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RECOMMENDED PRACTICE

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APTA ZEB Maintenance Training Working Group

Zero-Emission Bus Maintenance Training

Abstract: This recommended practice provides guidance for developing zero emission bus maintenance training curricula and materials.

Keywords: zero emission bus, electric bus, battery-electric bus, fuel cell bus, fuel cell electric bus, hydrogen fuel cell bus, maintenance, mechanic, technician, training

Summary: This recommended practice is a guide for transit bus maintenance and maintenance training with a series of learning objectives that represent the knowledge and skills technicians should acquire as a result of zero-emission bus training. This recommended practice is divided into three modules. Level 100 identifies the knowledge and skills technicians will need to gain a basic understanding of how zero emissions buses operate, how they compare/contrast with other buses, general safety precautions, and function of each major component. Level 200 expands on familiarization material offered in the previous module by providing technicians with more detailed information on ZEB safety, components, systems and theory of operation. Level 300 then focuses on ZEB troubleshooting techniques, related special tools, and the knowledge and skills that technicians will need to perform common ZEB maintenance and repair tasks.

The American Public Transportation Association developed this recommended practice with a joint labor and management work group, with assistance from the International Transportation Learning Center.

Foreword

The American Public Transportation Association is a standards development organization in North America. The process of developing standards is managed by the APTA Standards Program's Standards Development Oversight Council (SDOC). These activities are carried out through several standards policy and planning committees that have been established to address specific transportation modes, safety and security requirements, interoperability, and other topics.

APTA used a consensus-based process to develop this document and its continued maintenance, which is detailed in the manual for the APTA Standards Program. This document was drafted in accordance with the approval criteria and editorial policy as described. Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

This document was prepared by the Zero-Emission Bus Maintenance Training Work Group as directed by the Standards Policy Planning Committee.

This document represents a common viewpoint of those parties concerned with its provisions, namely transit operating/planning agencies, manufacturers, consultants, engineers and general interest groups. The application of any recommended practices or guidelines contained herein is voluntary. APTA standards are mandatory to the extent incorporated by an applicable statute or regulation. In some cases, federal and/or state regulations govern portions of a transit system's operations. In cases where there is a conflict or contradiction between an applicable law or regulation and this document, consult with a legal adviser to determine which document takes precedence.

This is a new document.

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Introduction

This introduction is not part of APTA BTS-ZBT-RP-001-23, "Zero Emission Bus Maintenance Training."

The American Public Transportation Association publishes series of bus training recommended practices, developed jointly with labor and management representatives and with assistance from the International Transportation Learning Center (ITLC). These standards contain a series of learning objectives that represent the knowledge and skills technicians should acquire as a result of the training provided to them, thereby serving as a useful guide for those producing the related training materials.

Originally developed to standardize bus maintenance training related to the Automotive Service Excellence (ASE) testing and certification program, these recommended practices are useful to training providers seeking to evaluate, develop or enhance their training programs for more effective diagnosis, repair and maintenance of various transit bus systems. Individual operating agencies are encouraged to modify these guidelines to accommodate their specific equipment and mode of operation. The full suite of APTA bus training recommended practices can be found at https://www.apta.com/research-technical-resources/standards/bus-transit-systems-standards-program/.

Due to the increased popularity of both battery electric buses and hydrogen fuel cell electric buses, APTA again collaborated with the ITLC, this time under the Federal Transit Administration's Transit Workforce Center, to develop training standards specifically for these new propulsion alternatives. Doing so provides developers of maintenance training materials with the guidance needed to address the unique characteristics of these buses, especially high voltage and related safety.

Scope and purpose

This Zero-Emission Bus Maintenance Training Recommended Practice provides a series of learning objectives representing the knowledge and skills that transit bus technicians should acquire as a result of training related to battery electric and fuel cell electric buses. The document is divided into three modules, each representing incremental levels of knowledge that the technician will acquire. Each module builds upon the knowledge and skills acquired in the previous levels.

- **Level 100: ZEB Familiarization:** This module identifies the knowledge and skills technicians will need to gain a basic understanding of how zero emissions buses operate, how they compare/contrast with other buses, general safety precautions, and the role each major component plays in providing propulsion.

- **Level 200: Details of ZEB safety, components, systems, and theory of operation:** This module expands on familiarization material offered in the previous module by providing technicians with more detailed information on ZEB safety, components, systems, and theory of operation.

- **Level 300: ZEB maintenance, troubleshooting and repair:** This module focuses on ZEB troubleshooting techniques, related special tools, and the knowledge and skills that technicians will need to perform common ZEB maintenance and repair tasks.

