Applying Laminated Busbars to Enhance DC Power Distribution Systems

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Abstract- The intent of this paper will be an overview of how to design and implement laminated busbars into DC power distribution systems. It will include; electrical, physical and thermal characteristics obtained by utilizing a laminated busbar for DC power distribution.

The power density of today’s technology requires the power distribution system to play an active role in compacting size while not sacrificing electrical, physical or thermal constraints of the devices it supplies. In systems where high levels of electrical power are being used, designers must analyze and optimize the method by which power is being distributed.

Power distribution issues can have a dramatic affect on the cost, performance, reliability and size of systems. Designing a complete power distribution package that incorporates both power and signal level distribution, along with circuit protection into one sub-system can greatly reduce overall system size.

I. BASIC STRUCTURE
As the definition laminate refers “to make by uniting superposed layers of one or more materials”. The basic structure of a laminated busbar is to stack conductive materials; i.e.; copper, brass or aluminum with insulation materials; i.e.; polyester, aramid paper or epoxy glass in between. This creates a structure of discreet circuits with multiple polarities.

A MATERIAL STACK-UP
The typical method of creating a laminated busbar starts with the material stack-up. In the configuration of the bus bar electrical and environmental requirements have significant importance in determining the stack-up. The stack-up generally consists of insulation, conductor, insulation, conductor, insulation etc... This sequence will continue until all circuits are accounted for. See figure 1.

![Material Stack-Up Diagram](image)

![Conductor and Insulation](image)

B CONDUCTOR SIZING
The size of the conductor correlates directly to the current being distributed. A general rule for the cross-sectional area required is determined by multiplying W (width) by T (thickness). This is then divided by 400 amperes per square inch. See Figure 2.

\[ \frac{W(\text{in}) \times T(\text{in})}{0.00040} = \text{Amperage} \]

![Conductor Sizing Diagram](image)

A closer look at thermal requirements relative to busbar construction is defined in the thermal Section III.

C PERIMETER ISOLATION
The perimeter of the busbar has 3 options for design. They are 1) Insulation overlap 2) Insulation edge seal 3) Insulation fill.

Each of these options has advantages and disadvantages. Let’s take a look at each of them:

<table>
<thead>
<tr>
<th></th>
<th>Overlap</th>
<th>Seal</th>
<th>Fill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADV</td>
<td>DISADV</td>
<td>ADV</td>
</tr>
<tr>
<td>Clean Environment</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Dirty Environment</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Creepage Distance</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Strike Distance</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Envelope Size</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Robustness</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Construction Limitations</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cost</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
As shown in Table 1, there are many benefits in using an edge filled busbar. Its major drawback is that it can be cost prohibitive. The edge seal offers many of the advantages of the edge filled design while still being cost effective, if designed properly. The third option is to overlap the conductor edges sufficiently to create a creepage and strike barrier to eliminate short circuit potentials. This option is the most cost effective for the bus bar but can create other issues within a closely populated area.

D Insulation Selection

The insulation material has profound effects on the electrical characteristics of the busbar. The insulation's primary requirement is its dielectric breakdown strength. This is sufficient for most DC systems but for the designer to get the maximum benefit from using a laminated busbar, they need to take into account the dielectric constant ("K" factor) of the insulation.

<table>
<thead>
<tr>
<th>MAT'L</th>
<th>DIELECTRIC BREAKDOWN VOLTAGE(1)</th>
<th>DIELECTRIC CONSTANT (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy Powder Coating</td>
<td>10.0 KVAC (10 mil)</td>
<td>4.00</td>
</tr>
<tr>
<td>Kapton® (3)</td>
<td>13.8 KVAC (3 mil)</td>
<td>3.70</td>
</tr>
<tr>
<td>Mylar® (3)</td>
<td>10.0 KVAC (3 mil)</td>
<td>3.30</td>
</tr>
<tr>
<td>Nomex® (3)</td>
<td>1.6 KVAC (3 mil)</td>
<td>1.6</td>
</tr>
<tr>
<td>Tedlar® (3)</td>
<td>4.2 KVAC (2 mil)</td>
<td>11.0</td>
</tr>
</tbody>
</table>

(1) Tested per ASTM D149  
(2) Tested per ASTM D150  
(3) Registered trademark of the Du Pont Corporation

In reviewing table 2, the electrical characteristics shown are used in determining the system maximum operating voltage, capacitance and inductance. The formulas in table 3 are used to determine the capacitance and inductance. In reviewing the formulas, it is evident that the dielectric thickness has the greatest affect on the capacitance, whereas, the width is the determining factor for inductance.

So, to increase capacitance it would be advantageous to use as thin a dielectric with as high a "K" factor as possible. Likewise to increase inductance, the conductor should be as narrow as possible and separated as far as possible.

II. Reducing Noise

A Material Stack-up

The orientation of polarities is essential in reducing EMI and RFI (cross-talk). As shown previously, a typical stack-up consists of insulation, conductor, insulation, conductor, insulation, etc. In order to maintain minimal emitted interference, it is necessary to sequence the polarities in an opposing order. The opposing magnetic fields create a cancellation effect. This, along with the added capacitance values of close proximity results in minimal emissions.

An additional method of containing emissions is to use interleaved ground layers. The ground layers are commoned to create a Faraday cage. This method of coupled capacitance absorbs the voltage spikes created by inductance. Using insulation with a high dielectric constant increases the performance of this construction. See Figure 3.

