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Incident Summary

Onaping Depth BEV Fire

2020-07-06

Description of Incident

Incident type:

- Fire of a battery electric vehicle (BEV) in an underground mine

Date/Time and Location:

- Glencore's Sudbury Integrated Nickel Operations, Onaping Depth Mine
- July 6, 2020 – Approximately 10:40pm.

Cause of Incident:

- Prior to the incident, battery fuses were mistakenly removed and replaced with shunts. The vehicle was operated with *no overcurrent protection* in place.
- The BEV's traction inverter failed resulting in a short circuit.
- The uninterrupted short circuit produced a tremendous amount of heat for a prolonged period. This subsequently ignited the battery and front tires, destroying the front half of the vehicle.

Description of Incident

Incident Summary

- On the evening of July 6th, two technicians were troubleshooting a battery electric vehicle (BEV) located on the 47- 4 level at Craig Mine in Onaping, Ontario.
- At approximately 10:40pm, while working on the unit a sudden high intensity electrical arcing event and fire took place.
- Technicians were trapped behind the burning truck, but for a period of time were able to communicate with first responders to initiate an emergency response.
- They located a functioning compressed air line and remained at the air header until the Mine Rescue team extinguished the fire.
- The technicians were then safely extracted to surface.

Figure 1 – BEV Fire

Description of Incident

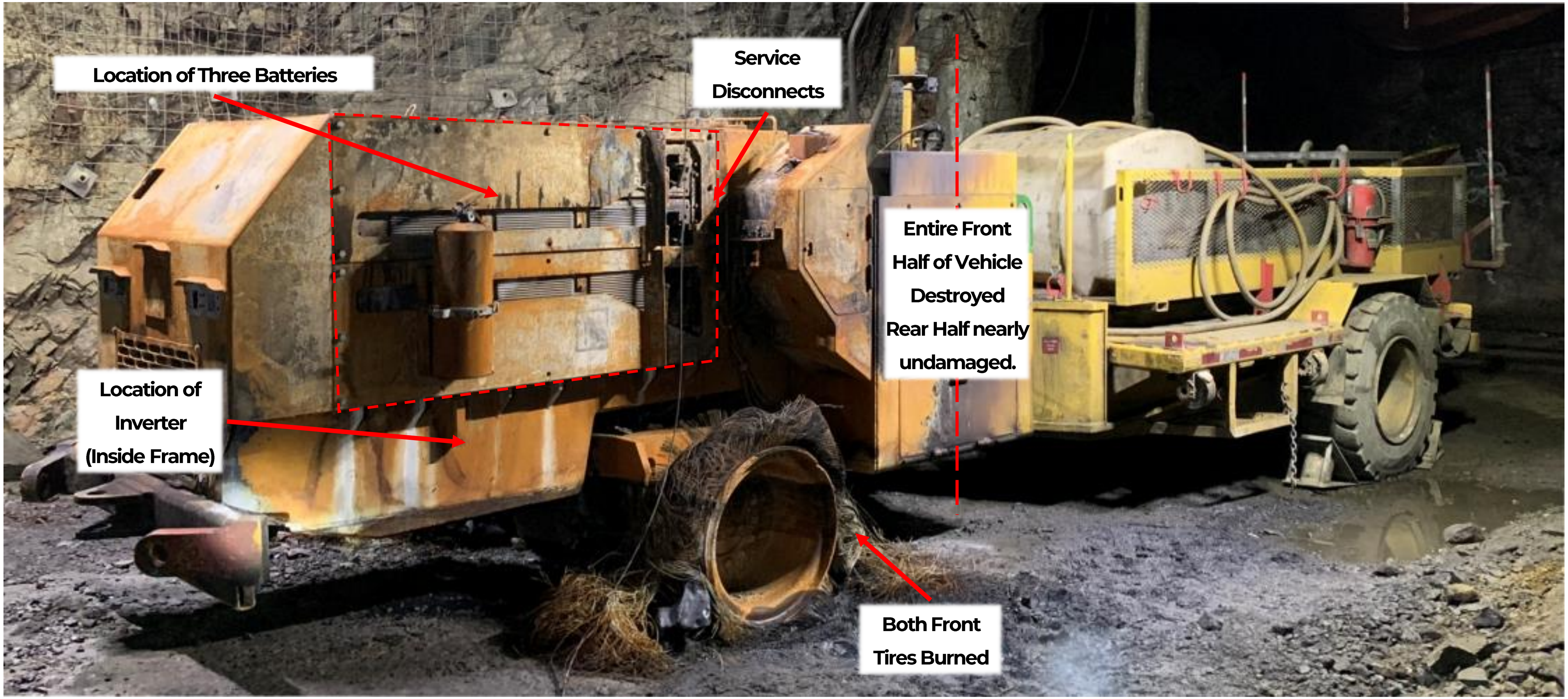