Zero Emission Bus Maintenance Training

1. Level 100: ZEB Familiarization

> **NOTE:** Standards apply to zero emission buses, consisting of battery electric buses (BEBs) and hydrogen fuel cell buses (HFCBs). *They do not apply to trolley buses where power is supplied via overhead catenary.*
>
> **NOTE:** APTA BTS-BMT-RP-004-10, "Training Syllabus to Instruct/Prepare for the ASE Transit Bus Electrical/Electronics Test," is required as a prerequisite: https://www.apta.com/research-technical-resources/standards/bus-transit-systems-standards-program/APTA-BTS-BMT-RP-004-10/.

The objective of this module is to provide technicians with a basic understanding of how ZEBs -- which comprise BEBs and HFCBs -- operate, how they compare/contrast with other buses, general safety precautions, and function of each major component.

1.1 Introduction to ZEB

1. Identify when battery electric and hybrid vehicles were first introduced (approximately).
2. Describe the principles of operation of a BEB, and identify its major components and systems.
3. Describe the principles of operation of an HFCB, and identify its major components and systems.
4. Explain the major similarities and differences between ZEBs and more traditional buses (hybrid, clean diesel and CNG buses). Include fueling and propulsion characteristics.
5. Explain the environmental benefits and why capital investments in ZEB technologies are being made.

1.2 Overview of ZEB safety

1.2.1 General safety

1. Define HV and explain the difference between high voltage and low voltage definitions in transit applications.
2. Describe the general areas on BEB and HFCB where HV is present.
3. Describe the effects of HV on the human body at 50 to 150 mA, 1 to 4.3 amps, and 10 amps.
4. Define arc flash, shock hazard and the potential for injury, and the conditions that can produce these hazards.
5. Define thermal runaway and potential consequences.
6. Describe the relevant workplace safety regulations applicable to HV systems and ZEBs (e.g., NFPA 70E, OSHA 1910)
7. Explain the significance of orange cables and looming.
8. Explain the purpose and need to deenergize a ZEB to ensure that zero voltage is present before working on HV equipment (per OEM).
    a. Explain how to verify that high voltage is absent based on OEM procedures.
    b. Explain why batteries/energy storage systems (ESS) can still be live based on OEM designs.
    c. Define and explain the purpose for lockout/tagout (LOTO) procedures.
        - Explain the concept of battery lockout/tagout (BLOTO)
        - Explain the concept of low-voltage LOTO

   d. Explain the need and procedures for roof access and fall protection.
   e. Explain special requirements for using jacking and lifting equipment on ZEBs.
      - Include special hoisting/lifting equipment for removing and replacing batteries.
   f. Describe basic accident and incident protocols needed for key personnel (e.g., operators, road service crews, first and second responders, dispatchers, road supervisors, and technicians).
      - Explain the different procedures needed for technicians and operators.

1.2.2 Onboard safety equipment

1. Describe the differences between HV and LV disconnects.
2. Describe the need to isolate HV grounds from the bus chassis.
3. Explain the concept of HV isolation detection in providing protection from HV system faults.
   a. Name at least two potential HV system faults that can be caught by isolation detection.
4. Explain the purpose of a high-voltage interlock loop (HVIL) and how it functions.
   a. Name at least two conditions that could trigger HV disconnect.
5. Explain the function of ESS disconnects.
6. Explain the function of high-voltage disconnect switches, including the following:
   a. manual service disconnects (MSDs)
   b. battery disconnect unit (BDU)
   c. contactors
7. Explain these additional applications:
   a. charging
   b. high-voltage junction box (HVJB)
   c. battery
   d. reducing battery voltage potential

8. Explain the following safety components:
   a. pressure relief device (PRD)
   b. over pressure valves
   c. vent lines
   d. gauges
   e. fuse protection
9. Identify general locations of MSDs.

   NOTE: They vary by OEM.

10. Explain the following safety equipment in ZEBs:

    NOTE: They vary by OEM.

    a. HV contactors, H2 sensors, smoke detector, sensors, overpressure devices
    b. ground fault monitor or battery management system

1.2.3 Personal protective equipment (PPE)

1. Refer/locate to the OEM service manual where OEM high-voltage PPE requirements are discussed.
2. Identify the conditions under which HV PPE is required when working on ZEBs.
3. Explain the need for different category electrical meters and leads when working on high-voltage applications.
4. Identify and explain the need for all applicable HV PPE, including arc flash suits, face shields, helmet, balaclava, insulated shoes, insulated gloves, ear plugs and others.
   a. Include cleaning and replacement procedures for arc flash–related PPE.

