calculated value of the filter capacitor has been detected to be out of limits. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. This is checked only at zero speed. If the TOD reset does not work, try a Hard Reset. Also refer to Table 6-2, Symptom 11 in Section 6.7.

FCD_F Abnormal Charging

Voltage on the filter capacitors detected to be less than 150 volts with current greater than 30 amps for 200ms. Or, the Line Switch contactor did not close within 1.5 seconds after the Line Charging Contactor was closed. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. If the TOD reset does not work, try a Hard Reset. If the hard reset does not work, the effected propulsion inverter must be cut out. Also refer to Table 6-2, Step 11-4 in Section 6.7.

GPLVD_F Gate Power Source Low Voltage

The 38 Vac from the Power Supply Unit to the gate driver boards has been detected to be less than 29.2 Vac. This condition will shut down the inverter and open the Line Switch contactor. Recovery voltage must be greater than 31.1 Vac and then select the PROP / HSCB Reset from the TOD screen at zero speed with a Full Service Brake. If reset does not recover, cut out the effected inverter. Also refer to Table 6-2, Step 6-1 in Section 6.7.

HB28_F HSCB Power Source Abnormality

The 28.5 volt vehicle battery input to the High Speed Circuit Breaker Control Panel has been detected to be less than 14.4 Vdc. This condition will shut down both inverters and open both Line Switch contactors and the HSCB. Recovery will occur with greater than 16.6 Vdc. Also refer to Table 6-2, Step 1-3 in Section 6.7.

HSCB_F HSCB Fault Detection

A fault has been detected with the closing or opening of the HSCB from the command signal and the feedback signal. This condition will shut down both inverters and open both line switch contactors. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. Also refer to Table 6-2, Symptom 1 and 2 in Section 6.7.

HSCBLOC_F HSCB Lockout

High Speed Circuit Breaker Locked Out. The HSCB has been tripped 3 times within 15 minutes by an overcurrent condition. This condition will shut down each inverter and open the Line Switch contactors. The lockout can be cleared by either using the PTU HSCB Lockout recovery screen or by cycling control power to the propulsion logic. Also refer to Table 6-2, Step 1-5 in Section 6.7.

HSCBT_F HSCB Tripped

The HSCB has been commanded open or has tripped from an overcurrent condition and must be reset. This condition will shut down both inverters and open both Line Switch contactors. To recover from his condition, select the PROP / HSCB Reset from the TOD screen at any speed. On the third detection of this fault within 15 minutes, the HSCB is locked out. The effected propulsion system should now be cut out. Also refer to Table 6-2, Symptom 2 in Section 6.7.

ID_F Truck ID Abnormality

Each PLU is assigned an identification to distinguish the A-end PLU (IDIN) and the B-end PLU (IDIN2). From the A-end, IDIN is high and IDIN2 is low. From the B-end, IDIN2 is high and IDIN is low. This fault condition will shut down the inverter and open the Line Switch contactor.

ILOV_F Input Overcurrent

Line Current has been detected to be greater than 1600 amps for longer than 1 second. This condition will shut down the inverter, open the Line Switch contactor and the HSCB. The opening of the HSCB causes the other propulsion system on the vehicle to be disabled and that Line Switch contactor opened.

To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. If this is a reoccurring fault, the effected propulsion inverter must be cut out. Also refer to Table 6-2, Step 14-4 in Section 6.7.

ITD_F Illegal Torque Detection

The torque delivered differs from the calculated torque requested. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake.

LCC_F LCC Fault Detection

The LCC command signal and status feedback do not match for longer than 1 second. This condition will shut down the inverter and open the Line Switch contactor and the HSCB. The opening of the HSCB will cause the other inverter to be disabled and its Line Switch contactor to open. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. Also refer to Table 6-2, Symptom 4 in Section 6.7.

LGD_F OCS Gap Detected

A catenary Overhead Catenary System gap has been detected. This is not a fault condition. If in Power above 20 mph, the inverter shifts to a negative Slip in the gap to supply power to the vehicle loads while in the gap. Reset to a positive Slip is automatic when the catenary voltage is detected on the other side of the gap.

LOFM_F Propulsion Protection Detection

A protection event has continued and is now identified as a fault. See PTU Manual Section 2.7.3.2 for a listing of the Protection events. Protection events become a fault condition if the protection condition occurs 3 times in 1 minute or lasts for longer than 30 seconds. This condition will shut down the inverter and open the Line Switch contactor. The inverter requires an operator reset. This is an indication of another fault condition detected from the PTU Protection screen.

LS_F LS Fault Detection

The Line Switch contactor either did not close or did not open as commanded within a specified time limit. This condition will shut down the inverter and open the Line Switch contactor and HSCB. The opening of the HSCB will cause the other inverter to be disabled and its Line Switch contactor to open. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. If the soft reset does not work, try a hard reset. Also refer to Table 6-2, Symptom 5 in Section 6.7.

LVD_F Filter Capacitor Low Voltage

The filter capacitor voltage has been detected to be less than 435 volts. This condition will shut down the inverter and open the Line Switch contactor. This condition is automatically reset when the filter capacitor voltage rises above 435 volts.

MCMIS_F Motor Lead Misconnection

Misconnection of wiring to one or more traction motors has been detected by monitoring the inverter output currents.

After the PLU is powered up (Hard Reset), on the first power request of the propulsion system, the current transducers CTU and CTU2 outputs are compared within the first 5 seconds when traction power is applied. This fault condition is detected with CTU greater than CTU2 by more than 60% or CTU2 less than CTU by more than 40%.

This condition will shut down the inverter and open the Line Switch contactor. This fault condition must be corrected before the propulsion system can be enabled again. To recover from this condition, cut out the effected propulsion system and repair the system as soon as possible.

MMOCD1_F Output Overcurrent

An overcurrent condition of 2600 amps has been detected on the output of the propulsion inverter to the traction motors as measured at CTU, CTV or CTW. This condition will shut down the inverter and open the Line Switch contactor. Automatic reset when the condition recovers. If this is a reoccurring fault, the effected propulsion inverter must be cut out. Also refer to Table 6-2, Symptom 7 in Section 6.7.

MMOCD2_F Frequent Output Overcurrent

An overcurrent condition of greater than 2600 amps has been detected on the output of the propulsion inverter 3 times since the last time the reverser was placed in Neutral. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. With this reoccurring fault, the effected propulsion inverter must be cut out. Also refer to Table 6-2, Symptom 7 in Section 6.7.

MTP_F Traction Motor Over Heat

The calculated temperature of the traction motors is done using the inverter output current and vehicle speed. An overtemp condition is detected when the calculated temperature exceeds 220 degrees C (428 degrees F). This condition will shut down the inverter and open the Line Switch contactor. When the calculated traction motor temperature has fallen to 200 degrees C (392 degrees F) the condition can be reset from the PROP / HSCB Reset on the TOD screen after the next Full Service Brake application at zero speed is detected. Also refer to Table 6-2, Symptom 17 in Section 6.7.

MVB_F MVB Fault

Multi-functional Vehicle Bus Channel Communication Fault. With the loss of the MVB (both Channel 1 and Channel 2), the Line Switch contactor will be opened. The condition is automatically reset when communications have been restored. Also refer to Table 6-2, Symptom 15 in Section 6.7.

MVB1_F MVB Fault

Multi-functional Vehicle Bus Channel 1 Communication Fault. This is a warning and not a fault condition. MVB1 and MVB2 are redundant communications channels. The failure of one channel will not disable the system. Also refer to Table 6-2, Symptom 15 in Section 6.7.

MVB2_F MVB Fault

Multi-functional Vehicle Bus Channel 2 Communication Fault. This is a warning and not a fault condition. MVB1 and MVB2 are redundant communications channels. The failure of one channel will not disable the system. Also refer to Table 6-2, Symptom 15 in Section 6.7.

OVD_F Filter Capacitor Overvoltage

The voltage on the filter capacitors has been detected as greater than 1000 volts. This condition will shut down the inverter and open the Line Switch contactor. When the filter voltage overvoltage condition is detected, the propulsion system is disabled, LS is opened, and the brake choppers are operated until the FC voltage is dropped to less than 50 volts. The Brake Choppers will be activated even if a Brake Resistor Overheat condition is detected.

P15LVD_F Transducer Power Source Fault

The 15 volt DC power supply to the power circuit current transducers and voltage detectors is out of range. The sum of the -15 Vdc and +15 Vdc (30 volts) is monitored to be less than 26.8 Vdc. This condition will shut down the inverter and open the Line Switch contactor. Automatic recovery will occur power supply output is within limits greater than 26.8 Vdc.

P28LVD_F Analog Signal Power Low Voltage

The PLU Power Supply board AVR39B1 internal 24 Vdc power supply is used to create the 12 volt, +/- 15 volt and 5 volt output power supplies. These voltages power the devices that create the analog signals to the PLU such as line current, line voltage and the phase currents. This fault is generated when the 24 volt power supply is less than 20 Vdc. This condition will shut down the inverter and open the Line Switch contactor. Automatic recovery when the 24 volt power supply output is greater than 20 Vdc.

PBFR_F Input Command Abnormality

FWD and REV command at the same time. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. If the TOD Reset does not work, try a Hard Reset.

PGF_F Propulsion Ground Fault

A difference of 50 amps for longer than 200 msec has been detected between the line current and the ground (return) current. This condition will shut down the inverter and open the High Speed Circuit Breaker and the Line Switch contactor. Opening of the HSCB will cause the other inverter to be disabled and its Line Switch contactor to open. Recovery is with a PROP / HSCB reset at zero speed and Full Service Brake. Also refer to Table 6-2, Symptom 14 in Section 6.7.

PUD_F Phase Current Imbalance

If the absolute value of the sum of each phase current has been detected of greater than 300 amps (+/- 10 amps) for 20 msec, this fault condition is detected. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. Also refer to Table 6-2, Symptom 8 in Section 6.7.

PWLV_F Control Circuit Power Low Voltage

PLU Power Supply board output voltage of 24 Vdc is less than 14.4 Vdc. This condition will shut down the inverter and open the Line Switch contactor. Recovery when the voltage is above 16.8 Vdc. Also refer to Table 6-2, Symptom 9 in Section 6.7.

RYTD_F Relay Abnormality

Conflict between the command and feedback of the NMRK No-motion relay for 1 second. The PLU sends a message to the TOD indicating a No-motion fault. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake. If the soft reset does not work, try a Hard Reset.

SOVD_F Filter Capacitor Voltage Rising

Filter capacitor voltage has been detected as greater than 950 volts for longer than 1 second. This condition will shut down the inverter and open the Line Switch contactor. This condition is automatically reset when the filter capacitor voltage falls to less than 950 volts.

SPD_F M axle Speed Sensor Fault

Motor axle speed sensor fault is detected if the T-axle speed is greater than the M-axle speed by 25% for longer than 1 second while in Coast. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at zero speed and Full Service Brake.

TEFF_F Propulsion Power Effort Fault

More than 5% difference between the calculated torque and the achieved torque. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at the next Full Service Brake application at zero speed. This fault condition is not detected during wheel Spin or Slide conditions.

THB_F Temperature Sensor Fault (Bch)

Fault detected with the temperature sensor (THBch) used for monitoring the brake chopper IGBTs. This fault is detected with a temperature of less than -20 degrees C. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at the next Full Service Brake application at zero speed. Also refer to Table 6-2, Symptom 10-6 in Section 6.7.

THD1_F Control Switching Due to Rising IGBT Temperature

The temperature of the Inverter Unit plate containing the IGBT’s has detected a temperature of greater than 76.4 degrees C (169.5 degrees F) Level 1. Dynamic braking is disabled with this fault condition. This condition is automatically reset when the temperature falls to 70 degrees C (158 degrees F). Also refer to Table 6-2, Symptom 10 in Section 6.7.

THD2_F IGBT Overheat Protection (Inverter)

The temperature of the Inverter Unit plate containing the IGBT’s has detected a temperature of greater than 80.2 degrees C (176.3 degrees F) Level 2. The propulsion system is now disabled and the Line Switch contactor is opened. This condition is reset from the PROP / HSCB reset from the TOD screen when the temperature falls to 75 degrees C (167 degrees F) at the next Full Service Brake application at zero speed detection. Also refer to Table 6-2, Symptom 10 in Section 6.7.

THDB_F IGBT Overheat Protection (Bch)

The temperature of the Inverter Unit plate containing the IGBT's, at the brake chopper IGBT's, has detected a temperature of greater than 76.4 degrees C (176 degrees F) which disables dynamic braking. This condition is automatically reset when the temperature falls to less than 70 degrees C (158 degrees F). Also refer to Table 6-2, Symptom 10 in Section 6.7.

THI_F Temperature Sensor Fault (Inverter)

The temperature sensor THUV or THVW has been detected as failed. The temperature detected by any of these sensors has been detected to be less than -20 degrees C. This condition will disable the inverter and open the Line Switch contactor. To recover from this condition, select the PROP / HSCB Reset from the TOD screen at the next Full Service Brake application at zero speed. If the soft reset does not work, try a Hard Reset. Also refer to Table 6-2, Step 10-6 in Section 6.7.

TL_F Trainline and PBED Fault

Command confliction between the status of the M and CM trainlines and the amplitude of the PBED signal. This condition will apply Full Service Brake. Reset is automatic once the fault condition is no longer detected. Also refer to Table 6-2, Step 13-2 in Section 6.7.

TSPD_F T axle Speed Sensor Fault

Trailer axle (center truck) speed sensor fault has been detected. This fault condition has no impact on the propulsion system. The M-axle speed has been detected to be greater than the T-axle speed by greater than 25% while in Coast.

WD_F Watch Dog Fault

One or more of the Propulsion Logic Unit CPU watchdog circuits have stopped cycling. This condition will shut down the inverter and open the Line Switch contactor. To recover from this condition, cycle control power to the PLU Off and On. Also refer to Table 6-2, Symptom 12 in Section 6.7.

WDC_F Wheel Diameter Fault

One power truck wheel diameter has been found to be less than 660 mm or different than the other wheel on the same truck by greater than 6 mm. This condition will not shut down the inverter. Correct wheel diameter problem then enter axle 3 wheel diameter into TOD and update to reset the detection.

6.2 Software Operating Parameters

The Propulsion Control Software is responsible for controlling the propulsion system based on the commands and feedback signals from the vehicle and propulsion system. To aid in troubleshooting, the following tables explain the normal operating parameters of the propulsion system. The parameters are broken down into major sections and then into functions as follows:

6.2.1 Inverter Control Functions

6.2.1.1 Powering and Brake Command
6.2.1.2 Dynamic Braking
6.2.1.3 Line Switch and Line Charging Contactor Control
6.2.1.4 High Speed Circuit Breaker Control

6.2.2 Vehicle Control Functions

6.2.2.1 Acceleration/Deceleration Rates
6.2.2.2 Tractive Effort Achieved Feedback
6.2.2.3 Dynamic Brake Blending
6.2.2.4 Tow Mode and Car Wash Control
6.2.2.5 Wheel Spin / Slide Control Functions
6.2.2.6 Roll Back Prevention Function
6.2.2.7 Odometer Function
6.2.2.8 Wheel Diameter Compensation Function

6.2.3 Inverter Protection Functions

6.2.3.1 Gate Driver Power Supply Monitor
6.2.3.2 Inverter Output Current Monitor
6.2.3.3 Filter Capacitor Monitor
6.2.3.4 Inverter Temperature Monitoring
6.2.3.5 Traction Motor Temperature Monitoring
6.2.3.6 Brake Resistor Temperature Monitoring
6.2.3.7 Dynamic Brake Monitoring
6.2.3.8 Low Voltage Power Supply Monitor
6.2.3.9 Watchdog Monitoring
6.2.3.10 Inverter Unit Fan Motor Monitor

6.2.4 Vehicle Protection Functions

6.2.4.1 Line Voltage Monitor
6.2.4.2 Tachometer Status Monitor
6.2.4.3 Rollback Detection and No Motion Monitor
6.2.4.4 Ground Fault
6.2.4.5 Friction Brake Released Monitoring
6.2.4.6 Vehicle Speed Monitoring

6.2.5 Communications

6.2.5.1 MVB and MDS Communications Fault Detection

6.2.5.2 Data Logger Output Functions

6.2.6 Specifications

6.2.6.1 Traction Motor Parameters

6.2.6.2 Gear Unit and Wheel Specifications

6.2.6.3 Car Weight

6.2.1 Inverter Control Functions

6.2.1.1 Power and Braking Commands

No.	Parameter	Value & Units
1	Time delay to declare an input command fault if FWD and REV trainlines are both active at the same time	0.3 sec
2	Delay time allowed for an invalid PBED request until SCEB or FSB is initiated.	1.0 sec

6.2.1.2 Dynamic Braking

No.	Parameter	Value & Units
1	The minimum speed at which dynamic braking can be initiated.	6 mph
2	Maximum dynamic brake current.	621 amps
3	Maximum dynamic brake voltage, continuous	950 volts
4	Brake resistor coil resistance, at room temperature	0.92 Ohms
5	Maximum resistor element hot spot temperature	600 deg C

6.2.1.3 Line Switch and Line Charging Contactor Control

No.	Parameter	Value & Units
1	Minimum line voltage before Line Switch contactor and Line Charging Contactor opens.	475 volts
2	Minimum line voltage before line current is reduced by 5 amps per volt.	600 volts
3	Minimum filter capacitor voltage before Line Switch contactor and Line Charging Contactor open.	435 volts
4	Maximum filter capacitor voltage before Line Switch contactor and Line Charging Contactor open. Value must be present for at least 1 second.	950 volts
5	Maximum filter capacitor voltage before Line Switch contactor and Line Charging Contactor immediately open.	1000 volts

6.2.1.4 High Speed Circuit Breaker Control

No.	Parameter	Value & Units
1	HSCB over current trip point.	3200 amps
2	HSCB trip time to open	8 msec
3	HSCB maximum Operational Voltage	1000 volts
4	HSCB rated short-circuit making and breaking capacity	30 kA
5	HSCB mechanical opening time	5 – 20 msec
6	HSCB mechanical closing time	100 msec
7	Time delay to open the HSCB when neither FWD nor REV direction is selected.	60 sec
8	Time delay to close HSCB when TOD reset button is selected	0.5 sec
9	Time delay to open HSCB when Propulsion Cut Out signal goes high or overcurrent is detected.	1.0 sec
10	Number of overcurrent trips of the HSCB that will cause a lockout	3 within 15 minutes

6.2.2 Vehicle Control Functions

6.2.2.1 Acceleration/Deceleration Rates

No.	Parameter	Value & Units
1	Maximum allowable acceleration Rate.	3.0 mph/ps
2	Maximum allowable average brake rates in Emergency Braking above 55 mph.	4.5 mph/ps
3	Maximum allowable average brake rates in Service Braking	3.5 mph/ps
4	Minimum allowable average brake rates in Emergency Braking from 3 to 20 mph.	3.5 mph/ps

6.2.2.2 Tractive Effort Achieved Feedback

No.	Parameter	Value & Units
1	Tractive effort difference between command and output before fault is declared	5%
2	Difference in current between command and feedback before tractive effort fault is declared	100 amps

