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SINGAPORE INSTITUTE OF TECHNOLOGY

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Electrical Protection of Battery Energy Storage Systems against Fire Hazards

by

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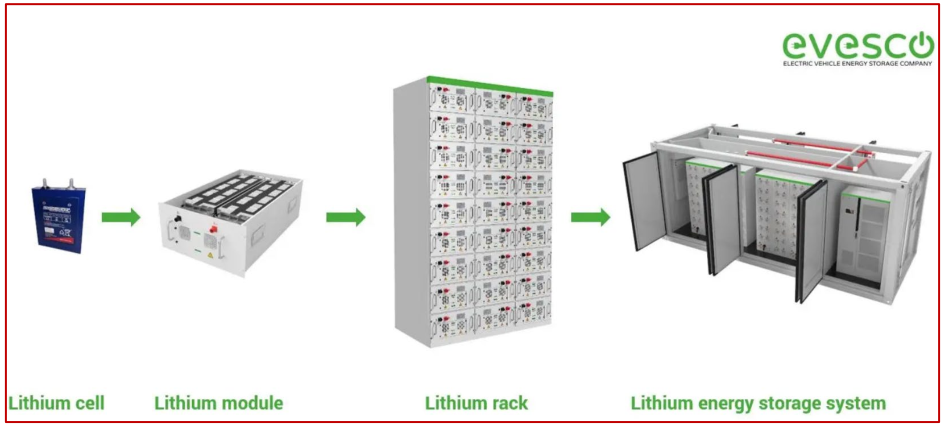
Introduction

- Battery energy storage systems (BESS) have unique challenges in protection against electrical faults like arcing faults and short circuits.
- Failure to adequately protect BESS against such faults can lead to catastrophic events such as battery thermal runaway and the consequential fire hazards.
- A BESS is commonly protected against electrical faults using a combination of fuses and circuit breakers.
- The ratings and characteristics of the protective devices must be properly selected, and their time-current characteristics and settings well-coordinated with the battery characteristics to ensure the safety and reliability of the BESS.

Lithium-ion Batteries - Applications

- Widely used, including EV, portable electronics, renewable energy storage systems
- Advantageous technical characteristics
  - Mature and proven technology
  - High energy density
  - Rechargeability
  - Low self-discharge rate
  - High cell voltage and voltage stability
  - Fast charging capability
  - Long cycle life and durability
  - Comparatively environmentally friendly
- LiB is prone to fire hazards primarily related to the chemistry and design of the batteries
- Understanding these hazards is crucial for safe handling, storage and safe usage of LiB



Fire Risks of Battery Energy Storage Systems

Lithium-ion BESS hazards

- Voltage – electric shock hazards
- Arc flash/blast
- Fire
- Vented gas combustibility
- Vented gas toxicity

Lithium battery factory fire Korea

https://youtube.com/shorts/b2xjs96Wf-o?si=WwwphsXqJeETFrhx

https://www.youtube.com/watch?v=PIyFtxiAx0E

Cause of EV fire that damaged 140 cars discovered

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South Korea sees panic selling of used EVs

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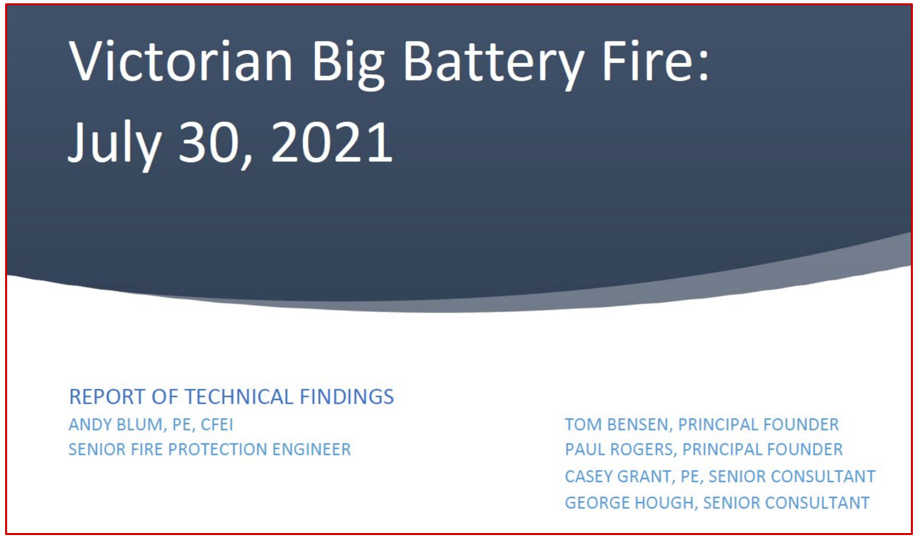