5. Explain the need for inspecting, testing and certifying insulated gloves. Include the significance of using authorized certification facilities, labeling notations (color coding and rating), air testing, and inspection intervals.
6. Explain the purpose of using insulating mats.
   a. Include inspection procedures and intervals.
7. Explain the purpose of using an insulated shepherd’s hook (also known as a hot stick) and related requirements for two-person jobs when working in HV conditions.
   a. Include inspection procedures and intervals for this equipment.
8. Explain the purpose of establishing arc flash and shock boundaries and related distancing requirements.
9. Explain the need for first aid kits and defibrillators for high-voltage applications.

1.2.4 Insulated tools

1. Identify common tools that require insulation when working on ZEBs
2. Explain how to identify unsafe insulated tools.
3. Explain why insulated tools are needed and under which conditions.
   a. Maintenance, troubleshooting, emergency response, etc.

1.3 Overview of major ZEB systems and components

1.3.1 Energy storage system (ESS)

2. Explain the purpose of an ESS:
   a. Explain the ESS’s major subcomponents including battery thermal management.
   b. Explain how the design of an ESS is different from a low-voltage battery system.
3. Identify the current ESS battery chemistries.
4. Explain how a capacitor functions, its purpose, and how it compares and contrasts with batteries.
5. Identify voltage ranges for BEBs and HFCBs. Include the advantages and disadvantages of each.
6. Explain why an ESS needs to be thermally managed (i.e., heated and cooled) and the equipment used to maintain optimum operating temperatures.
7. Explain the function of ESS conductors.
8. Explain the function of junction and fuse boxes.

1.3.2 High-voltage distribution

1.3.2.1 Cables, contactors, and relays

1. Explain the basic design and function of AC and DC high-voltage cables.
2. Explain the function and operation of shielding on high-voltage cables to protect vehicle control systems from electromagnetic radiation.
3. Explain the purpose of contactor/electrical switching devices and where they are used in a ZEB.
4. Explain the purpose of bus bars fusing/distribution blocks.
5. Explain the rationale behind insulation testing and the importance of reference points (i.e., high-voltage potential to coach chassis). (Include testing procedure in Module 2.)
6. Explain the relationship between AWG wire gauges and their ratings.

1.3.3 Grounding and bonding

1. Explain the difference between grounding and bonding points.
2. Identify grounding and bonding points.

1.3.4 High-voltage junction box

1. Describe the purpose and benefits of an HVJB and how it functions.

2. Describe at least two subcomponents contained within an HVJB.

1.3.5 Traction motors

1. Explain the purpose of AC induction motors and how they operate.
2. Explain how the traction motor captures energy through regenerative braking.
3. Explain why traction motors require a cooling system and how the cooling system operates.

1.3.6 Power electronics

1.3.6.1 Auxiliary inverters and VFDs

1. Explain AC/DC characteristics.
2. Explain the advantages of using AC power in a ZEB.
3. Explain the purpose of an inverter.
4. Explain the difference between auxiliary and traction motor inverters.
5. Explain the purpose of a variable frequency drive (VFD).
6. Explain why inverters and power electronic subcomponents need to be cooled and how that cooling is achieved.
7. Explain the different types of coolants used in inverters, variable frequency drives and fuel cells.

1.3.6.2 Accessory power (DC–DC)

1. Describe the purpose of a DC–DC converter and why it is needed in a ZEB.
2. Provide at least three examples of where differing DC voltages are needed in a ZEB (e.g., MUX, CAN, Power Steering, etc.).

1.3.6.3 Accessory motors

1. Explain why motor-driven accessories are needed.
2. Identify typical motors/accessories that are powered electrically on a ZEB.
3. Provide at least three examples of electric motor–driven accessories.
4. Identify the power source for running electrically-driven motors/accessories.
    a. Include basic reasoning for using HV vs. LV and AC vs. DC to drive these accessories.

1.3.7 Thermal management systems

1. Explain why HVAC systems and thermal management systems are needed.
2. Summarize the difference between cabin HVAC and ZEB thermal management systems.
3. Explain the function of a coolant loop.
4. Discuss how coolant loops may be integrated into HVAC systems.
5. Explain the purpose of auxiliary heaters as they relate to propulsion and battery thermal management.
6. Explain the different types of coolants used in ZEBs.

1.3.8 Charging systems

1.3.8.1 Plug-in (conductive)

1. Describe two primary functions associated with a manual, plug-in (depot) charge connector.
2. Describe the purpose of charger–vehicle communication.
3. Identify the SAE standard (J1772) that applies to plug-in connectors.
4. Describe typical charging times for plug-in chargers.
5. Explain the advantages and disadvantages associated with plug-in chargers.
6. Describe the concept of smart charging and the various advantages associated with it.
7. Describe the basic precautions that must be taken before repairing or servicing depot chargers.
8. Describe the concept of smart charging (cascading/sequential) in relation to state of charge (SOC).