6.2.2.3 Dynamic Brake Blending

No.	Parameter	Value & Units
1	Adhesion level used to calculate brake rates to achieve desired deceleration rate.	18%
2	Adhesion level used to calculate brake rates to achieve desired deceleration rate when sliding or SCEB.	16%
3	Speed at which stopping brake signal to friction brake is activated.	6 mph
4	Combined braking effort of dynamic brakes and friction brakes at AW3 during Slide Controlled Emergency Braking. (per one unit)	70.4 kN

6.2.2.4 Tow Mode and Car Wash Control

No.	**Parameter**	Value & Units
1	Maximum speed in Tow Mode	20 mph
2	Maximum Torque in Tow Mode (per one inverter)	44.7kN
3	Maximum speed in Car Wash mode	2.0 mph

6.2.2.5 Wheel Spin and Slide Control Functions

No.	**Parameter**	Value & Units
1	Duration of Slide Detected signal used to prevent friction brake from compensating reduced brake effort.	10 seconds
2	Minimum vehicle speed for wheel Spin and Slide detection.	6 mph
3	Spin Detection Threshold	1.91 m/s/s
4	Slide Detection Threshold	2.43 m/s/s
5	Adhesion Failure Detection Threshold (Powering)	3.94 m/s/s
6	Adhesion Failure Detection Threshold (Braking)	5.49 m/s/s
7	Adhesion Failure Detection Threshold (Speed Differential)	25%

6.2.2.6 Roll Back Prevention Function

No.	**Parameter**	Value & Units
1	Maximum vehicle speed for roll back detection	1 mph
2	Minimum rollback distance for roll back detection	15 inches
3	Percentage of requested Tractive Effort to release the friction brakes	30%

6.2.2.7 Odometer Function

No.	**Parameter**	Value & Units
1	Distance of travel for each odometer pulse	0.1 mile

6.2.2.8 Wheel Diameter Compensation Function

No.	Parameter	Value & Units
1	New wheel size	28.0" (711 mm)
2	Minimum wheel size	26.0" (660 mm)
3	Maximum allowable differences in wheel diameters within a truck	0.25" (6 mm)
4	Minimum vehicle speed in Coast to compute wheel size	15 mph

6.2.3 Inverter Protection Functions

6.2.3.1 Gate Driver Power Supply Monitor

No.	Parameter	Value & Units
1	Nominal voltage	38 Vac
2	Minimum acceptable voltage for IGBT gate firing.	31.1 Vac
3	Voltage at which a gate driver power fault is declared.	29.2 Vac

6.2.3.2 Inverter Output Current Monitor

No.	Parameter	Value & Units
1	Absolute value of inverter output current before Phase Imbalance fault is detected, sum of all three phase currents.	300 amps
2	Maximum value of inverter current after which propulsion system is shut down, any phase.	2600 amps

6.2.3.3 Filter Capacitor Monitor

No.	Parameter	Value & Units
1	Approximate time to charge the filter capacitor to line voltage at 750 volts	<500 msec
2	Approximate time to discharge the filter capacitors to less than 50 volts	180 seconds
3	Nominal value of filter capacitors, all 4 measured together.	42,000 μF
4	Minimum value of the calculated filter capacitor values before the propulsion system is shut down (90% of nominal).	37,800 μF

6.2.3.4 Inverter Temperature Monitoring

No.	Parameter	Value & Units
1	Temperature at which a Warm condition is declared.	76.4 deg C
2	Temperature that allows an automatic reset from Warm.	70 deg C
3	Temperature at which an overtemperature condition is declared.	80.2 deg C
4	Temperature that allows an automatic reset from overtemperature.	75 deg C
5	Measured temperature at which a thermistor malfunction is identified and inverter shuts down.	-20 deg C

6.2.3.5 Traction Motor Temperature Monitoring

No.	Parameter	Value & Units
1	Maximum allowable motor temperature before propulsion system will be shut down.	220 deg C
2	Temperature that allows an automatic reset.	200 deg C

6.2.3.6 Brake Resistor Temperature Monitoring

No.	Parameter	Value & Units
1	Maximum brake resistor temperature allowed, calculated value based on thermal time constant and cycle time.	500 deg C
2	Temperature where an over temperature failure is reset. This is a calculated temperature based on the elapsed time.	450 deg C

6.2.3.7 Dynamic Brake Monitoring

No.	Parameter	Value & Units
1	Minimum dynamic brake voltage to allow rheostatic braking	900 volts
2	Minimum Dynamic Brake voltage.	435 volts
3	Maximum Dynamic Brake voltage.	950 volts
4	Difference in brake input power and output power before fault is detected.	350 kW
5	Brake chopper IGBT operating frequency	300 Hz
6	Duty cycle of brake chopper when line voltage or FC voltage is above 1000 volts.	50%

6.2.3.8 Low Voltage Power Supply Monitor

No.	Parameter	Value & Units
1	Minimum acceptable voltage for battery voltage to power low voltage circuits. Nominal is 28.5 V.	16.8 volts
2	Voltage at which battery voltage not supplied fault is declared.	14.4 volts
3	Minimum acceptable +/- 15 V voltage difference for transducer and speed sensors. If voltage difference is less, a fault is declared.	26.8 volts
4	Minimum acceptable difference between + 24 volts and -5 volts power sources used for analog signals. If voltage difference is less, a fault is declared.	24.5 volts

6.2.3.9 Watchdog Timer

No.	Parameter	Value & Units
1	Detection time for watchdog failure. Watchdog of each CPU is monitored by the System CPU and reported by Remote CPU.	200 msec

6.2.3.10 Inverter Unit Fan Motor Monitor

No.	Parameter	Value & Units
1	Time after train direction is moved out of FWD or REV before inverter cooling fans shut off. Fans are also shut off while in Car Wash mode.	180 seconds
2	Nominal cooling fan speed.	3250 rpm
3	Speed at which a fan failure malfunction is detected, must be below this value for 20 seconds.	2000 rpm
4	Speed which reset is allowed, must be above this value for 5 seconds.	2000 rpm

6.2.4 Vehicle Protection Functions

6.2.4.1 Line Voltage Monitor

No.	Parameter	Value & Units
1	Maximum Line voltage in Power.	950 volts
2	Maximum Line voltage in Brake.	950 volts
3	Minimum Line voltage in Power.	475 volts
4	Minimum Line voltage in Brake.	475 volts
5	Minimum Line voltage to restart in Power	525 volts
6	Minimum Line Voltage to restart in Brake	525 volts

6.2.4.2 Tachometer Status Monitor

No.	Parameter	**Value & Units**
1	Number of monitored tachs per powered truck.	1
2	Number of monitored tachs per trailer (center) truck	1
3	Number of power truck tachometer pulses per revolution of the traction motor rotor (number of tachometer wheel teeth).	60
4	Number of trailer (center truck) tachometer pulses per revolution (number of tachometer wheel teeth).	120
5	Number of failed powered truck tachs that will cause the propulsion system to shut down.	1

6.2.4.3 Rollback Detection and No Motion Monitor

No.	Parameter	Value & Units
1	Maximum speed to detect No-motion	0.5 mph
2	Minimum speed to detect motion	1.5 mph
3	Maximum speed to detect Rollback	1 mph
4	Maximum distance to detect Rollback	15 inches

6.2.4.4 Ground Fault Monitor

No.	Parameter	Value & Units
1	The maximum allowable difference between line and return current.	50 amps
2	Time delay for ground fault failure detection.	200 msec

6.2.4.5 Friction Brake Released Monitoring

No.	Parameter	Value & Units
1	Low speed for brake blending	6 mph
2	Time delay for brake blending	450 msec
3	Approximate minimum speed for high speed brake blending, depends on car weight.	50 mph

6.2.4.6 Vehicle Speed Monitoring

No.	Parameter	Value & Units
1	Maximum vehicle speed allowed.	65 mph
2	Maximum speed relative to speed limit to enable the Speed Governor Relay. Shuts down tractive effort, applies FSB and sounds alarms.	+4 mph
3	Maximum speed relative to speed limit before propulsion starts reducing tractive effort.	-2 mph
4	Maximum speed relative to speed limit before tractive effort is reduced to zero.	+2 mph
5	Speed limit when propulsion cutout or fault or friction brake cutout or fault	35 mph

6.2.5 Communications

6.2.5.1 MVB and MDS Communications Fault Detection

No.	Parameter	Value & Units
1	Cycle time for communicating with MVB	20 msec
2	Number of MVB communication cycles with no response from PLU before shutting down the inverter. (both channels)	3
3	Ethernet monitoring cycle time	1 second
4	Number of MVB communication channels that need to be failed before fault is declared and inverter shuts down.	2

6.2.5.2 Data Logger Output Functions

No.	Parameter	Value & Units
1	Number of digital signals displayed from the PTU	455
2	Number of analog signals displayed from the PTU	45
3	Seconds of data before fault event that are logged	2
4	Seconds of data after fault event that are logged	2
5	Sampling frequency for each trace	200Hz

6.2.6 Specifications

6.2.6.1 Traction Motor Parameters

No.	Parameter	Value & Units
1	Motor Winding Resistance, after running	0.05257 Ω
2	Motor Resistance to ground	5 mΩ
3	Number of traction motor poles	4
4	The rated Slip of the motor, continuous	1.3%
5	Input frequency	75 Hz
6	Input voltage, continuous	550 Vac
7	Maximum speed	2221 rpm
8	Maximum Rated Motor Torque	1200 N-m
9	Maximum motor current (RMS).	193 amps
10	Maximum motor current (peak) during normal operation	321 amps

6.2.6.2 Gear Unit and Wheel Specifications

No.	Parameter	Value & Units
1	Gear Ratio.	6.426 to 1
2	Size of new wheels.	711 mm (28.0 in.)
3	Size of condemned wheels	660 mm (26.0 in.)

6.2.6.3 Car Weight

No.	Parameter	Value & Units
1	Minimum car weight (AW0)	46,266 kg (101,999 lbs).
2	AW2 car weight	58,096 kg (128,080 lbs)
3	Maximum car weight (AW3)	61,234 kg (134,998 lbs)

6.3 Propulsion Input / Output List

Section 6.3.1 explains the propulsion system hard wired (Discrete) input and output signals.

Section 6.3.2 lists the propulsion system MVB input and output signals.

6.3.1 Propulsion Discrete Input / Output Signals

The purpose of this section is to list and define the discrete control system inputs and outputs for the propulsion equipment case.

The information provided in this section covers control system signals that are available at the various inverter equipment case connectors. It does not cover high voltage connections of any kind.

Signals that enter or exit the logic from the MVB or Gateway are not included in this list.

For each of the signals, the following information is available:

Abbreviation - Signal title and abbreviation as used in diagrams and drawings.

Type - Signal type such as analog, digital, or power supply.

Scaling - Signal scaling factor voltage range of the signal.

Description - Brief explanation of the signal.

Read By - Circuit board that outputs or reads the signal.

Connector - Equipment case connector and pin number where the signal enters or exits the propulsion equipment case (CN1 through CN6).

Some of the signals used by the propulsion system are not monitored by the logic as input signals and so are noted as Not Applicable (N/A) in the **Read by** fields.

Some of the logic output signals do not leave the equipment case and so are noted as Not Applicable (N/A) in the **Connector** fields.

Abbreviation:	AC 208V Detection
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	This signal is controlled from the Inverter Fan Relay 208VDK. When the vehicle APS is active, the fan relay is energized which inputs this signal into the propulsion logic as proof that the vehicle APS is running. This signal is required to activate the Inverter Unit cooling fans.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1
Connector	N/A

Abbreviation:	AC 38V Power Supply
Type:	Power Supply Output
Scaling:	38 Vac
Description:	This pulse width modulated power supply output is from the Power Supply Unit and used to power the PLU Power Supply Board and the gate driver boards in the Inverter Unit.
Read by:	AVR39B1 Power Supply Board
Connector	N/A

Abbreviation:	ATPBP Automatic Train Protection Bypass
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	The Status of the ATP By-Pass Trainline. High means that the Automatic Train Protection system has been bypassed. Low is the normal operation with ATP active. Propulsion monitors this signal but does not use it for control purposes.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin h

Abbreviation:	CBTF1 High Speed Circuit Breaker Fault A-unit
Type:	Digital output
Scaling:	28.5 Vdc Battery Voltage
Description:	Signal high indicates a fault is detected from the A-unit PLU that prevents the HSCB from closing. Signal low is normal operation. This is labeled as CBTFX inside the inverter box. From one PLU to the other preventing the HSCB from being closed with a lockout activated from the other logic.
Read by:	Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	CN5, Pin D (A-unit only) and CN 5, Pin n

Abbreviation:	CBTF2 High Speed Circuit Breaker Fault B-unit.
Type:	Digital output
Scaling:	28.5 Vdc Battery Voltage
Description:	Signal high indicates a fault is detected from the B-unit PLU that prevents the HSCB from closing. Signal low is normal operation. This is labeled as CBTF inside the inverter box. From one PLU to the other preventing the HSCB from being closed with a lockout activated from the other logic.
Read by:	Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	CN5, Pin D (B-unit only) and CN 5, Pin n

Abbreviation:	CM Coast / Motor Command Trainline
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Coast / Motor Command Trainline from the Master Controller. High is Motoring or Coast. Low is Braking mode.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin r

Abbreviation:	EB Emergency Brake Trainline
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	The Master Controller provides the supply and return circuits to the EB trainline through the ATP logic and the console EB pushbutton switch. The EB trainline active is a requirement to energize LSR controlling the Line Switch contactor. With the loss of the EB Trainline, propulsion and dynamic braking are disabled. High is EB not applied (normal). Low is EB applied.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin c

Abbreviation:	ETH Ethernet Signals for MDS
Type:	Communications Link
Scaling:	0 to 5 Volts DC
Description:	Monitoring and Diagnostic System, contains a 4-pin Ethernet connection.
Read by:	Serial Communications board to the Gateway Unit
Connector	CN4, Pin 1 Tx +, Pin 2 Rx +, Pin 3 Tx -, Pin 4 Rx -

Abbreviation:	Fan1K Command to activate the Inverter Unit Cooling Fans.
Type:	Digital Output
Scaling:	28.5 Vdc Battery Voltage
Description:	When a direction is set from the Master Controller, with the Fan Power Supply Status digital input ACOK active and the Fan Motor Relay FM1R energized, the four fans are commanded On.
Read by:	Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	N/A

Abbreviation:	FAN1F Cooling Fan 1 Status
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Normal fan speed is 3250 RPM. When Cooling Fan 1 speed is detected to be greater than 2000 RPM for longer than 5 seconds, this signal from the fan relay is high which is the normal condition. When Cooling Fan 1 speed is detected to be less than 2000 RPM for longer than 20 seconds, this signal goes low which is the fault condition. A cooling fan fault will not disable the propulsion system.
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	N/A

Abbreviation:	FAN2F Cooling Fan 2 Status
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Normal fan speed is 3250 RPM. When Cooling Fan 2 speed is detected to be greater than 2000 RPM for longer than 5 seconds, this signal from the fan relay is high which is the normal condition. When Cooling Fan 2 speed is detected to be less than 2000 RPM for longer than 20 seconds, this signal goes low which is the fault condition. The event is entered into the PTU Fault / Protection events. A cooling fan fault will not disable the propulsion system.
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	N/A

Abbreviation:	FAN3F Cooling Fan 3 Status
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Normal fan speed is 3250 RPM. When Cooling Fan 3 speed is detected to be greater than 2000 RPM for longer than 5 seconds, this signal from the fan relay is high which is the normal condition. When Cooling Fan 3 speed is detected to be less than 2000 RPM for longer than 20 seconds, this signal goes low which is the fault condition. The event is entered into the PTU Fault / Protection events. A cooling fan fault will not disable the propulsion system.
Read by:	IBA130A1 Digital Input Board 1 to the MCB107B1 Inverter System Control board.
Connector	N/A

Abbreviation:	FAN4F Cooling Fan 4 Status
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Normal fan speed is 3250 RPM. When Cooling Fan 4 speed is detected to be greater than 2000 RPM for longer than 5 seconds, this signal from the fan relay is high which is the normal condition. When Cooling Fan 4 speed is detected to be less than 2000 RPM for longer than 20 seconds, this signal goes low which is the fault condition. The event is entered into the PTU Fault / Protection events. A cooling fan fault will not disable the propulsion system.
Read by:	IBA130A1 Digital Input Board 1 to the MCB107B1 Inverter System Control board.
Connector	N/A

Abbreviation:	FBREL Friction Brake Released
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Friction Brake Released trainline activated by the friction brake ECU's when all of the friction braking has been released on the train. High is Friction Brakes are all released. Low is one or more of friction brakes is not released.
Read by:	IBA130A1 Digital Input Board 1 to the MCB107B1 Inverter System Control board.
Connector	CN5, Pin M

Abbreviation:	FWD Forward Trainline
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Forward trainline activated from the Master Controller. PLU A is connected to Direction 1 TL PLU B is connected to Direction 2 TL
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin K

Abbreviation:	HB24 HSCB Control Panel Power Supply Status.
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	HSCB Control Panel Power Supply Status. High is that the HSCB Control Panel has 24 volts. Low means that the HSCB Control panel does not have sufficient voltage. Low voltage is 14.4 volts with recovery at 16.8 volts.
Read by:	BA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin B

Abbreviation:	HBCC Energize HSCBCK Relay Command
Type:	Digital output
Scaling:	28.5 Vdc Battery Voltage
Description:	HBCC is a digital output from both PLU's to energize the HSCBCK control relay allowing the HSCB to be energized closed. High is the HSCBCK commanded closed. Low is the HSCBCK commanded open. With no failures detected, both the A-unit and B-unit activate the signal to energize the HSCBCK relays. With a failure from one of the propulsion systems, the remaining PLU will activate the signal to energize the HSCBCK and cause the HSCB to close.
Read by:	MCB107B1 Inverter System Control Board to OBA54A1 Digital Output Board
Connector	DOCN1, Pin J

Abbreviation:	HSCBS High Speed Circuit Breaker Status
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Signal output from limit switches in the HSCB. There are separate limit switches feeding the Status signal into the A-end and B-end PLU. High is that the HSCB is closed. Low indicates that the HSCB is open.
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1
Connector	CN5, Pin m

Abbreviation:	IB Brake Chopper Current
Type:	Analog Input
Scaling:	+/- 3000 amps = +/- 10Vdc to logic
Description:	This signal from the brake chopper current transducer CTB representing the current flow through the brake chopper resistors.
Read by:	MCB108B1 Inverter Control Board CTB 1 CTBN Output signal neutral (return) CTB 2 CTB Output signal CTB 3 M15B -15 Vdc power CTB 4 P15B +15 Vdc power
Connector	N/A

Abbreviation:	IDIN A-unit Truck (Propulsion Logic Unit) ID input
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Identification Input controlled by vehicle wiring to the Propulsion Logic Unit. IDIN high indicates that the PLU is the A-end.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1
Connector	CN5, Pin j

Abbreviation:	IDIN2 B-unit Truck (Propulsion Logic Unit) ID input
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Identification Input controlled by vehicle wiring to the Propulsion Logic Unit. IDIN2 high indicates that the PLU is the B-end.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin k

Abbreviation:	IL Line Current
Type:	Analog Input
Scaling:	+/- 3000 A = +/- 10 Vdc to logic
Description:	This signal from the line current transducer CTL representing the current flow at the DC input to the propulsion system.
Read by:	MCB108B1 Inverter Control Board
	CTL 1 CTLN Output signal neutral (return)
	CTL 2 CTL Output signal
	CTL 3 M15L -15 Vdc power
	CTL 4 P15L +15 Vdc power
Connector	N/A

Abbreviation:	IG Ground (Return) Current
Type:	Analog Input
Scaling:	+/- 3000 A = +/- 10 Vdc to logic
Description:	This signal from the ground (return) current transducer CTG representing the current flow at the power circuit DC return to the grounding system.
Read by:	MCB108B1 Inverter Control Board
	CTG 1 CTGN Output signal neutral (return)
	CTG 2 CTG Output signal
	CTG 3 M15G -15 Vdc power
	CTG 4 P15G +15 Vdc power
Connector	N/A

Abbreviation: IU Phase-U inverter output current

Type: Analog Input

Scaling: +/- 3000 A = +/- 10 Vdc to logic

Description: This signal from the U-phase inverter output current transducer CTU representing the current flow through the traction motor U-phase windings.