Victorian Big Battery Fire: July 30, 2021

REPORT OF TECHNICAL FINDINGS

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Background

The Victorian Big Battery (VBB) is a 300-Megawatt (MW)/450-Megawatt hour (MWh) grid-scale battery storage project in Geelong, Australia. VBB is one of the largest battery installations in the world and can power over one million Victorian homes for 30 minutes during critical peak load situations.[1] It is designed to support the renewable energy industry by charging during times of excess renewable generation. The VBB is fitted with 212 Tesla Megapacks to provide the 300-MW/450-MWh of energy storage. The Megapack is a lithium-ion battery energy storage system (BESS) consisting of battery modules, power electronics, a thermal management system, and control systems all pre-manufactured within a single cabinet that is approximately 7.2 meters (m) in length, 1.6 m deep and 2.5 m in height (23.5 feet [ft] x 5.4 ft x 8.3 ft).

On Friday, July 30th, 2021, a single Megapack at VBB caught fire and spread to a neighboring Megapack during the initial installation and commissioning of the Megapacks. The fire did not spread beyond these two Megapacks and they burned themselves out over the course of approximately six hours. There were no injuries to the general public, to site personnel or to emergency first responders as the Megapacks failed safely (i.e., slowly burned themselves out with no explosions or deflagrations), as they are designed to do in the event of a fire. Per the guidance in Tesla's Lithium-Ion Battery Emergency Response Guide[2] (ERG), emergency responders permitted the Megapack to burn and consume itself while nearby exposures were being monitored at a safe distance. The total impact to the site was two out of the 212 Megapacks were fire damaged, or less than 1% of the BESS.

2021 07 30 Tesla's Big Battery in Moorabool Victoria, Australia catches fire sending toxic smoke to

Fire Origin and Cause Determination

The origin of the fire was MP-1 and the most likely root cause of the fire was a leak within the liquid cooling system of MP-1 causing arcing in the power electronics of the Megapack's battery modules. This resulted in heating of the battery module's lithium-ion cells that led to a propagating thermal runaway event and the fire.

Other possible fire causes were considered during the fire cause investigation; however, the above sequence of events was the only fire cause scenario that fits all the evidence collected and analyzed to date.

Thermal runaway

- A phenomenon that can lead to fire hazards
- A self-perpetuating chain reaction of increasing temperature and heat generation within the battery
- Thermal runaway leads to rapid and uncontrollable release of heat and gas release (venting)
- As temperature rises, the flammable electrolyte within the battery can reach its ignition point, resulting in a fire
- The flammable gases released during thermal runaway can ignite, leading to the combustion of other components within the battery, generating smoke, toxic fumes and spreading the fire around
- Causes of thermal runaway
  - External physical damage to the battery
  - Internal defects or manufacturing flaws
  - Overcharging or over-discharging
  - Electrical faults – internal or external short

Fire hazards of lithium-ion Batteries

- Hazard causes – Electrical
  - Overcharge
  - Over-discharge
  - External short
  - Internal short
- High temperature hazards
  - Electrolyte decomposition and gas production - leading to venting, fire and vapor cloud explosion
  - Anode and cathode destabilization
  - Thermal runaway
- Mechanical damage hazards – EV crash-related fires
- Challenging to stop battery pack fire with water

Mitigation and safety measures

- Safety standards and regulations
- Battery design and materials used
- Battery management systems
- Thermal management
- Proper charging, charging and usage practices
- Training and education

