Laminated Bus Bars Reduce Inductance and Manufacturing Costs of Power Distribution Circuits

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A sound interconnection strategy in power electronics systems requires a reduction in stray bus inductance in the power circuit of IGBT modules, which can be achieved with a laminated bus bar.

Power distribution circuits in today's power electronics systems require design engineers to integrate IGBTs, heat sinks, capacitors and gate driver circuits. Although functionality is important, manufacturability and cost are two other elements that must be addressed.

One approach to obtaining the desired degree of integration in power electronics systems, while reducing cost and optimizing manufacturability is to use a laminated bus bar. It connects the entire power distribution system together and achieves the lowest possible system inductance, yielding maximum device performance and efficiency. The laminated bus bar consists of a "sandwich" of electrically conducting metal (usually copper) and insulating material, whereas a conventional bus bar uses only a single layer metal conductor.

A contributing factor to lowered manufacturing costs is that all conductors, insulation and terminations are laminated into a single structure. This approach also eliminates the need for installing discrete wires. It creates a modular component requiring less installation time and having better serviceability than the traditional "Erector Set" approach of power distribution systems that use single layer bus bars and individual copper bushings.

In high current, power electronics applications, a power distribution system containing low inductance power circuits is a critical element for safe and efficient operation of IGBT modules[1]. If not addressed in the early design stage, the stray inductance on the total source-return path of the DC bus from the DC capacitor bank to the inverter devices can lead to several undesirable results:

- In conventional hard switching converters, excessive transient overshoots can cause increased device heating during switching, which eventually exceeds the device's safe operating area and then the device fails.
- Reduced allowable switching frequency.
- Parasitic oscillations may get out of control and cause the inverter to exceed its safe operating area.

Stray inductance is a frustrating obstacle for design engineers who need long interconnection distances between switching devices to minimize the effects of heat generated by the power devices. Complex snubber circuits have been used to reduce the destructive effects of the bus inductance, but they add more components that make the system more costly and more difficult to manufacture[2]. Therefore, the challenge is how to achieve low inductance while maintaining low component count and a simplified design.

Conductor Inductance

In examining the effective inductance of a conductor it is necessary to discuss its two components; self inductance and mutual inductance. In comparing a round conductor (Lrnd,dc) and a single conductor bus bar (Lbar,dc), the self inductance can be calculated using the following formulas.

$$Lrnd, dc = 0.002\ell \, [2.303 \, Log10 \, (4\ell/d)-0.75)]$$

$$Lbar, dc = 0.002\ell \, [2.303 \, Log10 \, (2\ell / b+c) + 0.5 + 0.2235(b+c/\ell)]$$

Where:

ℓ = Conductor length

d = Round wire diameter

b = Bus bar width

c = Bus bar thickness

A rectangular bus bar has been shown to exhibit 1/3 to 1/2 the self inductance of a round conductor of equal length and cross sectional area [4]. When mutual inductance results in cancellation of flux, the result is a decrease in the effective inductance. Cancellation happens by placing two conductors with opposite current polarity in close proximity of each other.

The closer the conductors can be placed to each other, the greater the mutual cancellation and decrease in effective inductance. Single layer bus bars configured in a side-by-side layout (planar), exhibit less effective inductance than wiring harnesses because of their shape and the existence of some mutual cancellation along the conductor edges. However, bus bars in a side-by-side configuration do not provide the lowest effective inductance. The mutual inductance cancellation can be further increased by placing a wide DCplus plate directly on top of a wide DCminus plate. This provides greater surface area for flux cancellation. Bushings can be used to bring the contact surface down to the IGBT module. However, the designer must take into account that the conductors, insulation and bushings are all separate items, and must be assembled together.

This can result in the conductors not making a perfectly flush contact on the bushings. When this happens it could result in increased contact resistance around the bushing.

A laminated bus bar provides the lowest possible effective inductance for a system. This is made possible by laminating a thin piece of dielectric material between the DCplus and DCminus plates. The plates and dielectric are laminated together under heat and pressure, keeping the levels consistently close together. This construction provides the largest mutual inductance cancellation directly along the power distribution path. The closer these plates are laminated together, and the more uniform their separation is throughout the length of the bus, the more mutual cancellation will be realized.

To even further reduce the number of components in the system, the AC conductors can also be laminated into the bus assembly. Performing this operation will not decrease the mutual inductance cancellation of the plus and minus plates but does enhance the overall bus bar design. Once laminated, the resulting rigid structure is capable of withstanding several hundred pounds of force and can withstand several thousand volts across the conductor plates.