Read by: MCB108B1 Inverter Control Board

CTU 1 CTUN Output signal neutral (return)

CTU 2 CTU Output signal

CTU 3 M15U -15 Vdc power

CTU 4 P15U +15 Vdc power

Connector N/A

Abbreviation: IU2 Phase-U inverter output current

Type: Analog Input

Scaling: 3000 amps = 10 Vdc to logic

Description: This signal from the U2 current transducer is used to detect a mis-connection of the traction motor leads that would cause the traction motor magnetic fields to be opposite of what is intended.

Read by: MCB108B1 Inverter Control Board

CTU2 1 CTU2N Output signal neutral (return)

CTU2 2 CTU2 Output signal

CTU2 3 M15U2 -15 Vdc power

CTU2 4 P15U2 +15 Vdc power

Connector N/A

Abbreviation:	IV Phase-V inverter output current
Type:	Analog Input
Scaling:	+/- 3000 A = +/- 10 Vdc to logic
Description:	This signal from the V-phase inverter output current transducer CTV representing the current flow through the traction motor V-phase windings.
Read by:	MCB108B1 Inverter Control Board
	CTV 1 CTVN Output signal neutral (return)
	CTV 2 CTV Output signal
	CTV 3 M15V -15 Vdc power
	CTV 4 P15V +15 Vdc power
Connector	N/A

Abbreviation:	IW Phase-W inverter output current
Type:	Analog Input
Scaling:	+/- 3000 A = +/- 10 Vdc to logic
Description:	This signal from the W-phase inverter output current transducer CTW representing the current flow through the traction motor W-phase windings.
Read by:	MCB108B1 Inverter Control Board
	CTW 1 CTWN Output signal neutral (return)
	CTW 2 CTW Output signal
	CTW 3 M15W -15 Vdc power
	CTW 4 P15W +15 Vdc power
Connector	N/A

Abbreviation:	LCC Line Charging Contactor Status
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	This signal from a normally closed auxiliary switch on the contactor indicates to the logic if the Line Charging Contactor is open (status high) or is closed (0 volts).
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1
Connector	N/A

Abbreviation:	LCCRC Line Charging Contactor Operating Command
Type:	Digital Output
Scaling:	28.5 Vdc Battery Voltage
Description:	This signal from the Digital Output board is sent to the Line Charging Contactor coil to close the contactor.
Read by:	Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	N/A

Abbreviation:	LIMP HOME Limp Home Mode
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	The Limp Home Mode function is controlled from a sealed switch on the Cab Bypass / Cutout Switch Panel. Limp Home Mode is used with a loss of communications with the TCN. High is the normal operation with Limp Home not active. Low means that the switch has been thrown and Limp Home Mode is active.
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin e

Abbreviation:	LS Line Switch contactor Status
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	This signal from an auxiliary switch on the contactor indicates to the logic if the Line Switch contactor is open (0 volts) or is closed (high).
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	N/A

Abbreviation:	LSRC Line Switch Relay Command
Type:	Digital Output
Scaling:	28.5 Vdc Battery Voltage
Description:	This signal from the Digital Output board is sent to the Line Switch Relay which then energizes the Line Switch Contactor operating coil to close the contactor.
Read by:	From the Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	N/A

Abbreviation:	M Motor Command trainline
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Motor Command trainline from the Master Controller. High is Motoring. Low is Coast or Braking mode.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1
Connector	CN5, Pin p

Abbreviation:	MCKSR Master Controller Key Switch Relay
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Signal controlled from the MCKSR relay interlocks. High when a cab is the lead in the train. Low means that a cab is not the lead in the train.
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin J

Abbreviation:	MVB Signals, Lines A and B
Type:	Communication Link
Scaling:	0 to 5 Volts DC
Description:	Multi-functional Vehicle Bus has redundant channels 1 and 2 for reliability. Both are in the CN 3 connector. Each channel has lines 1 and 2. Each line has a P, N, and Shield connection. MVB is for train control.
Read by:	Gateway Unit and the Serial Communications board IFB137B1
Connector	CN3

Abbreviation:	ODP Odometer Pulse Output
Type:	Digital output
Scaling:	28.5 Vdc Battery Voltage
Description:	A momentary pulse reads high every 0.1 mile activating the odometer. Low is when no pulse is being received.
Read by:	B-unit Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	CN5, Pin F (active on B-unit only, signal not used on A-unit)

Abbreviation:	PCO Propulsion Cutout
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	This signal is controlled from the Propulsion Cutout switchs on the Cab Bypass / Cutout Switch Panel. The input signal from each switch is active when propulsion has not been cut out. Low is the propulsion system cutout.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin f

Abbreviation:	PDF or FDRC Propulsion Dynamic Fault
Type:	Digital Output
Scaling:	28.5 Vdc Battery Voltage
Description:	This output controls the Propulsion Dynamic Fault Relay. It is energized when the propulsion system is operational with no fault conditions and de-energized when a fault condition has been detected or a Protection Event has continued for 30 seconds or occurred 3 times in one minute. This signal provides the status of the PLU to the Propulsion Fault Trainline.
Read by:	Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	CN5, Pin E

Abbreviation:	PS Pantograph Status
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Pantograph Status is provided from the Pan Down trainline. This signal is High during the period when the pantograph is being lowered. Low means that the pantograph is not moving and could indicate either up or down position. When this signal is active, the HSCB is commanded open.
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin s

Abbreviation:	PWC Power Cut
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Input from the Automatic Train Protection system. High input indicates that the propulsion system is in normal operation. Low when propulsion is in Coast commanded by ATP from the current overspeed condition.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin u

Abbreviation:	REV Reverse Trainline
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Reverse trainline from the Master Controller. PLU A is connected to Direction 2 TL PLU B is connected to Direction 1 TL
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin L

Abbreviation:	SCEB Slide Controlled Emergency Brake Trainline
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Slide Controlled Emergency Brake Trainline is disabled (Low) from a switch on the Master Controller in the SCEB position which results in a 5% PBED from the Master Controller. High is normal operation. Low is with SCEB applied.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1.
Connector	CN5, d

Abbreviation:	SGR Speed Governor Relay
Type:	Digital output
Scaling:	28.5 Vdc Battery Voltage
Description:	Speed Governor Relay output signal is energized when vehicle speed is 4 mph above the speed limit. This output signal to the SGR is also energized when the Propulsion Inhibit Trainline detects a fault. The energizing of SGR de-energizes control power to the Master Controller causing a Full Service Brake application.
Read by:	Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	CN5, Pin G

Abbreviation:	LIMP HOME Limp Home Mode
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Controlled from a sealed switch on the Cab Bypass / Cutout Switch Panel. Limp Home Mode indicates a loss of communications with the TCN. High is the normal operation with Limp Home not active. Low is Limp Home Mode active.
Read by:	IBA130A1 Digital Input Board 1 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin e

Abbreviation:	SND Sand Command
Type:	Digital output
Scaling:	28.5 Vdc Battery Voltage
Description:	The Master Controller applies sanding during EB and SCEB by energizing this trainline. Sand Command is high when the sanding command is being sent. Low indicates that no sanding command has been sent. Low is the normal operation.
Read by:	Inverter System Control board MCB107B1 to the Digital Output Board OBA54A1.
Connector	CN5, Pin H

Abbreviation:	TACH11 or TACH 101 Output of Channel 1 (or A) of Tachometer 1 or Tach 10
Type:	Analog Input
Scaling:	0V to 15 Vdc
Description:	This is Channel A of Tach 1 or Tach 10. Used for speed, wheel diameter and direction calculations. The speed sensor signal is frequency proportional to the vehicle A-unit, traction motor 1 (axle 1) speed.
Read by:	IFB138B1 Speed Signal Processing
Connector	CN6, Pin 25 VSP11, Pin 26 VS11, Pin 27 NA1, Pin 28 Tach11B

Abbreviation:	TACH12 or TACH102 Output of Channel 2 (or B) of Tachometer 1 or Tach 10
Type:	Analog Input
Scaling:	0V to 15 Vdc
Description:	This is Channel B (or channel 2) of Tach 1 of Tach 10. Used for speed, wheel diameter and direction calculations. The speed sensor signal is frequency proportional to the vehicle A-unit, traction motor 1 (Axle 1) speed.
Read by:	IFB138B1 Speed Signal Processing
Connector	CN6, Pin 32 VSP12, Pin 33 VS12, Pin 34 NB1, Pin 35 Tach12S

Abbreviation:	TACH4 or TACH5 Output of Tachometer 4 or Tachometer 5
Type:	Analog Input
Scaling:	0V to 15 Vdc
Description:	Used for speed calculations only. Speed sensor signal is frequency proportional to the unpowered axle center truck axle 3 (T-axle) shaft speed. This is the reference speed for the A-unit.
Read by:	IFB138B1 Speed Signal Processing
Connector	CN6, Pin 38 VSP4, Pin 39 VS4, Pin 40 NA4, Pin 41 Tach4S

Abbreviation:	TH11 Heatsink Temperature
Type:	Analog Input
Scaling:	0 - 10 Vdc to logic
Description:	This signal from the THUV thermistor indicates the temperature of the Inverter Unit IGBT tray between the U-phase and V-phase IGBT's.
Read by:	MCB107B1 Inverter System Control Board
Connector	N/A

Abbreviation:	TH12 Heatsink Temperature
Type:	Analog Input
Scaling:	0 - 10 Vdc to logic
Description:	This signal from the THVW thermistor indicates the temperature of the Inverter Unit IGBT tray between the V-phase and W-phase IGBT's.
Read by:	MCB107B1 Inverter System Control Board
Connector	N/A

Abbreviation:	TH13 Heatsink Temperature
Type:	Analog Input
Scaling:	0 - 10 Vdc to logic
Description:	This signal from the THBch thermistor indicates the temperature of the Inverter Unit IGBT tray at the Brake Chopper IGBT's.
Read by:	MCB107B1 Inverter System Control Board
Connector	N/A

Abbreviation:	TRBR Track Brake Status
Type:	Digital Trainline input
Scaling:	28.5 Vdc Battery Voltage
Description:	Track Brake Control Trainline. High is for the Track Brakes applied. Low is for track brakes not applied.
Read by:	IBA130A2 Digital Input Board 2 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin P

Abbreviation:	VC Filter Capacitor Voltage
Type:	Analog Input
Scaling:	1250 volts = 10 Vdc to logic
Description:	This signal from the filter capacitor voltage detector (DCVD2) represents the voltage on the power circuit filter capacitors.
Read by:	MCB108B1 Inverter Control Board DCVD2 1 M152 15 Vdc return (0 volts) DCVD2 2 P152 +15 Vdc feed DCVD2 3 V12N Output signal return DCVD2 4 V12P Output signal
Connector	N/A

Abbreviation:	VL Line Voltage
Type:	Analog Input
Scaling:	1250 volts = 10 Vdc to logic
Description:	This signal from the line voltage detector (DCVD1) represents the catenary voltage.
Read by:	MCB108B1 Inverter Control Board DCVD1 1 M151 15 Vdc return (0 volts) DCVD1 2 P151 +15 Vdc feed DCVD1 3 V11N Output signal return DCVD1 4 V11P Output signal
Connector	N/A

Abbreviation:	VNMRS Vehicle No-motion Relay Status
Type:	Digital input
Scaling:	28.5 Vdc Battery Voltage
Description:	Vehicle No-motion Relay Status. High is the No-motion Relay is energized. Low is the No-motion Relay is not energized.
Read by:	IBA130A2 Digital Input 2 to the Inverter System Control board MCB107B1.
Connector	CN5, Pin N

Abbreviation:	100a1 Vehicle battery supply return circuit
Type:	Ground Line
Scaling:	Battery voltage return.
Description:	Low voltage return for the vehicle battery / LVPS circuits.
Read by:	N/A
Connector	CN1, Pins B, D, or F

Abbreviation:	20 Vehicle battery supply to equipment case
Type:	Power Supply input
Scaling:	28.5 Vdc Battery voltage
Description:	Input from the vehicle batteries / LVPS.
Read by:	N/A
Connector	CN1, Pins A, C, or E

Abbreviation:	208U Auxiliary Power input U-phase
Type:	3-phase Power Supply input
Scaling:	208V, 60 Hz nominal
Description:	Input power to run the Inverter Unit cooling fans, phase-U from the vehicle APS.
Read by:	N/A
Connector	CN2, Pin A

Abbreviation:	208V Auxiliary Power input V-phase
Type:	3-phase Power Supply
Scaling:	208V, 60 Hz nominal
Description:	Input power to run the Inverter Unit cooling fans, phase-V from the vehicle APS.
Read by:	N/A
Connector	CN2, Pin G

Abbreviation:	208W Auxiliary Power input W-phase
Type:	3-phase Power Supply input
Scaling:	208V, 60 Hz nominal
Description:	Input power to run the Inverter Unit cooling fans, phase-W from the vehicle APS.
Read by:	N/A
Connector	CN2, Pin E

Abbreviation:	8ch Analog Output
Type:	Analog and digital signals. See PTU instructions for signal definitions.
Scaling:	-10 volts to +10 volts
Description:	Analog and digital output signals from the Chart PCB that can be sent to the chart recorder. There are 14 groups of signals available in the PTU. Select the most applicable group for the detected fault.
Read by:	IFBI38B1 Chart Output Board
Connector	CN6, Pins 1-23

6.3.2 Propulsion Input / Output Signals

This section explains the propulsion signals output to trainlines and the Multi-functional Bus and those signals on the trainlines and MVB that are monitored by the propulsion logic.

The signals on the MVB are on the Train Control Network (TCN) and cannot be monitored as active signals from the PTU screens. The hardware signals and trainlines can be monitored with the PTU.

The MVB Signals are defined in KI design document UER0618, LACMTA P3010 Vehicle MDS TCN Design Interface Control Document.

6.3.2.1 Propulsion MVB Signals

PLUA_Cutout (B-Unit also)

PLUA_Dynamic_Brake_Availability (B)

PLUA_Unit_Health_Status (B)

PLUA_Carwash_Status (B)

PLUA_Carwash_Mode (B)

HSCB_Lockout_PLUA_Status (B)

HSCB_Status_PLUA (B)

PLUA_Tow_Status (B)

PLUA_Tow_Mode (B)

PLUA_Direction_of_Actual_Movement (B)

HSCB_Command_PLUA (B)

PLUA_Slip_Detected (B)

PLUA_Rollback_Signal (B)

PLUA_Stopping_Brake (B)

PLUA_Speed_Govenour_Rly_Status (B)

PLUA_Sanding_Request (B)

PLUA_No_Motion_Status (B)

PLUA_WD_changed_flag (B) (WD is Wheel Diameter)

PLUA_Over_Head_Linew_Voltage_Gap_Detect (B)

PLUA_Actual_Line_Current_Value (B)

PLUA_Actual_Line_Voltage_Value (B)

PLUA_Overspeed_Indication (B)

PLUA_Overspeed_Torque_Command (B)

PLUA_Speed_Restriction_Limit (B)

PLUA_Power_Effort_Feedback (B)

PLUA_Distance_Counter (This is only on the A-unit)

PLUA_Reference_Speed (B)

PLUA_Axle1_WheelDiameter Note: A-only

PLUA_Axle2_WheelDiameter Note: A-only

PLUB_Axle6_WheelDiameter Note: B-only

PLUB_Axle5_WheelDiameter Note: B-only

ChkPLU_A_Status_1 (B)

PBEDSetPoint_TL

TrainReferenceSpeed_TL

6.3.2.2 Propulsion System Trainline Inputs

M_TL, Power mode

CM_TL, Brake mode

Direction1_TL, Forward or Reverse direction depending on cab

Direction2_TL, Forward or Reverse direction depending on cab

Friction_Brake_Release_TL

Emergency_Brake_TL

SCEB_TL, Slide Controlled Emergency Brake

Limp home_TL

Track_Brake_TL

Pantograph_Status_TL

6.4 Trainline Functions

In the following table:

1 = high (trainline at Battery+)

0 = low (trainline is floating)

X = do not care

< is less than

> is greater than

Table 6-1. Power and Brake Commands (PBED) Functions

Input										
Emer. TL	**SCEB TL**	**SCEB_TL (MVB)**	**PWC**	**M (TL)**	**M_TL (MVB)**	**CM (TL)**	**CM_TL (MVB)**	**PBED (via TCN)**	**Operating Mode**	**Description**
1	1	1	X	X	X	X	X	> 91.5%	FSB	Invalid State (Time Delay: 1.0 second) Trainline and PBED Fault
1	1	1	0	1	1	1	1	53.3 to 91.5%	Power	Normal Power Request
1	1	1	1	1	1	1	1		Coast	Power Cut (Coast) Request
1	1	1	X	0	0	X	X	53.3 to 91.5%	FSB	Invalid State (Time Delay: 1.0 second) Trainline and PBED Fault
1	1	1	X	1	1	0	0			
1	1	1	X	0	0	1	1	45.9 to 53.3%	Coast	Normal Coast Request
1	1	1	X	1	1	X	X	45.9 to 53.3%	FSB	Invalid State (Time Delay: 1.0 second) Trainline and PBED Fault
1	1	1	X	0	0	0	0			
1	1	1	X	0	0	0	0	16.1% to 45.9%	Service Brake	Normal Brake Application
1	1	1	X	1	1	X	X		FSB	Invalid State (Time Delay: 1.0 second) Trainline and PBED Fault
1	1	1	X	X	X	1	1			
1	1	1	X	X	X	X	X	5.5% to 16.1%	FSB	Invalid State (Time Delay: 1.0 second) Trainline and PBED Fault
1	1	1	X	1	1	X	X	5.5% to 45.9%	FSB	Invalid State (Time Delay: 1.0 second) Trainline and PBED Fault
1	1	1	X	0	0	1	1			

Input									Operating Mode	Description
Emer. TL	SCEB TL	SCEB_TL (MVB)	PWC	M (TL)	M_TL (MVB)	CM (TL)	CM_TL (MVB)	PBED (via TCN)		
1	0	0	X	0	0	0	0	5% to 5.5%	SCEB	Slide Controlled Emergency Brake
1	0	0	X	1	1	X	X		SCEB	Invalid State (Time Delay: 1.0 second) SCEB Fault
1	0	0	X	0	0	1	1			
1	0	1	X	X	X	X	X	5% to 5.5%	SCEB	Invalid State- SCEB (Time Delay: 1.0 second) SCEB Fault
1	1	0	X	X	X	X	X			
1	0	X	X	X	X	X	X	> 5.5% or < 5.0%	SCEB	Invalid State- SCEB (Time Delay: 1.0 second) SCEB Fault)
1	X	0	X	X	X	X	X			
1	0	1	X	X	X	X	X	X	SCEB	Invalid State- SCEB SCEB Fault
1	1	0	X	X	X	X	X			
1	1	1	X	X	X	X	X	> 0 and < 5%	FSB	Invalid State (Time Delay: 1.0 second) Trainline and PBED Fault
1	1	1	x	0	0	0	0	0%	FSB	Full Service Brake Application
0	X	X	X	X	X	X	X	X	EB	Emergency Brake Application
X	X	X	X	1	0	X	X	X	FSB	Invalid State (Time Delay: 1.0 second) Trainline and PBED Fault
X	X	X	X	0	1	X	X	X		
X	X	X	X	X	X	1	0	X		
X	X	X	X	X	X	0	1	X		

6.5 Power Circuit Grounds

A power circuit ground fault is detected by comparing the line current from current transducer CTL and the return current from CTG. With a difference of greater than 50 amps for longer than 200 msec the HSCB will be commanded open. The ground fault can occur from either the DC portion of the power circuit or the AC portion of the power circuit.

