Overview of the Unique Requirements and Challenges for Power Electronics in Mining Equipment

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Summary

1. Environmental Requirements
   a) Protection against extreme temperatures
   b) Dirt, debris and falling rocks
   c) Sealing against moisture
   d) Chemical resistance
   e) Explosive environments
   f) Vibration and shock

2. Voltage and Power Scalability

3. Serviceability Expectations
   a) Ease of serviceability
   b) Component level access

4. Modular Designs
   a) Caterpillar product line
   b) Power electronic building blocks
Protection Against Extreme Temperatures

• Extreme cold
  – -50C Ambient
  – Engine must be pre-heated to start
  – Equipment is left running between shifts to avoid this

• Extreme heat
  – Maximum Ambient: +65C
  – Coolant (water): +75C
  – Coolant (oil): +85C
  – Locomotive in a tunnel:
    • +85C for 10 minutes
    • +110C for 1 minute
    • Maximum delta: 15C/second
Dirt, Debris, and Falling Rocks

- Structural shielding required for protection against falling debris and collisions

- Excessive dust and rock material can be ingested by an inverter cooling system

- Conductive dust (surface mines)

- Explosive dust (coal mines)
Chemical and Weathering Resistance

• Power electronics enclosures must be resistant to many common mine chemicals including but not limited to:
  – Engine and transmission oils and additives
  – Gasoline, kerosene, diesel fuel, and Urea
  – Degreasers, soaps, and detergents
  – Battery acid, muriatic acid, paint strippers, and alkaline cleaner
  – Magnesium chloride and calcium chloride

• Enclosures must also be resistant to ambient conditions including:
  – Salt water splash and salt fog
  – Ozone
  – UV radiation
Sealing Against Moisture

Moisture/humidity

- In underground mining applications the humidity is almost always 100% with condensation, drip, and high pressure water spray (for dust control)

Submersion requirements

- Submersion up to 1 meter (including in salt water)

High pressure wash requirements

- High pressure wash in all directions (sometimes continuously during operation)
Explosive Environments

Underground soft rock mining (typically for coal) presents the added challenge of introducing an explosive atmosphere

- Enclosure must contain an explosion within and not allow ignition of the surrounding external gasses
- Explosion tests are performed with varying amounts of methane gas and ignition points
- Static pressure tests are performed at 150 psi or 1.5 times the maximum recorded pressure during the explosion testing
Vibration and Shock

Examples of applications with vibration up to 10Grms:
- Tracked equipment moving on hard rock or cement
- Driving on rough roads
- Chain conveyors
- Hard rock drills and cutting blades

Examples of applications with shock up to 100Grms:
- Material loading and handling
- Rail car coupling
- Frequent collisions with the tunnel wall

Typical verification testing includes:
- Capability testing (to failure)
- Response characterization
- Combined Environmental Testing
Voltage and Power Scalability

Voltage and power requirements vary greatly across the product line
• There is a need for products that can be easily scaled

AP1055E Track Asphalt Paver
70kW, 440Vac

794F AC Large Mining Truck
2.5MW, 2200Vac

8750 Dragline
~33MW, up to 32kVac

Inverter component
Inverter cabinet
Motor control center
Serviceability Expectations

• To avoid significant downtime, the electronics must be serviceable in the event of failure

• Each service component must be available to ship to anywhere in the world in less than 48 hours

• Each component must be able to be removed, re-installed, and checked-out in the field (often times in dark, damp, and dirty environments)

• Example: 795F AC Large Mining Truck inverter

• 220+ serviceable parts

• IGBTs, gate driver boards, capacitor, and heatsink are combined into one easily serviceable component (phase module)
Modular Designs

• The Caterpillar equipment product line consists of more than 300 different machines
  – Many include several different models and options
  – Volume ranges from several thousand to less than one per year
Modular Designs

• In order to reduce development costs, the power electronics must leverage multiple machines and be modular to fit new applications.

• The component requirements end up taking on the worst-case from each targeted application.

Phase Module

• Modular building block

- High vibration
- High power
- High temperature
- High shock

Large Mining Truck

Electric Rope Shovel

Locomotive

Hydraulic Mine Shovel
Summary

• Mining applications have unique and challenging requirements for power electronics components
• Easy scalability for power and voltage is needed
• Quick and efficient field serviceability at a component level is expected
• Modular designs are highly desirable
Thank you