Electrical protection of BESS

ESS Safety – Regulatory and Standards Requirements

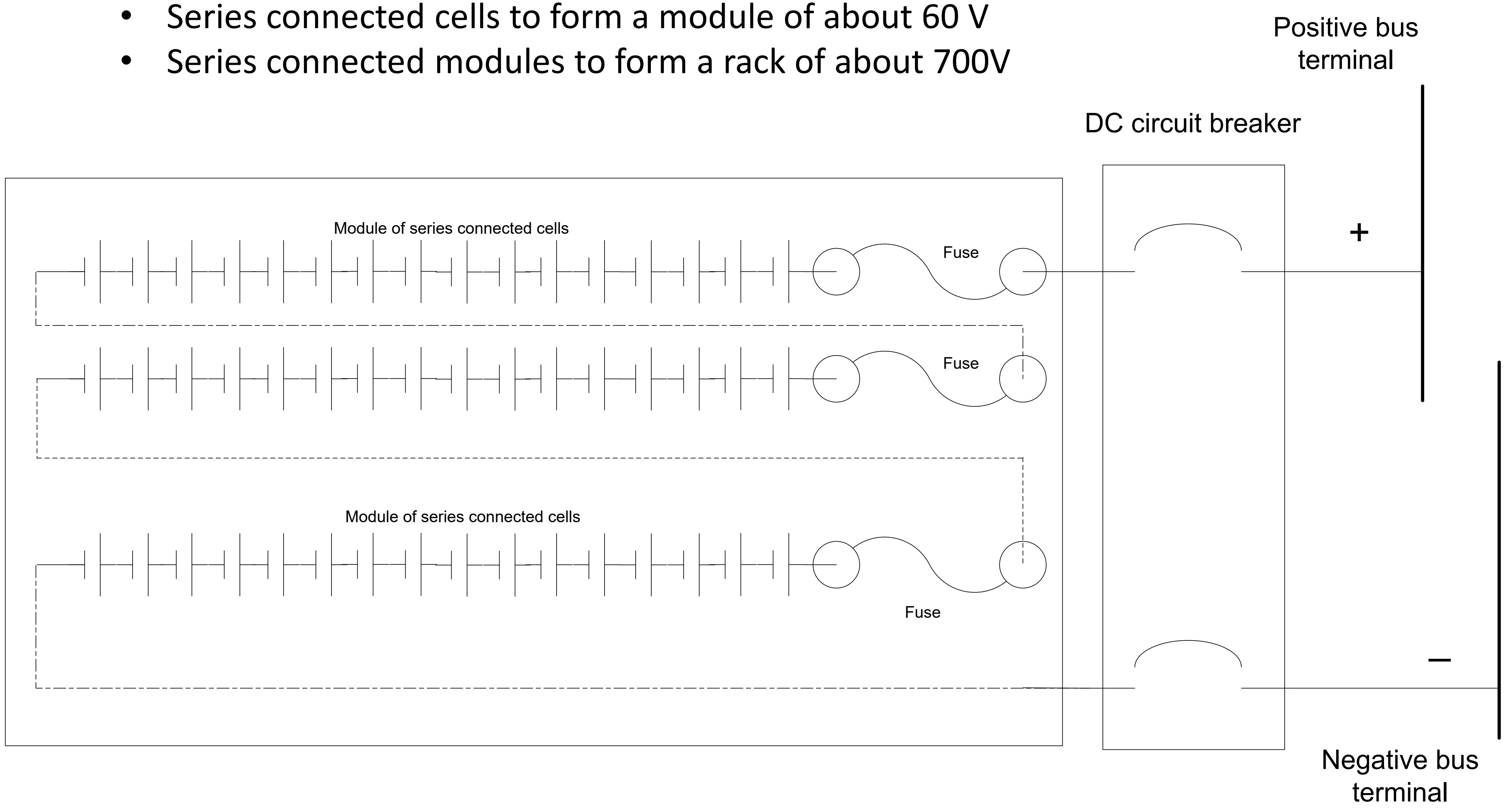
- Regulatory requirements
- Standards – e.g. UL Standards
  - Electrical tests, mechanical tests, environmental tests, …
  - Electrical tests – overcharge, high-rate charge, over-discharge, short circuit
  - Electrical safety – spacings (clearance & creepage distances), insulation levels and protective grounding/bonding, electrical connections and wirings
  - Production line tests – dielectric voltage withstand, continuing check of grounding and bonding system