9. Explain proper connections with various OEM connectors.

1.3.8.2 Overhead (conductive)

1. Describe the two most common overhead, pantograph-style charging methods.
2. Identify typical charging times for overhead, pantograph-style chargers.
3. Identify the SAE standard (J3105) that applies to overhead, pantograph-style charging.
4. Explain the advantages and disadvantages associated with overhead, pantograph-style charging.

1.3.8.3 Inductive

1. Define inductive charging.
2. Describe typical charging times for inductive charging.
3. Explain the advantages and disadvantages associated with inductive charging.
4. Identify the SAE standard (J-2954/2) that applies to inductive charging.

1.3.9 Data communication networks

1.3.9.1 Controller area networks (CANs)

1. Describe the principles of controller area network communication protocols and standards.
2. Identify the components in a CAN:
    a. Explain the function and operation of terminating resistors.
    b. Explain the function and operation of gateways.
    c. Explain the function and operation of shielding on data cables to protect from high-voltage cable interference.
3. Identify which subsystems commonly use CAN communication.
4. Explain J1939 and the associated data acquisition methods.
5. Explain the differences between SAE, IEEE and proprietary data on a communication network.
6. Explain the communication between the charger and the bus and why that communication is necessary.

1.3.9.2 Multiplexing (MUX)

1. Describe the principles of multiplexing communication protocols and standards.
2. Identify the components in a MUX network.
3. Identify which subsystems commonly use MUX communication.
4. Explain J1213/1 and the “Glossary of Vehicle Networks for Multiplexing and Data Communications.”

1.3.9.3 Telematics

1. Describe how the basic operation of vehicle telemetry system(s).
2. Explain the function and operation of gateways.
3. Explain the function and operation of shielding on data cables to protect from high-voltage cable interference.
4. Explain the system for communication with the vehicle’s 12/24 V system through multiplexing.

1.3.10 Hydrogen fuel cell bus overview

1. Identify the difference and similarities between a BEB and an HFCB.
2. Identify the conceptual operation of an HFCB.
3. Describe the function of a fuel cell.

4. Define the major subsystems found on an HFCB that are not found on a BEB:
    a. hydrogen system
    b. air intake system
    c. exhaust system
    d. cooling system
    e. interfaces to systems
    f. high-voltage system
    g. low-voltage system
    h. diagnostic system
5. Define the major safety components found on an HFCB that are not found on a BEB.
6. Explain what is meant by safety system and safety strategy.

1.4 Overview of ZEB maintenance

1.4.1 Special equipment and procedures

1. Identify unique service tools and other service information.
2. Identify the type(s) of digital multimeter(s) needed for ZEB applications.
3. Explain special towing procedures for ZEBs (if applicable).
4. Explain unique service line procedures for ZEBs (if applicable).
5. Explain the basic inspection and maintenance of AC and DC high-voltage cables.
6. Explain the differences and importance of grounding and bonding.
7. Compare the basic inspection of internal combustion engine (ICE) and zero emission vehicles (buses).

1.4.2 Maintenance intervals and general tasks

1. Demonstrate an ability to locate OEM documentation on maintenance intervals and tasks.
2. Describe common PM subsystems inspections.
3. Demonstrate the ability to locate and access ZEB service documentation.
4. Demonstrate the ability to locate and access ZEB service and parts manuals.
5. Demonstrate the ability to locate and access ZEB integration guides.
6. Demonstrate the ability to read schematics and drawings.
7. Demonstrate the ability to carry out warranty claim procedures (if applicable).
8. Explain how to contact OEM customer service.

2. Level 200: Details of ZEB safety, components, systems, and theory of operation

The objective of this module is to expand on familiarization material offered in the previous module by providing technicians with more detailed information on ZEB safety, components, systems, and theory of operation. It also provides technicians with more engaging exercises, such as locating various components on a ZEB, correctly applying PPE, safely de-energizing vehicles, and the proper use of diagnostic equipment and tools to perform ZEB inspections and general maintenance.