Figure 2 – Post-Incident Photo of BEV

Incident Timeline

Incident Timeline

July to August 2017

- Vehicle was delivered to OEM's shop in Sudbury in mid-2017.
- Energy storage system consisted of three identical battery packs. Each pack was equipped with an internal fuse, as depicted in Figure 3.
- During an early vehicle inspection, Glencore noted the absence of an external means of achieving a zero-energy state during maintenance and requested that this feature be added.
- To address this, one manual service disconnect per battery pack with unfused modules (i.e. shunts) was installed (see Figures 4 and 5).
- Vehicle was put into service at Craig Mine in Sept 2017.

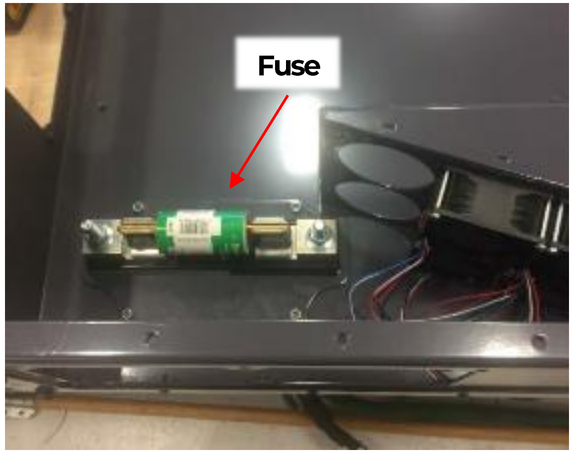

Figure 3 – Original Battery Fuse

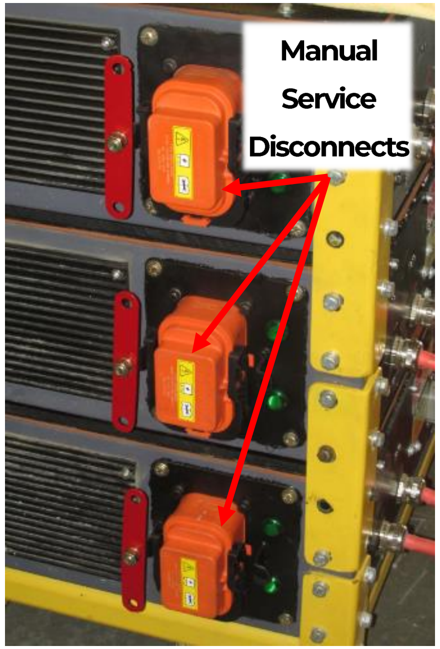

Figure 4 – Manual Service Disconnects

Figure 5 – Unfused Module

Incident Timeline

November 2017 to January 2018

- Improper towing resulted in traction inverter damage and blown fuses. The inverter and original fuses needed to be replaced.
- Accessing the fuses required unmounting and disassembling each battery pack. It was noted that a module with an integrated fuse was available for the manual service disconnect which would make replacing fuses easier in the future.
- The following modifications to the design were made in conjunction with changes to the towing procedure:
  - Three 250A fused modules were used to replace the unfused modules (see Figure 5)
  - The original, internal fuses were eliminated.
- The removed unfused modules were kept in inventory.

