UNDERSTANDING ZERO-EMISSION BUS MAINTENANCE

PART 1 – MAINTENANCE

Funding partners:

Implementing agencies:
MAINTENANCE OF ELECTRIC BUSES
ELECTRIC BUSES AROUND THE WORLD
<table>
<thead>
<tr>
<th></th>
<th>Environmental Impacts</th>
<th>Operation &amp; Maintenance</th>
<th>Capital Investments and O&amp;M Expenses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tail-pipe emissions</td>
<td>GHG emissions</td>
<td>Passengers comfort</td>
</tr>
<tr>
<td>Diesel</td>
<td>--</td>
<td>--</td>
<td>+</td>
</tr>
<tr>
<td>Hybrid</td>
<td>--</td>
<td>--</td>
<td>++</td>
</tr>
<tr>
<td>CNG</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>(H_2) Fuel cell</td>
<td>+++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Electric</td>
<td>+++</td>
<td>+</td>
<td>+++</td>
</tr>
</tbody>
</table>
UNDERSTANDING BASIC COMPONENTS

It is vital to have an understanding of the basic components of an electric vehicle, including the charging components.

• Power train parts, including the traction motor and transmission
• The battery packs and battery monitoring system (BMS)
• Charging ports and/or overhead charging interfaces
Major Components of Power Train
1. Battery Pack
2. Battery Management System
3. Traction Motor
4. Motor Controller
5. HV Power Distribution Unit
6. LV Power Distribution Unit
7. DC-DC Convertor
8. Vehicle Control Unit
9. Pneumatic System
10. Hydraulic System
11. Cooling System
12. Bus Aux unit
   • Compressor motor -> Compressor
   • Steering motor -> Steering
13. Lighting & Horn
EQUIPMAKE E-BUS CHASSIS
**BATTERY: COMPLEX FUEL TANK**

**Gasoline Powertrain**
- More Complex
- > 20,000 moving parts
- High Maintenance Cost

**Electric Powertrain**
- Less Complex
- < 20 moving parts
- Low Maintenance Cost

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http://www.circuitstoday.com/working-of-electric-cars; Images from Web
INSIDE LIB BATTERY

MONO-CELL
- BASIC CELL
- CHEMISTRY
- BASIC VOLTAGE LEVEL

CELL
- STACK OF (e.g., 20) MONO-CELLS CONNECTED IN PARALLEL

MODULE
- MANY CELLS IN SERIES

BATTERY PACK
- SEVERAL MODULES OR
- MANY CELLS
- VOLTAGE: 400 V

BATTERY SYSTEM
- SEVERAL BATTERY PACKS IN PARALLEL
- ENERGY: >15 KWH

UNDERSTANDING LIB

LCO/ NCA/ NMC/ LMO/ LFP

Graphite/ LTO

GIF: https://gifer.com/en/LCEZ; Other images from Web
LIB SAFETY: THERMAL RUNAWAY

Material Degradation

Stage 1

Stage 2

Stage 3

Battery Failure or Abuse

Temperature Increases

Thermal Runaway

Battery Management System (BMS) – To monitor and protect Li-ion battery during operation

https://advances.sciencemag.org/content/4/6/eaas9820.full;
LIB: CHARGE RATE

C-rate: Rate at which battery is charged / discharged

SOC: State of Charge (SoC) describes how full a battery is

LIB: CHARGE RATE

**LIB: DEPTH OF DISCHARGE**

DoD: Depth of Discharge (DoD) measures how much of stored energy is used at each cycle.
LIB: EFFECT CHARGE RATE & DOD

Cycle Life vs. Depth of Discharge (DOD)
Discharge 0.5 C / Charge 0.5C @ 25°C (77°F)

Remaining Capacity

0  2000  4000  6000  8000  10000  12000  14000

50% DOD
80% DOD
100% DOD

https://batteryuniversity.com/learn/article/ultra_fast_chargers
https://modernsurvivalblog.com/alternative-energy/lithium-iron-phosphate-battery-cycles/
https://solarbuildermag.com/energy-storage/know-your-battery-specs-nameplate-capacity-10-kwh-vs-usable-capacity-7-kwh/
LIB: STATE OF HEALTH (SOH)

SOH Indicates
- Performance of the battery
- Useful lifetime of the battery consumed

Any Arbitrary parameter defined by the Battery Management System
- Internal resistance / impedance / conductance
- Capacity
- Voltage
- Self-discharge
- Ability to accept a charge
- Number of charge–discharge cycles
- Age of the battery
- Temperature of battery during its previous uses
- Total energy charged and discharged

SOH does not correspond to one physical parameter but a combination!
A typical Open Circuit Voltage (OCV)-State of Charge curve for Li-ion Battery

Predictable Cycle
UNDERSTANDING BATTERY - BMS - CAN
BMS

• Continuously monitors temperature, voltage and current out of the battery pack and to operate in safe conditions
FUNCTIONS OF BMS

• Safety
  – Overheating
  – Overcharging
  – Electrical isolation
• Performance Optimization
• Health Monitoring and Diagnostics (SoC and SoH)
• Communication – Responsible for communication with all the ECUs
CAN COMMUNICATION

- Control Area Network Bus (CAN) – ISO standard for on-board vehicle communication between electronic components and the vehicle
POWER DISTRIBUTION UNIT

• It supports function converting and power distribution to every systematic unit.
  – motor control unit,
  – battery management system,
  – charging system, heating system, etc.

PDU can also provide short circuit protection, current leaking protection and IP protection.