2.1 Electrical principles

1. Examine the fundamental laws of electricity:
    a. Ohm's law (Ohm's wheel)
    b. Watt's law
    c. Kirchhoff's current and voltage laws
    d. Faraday's law
    e. Lenz's law
    f. Coulomb's law
    g. Gauss's law
    h. conventional vs. electron current
    i. right-hand rules
    j. "ELI the ICE Man" (voltage and current phase for inductive/capacity circuits [trigonometry])
2. Explain parallel vs. series voltage mathematics (calculations).
3. Describe how to convert horsepower ratings to kilowatt ratings.
4. Explain the various electrical waveforms found in ZEB applications.
5. Differentiate between kilowatt and kilowatt-hour.
6. Explain energy values.
7. Demonstrate ability to correctly use digital multimeters and other electrical testing equipment relevant to ZEBs.
    - Standard functions
        - voltage measurement
        - resistance measurement
        - current measurement
        - continuity measurement
    - Advanced functions
        - insulation measurement
        - frequency measurement
        - wave measurement
    - Measurement and schematic symbols
    - Testing equipment specifications
        - Describe which testing equipment is applicable for different applications
    - Accessories
        - Clamp-on ammeter (AC, DC), thermal tester, etc.
8. Describe the energy characteristics of the following battery chemistries:
    a. lithium-ion (Li-ion):
        - lithium-nickel-cobalt-aluminum (NCA)
        - lithium-nickel-manganese-cobalt (NMC)
        - lithium-manganese-spinel (LMO)
        - lithium-titanate (LTO)
        - lithium-iron-phosphate (L0FP)
    b. lead acid (AGM)

   c. nickel-metal-hydride (NMH)
   d. For each of the chemistries in this list, describe the configuration, nominal cell Voltage, Ah rating and energy ratings.

2.2 Details of ZEB safety

2.2.1 General safety

1. Locate specific areas on a BEB and HFCB as applicable where HV is present.
2. Locate and differentiate between HV and LV cables on a ZEB.
3. Demonstrate LV and HV lockout/tagout procedures per OEM procedures.
4. Demonstrate the ability to de-energize a ZEB and confirm that zero voltage is present per OEM procedures.
9. Interpret key information found within the safety data sheet (SDS):
   a. first aid (pertains to chemicals in ESS)
   b. battery chemistry
   c. energy density
   d. first and second response procedures
      - Information to local responders
5. Demonstrate procedures for roof access and fall protection.
6. Explain any special requirements for using jacking and lifting equipment on ZEBs.
7. Demonstrate the ability to perform basic accident and incident protocols needed for key ZEB personnel (e.g., road service crews, first and second responders, and technicians).
   a. Energy isolation
   b. Towing and recovery
   c. Post-recovery quarantine area and time
8. Demonstrate the ability to check the high-pressure hydrogen safety system for HFBC.

2.2.2 Onboard safety equipment

1. Locate HV and LV disconnects, and describe how they operate.
2. Locate the following high-voltage disconnect switches:
   a. manual service disconnect (MSD)
   b. service disconnect (HVJB, etc.)
   c. battery disconnect unit (BDU)
   d. charging contactors (shore power/bus side connector)
   e. proximity switches and micro-switches (to activate interlock)
3. Explain the difference between measured (isolation monitoring device [IMD]) and calculated (software) high-voltage isolation status.
4. Locate two specific subsystems where the HVIL is utilized, and describe how it operates.
5. Locate hydrogen overpressure devices, and describe how they operate.

2.2.3 Personal protective equipment (PPE)

1. Identify the correctly rated electrical meters and leads for different HV applications.
2. Demonstrate the ability to determine if meter and leads are in good working order.
   a. Demonstrate the ability to perform “live, dead, live” test according to established agency written procedure.
3. Identify the correctly rated PPE for different HV applications.
4. Demonstrate the ability to determine if specific PPE has been inspected, tested, and certified.
5. Demonstrate the ability to establish proper boundaries when working in areas of HV.

6. Demonstrate the proper use of all applicable HV PPE, including arc flash suits, face shields, helmet, balaclava, insulated shoes, insulated gloves, ear plugs and others.
    a. Explain proper cleaning procedures for arc flash–related PPE.
7. Demonstrate proper use and inspection of insulating rubber mats.
8. Demonstrate proper use of insulated shepherd's hook.

2.2.3.1 Insulated tools

1. Identify the correct scenarios where insulated tools are required to perform work.
2. Demonstrate the ability to determine if insulated tools are in good working order.
3. Demonstrate proper use of insulated tools.

2.3 Details of major ZEB systems and components

2.3.1 Energy storage system/modules/battery packs

1. Locate the ESS on a ZEB and its major subcomponents, and describe how they operate.
2. Locate an energy storage capacitor [if applicable] on a ZEB, and describe how it operates.
3. Locate various ESS conductors on a ZEB, and describe how they operate.
4. Locate junction and fuse boxes on a ZEB, and describe how they operate.
5. Explain how energy is used in an ESS.
6. Explain the process for removing and replacing components inside enclosures or tubs per local regulations, OEM requirements and agency SOPs.
7. Explain the purpose of load-shedding as the SOC drops.
8. Demonstrate the ability to use manufacturer-specific schematics.
9. Describe the characteristics of ESS configuration, including string controllers, battery management system controller, disconnects, MSD and shunts.
10. Describe procedures to ensure the integrity of ESS insulation properties.

