An Overview of the Part Acceptance Process for Regulated Lithium Ion Batteries in Transportation"

Transportation Power Electronics

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Eric Schneider

Outline

- Introduction
- Ground Vehicle Applications
- Maritime Propulsion
- Aviation
- Testing Standards Overview
- Summary

Introduction

- Lithium ion battery systems go through many of the same types of testing that power electronics do
  - product validation/qualification
  - hazardous voltage safety requirements
- Lithium ion batteries and systems have extra requirements because of other safety concerns
  - Thermal runaway
- This presentation focuses on the testing procedures or requirements
  - ground transportation, maritime, and aviation industries
  - Mostly for propulsion, so these can be large batteries.
  - Definition: “regulated” means that the battery or battery system has a capacity of more than 100 Wh, which requires special shipping containment and testing

Propulsion Batteries in Ground Transportation

- Passenger vehicle applications are the most mature
- Early development of consortia in the US and Europe specifically addressed the need for testing standards
  - EUCAR in Europe
  - USABC/FreedomCar in the US
    - Developed in cooperation with Sandia National Labs.
    - You can find the test manuals on the USCAR website
      - Link at the end of the presentation
- Commercial vehicle standards are less mature
  - starting point for creating tests tend to be the passenger car standards

Propulsion Batteries for Maritime Applications

- The US Navy developed requirements last decade, mainly because Li-ion batteries were useful for small underwater vehicles
  - A good guide to the Navy battery safety program can be found in a link at he end of this presentation
  - It is a very difficult set of requirements and tests
    - Safety Data Package
    - Safety Testing
    - Safety Review
    - Approval
  - Lithium Iron Phosphate chemistry is able to pass

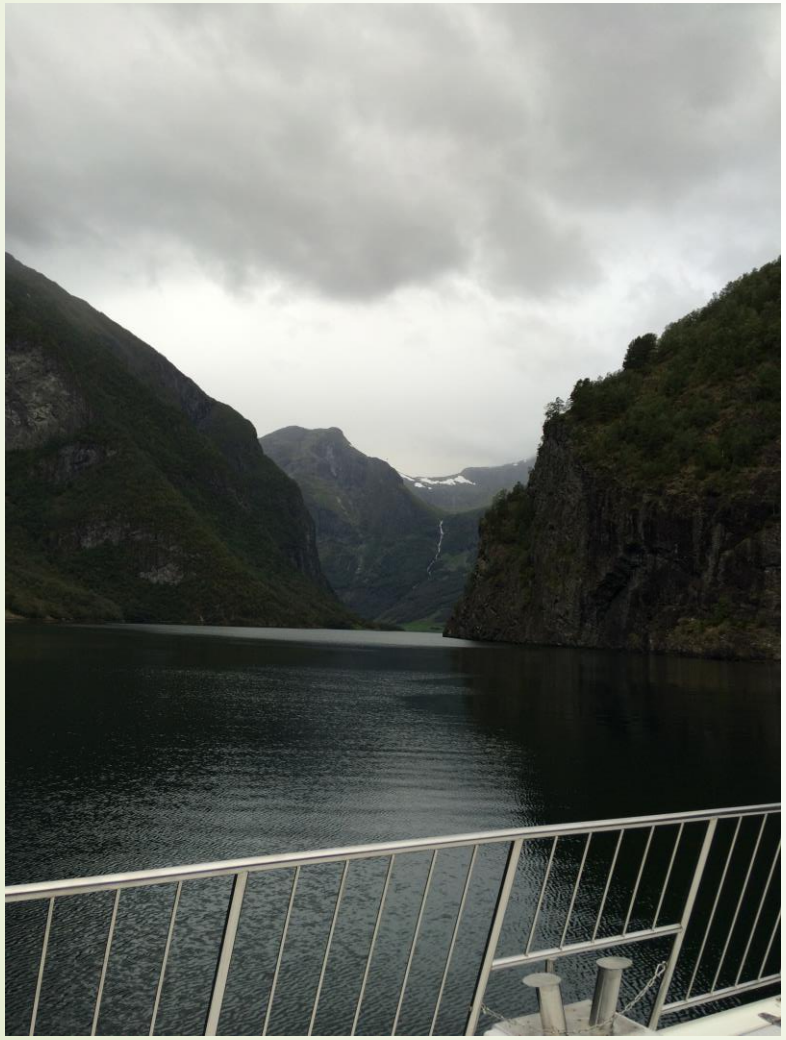
Commercial Maritime

- In commercial applications, Scandinavian countries such as Norway are leading the way forward
  - Hybrid and electric ferries or excursion boats
  - Risk management companies, such as DNV-GL, are developing testing standards.
  - Starting point was US Navy test standards
  - Li Iron Phosphate chemistry can pass
  - The Flag Country has the ultimate approval
  - You can find manuals for lithium battery approval for ships at a website included at the end