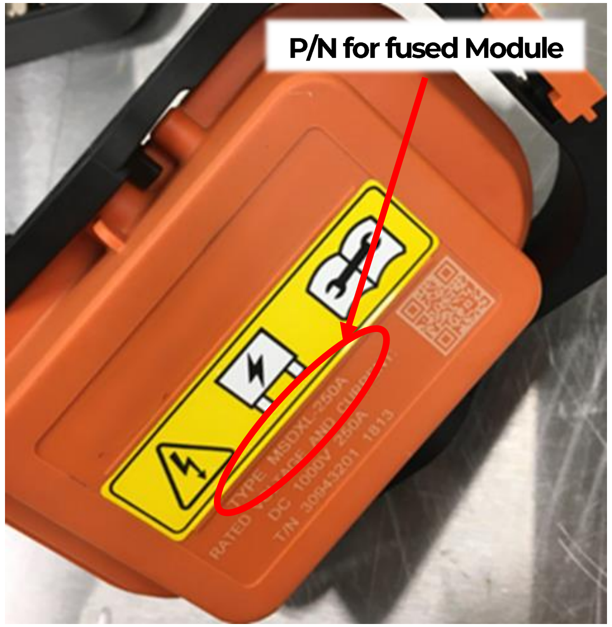

Figure 6 – Fused Module

Incident Timeline

June to October 2019

- Another improper towing incident occurred damaging the traction inverter
  - Once again the inverter and fuses needed to be replaced
  - A further revision to the towing method and procedure was also made.
- Instead of the required 250A fused modules, the unfused modules that were previously removed were erroneously re-installed.
  - The fused and unfused modules are identical in appearance apart from the model number printed in small text (see figure 7).
- The vehicle was returned to service and operated with ***no overcurrent protection in place*** for the main battery and traction inverter.

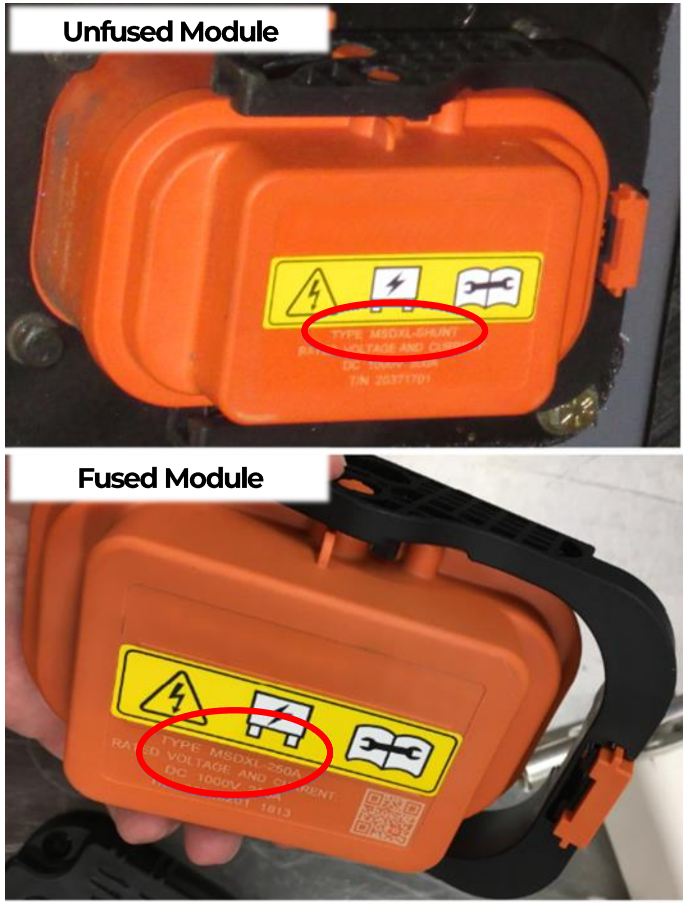

Figure 7 – Comparison of Modules

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Incident Timeline

July 6, 2020

- The inverter failed while OEM technicians were troubleshooting. With no overcurrent protection in place, a severe and uncontrolled electrical fault occurred.
- The investigation found unfused modules installed instead of the correct fused modules (see figure 8 and 9 comparing as found to new).