Refer to Section 8.4 Power Circuit Diagram B446242.

Before measurement activities, it must be confirmed that the primary voltage is de-energized.

Using a DVM, confirm that the filter capacitors are discharged, it will take about 3 minutes for them to discharge after power is removed.

The ground wire shall be disconnected from the external side of the enclosure.

All low voltage circuit connectors, CN1 to CN6, shall be disconnected.

Disconnect the following 3 connectors in the inverter to avoid induction voltage causing damage to electric equipment:

Power supply unit	PSCN2
Propulsion Logic Unit	PWIN
Inverter Unit	INVCN2

To check for a power circuit DC ground, open the inverter equipment case side cover to access the Line Switch contactor. Place the megger positive lead on the connection to the 505 power cable on the Line Switch contactor. Place the megger return lead on an unpainted metal surface and activate the megger. The reading should be above 10 megs.

To check for a power circuit AC ground, open the inverter equipment case bottom cover.

Cables 551U and 561U are the output cables for the U-phase to both traction motors.

Cables 551V and 561V are the output cables for the V-phase to both traction motors.

Cables 551W and 561W are the output cables for the W-phase to both traction motors.

Place the megger return lead on an unpainted metal surface and the positive lead to each of the cables noted above and activate the megger. The reading should be above 10 megs. If a ground is detected, split the connections to determine if the ground is at either traction motor or in the inverter equipment case or cables.

6.6 Short Circuit IGBT

A short circuit IGBT will cause an overcurrent trip of the HSCB. The IGBT's are located in the Inverter Unit LRU. Open the inverter equipment case bottom cover.

Refer to Section 8.4 Power Circuit Diagram B446242.

With a multimeter set for diode check, check the following circuits.

To check all of the upper phase IGBT's, place one meter probe on the 508A cable. Place the other meter cable to any of the output cables 551U or 551V or 551W.

If there is a short circuit (0 ohms) all three cables will show the short circuit because all of the circuits are connected through the traction motor windings. If there is no short circuit reading, all of the upper IGBT bricks (SPU, SPV and SPW) are good.

To check all of the lower phase IGBT's, place one meter probe on the 500B cable. Place the other meter cable to any of the output cables 551U or 551V or 551W. If there is no short circuit reading, all of the lower IGBT bricks (SNU, SNV and SNW) are good.

With a failed IGBT, replace the Inverter Unit.

The Gate Driver boards may have been damaged with a short circuit IGBT and needs to be checked on the bench tester prior to re-use.

6.7 Troubleshooting Table

Table 6-2 contains troubleshooting procedures for the most common propulsion fault or inoperative conditions. The troubleshooting table is divided into four columns:

Symptom - Lists the indication of the fault.

Step - Assigns the step numbers to explain the event or the corrective action.

Cause - Indicates the probable condition(s) which may cause the fault

Theory / Checks / Remedy - Describes how the events are detected and explains the checks and tests that can be done as well as the remedy (corrective action) for the event.

Troubleshooting should start at step 1 and follow the sub steps in order. Each progressive sub step is only required if the previous step does not resolve the problem.

This table uses PTU information to assist in the checks and testing. When an event (fault condition) is detected, it is saved by the PTU. When the event is opened there are digital and analog Trace Data signals that can be viewed. Troubleshooting flowcharts for faults can be viewed by clicking the name of faults shown on the PLU fault indication screen. The Trace Data is the state of each signal at the moment the event was detected.

The Trace Data digital input signals (INP) noted in this table are listed in the PTU Manual in Table 2-2. The Trace Data digital output signals (OUT) noted in this table are listed in the PTU Manual Table 2-3. The digital signals are shown as a line being either high or low. The Analog Trace Data signals are listed in Table 2-4.

The diagrams noted in this table are found in RMSM Section 8.4.

Table 6-2. Troubleshooting

Symptom	Step	Cause	Theory / Checks / Remedy
1 High Speed Circuit Breaker does not close	1-1	Overview	Each HSCBCK, PLU and HSCB Control Panel controls only the HSCB on that vehicle. The opening of one HSCB on a train will not cause any other HSCB in the train to open. As needed, see RMSM Section 6.2.1 Inverter Control Function Parameters sub-section 6.2.1.4 High Speed Circuit Breaker Control.
	1-2	Loss of Line Voltage	Verify that the pantograph is raised and the Knife Switch is in the Normal position.
	1-3	Low voltage Power Supply is missing or is lower than 17 Vdc or more than 30 Vdc.	Check the vehicle battery / LVPS voltage. As needed, see RMSM Section 6.2.3 Inverter Protection Functions sub-Section 6.2.3.8 Low Voltage Power Supply Monitor.
	1-4	PLU Rebooting Failure	Do a Prop / HSCB Reset from the TOD. If that did not work, do a Hard Reset and wait a few minutes for the PLU to completely the reboot.
	1-5	HSCB Lockout	On the third overcurrent trip of the HSCB, it will be locked out. To clear the lockout, do either a Hard Reset or use the PTU Lockout Recovery Screen as explained in the PTU Manual Section 2.15.
	1-6	Propulsion Cut-out and No Propulsion Faults Detected	If both of the propulsion system in a vehicle have been cut-out, HSCB will not be commanded to close. If both of the PLU in a vehicle have detected a fault condition, HSCB will not be commanded to close. Examine the PTU Fault / Protection screen to examine and correct any fault conditions that would prevent HSCB from closing.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
1 High Speed Circuit Breaker does not close	1-7	High Speed Circuit Breaker Control Relay HSCBCK Malfunction	The HSCBCK relay is driven from the OBA54A1 Digital Output Board. HBCC is the digital output signal from both PLU's to energize the HSCBCK allowing the HSCB to be energized closed. High is the HSCBCK commanded closed. Low is the HSCBCK open. With HSCBCK energized, HSCBCK interlocks produce the HSCB Command signal (HSCBC) to feed the HSCB Control Panel which then controls the HSCB. HSCBCK does not have a Status feedback circuit back to the PLU so the status of the relay can not be determined by monitoring signals from the PTU. From the PTU, go into Sequence Test to close the HSCB. If the HSCB does not close, examine HSCBCK to see if it is energized. As seen in diagram B3018019, the HSCBCK coil connections are connection 2 (HBCC) and 11 (100b1). If HSCBCK is not energized, replace the Digital Output board. If the HSCBCK is energized closed and the HSCB is not closed, check that B+ is at HSCBCK connection 6 (HSCBC). If connection 6 is not energized, replace HSCBCK. If connection 6 is energized, the problem is in the Control Panel.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
1 High Speed Circuit Breaker does not close	1-8	Direction Signal not Detected.	To close the HSCB, a cab must be keyed up and direction set. From the PTU Digital Monitoring screen check the the Forward Trainline and Reverse Trainline signals. If the signal status does not match the Reverser position, check the voltage level of the Forward/Reverse Trainline signal at the Propulsion Inverter.. See B519943, Propulsion Inverter Connection Diagram at Zone B1 for the signal pin assignments for the Forward and Reverse trainlines. If the voltage level is appropriate (17 to 30Vdc), replace IBA130A1 Digital Input Board 1. If the voltage is not good, check the continuity of the Forward and Reverse trainlines.
	1-9	HSCB Control Circuit Malfunction	From the PTU Digital Monitoring Screen check the *HB28* signal which is High Speed Circuit Breaker 28.5 volt control power supply status. This is the vehicle battery input to the Control Panel. If this signal is low, the control panel has not detected the vehicle battery voltage input and the HSCB will not be allowed to close. Ensure that the High Speed Circuit Breaker Control circuit breaker (in the A-cab DC Circuit Breaker Panel) controlling the vehicle battery input to the Control Panel is closed. If the HB28 signal is still not high, check the contiuity of the wire sending the signal "HB28" between HSCB Control Panel and Propulsion Inverter (including connectors and connector pins), and voltage of the vehicle battery input at the HSCB Control Panel (wire No. 38AA). Replace the wire if broken wire is found. See B3010728, HSCB Circuit Diagram for the diagram, connector and wire No. If the HB28 signal is still not high, replace the Control Panel.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
1 High Speed Circuit Breaker does not close	1-9	HSCB Control Circuit Malfunction (cont'd.)	If the HB28 signal is high, check the continuity of the HSCB closing command signal cables between Propulsion Inverter and HSCB Control Panel (wire No. 38AB and 38AC), and that between HSCB Control Panel and HSCB (wire No. 38AH and 38AJ). Replace if broken wire is found. If the HSCB still does not close, record Trace Data when setting the reverser to "Forward" or "Reverse" while all the fault detection is reset and not detected and HSCB closing command is initiated, by using "Trigger Trace Data Record" function of the Propulsion PTU. Check the signals "HSCB Command" in OUT1_H and "HSCB contact feedback signal" in INP1_H of the recorded Trace Data. If the "feedback" signal is not received even though the "Command" signal is activated, "feedback" signal is always high regardless of the "Command" signal status or more than 1 sec of time delay is observed between initiation of "Command" signal and receipt of "feedback" signal, confirm if the fasteners of the HSCB Box is firmly tightened and then replace the HSCB. Inside of the replaced HSCB should be investigated to check if the auxiliary switch is malfunctioned or abnormality such as water ingress is found. Refer to Section 7.0 Chapter 3.3.2 of the Heavy Repair Maintenance Manual for removal and assembly of the HSCB. If the HSCB still does not close, replace the HSCB Control Panel.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
1 High Speed Circuit Breaker does not close	1-10	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 15 - HSCB Power Source Abnormality. With this fault condition, Trace Data signal *OUT9_L – HSCB Power Source Abnormality* will be high. HSCB Power source (vehicle battery voltage less than 14.4 Vdc) at the control panel. Recovery at greater than 16.8 Vdc. Event # 16 - High Speed Circuit Breaker Fault Detected. With this fault condition, Trace Data signal *OUT9_H – HSCB Fault Detection* will be high. The HSCB Status signal did not match the Command signal for longer than 1 second and the Command signal was then disabled. Check PTU Trace Data signal - *OUT1_H – HSCB Command.* This signal must be high to close the HSCB. Event # 33 - Input Command Abnormality With this fault condition, check Trace Data signals *INP2_L - Forward Trainline* and *INP2_L - Reverse Trainline.* Event # 52 – HSCB Lockout With this fault condition, Trace Data signal *OUT3_L – HSCB_Lock_PLU_Status* Signal will be high.
	1-11	Theory of Operation	See RMSM Section 3.5.1 HSCB

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
2 High Speed Circuit Breaker opens immediately after closing	2-1	HSCB Command Circuit Fault	To close the HSCB, the pantograph must be up and a direction selected from the Master Controller. The command to close the HSCB is from both the A-section and B-section PLU's. If for whatever reason one of the command signals should fail, the HSCB will still be closed from the other PLU. The Close command for HSCBCK comes from OBA54A1 Digital Output Board signal HBCC. The closing of HSCBK produces the HSCBC signal to the HSCB Control Panel. HSCBCK does not have a Status feedback circuit back to the PLU. The detection of the HSCBC signal is proof that the relay is energized. With the command to close the HSCBCK active, check the HSCBCK relay to see if it is energized closed. If the HSCBCK relay is not closed, as seen in diagram B3018019, with a voltmeter check the HSCBCK relay connection 2 (HBCC) to connection 10 (100b1). If connection 2 is at 28.5 Vdc, the problem is the relay. If the Close command connection is not active, the problem is the Digital Output Board. If HSCBCK connection 6 (HSCBC) is energized, the problem is in the Control Panel. If replacing HSCB Control Panel does not resolve the issue, the problem is in the wiring. Check the continuity of the cables connecting the Propulsion Inverter/HSCB and HSCB Control Panel, and confirm that the battery voltage power is supplied to the HSCB Control Panel (line No. 38AA of the vehicle circuit).

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
2 High Speed Circuit Breaker opens immediately after closing	2-2	HSCB Status signal back to each PLU	The Status signals from the HSCB goes back to each PLU from separate Limit Switch interlocks in the HSCB. If the Status signal is not detected as closed from either PLU within 1 second of the Close command, the Close command is disabled from both PLU's and a fault is detected. Check the PTU Trace Data signal *INP1_H - HSCB Contact Status* Signal from both the A-unit inverter and the B- Unit inverter. High was that the HSCB was closed. Low indicates that the HSCB was detected as open. This fault is either from the HSCB limit switches or a failure of the HSCB Status signals back to the PLU. The HSCB Status is input to the PLU from the IBA130A1 Digital Input Board 1. From the PTU Digital Monitoring Screen, access the HSCB Status signal HSCBS. Set up the cab to command the HSCB closed. If the Status does not detect Closed, the probable cause is the HSCB Limit Switch interlocks. NOTE – The HSCB can not be operated manually to check the Limit switches and the Limit switches can not be accessed with the HSCB on the vehicle.
	2-3	Line Overcurrent Ground Fault	When Line Overcurrent (input line current more than 1600A) or Ground Fault (line current input and return do not match) is detected, HSCB will be opened. Check the propulsion high voltage circuit to find the cause. RMSM Section 6.5 explains how to check for a power circuit ground fault. If this fault condition is detected while in revenue service, the affected propulsion system must be cutout.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
2 High Speed Circuit Breaker opens immediately after closing	2-4	Line Switch Contactor or Line Charging Contactor Fault Detected.	If the LS or LCC Status signal from either PLU does not match the contactor Operation Command for longer than 1 second, a fault is detected and HSCB opens. Control and monitoring of LCC is explained in Section 4 below. Control and monitoring of LS is explained in Section 5 below.
	2-5	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 16 - HSCB Fault Detected. With this fault detected, check Trace Data signal *OUT9_H – HSCB Fault Detection*. With this signal high, the HSCB Command signal and Status signal did not match after 1 second and the Command signal was then disabled. *INP1_H - HSCB Contact Feedback Signal* This signal needs to be high from both propulsion systems.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
3 High Speed Circuit Breaker is Tripped open (HSCBT)	3-1	Overcurrent Trip at 3200 amps	The HSCB Tripped fault condition is when the HSCB is opened unexpectedly. The HSCB opens even though there is a Close HSCB Command being sent from the PLU. With a current flow of greater than 3200 amps through the HSCB, the HSCB overcurrent latch was activated and the HSCB is tripped. On the third overcurrent trip of the HSCB, it will be locked out. To determine which power circuit caused the overcurrent trip, the PTU Fault / Protection screen from the affected propulsion system will have the HSCB Tripped fault. The most likely cause of this fault is a short circuit power circuit IGBT (which will cause a HSCB Lockout). RMSM Section 6.6 explains how to check for a short circuit power circuit IGBT.
	3-2	Power Circuit Ground Fault	A ground fault detection from either propulsion system on the vehicle will cause the HSCB to open. The PTU Fault / Protection screen from the affected propulsion system will have the ground fault detected. RMSM Section 6.5 explains how to check for a power circuit ground fault.
	3-3	Input Overcurrent at 1600 amps	Input current flow greater than 1600 amps for longer than 1 second from either propulsion inverter will cause the HSCB to open. The PTU Fault / Protection screen from the affected propulsion system will have the overcurrent fault.
	3-4	Hardware Faults	Defective hardware such as the control circuit wiring or the HSCB coil, or a failure of the HSCBCK relays (or digital outputs driving the relays) can also trigger this fault.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
3 High Speed Circuit Breaker is Tripped open (HSCBT)	3-5	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 1 – Ground Fault. With this fault detected, review Section 14 Ground Fault Detection. Event # 17 HSCB Tripped Check Trace Data signals – *OUT3_H - HSCB Command* *INP1_H - HSCB Status* *OUT9_L – HSCB Tripped* *OUT10_H – Input Overcurrent* From the Analog Trace Data, examine *Line Current*. Event # 19 - Input Overcurrent. With this fault detected, check the Analog Trace Data signal *Line Current* Check Trace Data signal - *OUT10_H – Input Overcurrent* From the Analog Trace Data, examine *Line Current*. If the HSCB has Tripped and the line current did not exceed 3200 amps, the fault is in the control system and not a short circuit IGBT.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
4 Line Charging Contactor does not close	4-1	HSCB Open	Confirm that the pantograph is up and the Knife Switch is in the Normal position. Confirm that a cab has been keyed up and direction set at the Master Controller. If the HSCB does not close, try Prop / HSCB Reset on the TOD or a PLU Hard Reset if necessary. If HSCB does not close, see Section 1 above. As needed, use the PTU Sequence Test to close the HSCB and then the charging contactor.
	4-2	Direction Signal	To close the LCC, a direction must be detected from the Master Controller. This was also a requirement to close the HSCB. With the HSCB closed when a direction is selected from the Master Controller, a direction has been detected by the PLU.
	4.3	Emergency Brake Trainline	To close LCC (and LS), the Emergency Brake Trainline must be activated. The EB Trainline is activated with a cab keyed up and direction set. The EB Trainline energizes the Emergency Brake Relay (EBR) which then energizes the Emergency Brake Relay Timer. EBRT interlocks then complete a circuit from the battery return circuit to the LCC (and LS) control coils. LCC is closed for approximately 500 msec to insert a current limiting resistor as the filter capacitors are being charged. Once the capacitors are charged, LCC is opened. When the Emergency mushroom is depressed or the ATP activates Emergency Brake, the EB Trainline is disabled. EBR is then deenergized which de-energizes EBRT. EBRT is seen in diagram B3018019. The circuits and functions of EBRT are explained in RMSM Section 2.9. EBRT is a 3 second off-delay relay which will isolate the LCC and LS coil return circuits 3 seconds after the EB Trainline is disabled. From the PTU Digital Monitoring screen check the status of the EB Trainline.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
4 Line Charging Contactor does not close	4-4	Line Voltage Detection	If line voltage is not within limits, the contactor will not be commanded to close. As needed, review RMSM Section 6.2.1.3 Line Switch and Line Charging Contactor Control for the lIne voltage and filter capacator voltage limits. Line voltage is monitored by DCVD1 and input to the PLU at the MCB108B1 Inverter Control Board. Line Voltage can be examined from the PTU Analog Monitoring Screen. If LCC did not close, examine the Line Voltage from the PTU Analog Monitoring screen. If the signal is wrong (indicating too low voltage) connect the PTU to the other propulsion system on the vehicle and monitor the line voltage. If there is a difference between the two, troubleshoot as follows. Replace the Inverter Control Board first and then DCVD1 if necessary.
	4-5	Propulsion Cut-out and No Propulsion Faults Detected	If the propulsion system has been cut-out, LCC will not be commanded to close. If the PLU has detected a fault condition, LCC will not be commanded to close. Examine the PTU Fault / Protection screen to examine and correct any fault conditions that would prevent LCC from closing.
	4-6	Line Charging Contactor Malfunction	LCC is driven from the PLU OBA54A1 Digital Output board from signal LCCC. LCC Status is monitored from the PLU IBA130A1 Digital Input Board 1 from the signal LCC. The Line Charging Contactor has a normally closed interlock that feeds the LCC Status signal back to the PLU. When the contactor is open, the Status signal is high. When the contactor is closed, the Status signal is low.