Hybrid Fjord Tour Boat Docked in Flam, Norway

- Diesel and/or Electric propulsion
- Li battery for limited "quiet" electric operation
- Quick dockside recharge

View from the Boat While in All Electric Propulsion – Maritime Battery Forum, Sep 2016

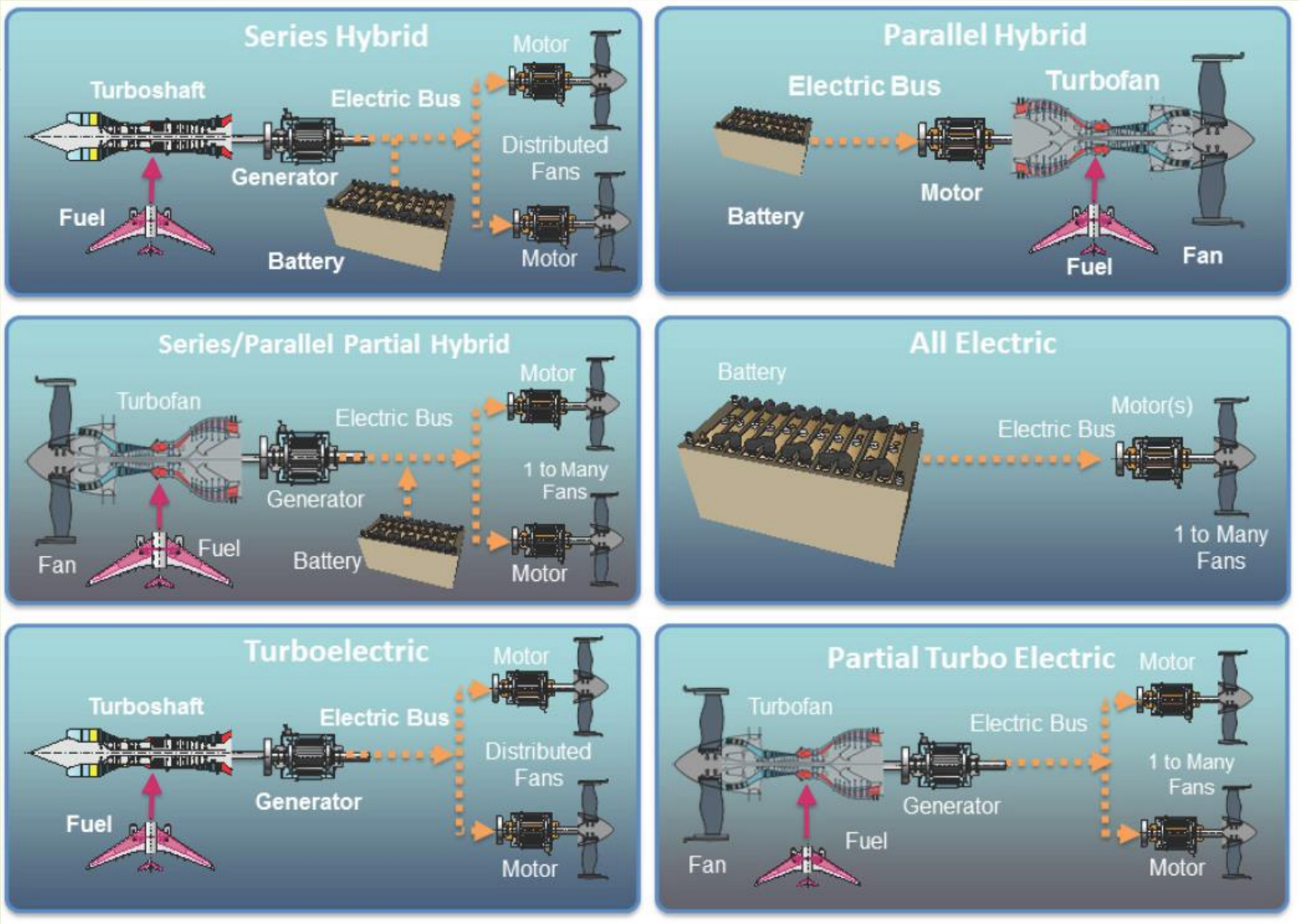


- Glaciers and waterfalls in the Aurlandsfjorden region

Li-ion in aviation - research

- Propulsion capable batteries for aircraft are still in the research stage
  - Studies by Boeing, NASA, and others set specific energy goals quite high-
    - 4 times more than today's batteries
- A web resource by the National Academies Press summarizes the various studies and goals for electric propulsion (Included at end)
    - A committee of the National Academies of Sciences, Engineering and Medicine looked at various architectures
      - All electric
      - Hybrid electric —Parallel hybrid
      - —Series hybrid
      - —Series/parallel partial hybrid
      - Turboelectric —Full turboelectric
      - —Partial turboelectric
    - Conclusion – partial turboelectric likely first