Figure 8 – Unfused Module (Internal)

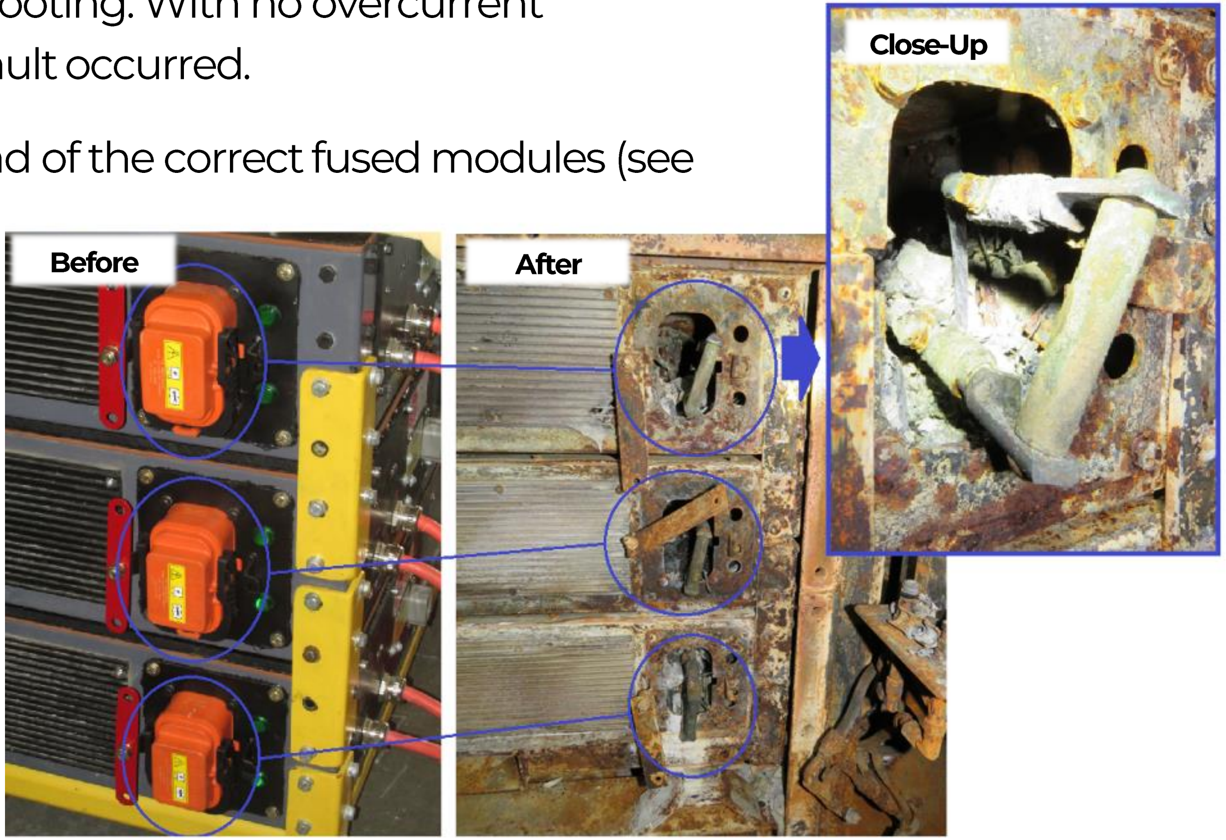

Figure 9 – Manual Service Disconnects – Before and After Incident

Incident Timeline

July 6, 2020

- The traction inverter was totally destroyed as a result of the failure.
- The failed inverter was further disassembled which revealed a significant portion of the traction inverter copper bus melted away (see figure 10).
- This is clear evidence of a prolonged and uncontrolled electrical fault that originated in the traction inverter which generated a tremendous amount of heat.