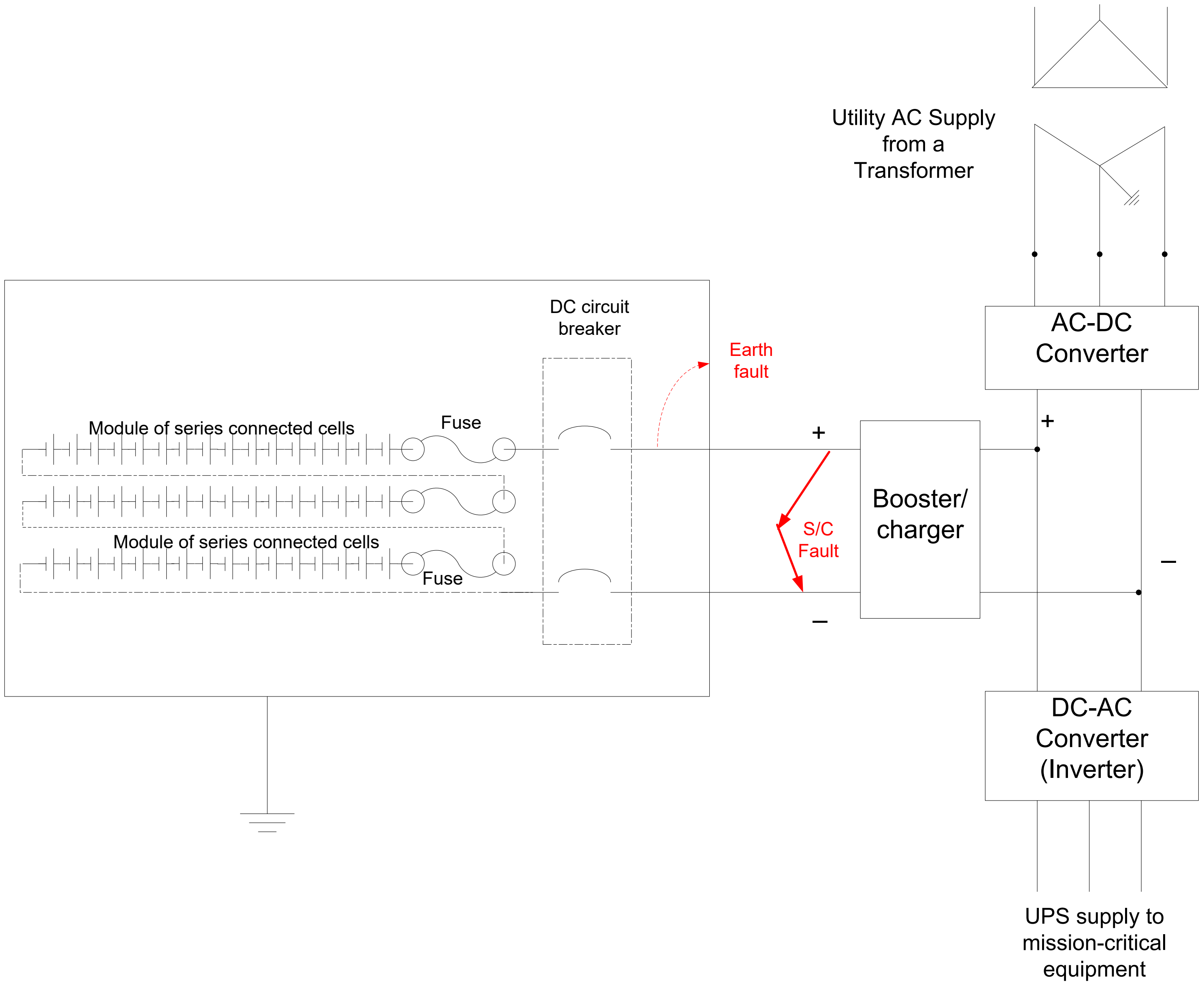
Electrical protection

- Overload – fuses, circuit breakers with relays, electronic current limiting
- Short circuit – fuses, circuit breakers
- Ground fault – RCD (residual current device), earth fault relay, insulation monitoring
- Arcing fault (fire) – arc detection device (signature current, light detection)
- Battery Management System (BMS) – active (proactive) protective device that monitors and maintains the cells within their safe operating region
- Passive protection – fuses & circuit breakers