Battery lifespan is longer and maintenance cost of EV is reduced with this unit (Easy maintenance, convenient installation, space saving and reliable electric connection).
PERMANENT MAGNET SYNCHRONOUS MOTOR

• Similar in construction to the BLDCs.
• But the major difference is in the back emf.
• PMSM has a sinusoidal back emf whereas BLDC has trapezoidal one.
• They have a high power rating and can be used in high-performance applications such as buses.
DIFFERENCE BETWEEN EV MAINTENANCE AND DIESEL MAINTENANCE

EV maintenance involves more visual inspections and checks.

Vs

Diesel maintenance includes parts and fluid replacement.
MAINTENANCE COSTS

Cost per mile maintenance needs by a bus system

Based on study of King County metro fleet
<table>
<thead>
<tr>
<th>System</th>
<th>Battery Cost per Mile ($)</th>
<th>Battery Percent of Total (%)</th>
<th>Diesel Cost per Mile ($)</th>
<th>Diesel Percent of Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion-related</td>
<td>0.05</td>
<td>18.6</td>
<td>0.13</td>
<td>27.8</td>
</tr>
<tr>
<td>Cab, body, and accessories</td>
<td>0.13</td>
<td>49.7</td>
<td>0.24</td>
<td>50.7</td>
</tr>
<tr>
<td>PMI</td>
<td>0.03</td>
<td>10.8</td>
<td>0.04</td>
<td>8.4</td>
</tr>
<tr>
<td>Brakes</td>
<td>0.01</td>
<td>4.5</td>
<td>0.03</td>
<td>5.9</td>
</tr>
<tr>
<td>Frame, steering, and suspension</td>
<td>0.00</td>
<td>1.0</td>
<td>0.00</td>
<td>0.4</td>
</tr>
<tr>
<td>HVAC</td>
<td>0.01</td>
<td>4.4</td>
<td>0.02</td>
<td>5.0</td>
</tr>
<tr>
<td>Lighting</td>
<td>0.01</td>
<td>2.7</td>
<td>0.00</td>
<td>0.3</td>
</tr>
<tr>
<td>General air system repairs</td>
<td>0.01</td>
<td>4.1</td>
<td>0.00</td>
<td>1.1</td>
</tr>
<tr>
<td>Axles, wheels, and drive shaft</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.2</td>
</tr>
<tr>
<td>Tires</td>
<td>0.01</td>
<td>4.1</td>
<td>0.00</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.26</strong></td>
<td><strong>100</strong></td>
<td><strong>0.46</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
MAINTENANCE PRACTICES

• Promoting energy efficient driving behaviors
• Understanding and preparing for bus and fueling
• Infrastructure maintenance activities, including spare part
• Monitoring battery state of health
• Inventories and lead times
E-BUS MAINTENANCE

- Li ion Battery packs
- Battery Management System
- Power Distribution unit
- Traction Motor Drive
- Wire Harness systems
- Converter & Onboard Charger
- Vehicle Control Unit
- Mechanical Transmission system

Maintenance mostly electrical in nature

Maintenance mechanical in nature
Experience has shown that there are some driving differences with electric buses that reduce some of the wear and tear on brake pads. Bus drivers slow down differently with regenerative brakes. (Aber, 2016)
SPARE PARTS INVENTORIES

- Parts availability is a common issue with transit
- Require your bus and fueling infrastructure OEMs to provide a list of critical and recommended spare parts for on-site inventory to speed the repair process.
- Spare parts, request that they provide pricing and common lead times to determine expectations for vehicle downtime.
PREVENTIVE MAINTENANCE

• Require your bus and infrastructure OEMs to provide a list of activities, the time interval, skills needed, and required parts to complete each task.

• Some activities may require expertise from licensed electricians or from OEM technicians.
BUS MAINTENANCE

- Oil change for mechanical transmission parts:
  - Gearbox
  - Differential

- Coolant change in case of liquid cooled e-powertrain

- Electrical checks at key check points in a e-powertrain
  - Battery terminals
  - PDU input/output
  - Converter output for 12V/24V power lines
  - Continuity and electrical insulation check for the entire vehicle to ensure health of all electrical connection and avoid chassis short or any other critical leakage
BUS MAINTENANCE

- Signal checks at key check points viz:
  - CAN communication between all subsystems
  - Feedback signal from motor
  - Feedback signal from Battery Management System
  - Signal check between driver input (throttle) to Vehicle Control Unit

- Vehicle local log files check for powertrain error history:
  - This is an important implementation where a local storage on vehicle control unit should store all key powertrain errors and faults with time history.
OEMs provide maintenance manuals that outline preventative maintenance activities, as well as the time and skill to complete them, fault codes and troubleshooting.

- Depot charging stations
  - Often modular in design and require minimal maintenance

- Fast charging stations
  - Require ongoing preventative maintenance as they typically have cooling systems, filters, and other components
CHARGER MAINTENANCE

- Visual Inspection
- Tightening and retorquing of connectors
- Cleaning or replacement of filters
- A software diagnostic
- Replacement of cords and connectors due to wear and tear
USE OF MULTIMETER

Become familiar with this tool to keep you safe while performing a maintenance check on the electric bus.
• confirms there is no energy when checking a component on an electric vehicle.
• Reduces the amount of time spent troubleshooting.

measure electrical continuity and voltage drops across a fuse, circuit breaker, or component.
A good maintenance practice of electric buses can go a long way in durability and safety of buses.
GRACIAS