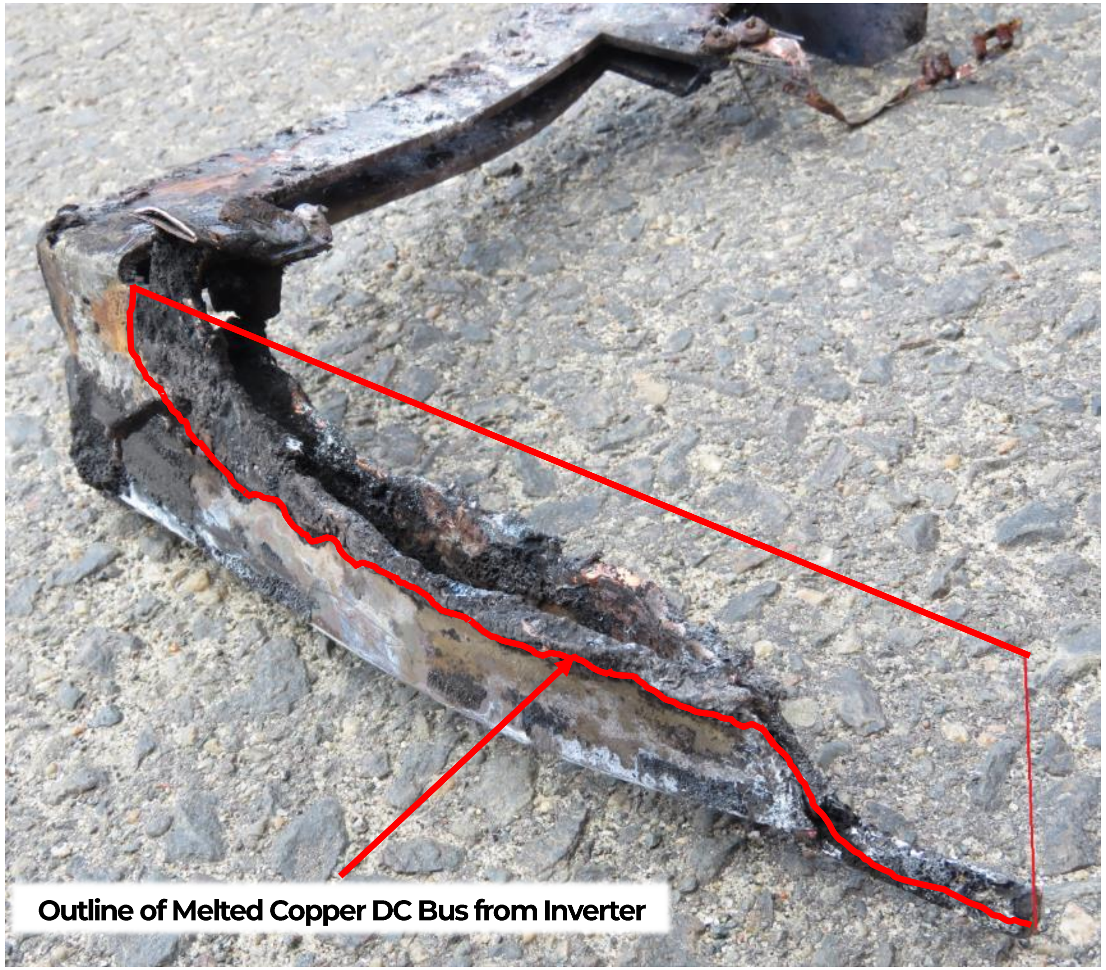

Figure 10 – Internal DC Bus Bar extracted from Failed Traction Inverter

Incident Timeline

- Figure 11 is a set of simplified battery pack schematics depicting the modifications that took place over the life of the battery electric vehicle leading up to the fire