Making the electrical connection to the power components becomes a matter of selecting from a variety of metal forming options such as embossments, brazed bushings or formed tabs. Permanently incorporating these contact surfaces into the structure provides low contact resistance between the bushing surface and the conductor plates.

Manufacturability

Manufacturing costs come into play in today's Design for Manufacturability environment. Therefore, component count, assembly time, and system size are all factors that must be taken into consideration. A laminated bus bar helps to incorporate all the components in a power distribution application into a single structure that contributes to cost effectiveness and efficiency. Component count and assembly time can be reduced by

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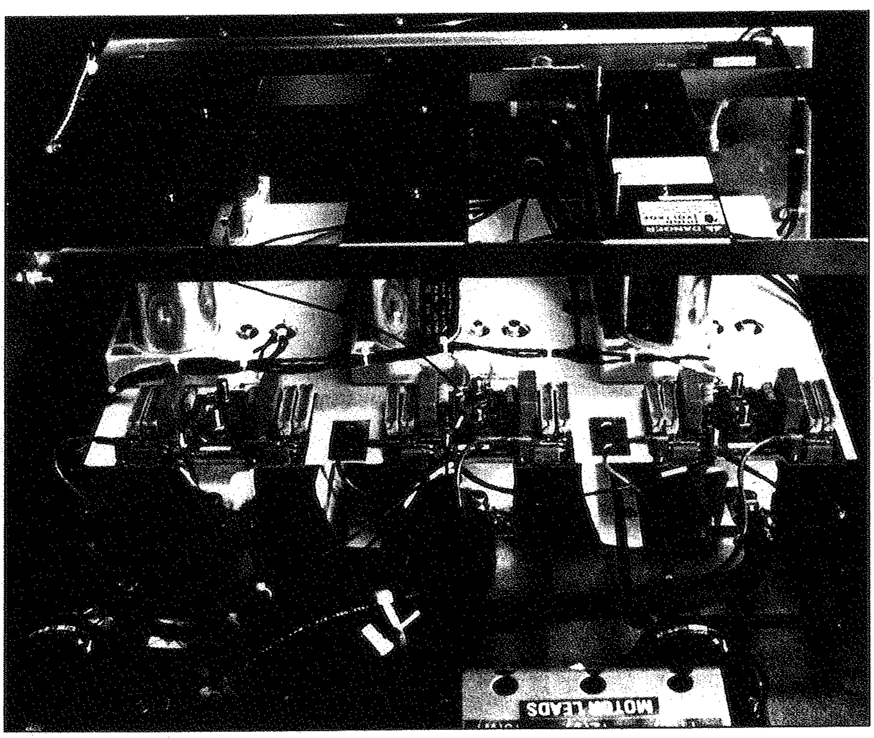

Figure 1. Complete AC Drive Unit With Laminated Planar Bus Bar Installed. The Bus Bar Contains All Necessary Interconnections Between IGBTs, SCRs, Capacitors and Fuse Links.