2.3.2 High-voltage distribution

2.3.2.1 Cables, contactors and relays

1. Locate examples of shielding on HV and LV cables.
2. Differentiate among wire gauges.
3. Locate LV and HV contactors on a ZEB.
4. Explain where fuses, busbars and circuit breakers are used in an electrical circuit and why.
5. Demonstrate correct insulation testing procedures.
6. Describe the operation of a BDU.
7. Describe the purpose of a relay in providing isolation between high-voltage and low-voltage systems.

2.3.2.2 High-voltage junction box

1. Describe the various electrical enclosure ratings and how apply to personnel and equipment (e.g., IP, NEMA, UL, etc.)
2. Describe the components found in an HVJB and their functions.
3. Identify components that can be repaired or replaced in the HVJB.
4. Using manufacturer-specific schematics, trace the circuit that originates at the ESS and connects to the HVJB.

2.3.2.3 Traction motors/generator

1. Describe the subcomponents of the traction inverter.
2. Illustrate the rotation of each phase of the magnetic field in AC induction motors.
3. Describe the difference between Wye and Delta windings.

4. Using generic schematics, determine if a traction motor is Wye or Delta wound, and whether the application is utilizing a neutral connection.
5. Illustrate how each phase in a three-phase traction motor is applied.
6. Describe how the traction motor slows the vehicle during regenerative braking.
7. Illustrate how the traction motor generates energy through regenerative braking.
8. If applicable, explain the purpose of a transmission on a ZEB.
9. If applicable, locate a fuel cell inductor and explain its operation.

2.3.3 Power electronics

2.3.3.1 Inverters/rectifiers and variable frequency drive (VFD)

1. Describe the function of a VFD.
2. Describe the subcomponents of a VFD.
3. Differentiate between a VFD and traction inverter.
4. Illustrate the direction of coolant flow of the cooling loops for the inverters and power electronic subcomponents.
5. Explain the normal operating ranges (in terms of voltages, thermal capacities and input voltage) of the auxiliary inverters and VFDs.
6. Describe the function of the traction inverter during regenerative braking.
7. Explain the DC-to-AC conversion process for propulsion.
8. Explain the AC-to-DC conversion process for regenerative braking/battery recharging.

2.3.3.2 Power supply from HV DC to the LV DC converter (DC–DC converter)

1. Locate at least one DC–DC converter and describe how it operates.
2. Explain when the DC–DC converter is active and inactive.
3. Identify the standard operating ranges of the LV subsystems.
4. List the components that utilize LV power unique to ZEBs.
5. Explain the purpose of an LV battery equalizer.

2.3.3.3 Auxiliary drive motors

1. Locate at least three motor-driven accessories on a ZEB and describe how they operate.
2. Identify whether the motor utilizes HV or LV power.
3. Utilize OEM schematics to identify the power source for running electrically driven motors/accessories.

2.3.4 Thermal management applications

2.3.4.1 Battery thermal management system (BTMS)

1. Differentiate between the battery coolant loop and the electronics coolant loop.
2. Describe and locate the subcomponents of the BTMS.
3. Explain how the BTMS heats/cools the ESS.
4. Describe the typical operating temperatures of lithium-ion batteries.
5. Explain the operation of a battery chiller to regulate optimum battery temperatures.

2.3.4.2 HVAC

1. Differentiate between the passenger heating and cooling systems found on ZEB and ICE buses.
2. Describe and locate the subcomponents of the HVAC.
3. Describe the location, purpose, and theory of operation of a heat pump.

2.3.4.3 Auxiliary heat

1. Describe the theory and operation of auxiliary heating systems, including diesel-fired and electric.
2. Describe and locate the subcomponents of the auxiliary heating system.
3. Describe the advantages and disadvantages of diesel-fired and electric auxiliary heating systems.

2.3.4.4 Main and auxiliary coolant loop for HFCB

1. Describe the theory and operation of main and auxiliary HFCB coolant loops.
2. Describe and locate the subcomponents of the main and auxiliary HFCB coolant loops.

2.3.5 BEB charging details

1. Describe intelligent or managed charging (dynamic, sequential, etc.) advantages and disadvantages, and associated equipment.
2. Describe the safety precautions associated with repairing charging equipment.
3. Demonstrate the ability to distinguish charger-related faults vs. bus-related faults.
4. Demonstrate the procedure for connecting/disconnecting charging and emergency shutdown equipment.
5. Describe the different SAE charging standards (J1772, J3105, J2954, J3271 [megawatt charging]).
6. Locate and identify the charger interface circuitry (bus side) and explain the theory of operation.
7. Distinguish between a standard J1772 signaling circuit and J3105 (-1, -2 and -3).