The last method is to wrap the insulated busbar with an EMI shield. This is typically a copper foil with tin plating. This can either have a conductive adhesive applied to it or be soldered or clamped into place.
Each of these construction methods has applications depending on the level of noise allowable and cost effectiveness of the design.

III. THERMAL REQUIREMENTS

A CONDUCTOR SIZING

In order to control temperature rise in the busbar, the cross-sectional area must be sufficient relative to the amperage passing through it.

The size required to maintain thermal increases in the busbar structure are determined by a general rule as depicted in Section I. The calculation listed is conservative by nature and will result in less than a 30 degree C rise in a two layer busbar at sea level with both conductors external to convection heat dissipation.

Issues arise when multiple conductors are stacked and sealed externally. This results in thermal dissipation through the conduction of the adjoining layers. Since the thermal path is elevated above ambient, the inner conductors are at an elevated temperature even without power. This requires the inner layers to be de-rated. The de-rated amount is relative to the adjacent layers expected thermal rise. The higher thermal rise in the outer layers limits the allowable increase in the inner layers resulting in a greater de-ration for the inner conductors.

B CONFIGURATION SOLUTIONS

Thermal issues of an entire system can be eased by the configuration of the busbar power distribution. The flat strips of copper laminated into specific shapes alleviate restrictions and enhance airflow through the enclosure. The busbar can be designed to create specific flow paths or situated out of the way, not to affect airflow; See Figure 3. The advantage being, that the monolithic nature of the busbar allows the designer this option, that cabling does not. The busbar is fully capable of operating with only thermal convection. No forced air is necessary to cool the busbar.

IV. POWER DISTRIBUTION CAPABILITIES

A CONNECTER OVERVIEW

There are a growing number of connector manufacturers specifically designing to meet the need for “power” connectors. This increasing supplier base allows the designer greater flexibility in system design. The high current connector has changed how power is managed from input through output. Forming of the busbar enables the connector to be positioned in virtually any position required to make the interconnection.

B INPUT POWER

The input power can easily be routed through blind-mate and hot-pluggable connectors. These high power interconnects are regulatory approved at continuous operating currents of over 250Amps and are mounted directly to the conductor layers. This method of interconnecting to the busbar, can be made via several different options, 1) fasteners such as screws and nuts, as shown in Figure 4, 2) solder tails as commonly found for PC board applications 3) compliant pin (press fit) tails.

C OUTPUT POWER

Output of power from a busbar is typically more manageable than the input side. A single output connection is only a fraction of the overall system. Therefore, the connector is smaller in size, has more mounting options and can be used for multiple circuits in a single housing, as shown in Figure 5. This architecture, when coupled with circuit protection, creates a complete power distribution unit.
D  CIRCUIT PROTECTION OVERVIEW

Circuit protection is perhaps the most overlooked area of a busbars’ capabilities. The inclusion of circuit protection to the busbar structure creates a true power distribution unit. As shown in figure 6, the availability of placing components along the path of the circuit allows for versatile configurations.

The type and style of circuit breakers used ranges from solder tail, as shown in figure 6 to pluggable, as shown in figure 7.

Secondary circuit protection can also be provided by fuses installed onto the busbar, as shown in figure 8.

This secondary overload protection is used in conjunction with circuit breaker protection. The circuit breaker is used for in-rush currents while the fuse is integrated to provide individual device protection. This provides system level protection with each device overload protected to meet its specific requirements. The placement of the fuse, along with registration markings for fuse requirements, eliminates confusion as to what current protection is required.
V. REGULATORY COMPLIANCE

The UL/CSA, EN 60950 and UL 1801 are the most common of the regulatory requirements to be tested to when designing a busbar for telecommunications.

As discussed in prior sections the busbar conductor sizing is important to meet thermal rise characteristics required by the specifications. The conductor cannot generate heat that, along with the ambient temperature, will cause the insulation to rise above its’ specified maximum temperature under normal load. Table 3 lists commonly used materials and their continuous use temperatures.

<table>
<thead>
<tr>
<th>MAT'L</th>
<th>CONTINUOUS TEMPERATURE (°C)</th>
<th>FLAME RATING</th>
<th>THERMAL CONDUCTIVITY (W/m·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy Powder Coating</td>
<td>130</td>
<td>UL 94 V-0</td>
<td>.60 @ 50° C</td>
</tr>
<tr>
<td>Kapton® (1)</td>
<td>400</td>
<td>UL 94 VTM-0</td>
<td>.18 @ 50° C</td>
</tr>
<tr>
<td>Mylar® (1)</td>
<td>105</td>
<td>UL 94 VTM-0</td>
<td>.37 @ 50° C</td>
</tr>
<tr>
<td>Nomex® (1)</td>
<td>220</td>
<td>UL 94 V-0</td>
<td>.11 @ 50° C</td>
</tr>
<tr>
<td>Tedlar® (1)</td>
<td>107</td>
<td>UL 94 HB</td>
<td>.35 @ 50° C</td>
</tr>
</tbody>
</table>

TABLE 3

(1) Registered trademark of the Dupont Corporation

VI. CONCLUSION

Laminated busbar power distribution systems are more than just a method of supplying the power to components. A properly designed power distribution system will improve performance and reliability of an electrical/electronic system, while decreasing overall system costs. The increased need for low inductance and efficient use of space makes laminated busbar assemblies, the optimal tool for distributing power.