High power, high voltage application, e.g. for UPS

- Series connected cells to form a module of about 60 V
- Series connected modules to form a rack of about 700V





Electrical circuit protection is challenging

- Battery modules protected by fuses
- Battery rack protected by circuit breaker
- Protection coordination/discrimination
- DC arcing fault may self-sustained
- DC earth fault path not easily identified
- Challenging to determine DC earth fault current for protection setting
- Fault contributions from BESS and charger

Circuit breaker tripping characteristics

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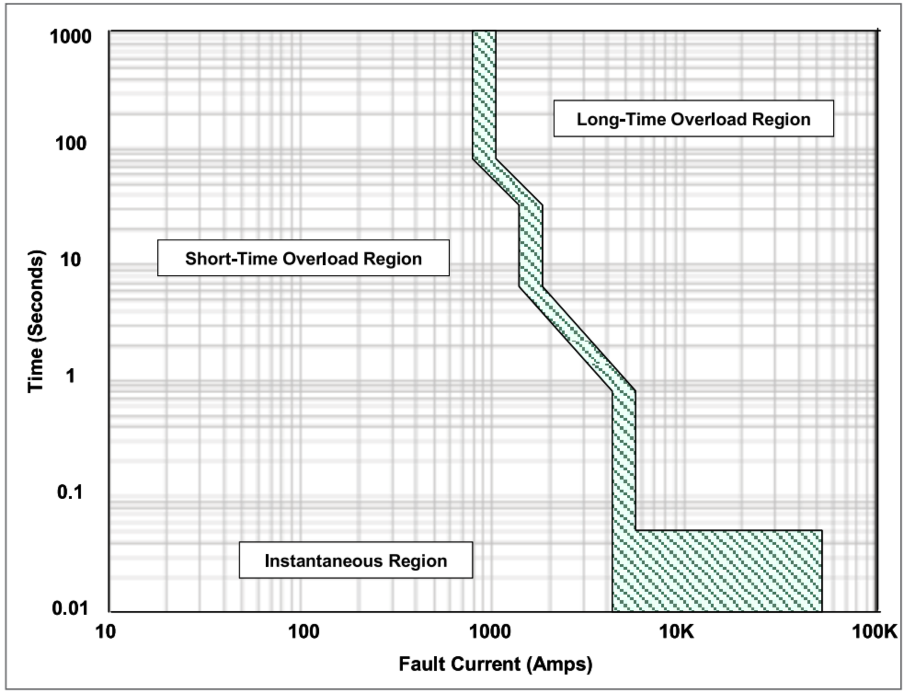
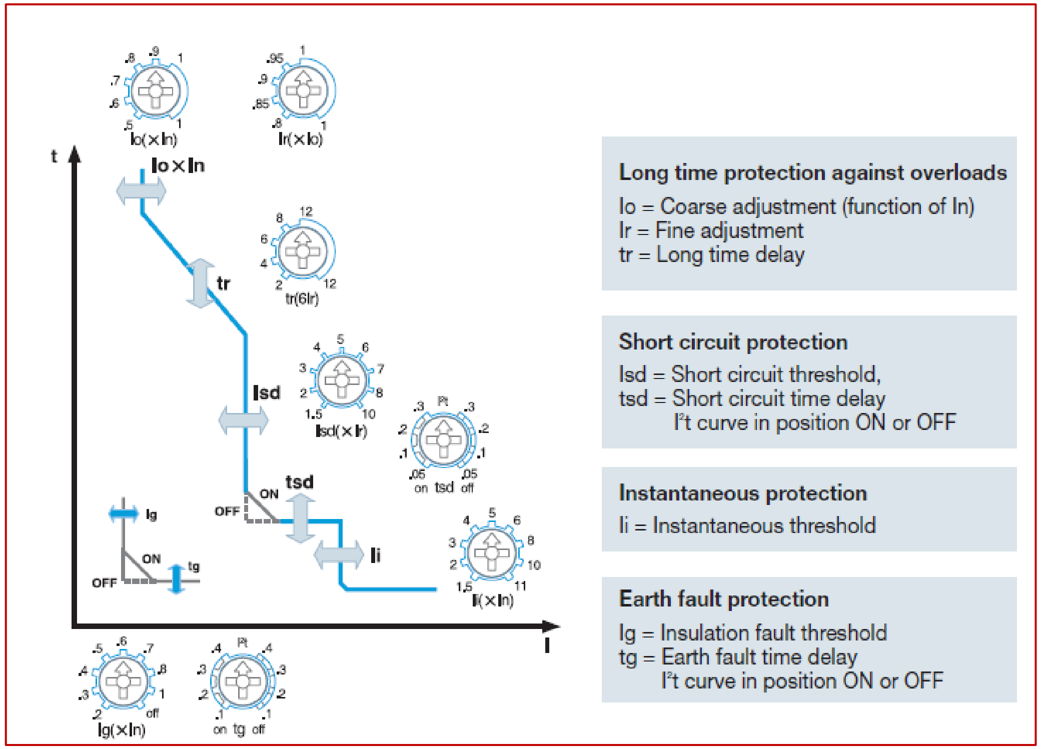
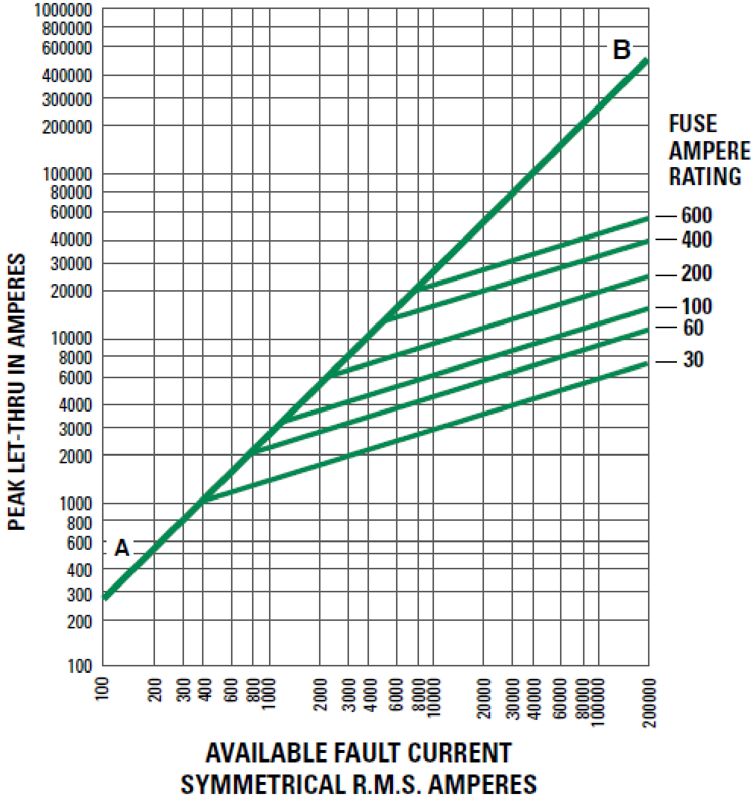