Table 6-2. Troubleshooting (cont'd.)

4 Line Charging Contactor does not close	4-6	Line Charging Contactor Malfunction (continued)	Use the PTU Sequence Test to cycle the charging contactor. If the contactor did not momentairly close, the problem is either the Digital Output Board or the contactor. If the contactor did momentarly close, check the PTU Digital Monitoring Screen signal LCC Status to see that the signal changed state as the contactor closed. If the status signal did not change state, the problem is either the Digital Input Board 1 or the LCC auxiliary contacts. The low voltage circuits for LCC can be seen in diagram B3018033. As needed, use the PTU Sequence Test to operate the Line Charging Contactor.
	4-7	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 1 – Ground Fault With this fault detected, review Section 14 Ground Fault Detection. Event # 21 - LCC Fault Detected With this fault detected, check PTU Trace Data signal *OUT9_L LCC Fault Detection* is high. The feedback signal did not match the command signal after 1 second and the Command signal was then disabled. Check PTU Trace Data signal *OUT1_H – LCC Command.* This signal must be high to energize LCC. Check PTU Trace Data signal *INP1_H – LCC Contact Feedback Signal* This signal will be high with LCC closed. Check PTU Trace Data signal *INP3_H – EB Trainline*. If this signal was high, the EB Trainline was energized. Check PTU Trace Data signal *OUT8H – Line Low Voltage*. If this signal was high, the line voltage was detected to be out of limits low.
	4-8	Theory of Operation	See RMSM Section 3.5.2 3.5.2 Line Charging Contactor Control and Monitoring

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
5 Line Switch Contactor does not close	5-1	Overview	With the HSCB closed and the Line Charging Contactor operational (to charge the filter capacitors), the next step is to energize the Line Switch contactor. This section presumes that the HSCB is closed and LCC is operational.
	5-2	Prerequites	To energize the Line Switch contactor, the following conditions must already be true (to close the HSCB and LCC) and will not be explained again in this section: The pantograph is raised and line voltage is within limits. Cab keyed up and direction set. HSCB is closed. Emergency Brake Trainline is energized. Slide Control Emergency Brake Trainline is energized. Emergency Brake Relay (EBR) energized. Emergency Brake Relay Timer (EBRT) energized. The Line Charging Contactor has operated. No propulsion faults detected. Propulsion inverter not cut-out Emergency mushroom is not depressed
	5-3	Filter Capacator Voltage Detection	The operation of LCC (Section 4) has charged the filter capacitors. If the detected filter capacitor voltage is not within limits, the LS contactor will not be commanded to close. Capacitor voltage is monitored by DCVD2 and input to the PLU at the MCB108B1 Inverter Control Board. If LS did not close, examine the Filter Capacitor Voltage from the PTU Analog Monitoring screen. If the filter capacitor voltage is not the same as the Line Voltage, replace the Inverter Control Board first and then DCVD2 if necessary.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
5 Line Switch Contactor does not close	5-4	Line Switch Relay (LSR) Malfunction	The Line Switch Relay controls the feed to the Line Switch contactor coil. LSR is driven from the OBA54A1 Digital Output Board. EBRT interlocks are used in the 0 volt return circuit for the LS (and LCC) coil. The LSR has no feedback circuit back to the PLU. The closing of the Line Switch contactor is proof that LSR is closed. When the Emergency mushroom is depressed or the ATP activates Emergency Brake, the EB Trainline is disabled which is monitored by the PLU and de-energizes the Line Switch Command signal. With this condition, LSR is disabled which opens the Line Switch contactor. EBRT is a 3 second off-delay relay which will isolate the LS coil return circuits 3 seconds after the EB Trainline is disabled. The feed to the LSR coil can be checked from the relay connections A1 (LRSC) and A2 (LSR1) as seen in diagram B3018019 at LSR. As needed, use the PTU Sequence Test to operate the Line Switch Contactor.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
5 Line Switch Contactor does not close	5-5	Line Switch Contactor Malfunction	If LSR is closed and the LS contactor did not close, the feed to the LS contactor coil can be checked from the LSR interlocks from connections 1/L1 (20) to 6/T3 (L2) as seen in diagram B3018019 at LSR. The two interlocks are connected in series. The feed is wire 20 (B+) through both L1 connections to L2 which feeds the LS contactor. When the Line Switch contactor closes, auxiliary interlocks send a Status signal back to the PLU IBA130A1 Digital Input Board 1. From the PTU Digital Monitoring screen, check the LS Contactor Status signal. If the LS contactor did close, but the contactor Status signal from the PTU still says Open, the fault is either the LS contactor auxiliary interlocks or the Digital Input Board 1. The low voltage circuits for LS can be seen in diagram B3018033. As needed, use the PTU Sequence Test to operate the Line Switch Contactor.
	5-6	PTU Logged Event	See the PTU Manual Section 2.10 Description of Logged Events – Event # 23 – Line Switch Contactor Fault Detected. Check PTU Trace Data signal *OUT9_L – LS Fault Detection*. If this signal is high, it means that the Command signal and Status signal were not in the same state after 1 second and the Command signal was then disabled. Check PTU Trace Data signal *OUT1_H – LS Command.* This signal must be high to close LS. Check PTU Trace Data signal *INP1_H – LS Contact Feedback Signal* This signal will be high with LS closed.
	5-7	Theory of Operation	See RMSM Section 3.5.3 Line Switch Contactor Control and Monitoring

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
6 Inverter Gate Driver Fault or Power Supply Fault	6-1	Power Supply Unit Malfunction	The Gate Driver circuit boards are powered from the 38 Vac from the Power Supply Unit. If the voltage falls to 29.2 Vac, a voltage source fault is detected.
	6-2	Gate Driver Malfunction	A gate driver fault will disable the inverter. This fault is detected when the Firing signal disagrees with the gate driver Feedback signal. Cut out the propulsion system that does not have the fault and attempt to move the vehicle under power from only the suspect inverter. If the vehicle moves, there is no problem. If the vehicle does not move, check the PTU events to see if one of the gate driver phase circuits failed. Reboot the PLU by cycling control power Off and On. Run the PTU Sequence Test to operate the three-phase gate drivers.
	6-3	PTU Loggged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 6 – Inverter Gate Fault Check Trace Data signal *OUT7_H - Gate Driver Source Fault*. If this signal was high,the fault was detected. Check the PTU Trace Data signal *OUT2_H – Gate Firing Command* Check PTU Trace Data signals - *INP4_L - U-phase IGBT Gate mismatch* *INP4_L - V-phase IGBT Gate mismatch* *INP4_L - W-phase IGBT Gate mismatch* Event # 7 –Bch Gate Fault *INP4_L – Brake Chopper Gate mismatch* Event # 14 - Gate Power Source Low Voltage. Check Trace Data signal - *OUT7_H - Gate Voltage Source Fault*. If this signal was high, the fault was detected. Check Trace Data signal - *INP12_H - Gate Control Circuit Power Supply Status*

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
7 Inverter Output Overcurrent (MMOCD1, MMOCD2)	7-1	Cause Estimation	Check the logged power truck speed and center truck speed. If the logged power truck speed value is significantly different from center truck speed, the speed sensors could be causing this condition. From the PTU Analog Monitoring screen check the Line Voltage and the inverter output currents. Reset the propulsion by setting the master controller to FSB position and press "Prop Reset" button on the TOD, then move the vehicle a short distance under power. If no problems are detected, the propulsion inverter is OK.
	7-2	Current Transducer Malfunction	Open the PTU to the Test Screen and then to the Detector Test Screen and see if any of the current transducers have a static output signal offset. Cut out the propulsion system that is not being tested. Access the PTU Analog Monitoring screen. View all current transducer signals. Move the car under power and check the inverter output current flow. The current transducers are monitored by the PLU from the MCB108B1 Inverter Control Board.
	7-3	Speed Sensor Malfunction	The speed sensors are powered by and monitored from the IFB138B1 Speed Signal Processing Board. If one speed sensor output signal is significantly different from the others, replace the circuit board first. Move the car under power and access the PTU Analog Monitoring screen. View speed sensor signals and replace the speed sensor which reads the lower speed if the speed values are significantly (about 25% or more) different.
	7-4	Power Circuit Ground Fault	Depending on the location of a ground, the ground fault could cause an output overcurrent condition. Using RMSM Section 6.5, check the power circuit for grounds.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
7 Inverter Output Overcurrent (MMOCD1, MMOCD2)	7-5	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 1 – Ground Fault With this fault detected, review Section 14 Ground Fault Detection. Event # 26 – Output Overcurrent Check Trace Data signal *OUT8_L Output Overcurrent* If this signal is high, the overcurrent condition was detected. Check PTU Trace Data signals *INP4_H – U-phase Overcurrent Detected* *V-phase Overcurrent Detected* *W-phase Overcurrent Detected* If any of the signals are high, the overcurrent condition was detected at the noted phase. From Trace Data *INP8_H*, examine the Status of all of the noted speed sensors. From the Analog Trace Data signals, examine all of the noted Wheel Speeds. Check the PTU Analog Monitoring screen Tach 1 for the A-Unit and Tach 10 for the B-Unit and center truck (Axle 3) speed signals as seen in Trace Data grouping INP8_H. Event # 27 – Frequent Output Overcurrent Check PTU Trace Data signal *OUT7_L - Frequent Motor Overcurrent*. If this signal is high, the overcurrent condition was detected 3 times since the last time the Reverser was thrown. Use the Event Recorder to check signal "Towing Mode TL" to see if the vehicle was operating in tow mode.
	7-6	Theory of Operation	See RMSM Section 3.2.4.7 Inverter Output Overcurrent

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
8 Inverter Output Phase Current Inbalance (PUD)	8-1	Overview	An imbalance of greater than 300 amps has been detected between the inverter output current transducers. The current transducers are monitored from the MCB108B1 Inverter Control Board.
	8-2	Inverter Output Current Transducer Malfunction	From the PTU Test Screen and then to the Detector Test screen, check for static output signal offsets. Move the vehicle under power and examine the motor phase current output signals from the Analog Monitoring screen.
	8-3	Traction Motor Ground Fault	A internal ground in a traction motor could also be detected as a phase current inbalance. Check for a propulsion system ground as explained tn RMSM Section 6.5. If a ground is detected, drop the Truck Quick Disconnect and check the ground again. If there is no longer a ground in the power circuit, from the motor side of the quick disconnect, check the resistance to ground of each of the 3 phases of both motors.
	8-4	PTU Logged Event	See the PTU Manual Section 2.10 Description of Logged Events – Event # 34 – Phase Current Imbalance. Check PTU Trace Data signal *OUT7_L - Phase Current Imbalance.* If this signal is high, the imbalance condition was detected. Check PTU Trace Data signal - *OUT8_H – Propulsion Ground Fault* With this fault detected, review Section 14 Ground Fault Detection.
	8-5	Theory of Operation	See RMSM Section 3.2.4.4 Phase Current Imbalance

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
9 Battery Voltage Control Power	9-1	Battery Voltage Low	Check the amplitude of the vehicle battery / LVPS voltage supply. Check the circuit breaker for the battery voltage supply as well.
	9-2	Low Voltage Circuit Ground Fault	If one of the inverter control circuits went to ground (or possibly short circuit), that would cause the tripping of a control circuit breaker.
	9-3	PTU Logged Event	See the PTU Manual Section 2.10 Description of Logged Events – Event # 35 - Control Circuit Power Low Voltage. Check Trace Data signal - *INP12_H - DC 28.5 volt power supply status*.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
10 Inverter Unit Cooling and Temperature Detection Inverter Unit Cooling	10-1	Starting Conditions	To start the Inverter Unit cooling fans, the vehicle 208 Vac APS output must be active, the circuit breaker for cooling fans are closed and a cab keyed up and direction set.
	10-2	Cooling air flow restriction	Clean the air mesh filter and the Inverter Unit heatsink fins. See Section 4.5.2-1
	10-3	Inverter Unit Overtemperature	The Inverter Unit is cooled by four fans powered from the vehicle 208 Vac supply. If one (or more) of the fans fail, the propulsion system will not be shut down. With a reduction of cooling air flow, this fault could cause the Inverter Unit temperature to rise and to possibly detect an overtemperature condition. High passenger load weight or Tow Mode over an extended period of time can cause the Inverter Unit temperature to rise. Use the Event Recorder to check signal "Towing Mode TL" to see if the vehicle was operasting in tow mode. The temperature of the IGBT's is monitored by three analog temperature sensors (thermistors) located in the Inverter Unit. The thermistors are powered from the PLU Power Supply Board AVR39B1 and monitored by the Inverter System Control Board MCB107B1. With a temperature of 76 degrees C (169 degrees F) from any of the temperature sensors, the propulsion system disables dynamic braking (Warm). With a temperature of 80 degrees C (176 degrees F) from any of the temperature sensors, the propulsion system is disabled (Hot) and the Line Switch contactor is opened.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
10 Inverter Unit Cooling and Temperature Detection	10-4	Fan Motor Relay FM1R Malfunction	If all the 4 fans are failed simultaneously, check to see if the Fan Motor Relay FM1R is energized. FM1R is energized from OBA54A1 Digital Output board. **WARNING** **THERE IS 208 VAC ON THE FM1R RELAY INTERLOCKS AND THE 208VDK RELAY COIL TERMINALS.** Check to see if the 208VDK relay is energized closed. As seen in diagram B3018019, check to see if 208 Vac is on the 208VDK relay coil (connections 13 and 14). When energized, the 208VDK relay interlocks input the AC 208V Detection signal (208VD) to the IBA130A2 Digital Input Board 2. If the AC 208V Detection signal is not detected, the Fan Motor Relay FM1R will not be commanded to close. If the 208 Vac is not detected on the FM1R interlocks, check to see if relay 208VDK is energized. The 208VDK relay coil is energized from one phase of the vehicle APS 3-phase supply. Check that the 208VDK interlock 9 (208VD) is at B+.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
10 Inverter Unit Cooling and Temperature Detection	10-4	Fan Motor Relay FM1R Malfunction (continued)	If the 208VDK relay is closed and all of the 3-phase voltages are not at the FM1R output side interlocks, the 208VDK relay is defective. If the 208 volt supply is on the 208VDK relay coil and the relay is not closed, relay 208VDK is defective. As needed, as seen on diagram B3018019, check the feed to FM1R relay coil from connections A1 (FM1RC) and A2 (100b1). If the FM1R relay still does not close, replace the relay. If the relay is energized closed and the fans are still not running, check that the voltage is on the load side of the FM1R relay interlocks. **WARNING** **THERE IS 208 VAC ON THE FM1R RELAY INTERLOCKS AND THE 208VDK RELAY COIL TERMINALS.**
	10-5	Inverter Unit Cooling Fan Malfunction	Each fan has a relay controlled by the fan speed. When the fan speed is at 3250 RPM, the relay is energized and B+ feeds into the PLU IBA130A Digital Input 1 board (normal condition). When the fan speed falls to 2000 RPM, the relay is deenergized and 0 volts feeds the PLU input (fan fault). As needed, raise the pantograph and set a direction from the Master Controller. Visually check that all of the fans are running. Replace any malfunctioned fan.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
10 Inverter Unit Cooling and Temperature Detection	10-6	Inverter Unit Thermister Failure	There are 3 thermistors monitoring the temperature of the plate containing the IGBT's. Each thermistor's resistance changes depending on the temperature of the plate changing the input signal to the PLU. The thermistors are powered from the 12 Vdc supply on the PLU Power Supply Board AVR39B1 and monitored by the Inverter System Control Board MCB107B1. With a detection of less than -20 degrees C from any of the temperature sensors, that temperature sensor is declared failed and the affected inverter is shut down. Check the thermister output signals from the PTU Monitoring screen Analog signals - *TH1*, *TH2* and *TH3.* With this failure, replace the Inverter System Control Board. If needed, qualify the resistance from each thermistor (THB, THVW and THUV) using the Inverter Unit Wiring List Document B446295 or Connection Diagram 3018043.
	10-7	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 40 - IGBT Temperature Rising Check Trace Data *OUT9_L IGBT Temp Rising* Check the following Analog Trace Signals *Heatsink Temperature (Phase UV)* *Heatsink Temperature (Phase VW)* Event # 41 - IGBT Overheat Protection (Inverter) Check the following Analog Trace Signals *Heatsink Temperature (Phase UV)* *Heatsink Temperature (Phase VW)* Check Trace Data signal *OUT7_H - IGBT Overheat Protection* If this signal is high, an overtemp condition was detected.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
10 Inverter Unit Cooling and Temperature Detection	10-7	PTU Logged Events (continued)	Event #41 – IGBT Overheat Protection Inverter Check PTU Analog Trace Data signals - *Heatsink Temperature Phase U/V* *Heatsink Temperature Phase V/W* Event # 42 – Thermistor Failure Check PTU Trace Data signals *OUT9_H Thermistor Fault Inverter* or *OUT9_H Thermistor Fault (Bch).* If either of these signals are high, the thermister has failed. Event # 50 – Fan Motor Speed Fault Check PTU Trace Data signals *INP2_L Fan Status Signals No.1 FAN to No. 4 FAN* Any one that was low indicates that the fan has malfunctioned. Check PTU Trace Data signal *OUT1_H - Fan Contactor command*. If this signal was low, FM1R was not commanded to close and none of the fans were running. Check PTU Trace Data signals *INP2_L - No. 1 FAN Status signal* to *No.4 FAN Status Signal*. If all the status signals were at low, the FM1R relay did not close. Event # 56 - IGBT Overheat Protection (BCH) Check the Digital Trace Signal – *OUT9_L – IGBT Overtemperature Protection BCH* Event # 58 - AC Fan Power Supply Fault. Check PTU Trace Data signal - *INP3_L - AC208V condition signal.* This signal must be active to allow FM1R to be energized Check PTU Trace Data signal - *OUT6_H – AC Fan Power Supply Fault.* If this signal is high, the vehicle 208 Vac supply was not detected.
	10-8	Theory of Operation	See RMSM Section 3.8.1 Propulsion Equipment Case Cooling and Temperature Detection