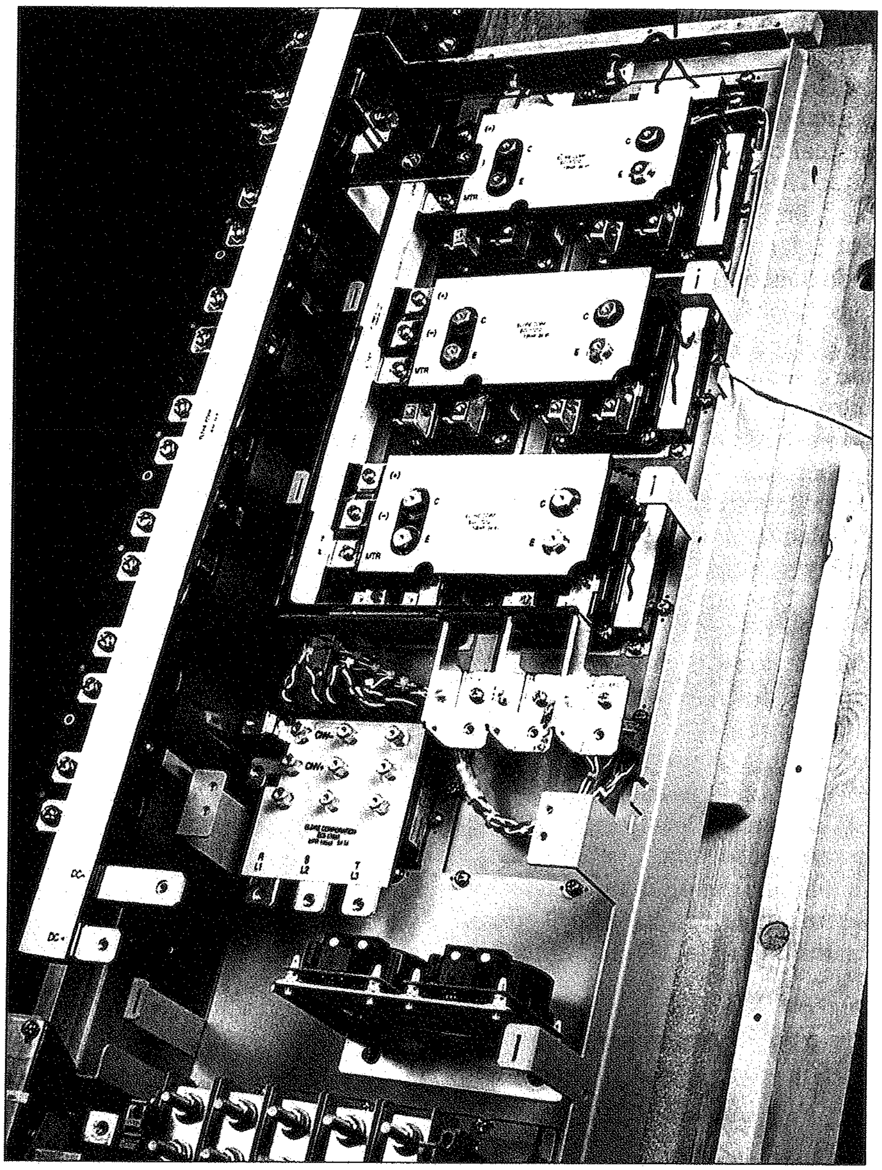

Figure 2. AC Motor Drive Unit Using Three Identical IGBT Bus Bars, Separate Capacitor Bus, Three-Phase Motor Output Bus and Tan Colored Rectifier Bus Assembly.

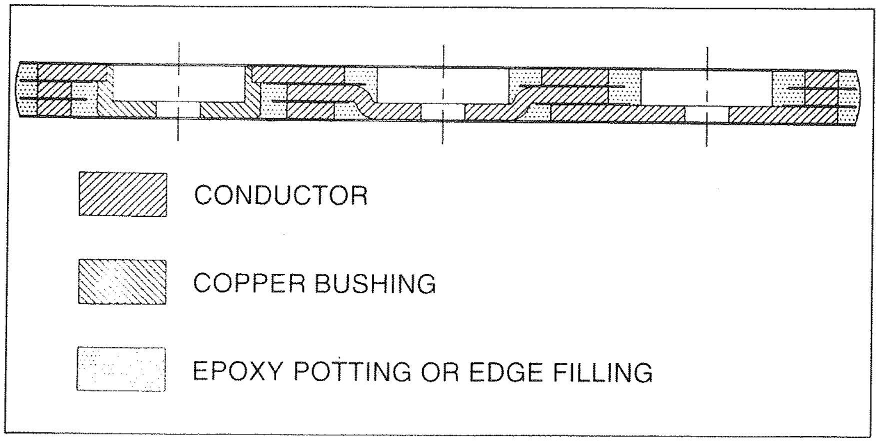

Figure 3. Examples of Brazed Bushing (left) and Embossment (center) in Laminated Bus Bar.

simplifying the snubber circuitry. This simplification is possible because the aforementioned reduction of stray inductance. The physical shape of the bus bar itself requires less space than traditional power distribution components because a wide flat conductor is capable of carrying the same amount of current as a bulky wire harness. Laminated bus bars can occupy up to 1/10 of the space of the traditional "Erector Set" approach of power distribution, allowing system size reduction and better heat dissipation.

Reliability is another aspect enhanced by this modular approach to power distribution. This is a result of the decreased component count as well all terminations being rigidly in place and integrated within the structure. This design reduces the likelihood of installation errors and subsequent failures because there are fewer components and wires to worry about installing. This can save significant time in terms of troubleshooting a system.

References:

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4. Skibinski, G.L., and Divan, D., "Design Methodology & Modeling of Low Inductance Planar Bus Structures," Proceedings EPE, 1993.

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