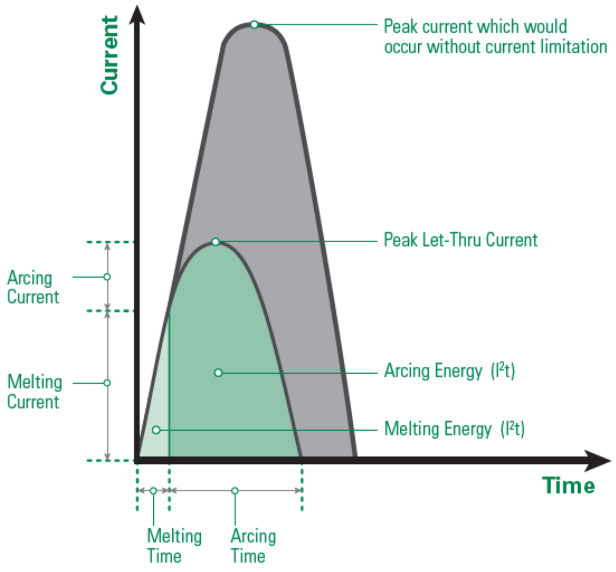


Example of Circuit Breaker Time-current Curve

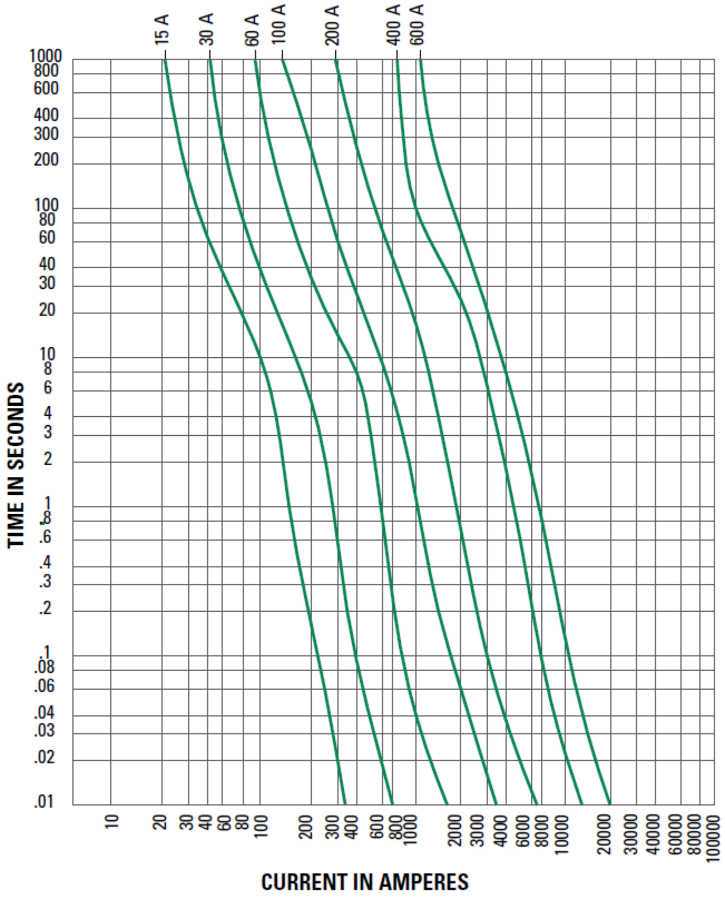
Source: Littelfuse Application Guide



Peak let-through charts

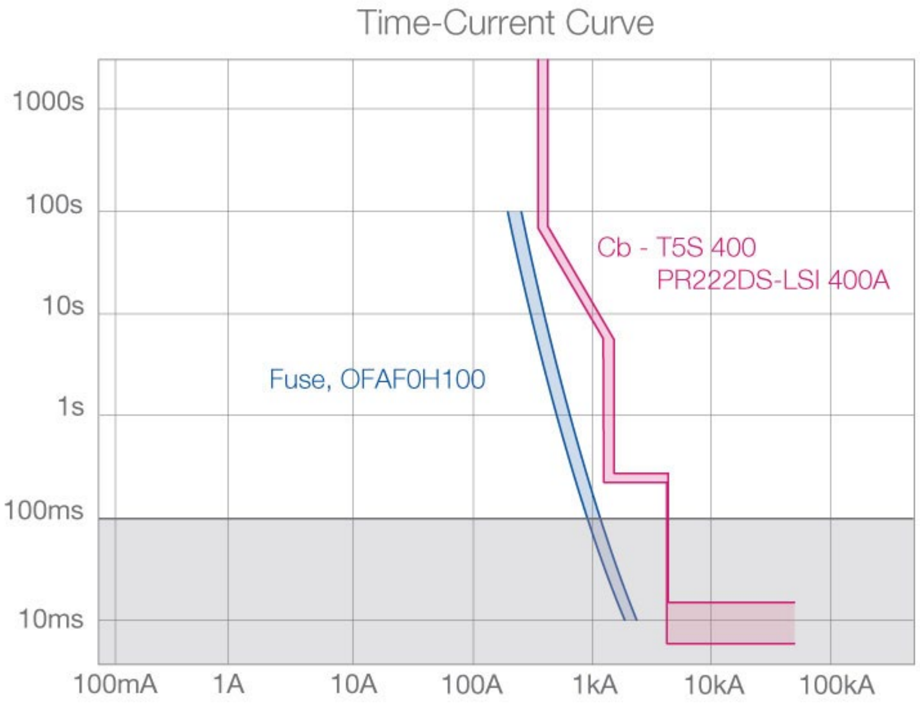


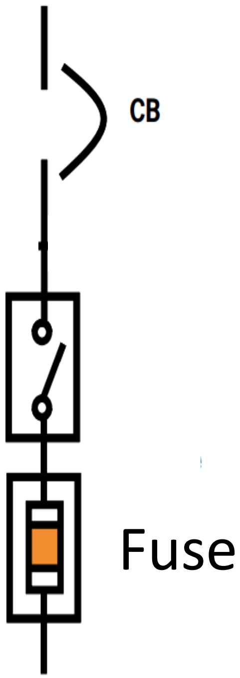
Current limiting effect of fuses

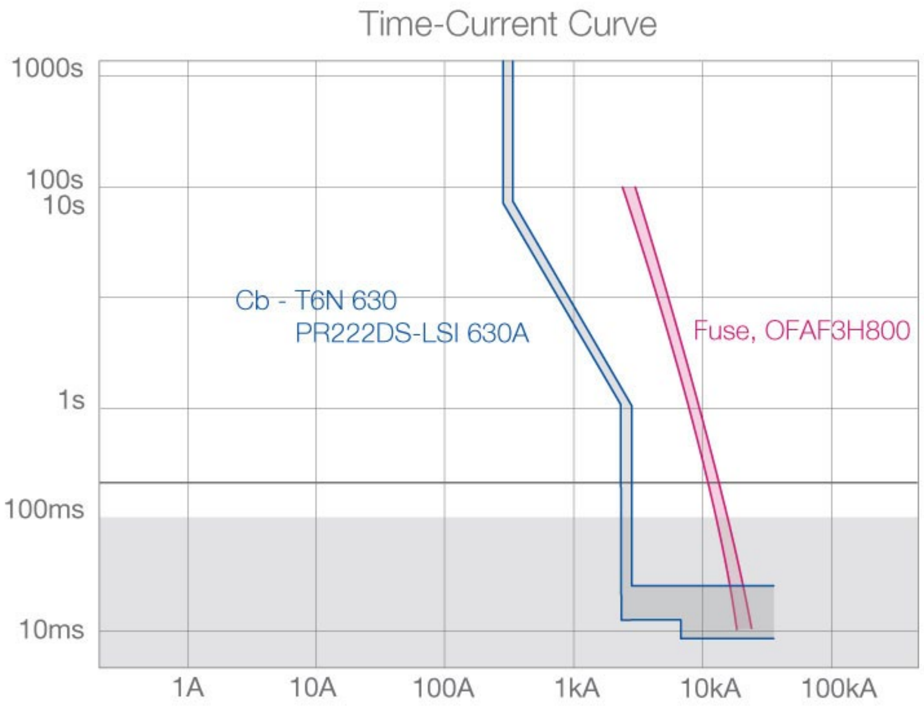


Average melting time curves for typical time-delay fuse

Challenges in electrical protection coordination-discrimination







Coordination curves of fuse and breakers taken from ABB website for discussion

https://new.abb.com/low-voltage/solutions/selectivity/focus-on/selectivity-with-fuses

Case study

- Arcing fault on DC busduct distributor
- Insufficient fault current to cause instantaneous tripping of circuit breaker
- Fuse for module protection rated at 150V, whereas BESS rack voltage of 700 V (the circuit voltage)
- The voltage rating of a fuse determines the ability of the fuse to suppress the internal arcing that occurs after a fuse link melts and an arc is produced.
- If a fuse is used with a voltage rating lower than the circuit voltage, arc suppression will be impaired, and the DC arcing may not be extinguished even after the fuse link has melted.
- A prolonged fault current due to arcing may cause thermal runaway of the battery cells leading to catastrophic failure and fire.
- Fuses use i^2t (thermal) protection characteristics, but thermal capacity of batteries before thermal runaway is generally not known. – a major challenge for protection coordination.

Thank you