Image of Architectures



From: https://www.nap.edu/read/23490/chapter/7
Citation: National Academies of Sciences, Engineering, and Medicine. 2016. *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*. Washington, DC: The National Academies Press. Permission granted, conf # **11690407** https://doi.org/10.17226/23490.
SOURCE: Modified from James L. Felder, NASA Glenn Research Center, "NASA Hybrid Electric Propulsion Systems Structures," presentation to the committee on September 1, 2015.

Li-ion in aviation – in use

- There are lithium ion batteries of the "regulated" size on the Boeing 787, Airbus A350, and the F-35 fighter.
  - They are not for propulsion
  - Accepted by authorities, like the FAA, on a case-by-case basis
- The aircraft transport industry is quite concerned about lithium ion batteries as cargo
  - Recommendations and compliance for shipping go through the IATA
    - a large group of aviation industry companies
    - A good resource page for guidance material is listed at the end

An Overview of Battery Testing Types and Standards

- If you plan to have a Li-ion battery as part of you system, there is a list of the test types and standards that you could be asked to perform
  - Depends on the customer and the application
- Standards for testing have been created by well-known organizations
    - UL, NEMA, IEEE, and SAE
- The type of tests include –
    - external short circuits, abnormal charge, reverse charge, internal short circuit, and environmental testing
- There is a very good table of types and standards
  - Presentation called "Safety Li-ion management" from RECHARGE, the Advanced Rechargeable & Lithium Battery Association (website included at the end)

Standards Table from "RECHARGE"

	UL					NEMA	SAE	IEEE		BATSO	Telcordia	JIS	INERIS
Test Criteria Standard	UL 1642	UL2054	UL Subject 2271	UL Subject 2580	UL2575	C18.2M	J2464	IEEE 1625	IEEE 1725	BATSO 01	GR-3150	JIS C8714	ELLICERT D
External short circuit	•	•	•	•	•	•	•	•	•	•	•	•	•
Abnormal charge	•	•	•	•	•	•	•	•	•	•	•	•	•
Forced discharge	•	•	•	•	•	•	•	•	•		•	•	•
Crush	•	•	•	•	•	•	•	•	•	•	•	•	•
Impact	•	•	•	•		•		•	•				
Shock	•	•	•	•	•	•	•	•	•	•	•	•	•
Vibration	•	•	•	•	•	•	•	•	•	•	•	•	•
Heating	•	•	•	•	•	•	•	•	•			•	•
Temperature cycling	•	•	•	•	•	•	•	•	•	•		•	•
Low pressure (altitude)	•		•	•	•	•		•	•	•		•	•
Projectile	•	•	•	•				•	•				
Drop			•	•		•				•		•	•
Continuous low rate charging												•	
Molded casing heating test						•							
Open circuit voltage						•							
Insulation resistance				•		•							
Reverse charge			•	•									
Penetration			•	•			•						•
Internal short cicuit	•			•								•	
Immersion													•
Fire											•		•

From Saft

Summary

- For propulsion sized lithium ion batteries ground transportation applications are the most mature
  - There are many examples of safe use in the field
  - This is mainly because of an early and earnest to develop standard tests
- Maritime applications are becoming more common in select areas
- Aviation is focused on the transport of large li-ion batteries as cargo
  - Usefulness for propulsion is in the research phase.
- Many well-known international bodies have developed testing standards
- Power electronics manufacturers will be interested in knowing about such tests if they also provide power systems that include li-ion batteries
  - Project planning needs to take this into account

Referenced Websites

- USCAR
  - http://www.uscar.org/guest/teams/12/U-S-Advanced-Battery-Consortium-LLC
- US NAVY
  - http://dtic.mil/dtic/tr/fulltext/u2/a532003.pdf
- Commercial ships/boats
  - https://www.dnvgl.com/maritime/advisory/battery-hybrid-ship-service.html
- National Academy of Sciences, Engineering and Medicine Study
  - https://www.nap.edu/read/23490/chapter/7
- IATA
  - http://www.iata.org/whatwedo/cargo/dgr/Pages/lithium-batteries.aspx
- RECHARGE
  - http://www.rechargebatteries.org/knowledge-base/safety/

Contact

- LinkedIn – Eric Schneider, Technical Specialist – Development and Application of Power Electronics, Energy Storage, and Rotating Machines
  - Send a message/question and I will get notification and respond