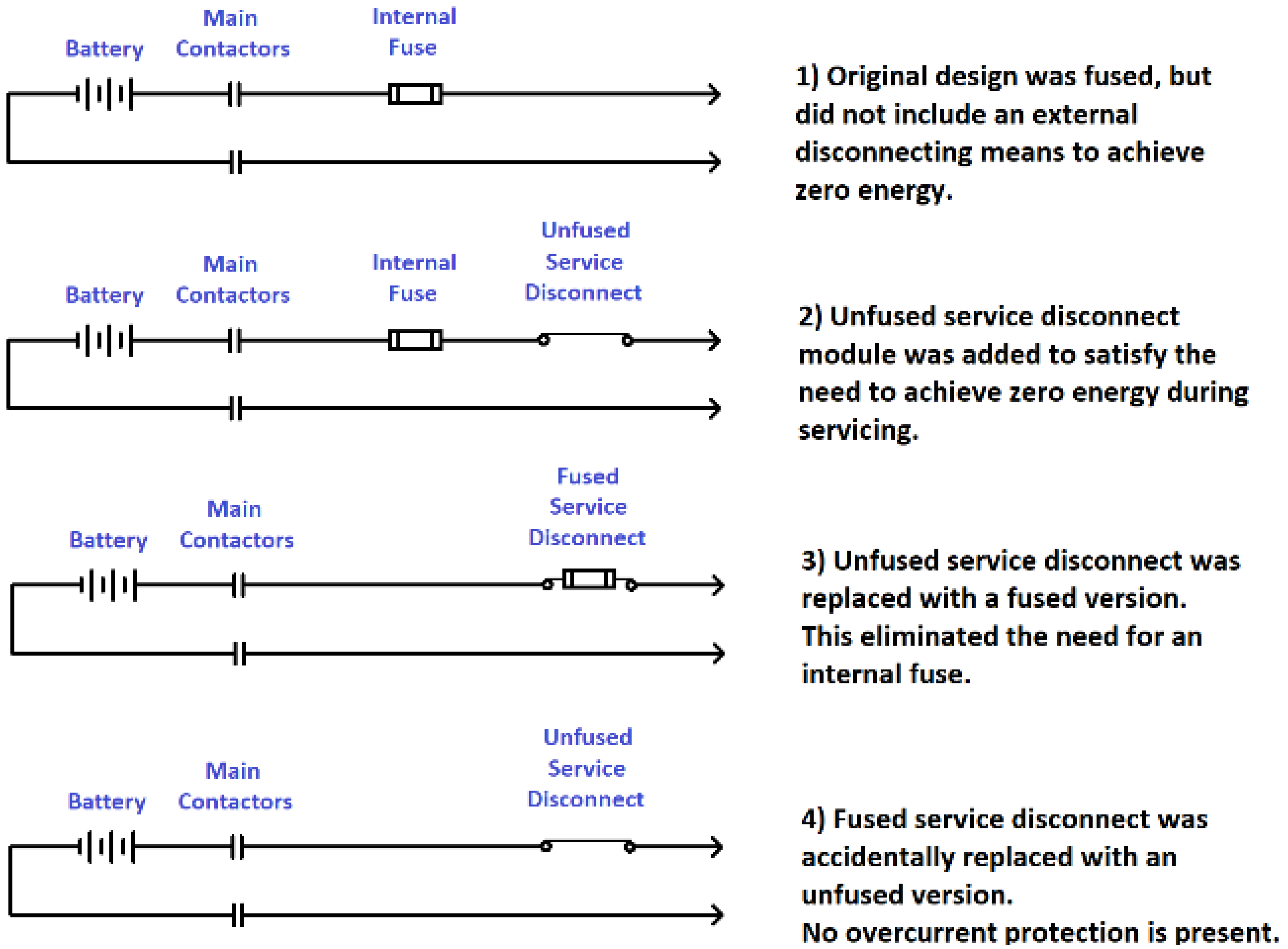

Figure 11 – Simplified Schematics depicting modifications to fuse arrangement.

