Ultracapacitor Interconnection

This paper discusses design principles for interconnecting Maxwell Technologies, Inc.'s BOOSTCAP® ultracapacitors in series or parallel.[1] They are no different than the principles one would use to interconnect any high-current energy storage cell, and should be familiar to anyone who has interconnected batteries. However, application-specific considerations of electrical and mechanical requirements must be included in the design. These considerations include attention to low resistance connections and interconnections, thermal management, galvanic potentials, and mechanical stresses due to vibration and thermal expansion.

The interconnection techniques used for assembling ultracapacitors affect the performance, reliability, life, and safety of a product. These techniques must take into consideration contact resistance, assembly surface preparation, torque requirements, material thermal expansion, oxidation prevention, bus bar current carrying capacity, dissimilar metals, and terminal leaks due to assembly-related stresses in order to maintain interconnection integrity throughout the operating environment. Indeed, inadequate interconnection design could result in system damage or even a module or pack fire.

Contact Resistance

Contact resistance between the bus bar and terminal will cause the assembly to heat. Control of this contact resistance is affected by the design, the terminal surface preparation, the screw torque, and material thermal expansion characteristics. Consequently, interconnects should be designed to have as much contact area with the cell as possible. A large contact area will provide low electrical resistance (reducing resistive heating), and low thermal resistance (providing a path for heat transfer between the cell terminal and interconnect).[2]

Assembly Surface Preparation and Oxidation Prevention

Metal surfaces tend to oxidize, increasing the contact resistance. Maxwell recommends removing surface oxidation prior to assembling electrically contacting surfaces. Preparing the surface with an electrical joint compound can also be considered.[3]

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[1] This paper is targeted at customers interconnecting BOOSTCAP threaded type cells, and many of the recommendations are specific to this model. However, the broader design principles are applicable to any situation requiring the interconnection of high-current energy storage cells.

[2] BOOSTCAP threaded type cells have a female threaded terminal. Torque information for each specific model type may be found on the product data sheet.

[3] A representative compound is Burndy Inc.'s Penetrox a-13 electrical joint compound, p/n #PENA13-PT

Thermal Expansion

Material thermal expansions must be considered when designing any assembly of different materials. Laboratory experiments have found that rigid copper bus bars will become loose after several thousand cycles. Additionally, the screw material choice affects thermal expansion during operation and environmental conditions. Expansion of the interconnection joint from temperature rises will affect the contact resistance of the joint. If the assembly loosens, the resistance increases, generating additional heat, expansion, and contact resistance. If possible, the design should match coefficients of thermal expansions to the greatest extent possible.

Pre-loaded connections can help reduce the effects of thermal expansion differences. The use of appropriately selected spring washers (such as Belleville washers) can flex and keep fasteners properly loaded, so that they do not become loose after multiple expansion-contraction episodes. This can also help in reducing the potential for vibration to loosen fasteners.

Thermal expansion of the overall assembly can introduce additional stresses to the cells. Cell to cell interconnects can be fabricated from flexible materials (laminations, multi-stranded cable, etc.) to reduce thermal expansion stresses, provided all other considerations (contact surface area, cross-sectional area, etc.) are maintained. Flexible interconnects will also minimize terminal stresses due to vibration and shock.

Bus Bar and Terminal Current Carrying Capacity

The designer should select interconnects meeting the continuous current cycling application[4], plus a factor of safety of 1.5 so that the design can withstand short circuit scenarios.

Insulation & Voltage Isolation

The shrink sleeving on the exterior of the ultracapacitor cell may not be adequate electrical insulation for assemblies. Additional inter-cell insulation may be necessary between adjacent cells, and between any cell and chassis ground. The choice of insulation (material, thickness, etc.) must be based on the total system voltage. For example, if the cells are being assembled into a 450 VDC system, the insulation must be rated for this voltage. If the cells are to be constructed at a modular level that is less than the system level, the system voltage defines the insulation requirement for the module.

Dissimilar Metals and Galvanic Corrosion

When interconnecting ultracapacitors, Galvanic Series relationships are useful as a guide for selecting metals to be joined together because they help identify metals with minimal tendencies to corrode one another. In addition, they indicate the need or degree of protection to be applied to reduce expected potential interactions.

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[4] Refer to each products data sheet for specific current carrying capacity of each model.

Maxwell recommends the selection of materials with little galvanic activity relative to aluminum.

Metals widely separated in the Galvanic Series must be protected if they are to be joined. Appropriate measures should be taken to avoid contact. This can be accomplished by applying to the cathodic member a sacrificial coating having a potential similar to or near that of the anodic member. When designing with a sacrificial coating, the sacrificial element should be on the more anodic side of the scale.

Another consideration is the Non-aerodynamic Area Rule, which states that designers should avoid using a small anodic area relative to the cathodic area in order to prevent corrosion. This is because the larger the relative anode area, the lower the galvanic current density on the anode, and thus the lesser the “attack” of corrosion. Further, the amount of galvanic corrosion may be considered proportional to the cathode/anode area ratio, so designers should work towards creating a small cathodic/anodic ratio. Finally, the more cathodic metal in the Galvanic Series relationship should be used for small fasteners and bolts.

Cell-To-Cell Forces

To prevent excessive loads on the terminals, which could cause cell leakage, interconnects should be stress relieved from terminal to terminal to allow for expansion, vibration, and shock, and to minimize the bending forces applied to the terminals. Over-torque of the terminal during bus bar assembly can result in damage to the terminal insulator or cause an internal short in the cell, and should also be avoided. Forces should not be applied to the outside diameter of the terminal for the same reasons.

Thermal Management

In many designs, the ultracapacitor will be used under load profiles which generate enough resistive heating to require some heat dissipation to keep the ultracapacitor within its operating temperature range. Interconnects are a primary path for conducting heat away from the ultracapacitor cell. Interconnects should be large enough to generate minimal resistive heating themselves, and should be designed as a key element of a thermal management system. Designers may choose to include additional thermal paths (e.g. tying interconnects to heat-sinks, airflow over interconnects, etc.), the design of which must include all other considerations discussed here.

Summary

The principles used in the design of ultracapacitor interconnects are no different than the principles one would use to interconnect any high-current energy storage cell. Application-specific considerations of electrical, mechanical, and thermal requirements must be included in the design, including attention to low resistance connections and conductors, thermal management, galvanic potentials, and mechanical stresses due to vibration, shock, and thermal expansion.