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
11 Filter Capacitor Charging Failure	11-1	Filter Capacitor Charging Failure	The calculation of the value of the filter capacitors is done as the capacitors are being charged from 0 volts with the Line Switch contactor open and the Line Charging Contactor closed. The line current and line voltage are monitored for the charging time of the capacitors. The calculated value of the capacitors is done on the MCB108B1 Inverter Control Board. All of the power circuit signals used in this calculation are input to the MCB108B1 Inverter Control Board. This fault can be caused by offsets in current transducer or voltage detector output signals. Go to the PTU Test Screen and to the Detector Test Screen to check for offsets. If offsets are detected, replace the Inverter Control Board. If that did not clear the offset, the problem is with the current transducer or voltage detector. If the value of the Charging Resistor (CHR) is out of limits, it can cause this fault. If this fault condition is detected while in revenue service, the affected propulsion system must be cutout. Test the filter capacitors using the Power Bench Test Unit or a DMM. Replace the capacitor if value is less than 9,450 µF for an individual capacitor. (10,500 µF minus10%)
	11-2	Capacitor Voltage Reading Incorrectly	Filter capacitor voltage is monitored from DCVD2 which feeds into the PLU at MCB108B1 Inverter Control Board. Replace MCB108B1 first. If the reading is still wrong, replace DCVD2.
	11-3	Discharging Resistor (DCHR) Breakdown	Check the resistance of each of the four DCHR resistors which should be 1250 ohms ±10% each.
	11-4	Charging Resistor (CHR) Breakdown	Check the resistance of the CHR which should be 4.3 ohms ±10%.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
11 Filter Capacitor Charging Failure	11-5	Power Circuit Ground Fault	RMSM Section 6.5 explains how to check for a power circuit ground fault.
	11-6	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 1 – Ground Fault With this fault detected, review Section 14 Ground Fault Detection. Event # 2 - Filter Capacitor Capacitance Fault With this fault detected, go into the PTU to the Test Screen and select Capacator Test. Then examine Analog Trace Data signal - *Calculated Capacitance (PTU Test)* Examine Analog Trace Data signals - *Line Current and Line Voltage*.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
12 PLU Watch Dog Failure	12-1	PLU Malfunction	Each board with a CPU has a Watchdog function with an associated LED. If a single Watchdog LED is not blinking, do a Hard Reset of the PLU. If the LED is still not blinking, replace the circuit board. If none of the Watchdog LED's are blinking, it is an indication of a failure of the 5 Vdc output from the PLU Power Supply Board AVR39B1.
	12-2	PTU Logged Event	See the PTU Manual Section 2.10 Description of Logged Events – Event # 45 – Watchdog Fault. Check PTU Trace Data signal - *OUT7_H – Watch Dog Fault*. The signal will be high if there is a CPU watchdog fault from one or more of the CPU's. Check PTU Trace Data signals – *INP4_L – Control CPU Fault Remote CPU Fault* *System CPU Fault*

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
13 Operation Command Failure	13-1	FWD / REV Command Discrepancy	If both the Forward Trainline and Reverse Trainline signals are high, check the trainline signal system. These signals are input to the PLU from IBA130A1 Digital Input Board 1.
	13-2	Powering / Braking Command Discrepancy	These command signals originate from the Master Controller. The trainlines are input to the PLU from the IBA130A2 Digital Input Board 2. PBED is input to the PLU from the IFB137B1 Serial Communications Board. See Figure 3-31 Master Controller signals and Table 6-1 Power and Brake Commands (PBED) Functions. If there is a discrepancy between the M / CM trainlines and the PBED signal, check the trainline / MVB signal system.
	13-3	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 33 - Input Command Abnormality Check PTU Trace Data signals - *INP2_L - Forward Trainline and Reverse Trainline* Check PTU Trace Data signals *OUT7_L – Direction Input Signal Mismatch* Event # 43 - Trainline and PBED Fault Check PTU Trace Data signals - *INP3_L - M Trainline* and *CM Trainline*. Check the Analog Trace Data signal *PBED Signal.*

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
14 Ground Fault Detection	14-1	Overview	A ground fault is declared with a difference between the CTL and CTG transducers of more than 50 amps for longer than 200 msec. Detected from the Inverter Control Board MCB108B1. If this fault condition is detected while in revenue service, the affected propulsion system must be cutout.
	14-2	Current Transducer Output signal Offset	Go to the PTU Test screen and then to the Detector Test screen and check for static offsets in the CT output signals from Line current and Ground current. If there is a offset beyond limits, the screen will display a red background. Replace the Inverter Control Board and recheck the offset. If the offset is still detected, the problem is with the transducer. If comparing with a clamp on ammeter, the trasnducer scaling is (+3000A/±10V)
	14-3	Current Transducer Malfunction	From the Analog Trace Data, examine *Line Current.* *Line Return Current* If the two signals are not the same amplitude at the moment the fault was detected (0 msec) either a ground fault was been detected or there is a control system fault. If it is a control system fault, the Inverter Control Board or the current transducers are the cause. See section 14-6 for more details.
	14-4	Power Circuit Ground Fault Check	RMSM Section 6.5 explains how to check for a power circuit ground fault.
	14-5	PTU Logged Event	See the PTU Manual Section 2.10 Description of Logged Events – Event # 1 – Propulsion Ground Fault. With this fault detected, examine Trace Data signal *OUT8_H - Propulsion Ground Fault.* With this signal high, the fault was detected.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
14 Ground Fault Detection	14-6	Power Circuit Ground or Control System Malfunction	With a ground fault detection, what needs to be determined is if there is a ground in the power circuit of possibly an error from the monitoring of the current transducer output signals. From the Analog Trace Data, examine these signals *Filter Capacator Voltage* *Line Current* *Line Return Current* Use the scroll bar at the bottom of the Analog Trace screen to view the exact value of each signal at the moment the fault was detected (0 msec). With a ground in the power circuit, there will be a difference of 50 amps between the line current and return curent and at the same moment there will be a ring on the filter capacator voltage. A voltage ring is an oscellation in the amplitude of the voltage caused by a sudden current surge. With a difference of 50 amps and a filter capacator voltage ring, it is a power circuit ground. With a difference of 50 amps and no voltage ring, it is possibly a control system fault from the monitoring of the current transducer signals caused the Ground Fault to be detected.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
15 Vehicle Control Communication Fault	15-1	Overview	The propulsion Gateway Unit has all of the external communications paths to the PLU except for the hardware signals at the CN connectors on the propulsion equipment case.
	15-2	Gateway Unit Malfunction	Examine the LED indicators on the front plate. The LED's are explained in RMSM Section 3.12.4. With a fault condition, cycle control power to the Gateway Unit and re-check the operation of the unit.
	15-3	PLU Interface	The Gateway Unit interfaces with the PLU Serial Communications Board IFB137B1.
	15-4	Vehicle Network System Malfunction	Check the vehicle network system documentation.
	15-5	PTU Logged Events	See the PTU Manual Section 2.10 Description of Logged Events – Event # 54 - MVB Channel 1 Fault With this fault detected, examine Trace Data signal *OUT6_H – MVB No.1 Fault* Event # 55 - MVB Channel 2 Fault. With this fault detected, examine Trace Data signal *OUT6_H – MVB No.2 Fault* The two channels are redundent. A failure of either channel will not cause an MVB communications failure. With a failure of both channels, there will be a MVB communications failure. Limp Home Mode must then be activated. With Limp Home Mode selected, the inverter operates at reduced performance with no dynamic braking and a speed limit of 35 mph. Examine Trace Data signal – *OUT6_H – MVB Fault*
	15-6	Theory of Operation	RMSM Section 3.12.4 Gateway Unit

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
16 Traction Motor Abnormal Vibration	16-1	Motor Bearing Failure	Dismount the traction motor from the truck and put it on a stable place, then rotate the motor by hands and hear the sound of motor rotation. Use a stethoscope on the bearing cover (near the shaft) and the speed sensor as necessary.  If stethoscope is not available, touch the bearing cover by the tip of a screwdriver shaft and put a ear on the other end (handle) of the screwdriver.  If there is a periodic sound (clicking noise) or a high-pitched sound, replace motor bearings.

Table 6-2. Troubleshooting (cont'd.)

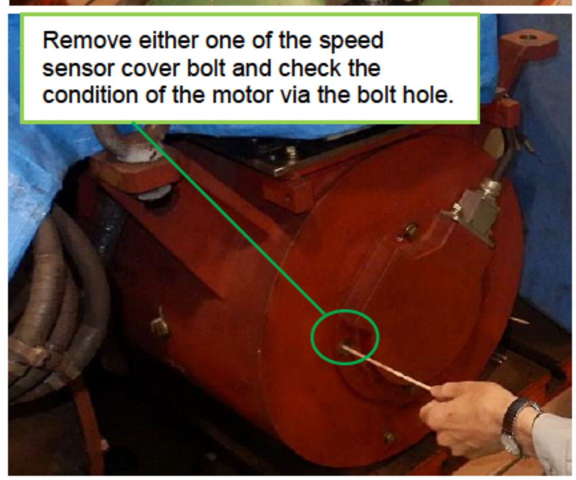
16 Traction Motor Abnormal Vibration	16-2	Accumulation of debris	Remove a bolt which fixes the speed sensor cover, then insert a fiberscope in the hole of the speed sensor cover bolt and move it close to the vent hole of the rotor and check the condition while slowly rotating the half coupling by hand. If there is debris in the hole, blow air into the hole to clean it up. If the debris is too hard to blow, poke the debris using a thin instrument (tool) and then blow air into the hole. Continue this process until the debris is removed.   Caution - When spinning the rotor, do not insert fiberscopes or instruments into the hole of the rotor. These can be broken inside the rotor and disassembly of the motor will be required to remove the broken parts.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
17 Traction Motor overheat detection	17-1	Inverter Output Overcurrent	Check the fault record and refer to Symptom 7, "Inverter Output Overcurrent (MMOCD1, MMOCD2)" if Inverter Output Overcurrent (MMOCD1 or MMOCD2) is detected.
	17-2	Overload	Overheat may be detected due to temporary overload condition. Bump the vehicle in the yard and no further corrective works are needed if no fault is detected.

Table 6-2. Troubleshooting (cont'd.)

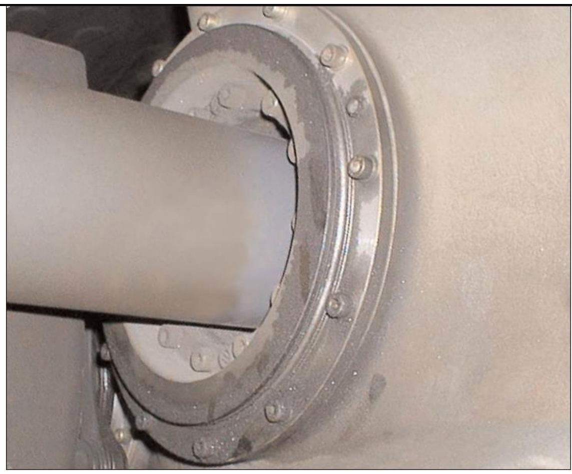
Symptom	Step	Cause	Theory / Checks / Remedy
18 Oil leaks on gear box	18-1	Dry oil dust	 Slight leakage of oil condensate mixed with brake dust and other dust, not shiny. This state is referred to as "oil-tight" and no remedy action is required.
	18-2	Dusty moist gearbox housing	 Leakage of oil condensate mixed with brake dust and other dust, not shiny. This state is referred to as "oil-tight" and no remedy action is required.

Table 6-2. Troubleshooting (cont'd.)

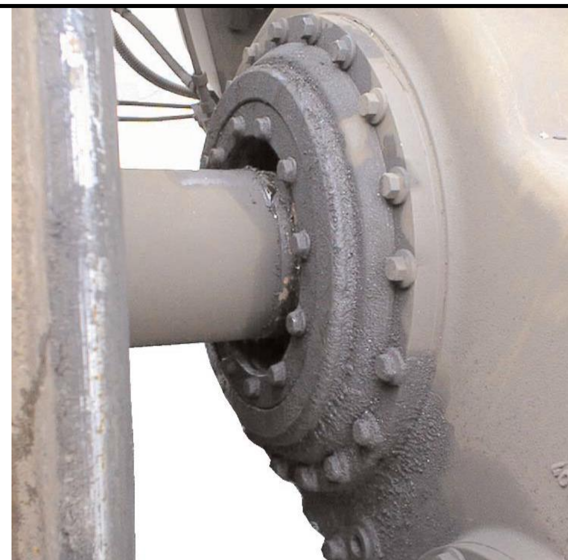
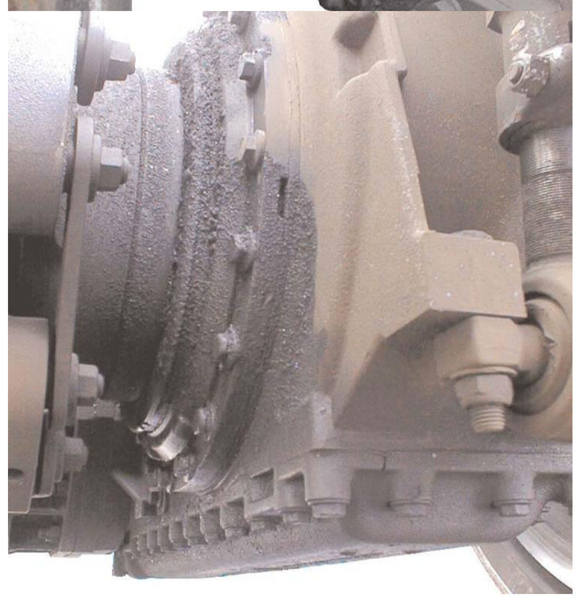
18 Oil leaks on gear box	18-3	Moist oil/dust mixture	  Heavier leakage of oil condensate from the labyrinth seal, mixed with brake dust and other dust, matt shine. This state may still be classified as ”oil-tight”. The oil/dust mixture should be cleaned with a suitable detergent. Visually inspect the cleaned area again after several operating hours. No steam jets may be used in the area of the labyrinth seal.

Table 6-2. Troubleshooting (cont'd.)

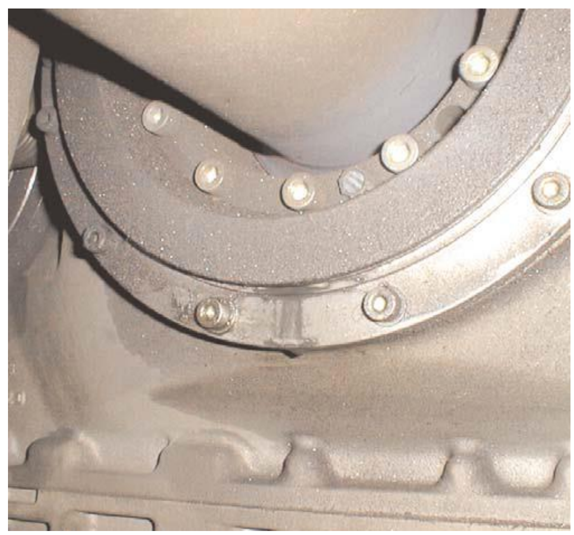
18 Oil leaks on gear box	18-4	Droplet formation/Labyrinth seal	Heavy oil leakage from the labyrinth seal with droplet formation. Following symptoms are observed; - Oil spray no longer completely dust-bound, some shiny zones.   - Oil carried to gearbox housing and to locomotive/vehicle case. This gearbox is not oil-tight. Check the transmission housing and add-on components for points of impact, cracks and damage. Replace damaged transmission and damaged add-on components.

Table 6-2. Troubleshooting (cont'd.)

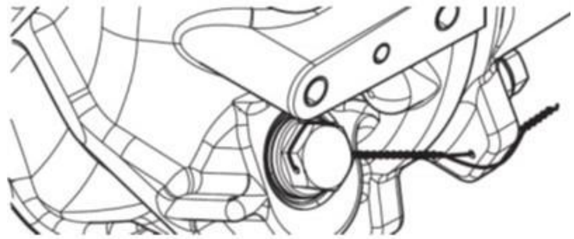
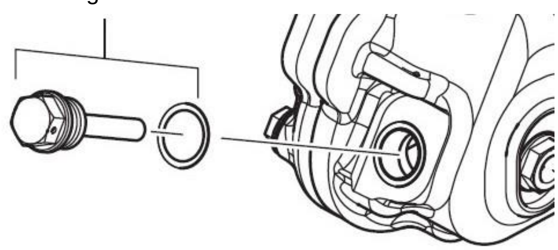
Symptom	Step	Cause	Theory / Checks / Remedy
19 Oil contamination in gear box	19-1	Water in oil	 Check for water at the Drail Plug. If water is present, check the tightness of the oil Filler Plug. Drain and refill oil.  If water is present at the next scheduled inspection,, replace the damaged transmission.
	19-2	Metal particals in oil	 The figure shows Filler plugs with metallic abrasive matter at the magnet as can be found during the run-in period before the second oil change. Afterward, the amount of abrasion should decrease. Fine, dust-like abrasive matter or abrasive sludge is harmless. If rough metal particles are found on the magnet and these are easy to feel, replace the damaged transmission.

Table 6-2. Troubleshooting (cont'd.)

Symptom	Step	Cause	Theory / Checks / Remedy
20 Coupling leaking grease	20-1	Grease leaking at coupling	 Replace damaged coupling.

CHAPTER 7.0

EQUIPMENT PAINT

7.1 Traction Motor

Primer (first): RUSTITE NC70 (Alkyd Resin Primer, Lead and Chromate Free) applied to castings prior to shipment from Toyo Denki Japan.

Primer (second): PPG/EPX-900 (Lead and Chromate Free Fast Dry Epoxy Primer) applied by traction motor assembler to traction motor parts including castings and suspension bracket.

Top Coat: PPG/AUE_400LG (Low Gloss Low VOC UROTEC Polyurethane Enamel) by traction motor assembler.

Color: RAL 7012 - Gray (P/N 49/71180) – Polyester DuPont charcoal gray, Color No. 6334 or equivalent.

Gloss: Low Gloss

NOTE: After repairs are performed, either PPG/EPX-900 or RUSTITE NC70 primer may be used before applying top coat.

7.2 Gear Unit

Primer: PPG/EPX-900 (Lead and Chromate Free Fast Dry Epoxy Primer)

Top Coat: PPG/AUE_400LG (Low Gloss Low VOC UROTEC Polyurethane Enamel) Color: RAL 7012 - Gray (P/N 49/71180) – Polyester

Equivalent to Sherwin Williams charcoal gray #SW50575

Gloss: Low Gloss.

