Developing Safe and Reliable Hot DC Interconnections

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Presented by

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Outline of Presentation

Reliable DC Interconnections

• Hot swap and defining class levels
• Physics - breaking and making the flow of current
• Interconnect designs for suppressing the arcs during make/break
  – Mechanical features using sacrificial surfaces
  – Using PPTC technology
  – Other contact and housing design considerations
Introduction and Motivation

High Voltage DC applications continue to grow

- Natural fit with photovoltaic systems
- Natural fit with battery storage systems
- Increase efficiency of power delivery

Connectivity Solutions Continue to Grow
Hot-Swap (or Hot-Pluggable)

- Hot-Swap is an application or condition occurring when
  - breaking an electrical circuit path that is supporting the flow of current great enough to degrade the contacts.
  - making an electrical circuit path where there is a potential difference established between the connecting contacts great enough to degrade the contacts.

A Basic Electrical Power System with Interconnections between the Source and the Load
Hot-Swap – Defining Class Levels

- **Hot-Swap Class 0** – *Unpowered*: Traditional unpowered condition
- **Hot-Swap Class 1** – *Staged System Power Levels*: These applications make and break connections at voltages under <50V with current below <0.1A.
  – Example: Peripheral Component Interface (PCI) bus operate in this class.
- **Hot-Swap Class 2** – *High Available Power*: Substantial amounts of power are available through the interconnection but no significant energy transfer during mating and disconnect events.
  – Redundant power supply systems fall into this class.
- **Hot-Swap Class 3** – *High Energy Transfer*: This is the realm of arcs and sparks. Major potential differences and large energy transfer lead to damaging and dangerous dynamic events
  – Inserting DC Server Blades and disconnecting photovoltaic panels would fall into this class.
Hot-Swap Interconnection Development: Goals

- Hot-Swap interconnection development and application is concerned with limiting the degree of damage to the interconnection so that interconnection reliability is maintained over the specified life of the application. There are two conditions that must be understood:

  - Breaking an electrical circuit path that is supporting the flow of current great enough to degrade the contacts. *Inductive loads would lead to arcs under this condition.*

  - Closing an electrical circuit path where there is a potential difference established between the connecting contacts great enough to degrade the contacts. *Capacitive loads would lead to damage under this condition.*
Physics Behind the Arc: Plasma Formation

- Steps that result in a damaged connector during a break event
  - Initial low resistance wiping is followed by decreasing normal force and increasing contact resistance.
  - This results in a molten metal bridge being drawn between the separating contacts.
  - The bridge explosively vaporizes filling the gap with easily ionized metal vapor.
- These actions can punch holes in plating.
- With sufficient voltage and current, a conducting plasma forms in the gap which will vaporize any material near it for as long as it lasts.
- A fast velocity break reduces the effects of the arc.

Formation of plasma arc likely in HVDC applications
Breaking the Connection – Inductive Load

• Arches form between contacts due to the flow of electrons
  – Inductance is a big proponent for creating voltage spikes in the system that are often much higher than the system voltage.

The plot shows a relay that was energized at 24Vdc and disconnected.

• The voltage spike generated by the coil inductance is -260V
  – This voltage is what is actually being disconnected, not the 24Vdc.
Making the Connection – Capacitive Load

• Damage is done to contacts due to the flow of electrons
  – Capacitance in a circuit is a big proponent for creating current spikes in the system that are often much higher than the system’s steady current.

• The plot shows a contact being made on a 25mA steady state circuit with a 10uF capacitor
• A 7A current spike generated by the circuit charging to the source potential when mating
  – The spike decays to the steady state current in ~180us
Example of Arc Damaged Contacts

Separating Velocity and Arc Time
Tested at 42V, 60A

- $V = 0.25 \text{ in/s}$
  - Arc Time = 890.0 ms

- $V = 1.0 \text{ in/s}$
  - Arc Time = 328.0 ms

- $V = 3.0 \text{ in/s}$
  - Arc Time = 97.0 ms

- $V = 6.0 \text{ in/s}$
  - Arc Time = 50.6 ms
Designs for Arc Protection – Sacrificial Areas

Example: Crown Clip Junior - 150A Bus Bar Connector

- Clean Contact Interface
- First Make / Last Break
- Sacrificial Area: May be damaged by Sparks
- Copper Bus Bar Conductor
Example: MULTI-BEAM XL / XLE

Original Right Angle PCB Plug Contact – Dual Beam Design

New Right Angle Plug Contact – Multi-Beam Design (8 beams)

Original designs were not designed for true-hot-plug applications.
• They have been submitted and pass the UL requirement at lower ratings, however, the entire leading edge of the contact is destroyed during the hot-mating.