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Incident Discussion

Preventions and Mitigations

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Incident Discussion

Preventions & Mitigations

- The following slides present ideas and suggestions for preventing such an incident in the future.

Incident Discussion

Preventions & Mitigations

Overcurrent Protection

- Overcurrent protection on BEVs is critical!
    - Give robust coverage / consideration of this topic in BEV specifications.
    - OEMs should provide clarity and transparency on this topic.
    - Purchasers of BEVs should have a clear understanding of the overcurrent protection scheme being employed.

Incident Discussion

Preventions & Mitigations

Overcurrent Protection

- Combination disconnect/fuse modules, like the one depicted in Figure 12, can be convenient. But perhaps they are ***too*** convenient.
  - Anyone can remove/change the module.
  - Easy to change fuse ratings, or as in this incident, eliminate the fuse altogether.
  - Not clearly/boldly marked as to what it is (rating, etc..)
  - Dual purpose – fuse *and* isolation means. This may not be a good thing.
  - If the main battery fuse does blow, should it be really easy to replace?

Figure 12 – Service Isolation Device

Incident Discussion

Preventions & Mitigations

Overcurrent Protection (continued)

- Consider specifying that Main fuses/overcurrent protection require a tool to remove or replace. This may help ensure that only authorized persons perform this task.
    - Battery fuses in particular should *never* blow unless a severe fault has occurred. It should not be a "routine" task to replace these – qualified person should be involved.
    - Still need to make sure it is safe for the person to remove/replace the fuses.
- Should ensure that labels are present, indicating make/model/rating of each overcurrent device. This way, it is clear to maintenance personnel what *should* be installed.
- Also need to ensure that the overcurrent protection devices themselves are well marked and easy to identify.
    - A fuse should *look* like a fuse. A circuit breaker should *look* like a circuit breaker. And a copper shunt should *look* like a copper shunt.

Figure 13 – Example of Fuse for EV Use

Incident Discussion

Preventions & Mitigations

Overcurrent Protection (continued)

- Give consideration to redundancy where overcurrent protection is concerned. On this vehicle, the main battery fuses were the *only* overcurrent protection in place between the batteries and the traction inverter.
  - If there had been a set of dedicated, properly rated inverter fuses, this incident would have been prevented – even in the absence of the main battery fuses.
  - At least two layers of overcurrent protection is advisable. This provides a layer of redundancy, and also could help with protection co-ordination.
- Finally, make sure the overcurrent protection is in place:
  - Carefully review the design during the engineering process.
  - Include overcurrent protection checks on commissioning checklists.
  - If the vehicle undergoes an overhaul or major repair, be sure to re-commission / re-check the overcurrent protection.
  - Check for the presence and condition of overcurrent protection during routine maintenance, at appropriate intervals.

Incident Discussion

Preventions & Mitigations

Towing

- The inverter failure was a result of towing the vehicle with the motor still coupled to the inverter.
  - Many vehicles use permanent magnet traction motors. These will generate a voltage when the rotor is turned.
  - This voltage can cause damage to the inverter.

- Give careful consideration to how a vehicle might be towed
  - OEMs should make the towing procedure as simple and straightforward as possible.
  - Operators of BEVs should understand the towing procedures.

- Ideally, the BEV should automatically switch to a "towing friendly" mode anytime it is not driving. The only operator action to initiate towing should be to disengage the brakes.

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Additional Thoughts

Additional Thoughts

Electrical Design / Arc Flash

- Need for transparency with respect to electrical design.