7.3 Propulsion Inverter - INTERIOR

Powder Coat: Tiger Drylac Series 49

Color: RAL 9016 - White (P/N 49/11340) - Polyester

Gloss: 80 - 90%

7.4 Propulsion Inverter - EXTERIOR

Powder Coat: Tiger Drylac Series 49

Color: DuPont charcoal gray, Color No. 6334 or equivalent

Gloss: 80 - 90%

7.5 Line Reactor

Powder Coat: Tiger Drylac Series 49

Color: DuPont charcoal gray, Color No. 6334 or equivalent

Gloss: 80 - 90%

7.6 Knife Switch Mounting Brackets

Powder Coat: Tiger Drylac Series 49

Color: DuPont charcoal gray, Color No. 6334 or equivalent

7.7 HSCB Control Panel

Powder Coat: Tiger Drylac Series 49

Color: RAL 9005 Black (P/N 49/80350) - Polyester

Gloss: 20 - 25%

7.8 Liquid Paint Application

a. Preparation

The surfaces to be painted shall be grit blasted to remove any rust or scale in accordance with ASTM D 2200 (Method B) using a fine (100/170) grit. Blasting shall be done in a separate area from application of paint. The grit blasting shall be done when the relative humidity is 85% or less in the blasting area.

Upon completion of the grit blasting, the grit blasted areas shall be thoroughly cleaned, using Xylene cleaning solvent, to remove any oil, grease, and/or dirt. The entire surface shall then be wiped down with a lint free solvent resistant tack cloth.

b. Primer Application

Within three hours after the surface has been cleaned and tacked, one (1) coat of primer shall be applied in accordance to the manufacturer's recommendations. Mixing, thinning, pot life, pressure settings, and volume delivery settings, where applicable, shall be set to the manufacturer's recommendations. One coat consists of two wet on wet applications applied crosswise at 5 to 30 minute intervals. The primer shall be allowed to dry in accordance to the manufacturer's recommendations, at least 1 but less than 96 hours.

After drying, the surface shall be inspected to ensure complete coverage. Areas not properly covered shall be cleaned, tacked, re-coated and allowed to dry prior to application of the top coat.

c. Top Coating Application

One (1) coat of paint shall be applied in accordance to the manufacturer's recommendations. Mixing, thinning, pot life, pressure settings, and volume delivery settings, where applicable, shall be set to the manufacturer's recommendations. One coat consists of two wet on wet applications applied crosswise at 5 to 30 minute intervals. The top coat shall be allowed to dry in accordance to the manufacturer's recommendations, 1 hour before touching, 3 hours before handling, 24 hours to dry and 7 days for full cure strength.

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CHAPTER 8.0

CONNECTION DRAWINGS, WIRING DIAGRAMS and WIRE LISTS

8.1 Introduction

The following tables, connection drawings and wiring diagrams contained in this section are displayed to help the reader understand system operation and troubleshooting.

8.2 Definitions, Acronyms and Abbreviations

The following abbreviations and definitions are applicable to the signal titles found in the various connection drawings and wiring diagrams found in this chapter.

Abbreviation	Definition
ATPBP	Automatic Train Control By-Pass
AT11	Chart Recorder Output Channel 1
AT21	Chart Recorder Output Channel 2
AT31	Chart Recorder Output Channel 3
AT41	Chart Recorder Output Channel 4
AT51	Chart Recorder Output Channel 5
AT61	Chart Recorder Output Channel 6
AT71	Chart Recorder Output Channel 7
AT81	Chart Recorder Output Channel 8
BATIN	Power Supply Unit PWCN2 Pin A5
BATOK	Power Supply Unit PWCN2 Pin B5
Bch	Brake Chopper
BchFI	Brake Chopper Internal Signal
BchFO	Brake Chopper Internal Signal
BchFS	Brake Chopper Internal Signal
BchS	Brake Chopper Internal signal
CBTF1	HSCB Lockout Command from A inverter
CBTF2	HSCB Lockout Command from B inverter
CBTFX	This is used to designate CBTF1 or CBTF2. Both signals use the same pin on CN5, Pin “n”.
CCN	Control CPU Circuit Board
CM	CM Trainline Input to the Propulsion Logic Unit
CTB	Brake Current Transducer

Abbreviation	Definition
CTBN	Brake Current Transducer Neutral
CTG	Current Transducer Ground
CTGN	Current Transducer Ground Neutral
CTL	Current Transducer Line Output Signal
CTLN	Current Transducer Line Neutral
CTU	Current Transducer Inverter Output U-phase
CTUN	Current Transducer U-phase Neutral
CTU2	Reverse Connection Current Transducer
CTV	Current Transducer Inverter Output V-phase
CTVN	Current Transducer Inverter Output V-phase neutral
CTW	Current Transducer Inverter Output W-phase
CTWN	Current Transducer Inverter Output W-phase neutral
DCVD1	Line Voltage detector Direct Current Voltage Detector
DCVD2	Filter Capacitor Voltage detector
DICN1	Digital Input Circuit Board 1
DICN2	Digital Input Circuit Board 2
DOCN1	Digital Output Circuit Board
EB	Emergency Brake Relay
EBG	Emergency Brake Relay Ground (return)
EBRS	Emergency Brake Relay Start
EBRT	Emergency Brake Relay Timer
ETH	Ethernet
EX15UG	DC 15V Ground, Phase U
EX15UP	DC 15V Power Supply, Phase U
FAN1F	Fan 1 Fault
FAN2F	Fan 2 Fault
FAN3F	Fan 3 Fault
FAN4F	Fan 4 Fault
FBREL	Friction Brake Release
FM1C	Inverter Fan Motor Relay Command
FM1R	Inverter Fan Motor Relay
FM1RC	Digital Output Command to Energize FM1R
FWD	Forward Trainline

Abbreviation	**Definition**
GAFG1	Power Supply Unit PWCN2 Pin A6
GAFG2	Power Supply Unit PWCN2 Pin B6
GAOK	Power Supply Unit PWCN2 Pin B4
GU	38 Vac from the PSU to the Gate Driver Boards
GV	38 Vac from the PSU to the Gate Driver Boards
GW	38 Vac from the PSU to the Gate Driver Boards
G12D	Speed Circuit Boat, Connector PCN, Pin 15
HB28	HSCB Control Power Supply Status
HB24A	24 Vdc supply to HSCB Control Panel A Section
HB24B	24 Vdc supply to HSCB Control Panel B Section
HBCC	Energize HSCBCK control relay for High Speed Circuit Breaker
HSCBCK	High Speed Circuit Breaker Command Relay
HSCBS	High Speed Circuit Breaker Status
IDIN	Truck ID input (A-unit) to the Propulsion Logic Unit
IDIN2	Truck ID input (B-unit) to the Propulsion Logic Unit
LCC	Line Charging Contactor
LCCC	Line Charging Contactor Command
LS	Line Switch
LSR	Line Switch Relay
LSRC	Line Switch Relay Command
M	M Trainline
MCKSR	Master Controller Key Switch Relay
M15G	-15 Vdc to CTG
M15L	-15 Vdc to CTL
M15U	-15 Vdc to CTU
M15U2	-15 Vdc to CTU2
M15V	-15 Vdc to CTV
M15W	-15 Vdc to CTW
NMRS	No Motion Relay Status
MN11S	S = Cable Shield
NA1	Ground
NA4	Ground
NAT1	Chart Recorder Output Channel 1 return
NAT2	Chart Recorder Output Channel 2 return
NAT3	Chart Recorder Output Channel 3 return

Abbreviation	Definition
NAT4	Chart Recorder Output Channel 4 return
NAT5	Chart Recorder Output Channel 5 return
NAT6	Chart Recorder Output Channel 6 return
NAT7	Chart Recorder Output Channel 7 return
NAT8	Chart Recorder Output Channel 8 return
NB1	Ground
NMRC	Digital Output No Motion Relay Command
NMRK	No Motion Relay
MN311	Gateway Unit RS485 Signal
MN321	Gateway Unit RS485 Signal
MN331	Gateway Unit RS485 Signal
NM3S1	S1 = Cable Shield
MVB1	Multi-Functional Vehicle Bus Channel 1
MVB2	Multi-Functional Vehicle Bus Channel 2
MN12	Gateway Unit MVB1 Signal
MN12S	S = Cable Shield
MN11	Gateway Unit MVB1 Signal
MN111	Gateway Unit RS485 Signal
MN12	Gateway Unit MVB1 Signal
MN121	Gateway Unit RS485 Signal
MN13	Gateway Unit MVB1 Signal
MN131	Gateway Unit RS485 Signal
MN14	Gateway Unit MVB1 Signal
MN21	Gateway Unit MVB2 Signal
MN22	Gateway Unit MVB2 Signal
MN23	Gateway Unit MVB2 Signal
MN24	Gateway Unit MVB2 Signal
MN31	Gateway Unit Ethernet Signal
MN311	Gateway Unit RS485 Signal
MN321	Gateway Unit RS485 Signal
MN33	Gateway Unit Ethernet Signal
MN331	Gateway Unit RS485 Signal
MN1S	Cable Shield
MN3S	Cable Shield
NA1	Speed Circuit Board, Connector PCN, Pin B1

Abbreviation	Definition
NB1	Speed Circuit Board, Connector PCN, Pin B3
NMR1	No Motion Relay
NMRO	No motion Relay Output
ODP	Odometer Pulse output
PC	Power Cut
PCN	Speed CPU Circuit Board
PCO	Propulsion Cutout
PDF	Propulsion Dynamic Fault
PIU	Propulsion Inverter Unit
PS	Pantograph Status
PWCN1	Power Supply Unit Connector 1
PWCN2	Power Supply Unit Connector 2
PWIN	Power Supply Circuit Board in PLU, Power Input Connector
PWOUT1	Power Supply Circuit Board in PLU, Power Input Connector
PWOUT2	Power Supply Circuit Board in PLU, Power Input Connector
P12D	Speed Circuit Boat, Connector PCN, Pin A4
P15B	+15 Vdc to CTB
P15G	+15 Vdc to CTG
P15L	+15 Vdc to CTL
P15U	+15 Vdc to CTU
P15U2	+15 Vdc to CTU2
P15V	+15 Vdc to CTV
P15W	+15 Vdc to CTW
P121	+12 Vdc to Thermistor THUV (cable TH11)
P122	+12 Vdc to Thermistor THVW (cable TH12)
P123	+12 Vdc to Thermistor THBch (cable TH13)
P151	+15 Vdc to DCVT1
P152	+15 Vdc to DCVT2
RCN	Remote CPU Circuit Board
REV	Reverse Trainline Input to Propulsion Logic Unit
SCN	System CPU Circuit Board
Tach4S	Tachometer 4 Cable Shield
Tach11S	Tachometer 11 Cable Shield
Tach12S	Tachometer 12 Cable Shield

Abbreviation	Definition
TH11	Inverter Unit Thermistor THUV Output
TH11S	Inverter Unit Thermistor THUV Cable Shield
TH12	Inverter Unit Thermistor THVW Output
TH12S	Inverter Unit Thermistor THVW Cable Shield
TH13	Inverter Unit Thermistor THBch Output
TH13S	Inverter Unit Thermistor THBch Cable Shield
TRBR	Track Brake
VNMRS	Critical No Motion Relay Status
SCEB	Speed Control Emergency Brake
SND	Sand Command
SRG	Speed Governor Relay
UNR	Gate Firing Signal, Phase U, Negative
UPR	Gate Firing Signal, Phase U, Positive
UPFI	Gate Firing Feedback, Input, Phase U, Positive
UPFO	Gate Firing Feedback, Output, Phase U, Positive
VSP11	Speed Sensor Signal Power Supply (TACH1/10 CH: A)
VSP4	Speed Sensor Signal Power Supply (TACH4/5)
VS4	Speed Sensor Signal, Tach 4 or 7
VS11	Speed Sensor Signal, Tach 1 or 10, Ch. A
VS12	Speed Sensor Signal, Tach 1 or 10, Ch. B
V11N	Output Return (neutral) Signal from DCVD1
V11P	Output Signal from DCVD1
V12N	Output Return (neutral) Signal from DCVD2
V12P	Output Signal from DCVD2
100b1	Vehicle Battery Return Circuit
13A	Digital Input Circuit Board 1, pin 12
13B	Digital Input Circuit Board 1, pin 51
20	Vehicle Battery Positive
208U	APS phase-U Input to the Fan Unit
208V	APS phase-V Input to the Fan Unit
208W	APS phase-W Input to the Fan Unit
208S	S = Cable Shield
208VD	Input to Propulsion Logic Confirming 208 Volt Detection
208VDK	Inverter Fan Relay
40IN	Power Supply Unit PWCN2 Pin A4

8.3 Connectors and Layout Drawings

Table 8-1. Connectors and Terminal Locations

Location	Connector
Propulsion Inverter Unit Exterior	CN1
PIU Exterior	CN2
PIU Exterior	CN3
PIU Exterior	CN4
PIU Exterior	CN5
PIU Exterior	CN6
PIU – Propulsion Logic Unit	CCN
PIU - PLU	RCN
PIU - PLU	DICN1
PIU - PLU	DICN2
PIU - PLU	PWIN
PIU - PLU	PWIOUT1
PIU - PLU	PWOUT2
PIU - PLU	SCN
PIU - PLU	DOCN1
PIU - PLU	PCN
PIU - PLU	CHART
PIU - CT UNIT 1	CTLCN
PIU - CT UNIT 1	CTGCN
PIU - CT UNIT 1	CTBCN
PIU - CT UNIT 2	CTUCN
PIU - CT UNIT 2	CTVCN
PIU - CT UNIT 2	CTWCN
PIU - CT UNIT 2	CTU2CN
PIU - POWER SUPPLY	PWCN1
PIU - POWER SUPPLY	PWCN2
PIU - GATEWAY	PWR
PIU - GATEWAY	RS485
PIU - GATEWAY	ETH-1
PIU - GATEWAY	MVB-M1
PIU - GATEWAY	MVB-M2
PIU - DCVD UNIT	DCVD1CN
PIU - DCVD UNIT	DCVD2CN
PIU - RELAY UNIT	RLCN1
PIU - RELAY UNIT	RLCN2
PIU	HOUSING 1
PIU	HOUSING 2
PIU	HOUSING 3

Location	Connector
PIU	HOUSING 4
PIU	HOUSING 5
PIU	HOUSING 6
PIU	HOUSING 7
PIU	HOUSING 8
INVERTER	INVCN1
INVERTER	INVCN2
INVERTER	INVCN3
INVERTER	INVCN4
INVERTER	INVCN5
INVERTER-FANS	FANCN1
INVERTER-FANS	FANCN2

Table 8-2. Inverter Connections

Line No.	Cable Size	Description
504	373 MCM	Main Input Cable to the Inverter Box
500A	AWG 4/0	Main Output Cable (Return Current)
506	AWG 4/0	Input Cable from Line Reactor 1
507	AWG 4/0	Input / Output Cable from / to Line Reactor 1, 2
508	AWG 4/0	Input Cable from Line Reactor 2
509A	AWG 1	Dynamic Brake Cable to the Resistor Box
519A	AWG 1	Dynamic Brake Cable to the Resistor Box
500C	AWG 4/0	Return Cable to the Resistor Box
CN1	Multi-conductor	Control Signals
CN2	Multi-conductor	Control Signals
CN3	Multi-conductor	Control Signals
CN4	Multi-conductor	Control Signals
CN5	Multi-conductor	Control Signals
CN6	Multi-conductor	Control Signals
551U	AWG 2/0	Motor #1 (A-Unit), Motor#6 (B-Unit)
551V	AWG 2/0	Motor #1 (A-Unit), Motor#6 (B-Unit)
551W	AWG 2/0	Motor #1 (A-Unit), Motor#6 (B-Unit)
500E1	AWG 1	Motor #1 Return (A-Unit), Motor#6 (B-Unit)
561U	AWG 2/0	Motor #2 (A-Unit), Motor#5 (B-Unit)
561V	AWG 2/0	Motor #2(A-Unit), Motor#5 (B-Unit)
561W	AWG 2/0	Motor #2(A-Unit), Motor#5 (B-Unit)
500E2	AWG 1	Motor #2 Return (A-Unit), Motor#5 (B-Unit)

Table 8-3. CN5 Pinout and Signal Names

See Figure 8-5: Equipment Case CN5 Connector Layout Drawing		
Pin Number	Signal Name	Purpose
B	HB24 A/B	HSCB Power Supply Status
C	HBCBCA/B	HSCB Command
D	CBTF1/2	Circuit Beaker Fault
E	PDF	Propulsion Dynamic Fault
F	ODP	B-Unit only, Odometer Pulse Signal
G	SGR	Speed Governor Relay
H	SND	Sanding
J	MCKSR	Master Controller Key Switch Relay
K	FWD	Forward
L	REV	Reverse
M	FBREL	Friction Brake Released
N	VNMRS	Critical No Motion Relay Status
P	TRBR	Track Brakes Released
S	NMRI	No Motion Relay Input
U	PWC	Power Cut
W	NMRO	No Motion Relay Output
X	TDU	Toyo Denki Test Mode (receptacle contact only)
a	EBG	Emergency Brake (negative)
c	EB	Emergency Brake (positive)
d	SCEB	Slide Controlled Emergency Brake
e	LIMP HOME	Limp Home
f	PCO	Propulsion Cut Out
h	ATPBP	ATP Bypass
j	IDIN	Truck Identification Input
k	IDIN2	Truck Identification Input 2
m	HSCBS	HSCB Status
n	CBTF1	Circuit Breaker Fault Lockout
p	M	M Trainline
r	CM	CM Trainline
s	PS	Pantograph Status

Table 8-4. CN6 Pinout and Signal Names

See Figure 8-6: Equipment Case CN6 Connector Layout Drawing		
Pin Number	Signal Name	Purpose
1	AT11	Chart Recorder output, ch. 1 P
2	NAT1	Chart Recorder output, ch. 1 N
3	AT1S	Chart Recorder output, shield 1
4	AT21	Chart Recorder output, ch. 2 P
5	NAT2	Chart Recorder output, ch. 2 N
7	AT31	Chart Recorder output, ch. 3 P
8	NAT3	Chart Recorder output, ch. 3 H
9	AT2S	Chart Recorder output, shield 2
10	AT41	Chart Recorder output, ch. 4 P
11	NAT4	Chart Recorder output, ch. 4 N
13	AT31	Chart Recorder output, ch. 5 P
14	MAT5	Chart Recorder output, ch. 5 N
15	AT3S	Chart Recorder output, shield 3
16	AT61	Chart Recorder output, ch. 6 P
17	NAT6	Chart Recorder output, ch. 6 N
19	AT71	Chart Recorder output, ch. 7 P
20	NAT7	Chart Recorder output, ch. 7 N
21	AT4S	Chart Recorder output, shield 4
22	AT81	Chart Recorder output, ch. 8 P
23	NAT8	Chart Recorder output, ch. 8 N
25	VSP11	Speed sensor, Tach 1 (Tach 10), Channel A Power Supply
26	VS11	Speed sensor, Tach 1 (Tach 10), Channel A output signal
27	NA1	Speed sensor, Tach 1 (Tach 10), A GND
28	TACH11S	Speed sensor, Tach 1 (Tach 10) shield
32	VSP12	Speed sensor, Tach 1 (Tach 10), Channel B Power Supply
33	VS12	Speed sensor, Tach 1 (Tach 10), Channel B output signal
34	NB1	Speed sensor, Tach 1 (Tach 10), B GND
35	TACH12S	Speed sensor, Tach 1 (Tach 10) shield
39	VSP4	Speed sensor, Tach 4 (Tach 5) Power Supply
40	VS4	Speed sensor, Tach 4 (Tach 5) output signal
41	NA4	Speed sensor, Tach 4 (Tach 5) GND
42	TACH4S	Speed sensor, Tach 4 (Tach 5) shield