2.3.6 Data communication networks

2.3.6.1 Controller area networks (CANs)

1. Describe the various software and diagnostic connectors used to interface with CAN signals on ZEBs.
2. Identify the subsystems that most commonly use CAN communication on ZEBs.
3. Describe the logic waveform of CAN signals and their voltage range.
4. Explain how to verify network connections.
5. Explain the difference between CAN and CAN flexible data.
6. Explain the importance of baud rate.
7. Describe available J1939 communication protocols.
8. Explain the purpose and function of propulsion, CAN open and vehicle CAN networks.

2.3.6.2 Multiplexing (MUX)

1. Describe the various software and diagnostic connectors used to interface with MUX signals on ZEBs.
2. Identify the components in a MUX network.
3. Describe how MUX and CAN networks integrate and how they differ.
4. Identify a Parameter Group Number (PGN).
5. Explain the purpose and importance of a PGN found on ZEBs and how it can be used for diagnostics.
6. Explain what Suspect Parameter Numbers (SPNs) are and how they can be used for diagnostics.
7. Explain multiplexing ladder logic and how it is used in diagnostics.

2.3.6.3 Telematics

1. Describe some of the accessible data that the telematics subsystem captures.
2. Discuss the various ways to access telemetry data (remote vs. physical connection to the vehicle).
3. Explain how telemetry data is used to manage and maintain ZEBs.
4. Demonstrate how to capture a trace file and examine the data.
5. Describe the function of a telematics module and the connections to the ZEB.

2.3.6.4 Fuel cell details

1. Explain the operation of a fuel cell and the chemical reaction that creates an electrical charge.
2. Describe how the electrical output created by the fuel cell is used to charge the ESS batteries.
3. Explain the requirements surrounding SOC for the ESS.
4. Explain the fueling procedures for an FCB.
5. Describe the system architecture of an FCB.

3. Level 300: ZEB maintenance, troubleshooting and repairs

The objective of this module is to provide technicians with a strong understanding of ZEB troubleshooting techniques, related special tools, and the knowledge and skills needed to perform common ZEB maintenance and repairs. Much of the learning will take place through hands-on exercises performed on actual ZEB vehicles and related equipment.

3.1 General ZEB maintenance

1. Demonstrate the ability to locate special equipment and inspection procedures according to OEM recommendations.
2. Demonstrate the ability to prepare vehicles for maintenance (isolate contactors, ensure LV and HV are disconnected, follow LOTO procedures).
3. Explain the purpose of service tools and OEM service information.
4. Demonstrate the ability to use the proper type of digital multimeter needed for HV ZEB applications.
5. Describe special towing procedures for ZEBs (as applicable).
6. Demonstrate unique service line procedures for ZEBs (as applicable).
7. Demonstrate basic inspection and maintenance of AC and DC high-voltage cables.
8. Demonstrate the ability to perform a basic insulation test and evaluate the results.
9. Demonstrate ability to analyze fault and trace data to determine root cause failure.

3.2 Maintenance inspection procedures

1. Demonstrate correct OEM inspection procedures of the driver’s area and controls as they relate to ZEBs.
2. Demonstrate correct OEM inspection procedures of the pneumatic system and air compressor.
3. Demonstrate correct OEM inspection procedures of the passenger compartment.
4. Demonstrate correct OEM inspection procedures of the fire suppression system unique to ZEBs, if applicable.
5. Demonstrate correct OEM inspection procedures of the HVAC subsystem unique to ZEBs.
6. Demonstrate correct OEM inspection procedures of the auxiliary heat system unique to ZEBs, if applicable.
7. Demonstrate correct OEM inspection and lubrication procedures of underbody equipment, traction motor(s), suspension, and steering systems.
8. Demonstrate correct OEM inspection procedures of wheels and brakes.
9. Demonstrate correct OEM inspection procedures of the differential, drive axle and/or e-axle.
10. Demonstrate correct OEM inspection procedures of the rooftop area of the bus.
11. Demonstrate correct OEM inspection procedures of the ESS and HV systems.
12. Demonstrate correct OEM inspection procedures of the telematics and determine if any failure codes are present.
13. Demonstrate correct OEM inspection procedures of the exterior body, mirrors, indicators, and lights.
14. Demonstrate the ability to analyze historical telemetry data.

3.3 Power inverter/power electronics

1. Demonstrate the ability to follow OEM guidelines for removal and replacement (R&R) of power inverter/power electronics components.
2. Demonstrate the ability to follow OEM guidelines for troubleshooting power inverter and power electronic faults.
3. Demonstrate the ability to measure, interpret and record power inverter resistance values.
4. Demonstrate the ability to program inverters (if applicable).