Improved “XLE” Contact:
- 17% thicker material
- Multiple contact points (6 beams)
- Extended tip acts as sacrificial contact in hot-plug applications

Low Power contact – after hot-plug testing

High Power contact
Designs for Arc Suppression – Auxiliary contact

Example: HVdc Connector

- The Ground Contacts engage first for safety
- The Auxiliary/Sacrificial Contact engages second
  - Auxiliary/Sacrificial Contact is in parallel with Power (PWR) Contact
  - A PPTC device can be used
- Housing features add acceleration into mating sequence to quench arc
- Power Contacts engage last
Introduction to Polymer Positive Temperature Coefficient (PPTC) Materials

• PPTC Material a blend of polymer and conductive particles
  – Creates network of conductive paths
• When the part trips, the polymer melts, breaking up the network of conductive particles
  – The volume of the material increases
  – The resistance increases as well
Under normal operating conditions, PPTC device remains low in resistance.

When fault occurs, the PPTC device heats up and increases in resistance, thereby protecting the equipment from fault.

PPTC device resets when fault is removed and cycled – returns to low resistance.

Resistance of the PPTC device increases with temperature.

The PPTC device is in series with the load.

Switched resistance $I = V/R_s$.
Examples of Market Uses of PPTC Devices

Battery Pack

Electric seat and window motors for automotive
Using PPTC Technology for Arc Protection

• With an unprotected connector, as the connection is broken, there is a large voltage drop across the connector
  – This may result in a large plasma arc

• If a PPTC device is placed in parallel with the contacts, when the connector is separated the current diverts to the PPTC device until it heats up and goes into a high impedance state
  – This reduces the main contact voltage and the auxiliary contact current and provides a safe disconnect
Example of PPTC Device + Connector
42V Automotive Application - Testing at 59V, 60A

In mated operation the majority of the current flows through the main power contact.

When separating, the PPTC device stops the current flow before the auxiliary contact separates.

With PPTC Device

Without PPTC Device

in normal operation
Example of PPTC Device + Connector
Photovoltaic SOLARLOK Connector - Testing at 550Vdc, 20A

Without PPTC Device

With PPTC Device
Contact Critical Zone

- Contact critical zone is the distance between first touch and adequate normal force.

- The longer the distance the more chances for damage and the longer time these events can last.
- The longer distance also allows damage and heating to the spring member and can lead to performance and reliability issues.
Connector Design Solutions

Housing Design Considerations

• For Hot Swap applications, the housing must also provide the means to control the engagement and separation velocity.
  – Velocity is critical
  – Housing features that quicken the transition between first touch and the full normal force contact position are desirable.
  – Auxiliary contacts and circuit protection devices provide additional protection. The time between auxiliary and main contact touches must be controlled by the housing design.

• The simplest way to stop an arc is to stretch it until it breaks
  – Magnets can force the arc into a longer path and air pressure can be used to blow it out of position.
  – The housing material can be selected to released chemicals that can absorb the arc energy, causing it to distinguish.
Conclusion

• There are different classes of hot swaps that represent how much energy is available to generate arcs during a make or break in the circuit
  – Some conditions can create significant damage on contacts
• New contact designs have been created to mitigate arcs during a highly energized hot swap
• Other technologies, such as PPTC devices, have been used with connectors to suppress arcs without any degradation to the contact surfaces
About the Authors

- **Robert Cid** is the Product Engineering Manager for TE Connectivity’s Circuit Protection Division. Robert’s work at TE Connectivity is focused on using circuit protection technologies in high voltage DC applications. He has been at TE Connectivity for 6 years. Before joining TE Connectivity, Robert worked at various revenue and venture capital start up companies throughout Northern California. He received his B.Sc in Applied Physics and a M.Sc in Engineering-Applied Science from the University of California, Davis.

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- **Ben Mosser** is an Engineering Director in the Communications and Industrial Solutions Business Unit at TE Connectivity. He has served in various development and sustaining engineering roles involving the design of electrical interconnections. He now has responsibility for the design of power interconnects for the data communications industry. He has been with AMP and TE Connectivity for 33 years and has contributed 23 issued patents. He holds a BSME from the Pennsylvania State University.