- Modelling of the electrical system
  - Single Line Diagram (SLD) of overall system is a must!
  - Available short circuit current from the battery system.
  - Are protective/control devices (fuses, circuit breakers, contactors...) appropriate for application?
  - Protection co-ordination / TCC curves

- Arc Flash Analysis - Challenging with DC systems - Dependent on:
  - Number + Capacity of batteries
  - Battery internal resistance / Available Fault Current
  - Selection and arrangement of Fuses

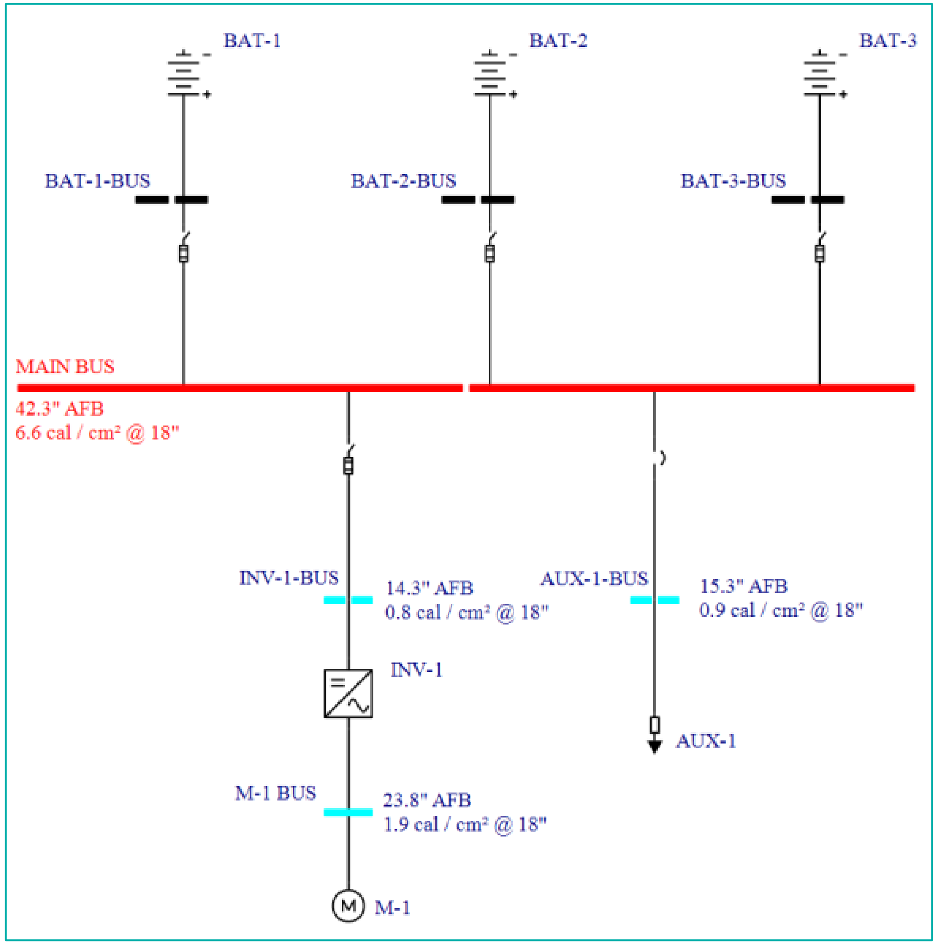

Figure 14 – Example of Electrical Single Line / Model

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Additional Thoughts

Transportation and Testing

- Li-Ion Batteries fall under Transportation of Dangerous Goods Regulations
  - Classified under UN3480.
  - Testing according to UN "Manual of Tests and Criteria" section 38.3.

- In addition, many other safety testing regimens
  - UL 2580 – Batteries for Use In Electric Vehicles
  - UNECE 100
  - SAE J2464, J2929

ANSI/UL 2580-2020

Addendum 99: Regulation No. 100

UNITED NATIONS

J2929

Additional Thoughts

Electrical / Battery Design Aspects

- Design to minimize likelihood of propagation
  - Modularized battery system, with thermal breaks
  - Selection of battery chemistry / configuration
  - Isolate / separate contactors, circuit breakers, etc... from batteries/cells.

- Monitoring / Troubleshooting of battery, drivetrain & electrical system
  - Robust BMS system – monitor battery parameters.
  - "Software" overcurrent / power flow monitoring
  - Fault Codes – Telemetry, remote support and strong documentation for troubleshooting

Thank You!

Questions?