Table 8-5. HSCB Control Panel CN1 Pinout and Signal Names

See Figure 8-9: HSCB Control Panel Connector Layout Drawing		
Pin Number	Signal Name	Purpose
A2	38AK	HSCB Status Positive 1
A3	38AL	HSCB Status Negative 1
A4	R3	HSCB Status Positive 2
A5	R4	HSCB Status Negative 2
A6	L5	HSCB Status Positive 3
B1	L6	HSCB Status Negative 3
B2	38AN	HSCB Status Positive 4
B3	38AM	HSCB Status Negative 4

Table 8-6. HSCB Control Panel CN2 Pinout and Signal Names

See Figure 8-9: HSCB Control Panel Connector Layout Drawing		
Pin Number	Wire Marker	Purpose
A2	38AB	HSCB Command from A Unit
A3	38AC	HSCB Command from B Unit
A4	38AD	HSCB Status for A Unit
A5	38AE	HSCB Status for B Unit
B1	VD24A	HSCB Power Status for A Unit
B2	VD24B	HSCB Power Status for B Unit

Table 8-7. HSCB Control Panel CN3 Pinout and Signal Names

Pin Number	Wire Marker	Purpose
2	38AH	HSCB Command Positive
3	38AJ	HSCB Command Negative

Table 8-8. HSCB Control Panel CN4 Pinout and Signal Names

See Figure 8-9 HSCB Control Panel Connector Layout Drawing		
Pin Number	Wire Marker	Purpose
A2	38AA	HSCB Power Positive
A3	38LVGA	HSCB Power Negative
B1	CICB	To CIBA
B2	HSCB T1	HSCB T1

The following are layout drawing of the noted connecters:

Figure 8-1: Inverter Box CN1 Connector Layout Drawing

Figure 8-2: Inverter Box CN2 Connector Layout Drawing

Figure 8-3: Inverter Box CN3 Connector Layout Drawing

Figure 8-4: Inverter Box CN4 Connector Layout Drawing

Figure 8-5: Inverter Box CN5 Connector Layout Drawing

Figure 8-6: Inverter Box CN6 Connector Layout Drawing

Figure 8-7: Gateway Unit PWR Connector Layout Drawing

Figure 8-8: MVB1 and MVB2 Connector Layout Drawing

Figure 8-9: HSCB Control Panel Connector Layout Drawing

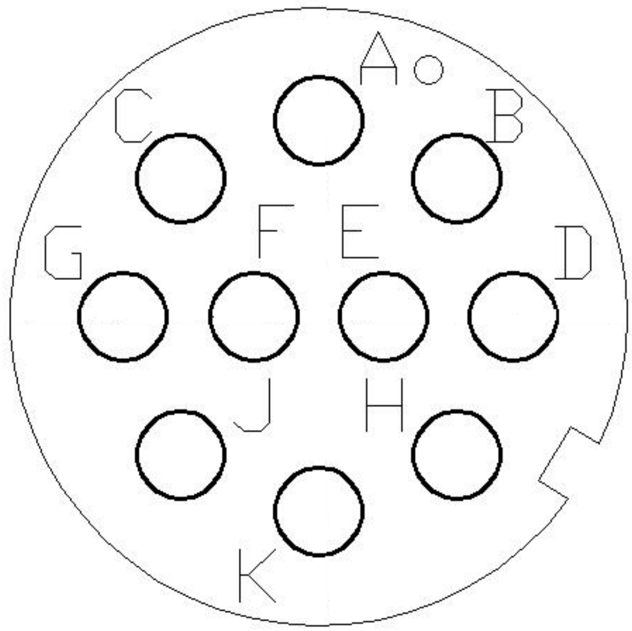

Figure 8-1: Inverter Box CN1 Connector Layout Drawing

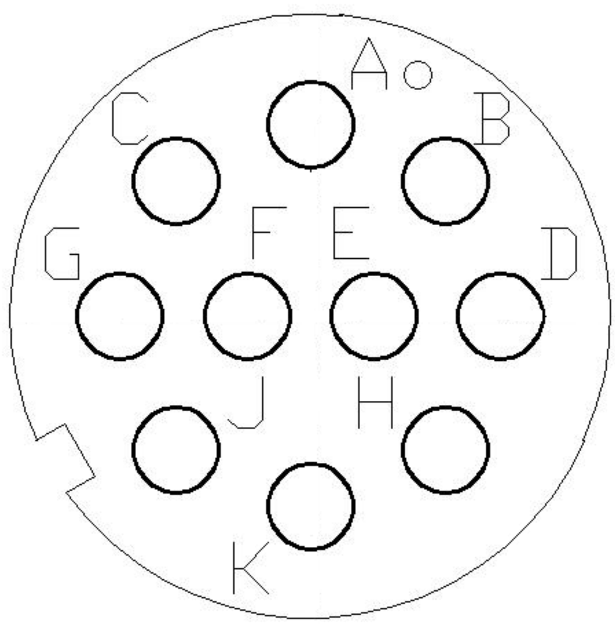

Figure 8-2: Inverter Box CN2 Connector Layout Drawing

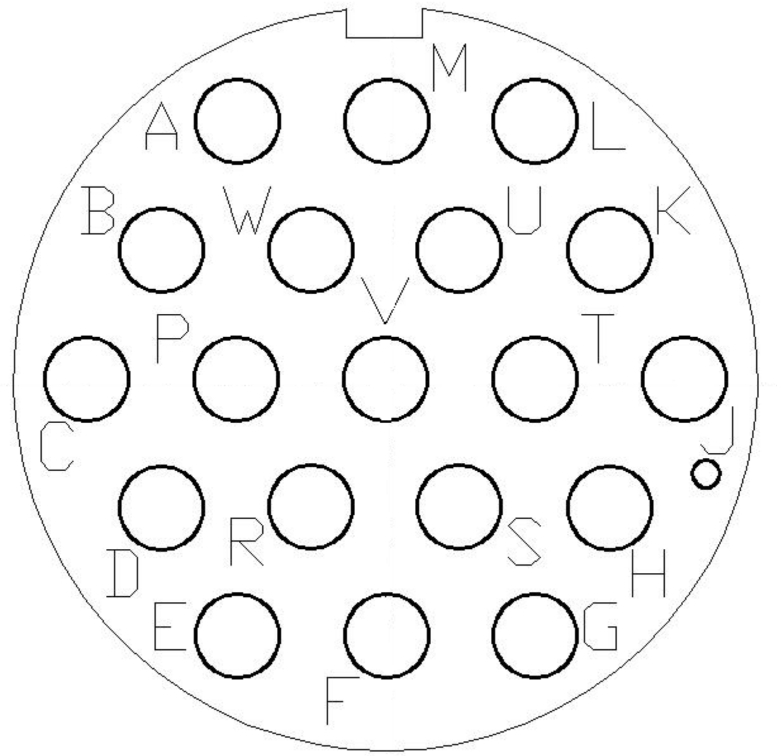

Figure 8-3: Inverter Box CN3 Connector Layout Drawing

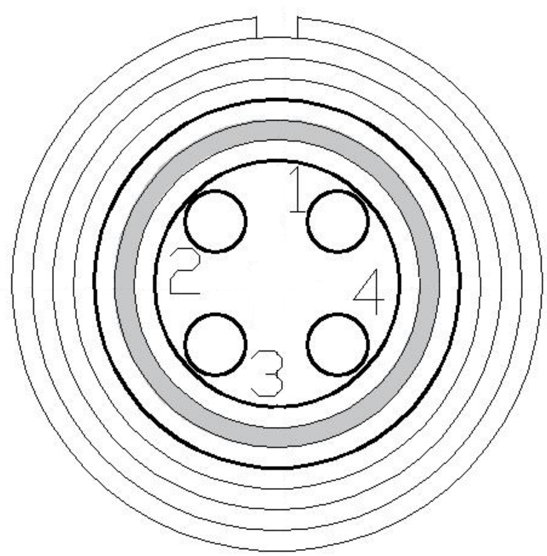

Figure 8-4: Inverter Box CN4 Connector Layout Drawing

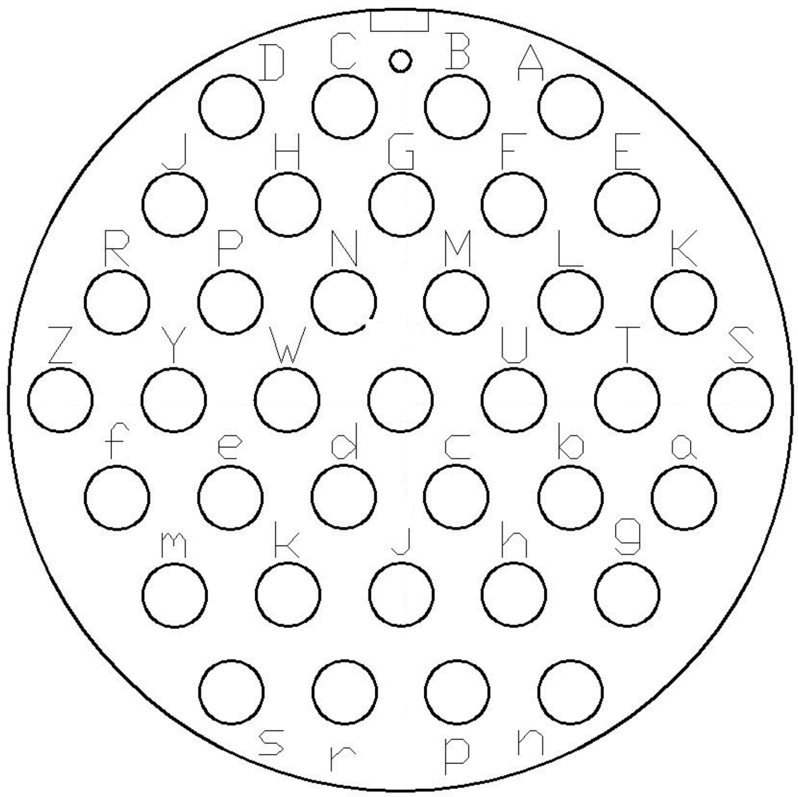

Figure 8-5: Inverter Box CN5 Connector Layout Drawing

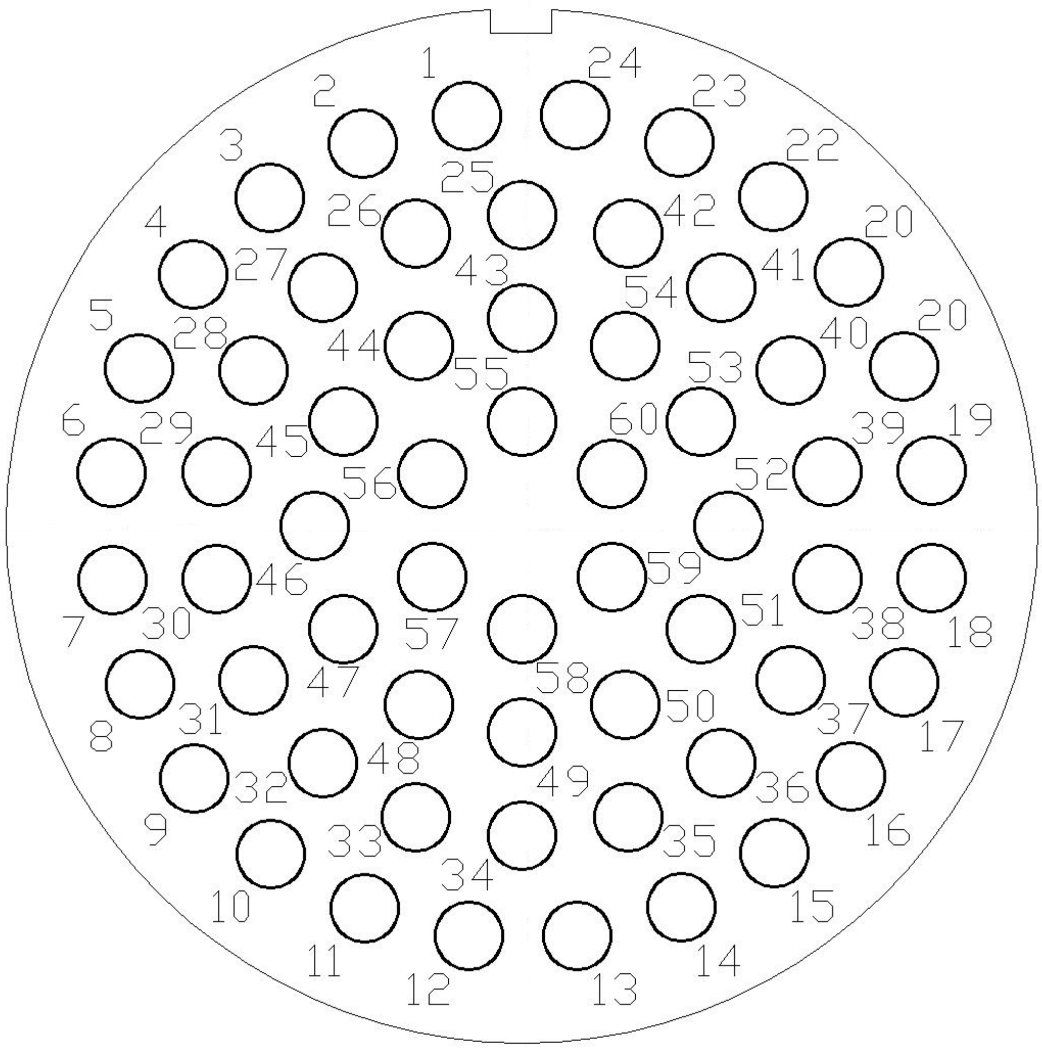

Figure 8-6: Inverter Box CN6 Connector Layout Drawing

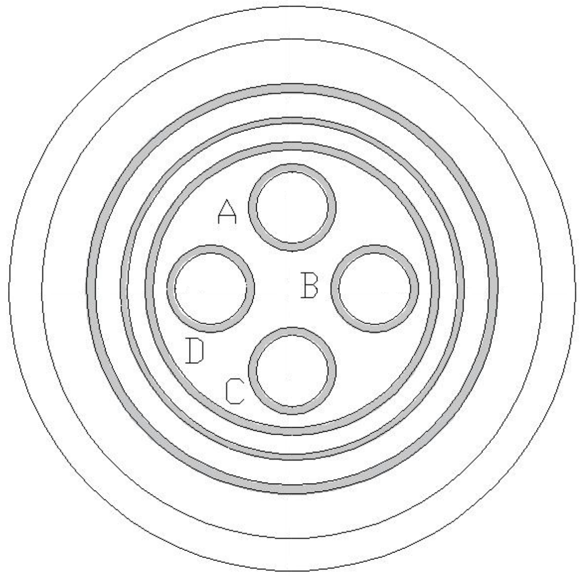

Figure 8-7: Gateway Unit PWR Connector Layout Drawing

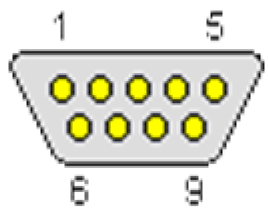

Figure 8-8: MVB1 and MVB2 Connectors Layout Drawing

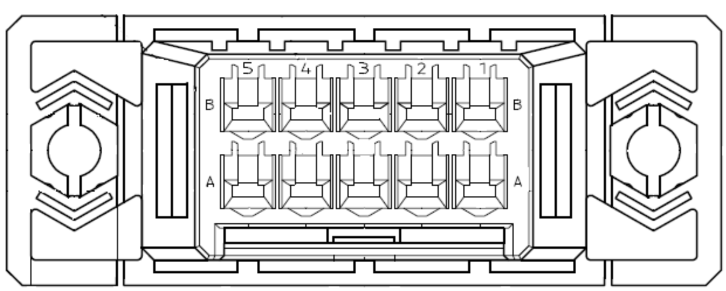

Figure 8-9: HSCB Control Panel Connectors Layout Drawing

8.4 Connection Drawings and Wiring Diagrams

The following is a listing of connection drawings and wiring diagrams located in this section:

B3018019, Relay Unit Connection Drawing

B3018020, PLU AVR3981 Connection Drawing

B3018021, PLU MCB108B1 Connection Drawing

B3018022, PLU MCB107B1 Connection Drawing

B3018023, PLU IFB137B1 Connection Drawing

B3018024, PLU IFB139B1 Connection Drawing

B3018025, PLU IBA130A1 Connection Drawing

B3018026, PLU IBA130A2 Connection Drawing

B3018027, PLU OBA54A1 Connection Drawing

B3018028, PLU IFB138B1 Connection Drawing

B3018029, Power Supply Unit Connection Drawing

B3018030, Gateway Unit Connection Drawing

B3018031, Propulsion Inverter CN1 Connection Drawing

B3018032, Propulsion Inverter CN2 Connection Drawing

B3018033, Propulsion Inverter CN3 Connection Drawing

B3018034, Propulsion Inverter CN4 Connection Drawing

B3018035, Propulsion Inverter CN5 Connection Drawing

B3018036, Propulsion Inverter CN6 Connection Drawing

B3018037, Noise Filter Connection Drawing

B3018038, Line Contactors Low Voltage Connection Drawing

B3018039, Housing Connection Drawing

B3018040, Housing Connection Drawing

B3018041, Inverter Unit INVCN1 Connection Drawing

B3018042, Inverter Unit INVCN2 Connection Drawing

B3018043, Inverter Unit INVCN3 Connection Drawing

B3018044, Inverter Unit INVCN4 Connection Drawing

B3018045, Inverter Unit INVCN5 Connection Drawing

B3018046, Inverter Unit INVCN6 Connection Drawing

B3018047, Gate Driver PCB Connection Drawing

B3018048, Fan Unit FANCN1 Connection Drawing

B3018049, Fan Unit FANCN2 Connection Drawing

The following are 11 x 17 diagrams found at the end of this section:

B446242, Main Power Circuit Diagram, Rev. R

B519943, Propulsion Inverter Connection Diagram, Rev. AB

B446295, Inverter Unit Circuit Diagram, Rev. E

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8.5 Wire Lists

During troubleshooting (or after damage to the equipment) there may be a need to rewire a connector or device or do point to point continuity checks.

There are two types of documents in this section.

There are three wire lists in this section. There is an equipment case (PIU) wire list, an Inverter Unit wire list and a Relay Unit wire list. The Wire Lists show point to point connections (source and destination) for each wire.

The Connection sheets show only the wires connected to a connector or device.

The information in this section is presented in the following order:

- Propulsion Equipment Case (PIU) Wire list
- Inverter Unit Wiring List
- Relay Unit Wiring List
- Propulsion Logic Unit Connections
- Inverter Unit Connectors
- Direct Current Voltage Detectors (DCVD) Connectors
- Power Supply Unit Connectors
- Propulsion Equipment Case (PIU) Housing Connectors
- Fan Connectors
- Propulsion Equipment Case (PIU) Connectors
- CT Unit Connectors
- Gateway Unit Connectors
- Relay Unit Connectors

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