5. Demonstrate the ability to diagnose and determine if the inverter needs reprogramming or replacement.

3.4 Energy storage system

1. Demonstrate the ability to follow OEM guidelines for R&R of ESS components.
2. Demonstrate the ability to follow OEM guidelines for safely troubleshooting ESS faults.
3. Demonstrate the ability to identify ESS thermal management system faults and to troubleshoot/repair as needed.
4. Demonstrate the ability to diagnose/troubleshoot control system faults (positive contactors, negative contactors, pre-charge resistors, etc.).
5. Demonstrate the ability to perform string equalization/battery balancing using appropriate procedure, as required.

3.5 Power generation/charging

1. Demonstrate the ability to follow OEM guidelines for R&R of power generation/charging components.
2. Demonstrate the ability to follow OEM guidelines for troubleshooting power generation/charging faults.
3. Demonstrate the ability to inspect all charging interfaces (J1772, J3105, J2954, J3271) as applicable for faults and/or damage (burn marks, pitting, corrosion, etc.), and troubleshoot and repair as necessary.
4. Demonstrate the ability to differentiate charger vs. bus-related faults and to repair/troubleshoot as necessary.
5. Demonstrate the ability to diagnose ground fault monitoring for proper functionality and to troubleshoot/repair as necessary.
6. Demonstrate the ability to test and identify insulation resistance values and deviations and to repair faults as necessary.
7. Demonstrate the ability to determine isolation resistance values, recognize when they are out of specification, and troubleshoot and repair as necessary.

3.6 High-voltage cables

1. Demonstrate the ability to follow OEM guidelines for R&R of high-voltage cable and bus bar components.
2. Demonstrate the ability to follow OEM guidelines for troubleshooting high-voltage cable and bus bar faults.
3. Demonstrate the ability to diagnose whether high-voltage cabling needs to be repaired or replaced and carry out procedures as necessary.
4. Demonstrate the ability to correctly build or repair cables (stripping insulation, crimping lugs, etc.), and carry out procedures as necessary.

3.7 Traction motors

1. Demonstrate the ability to follow OEM guidelines for R&R of traction motor components.
2. Demonstrate the ability to follow OEM guidelines for troubleshooting traction motor faults.
3. Demonstrate the ability to perform insulation/winding resistance tests on each motor phase.

3.8 Data communication networks

1. Follow OEM guidelines for R&R of data communication network components.
2. Follow OEM guidelines for troubleshooting data communication network faults.

3. Demonstrate the ability to analyze CAN network/messages.
4. Demonstrate the ability to determine CAN network integrity.
5. Demonstrate the ability to use oscilloscope to identify noise on the CAN bus network/data communication line.
6. Demonstrate the ability to graph and interpret live data, or that of a recent trace file.
7. Using fault data, demonstrate the ability to perform root cause analysis on ZEB subsystems.

3.9 Control systems (propulsion, multiplexing, battery management system, etc.)

1. Demonstrate the ability to follow OEM guidelines for R&R of control system components.
2. Demonstrate the ability to follow OEM guidelines for troubleshooting control system faults.
3. Demonstrate the ability to interpret OEM schematics when determining control system faults.
4. Demonstrate the ability to troubleshoot control system faults using ladder logic documents, when applicable.

Related APTA standards

APTA BTS-BMT-RP-004-10, "Training Syllabus to Instruct/Prepare for the ASE Transit Bus Electrical/Electronics Test"

References

29 CFR Part 1910 Subpart S

NFPA 70E Standard for Electrical Safety in the Workplace

SAE J1772, Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler

SAE J3105/1, Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices Infrastructure-Mounted Pantograph (Cross-Rail) Connection

SAE J2954/2, Wireless Power Transfer for Heavy-Duty Electric Vehicles

SAE J3271, Megawatt Charging System for Electric Vehicles

Abbreviations and acronyms

AC alternating current
ASE Automotive Service Excellence
AWG American Wire Gauge
BDU battery disconnect unit
BEB battery electric bus
BTMS battery thermal management system
CAN controller area network
CNG compressed natural gas
DC direct current
ESS energy storage system
HFCB hydrogen fuel cell bus
HV high voltage
HVAC heating, ventilation, air conditioning
HVIL high-voltage interlock loop
HVJB high-voltage junction box
ICE internal combustion engine
LOTO lockout/tagout
LV low voltage
mA milliampere
MSD manual service disconnect
MUX multiplexing
OEM original equipment manufacturer
PGN Parameter Group Number
PM preventive maintenance
PPE personal protective equipment
R&R removal and replacement
SAE Society of Automotive Engineers
SOC state of charge
VFD variable frequency drive
ZEB zero emission bus

Document history

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