ENHANCING POWER ELECTRONIC CONVERTERS WITH PASSIVE PE COMPONENT BUNDLING

POWER ELECTRONICS NOTE 1

BY MERSEN POWER ELECTRONIC SPECIFICATION TEAM

Figure 1: Mersen offers custom-designed laminated bus bars, which help in the development of power converters to achieve the lowest possible system conductivity

Today's state-of-the-art power electronics converters require the design engineer to employ a bundling approach utilizing power semiconductor components like but not limited to IGBTs, heatsinks, capacitors, and protection devices. Pushing the converters to their peak performance is of the utmost importance; manufacturability and cost are two other elements that need to be factored into the equation. The use of laminated bus bar ties the total system together and achieves the lowest possible system inductance, yielding maximum device performance and efficiency (see fig.1). On-state and commutation losses must be dissipated. High switching frequency will lead to increased commutation losses if parasitic inductance isn't minimized. The bus bar is a key component for reducing stray inductance and cooling devices are paramount for keeping the power semiconductor junction under control. This short article aims to explain why bus bar has become a key component in power electronic applications.

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. If not addressed in the early design stage, the stray inductance on the total DC bus from the DC capacitor bank to the inverter devices' commutation loop can result in several undesirable consequences. Hard switching converters' excessive transient overshoots will lead to increased device temperature during switching, resulting in the need for an

DEFINITIONS

- **IGBT (Insulated Gate Bipolar Transistor):** An active component primarily used as an electronic switch, the Insulated Gate Bipolar Transistor is a power semiconductor device that can be triggered ON and OFF by action on its gate.
- **Heatsink:** A passive component that cools power semiconductor devices to operating values by dissipating heat into the surrounding air.
- **Capacitor:** A passive component that stores energy. It's also used to limit the rate of the rise of voltage across semiconductor at the turn off.
- **Bus Bar:** A passive component that allows electrical connection between passive and active components while limiting the parasitic inductance.

unnecessarily large heatsink or the need to tune the converter to a lower switching frequency leading to larger and more expensive passive components like capacitors. This stray inductance is an obstacle for design engineers who need interconnection distances between switching devices in order to dissipate the heat generated by power electronics semiconductors. Snubber circuitry has been designed to reduce the risk of the destructive effects of the bus inductance. Nevertheless the challenge remains how to achieve low inductance while maintaining low component cost and a simplified design. Once the IGBT modules have been placed onto the heatsink to allow for proper thermal dissipation, the designer is confronted with how to interconnect them with the lowest inductance power distribution path possible. The following will address the different alternatives.

The most common means to distribute power in a conventional circuit is through the use of a wiring harness. Wiring harnesses are inexpensive, readily available, custom to fit the application, and somewhat flexible. However, in IGBT inverter applications, the higher self inductance of wire is not desirable given the previously mentioned effects of DC bus inductance. The comparison of DC self inductance of a circular cross-section wire conductor and a bus bar has revealed that the bus bar is the preferred conductor to minimize stray inductance. Also, due to the difference in geometry, a solid cross-section of the bus bar versus a round wire bundle, a bus bar may only require 1/10 to ½ the space of a wire harness resulting in lower cost and lower weight.

On the DC bus amperage approaching 150 amps and above, the use of interconnect multiple layers is the solution to address large current carrying capability, low stray inductance, high frequency applications, smaller space requirements and reliability issues. For the traditional power distribution topology of IGBT modules, side-by-side bus bar conductors are still used in industry. However, the side-by-side conductors do not provide the lowest effective mutual inductance for the distribution path. There is some mutual inductance cancellation along the adjacent edges of the conductors. However, to minimize the mutual inductance, these bus bars would need to be placed directly on top of one another, not side by side.

Designers can further lower the mutual inductance by placing the wide DC+ conductor plate on top of the wide DC- plate, separating them with a thin dielectric material. This provides the greatest surface area for the flux cancellation. Prototyping using this technique is done frequently and provides the components in the inverter with enhanced electrical characteristics through lower inductance. Bushings can be placed on the bottom contact surface of the top plate to bring the power down to the IGBT module located below the bus. Bushings will seldom lie completely flat against a conductor plate; this could result in an increased contact resistance around the bushing.

Mersen custom-designed 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 DC+ and DC- plate. The dielectric plates are laminated

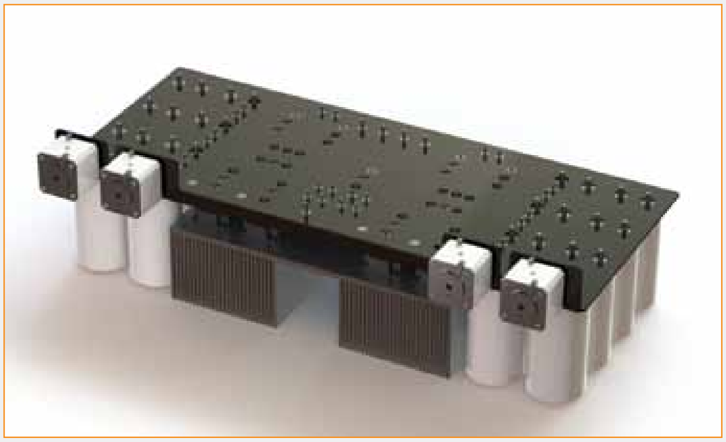

Figure 2: *Assembly showing laminated bus bar, semiconductor fuses, heat sink, capacitors, and IGBTs.*

together under heat and pressure keeping the levels consistently close together. This construction allows for the largest mutual inductance cancellation directly along the power distribution path. The closer these plates are laminated together, the more uniform their separation is throughout the length of the bus, and the more mutual cancellation that 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 design. Once laminated, the resulting rigid structure is capable of withstanding several hundred pounds of cleavage strength and designed to withstand several thousand volts across the conductor plates. Making the electrical connection to the power components becomes a matter of selecting from the variety of metal forming options such as embossments, brazed bushings, or formed tabs. By permanently incorporating these contact surfaces into the structure, there exists a low contact resistance between the bushing surface and the conductor plate.

Copper alloy is the standard and recommended conductive material in the majority of IGBT laminated bus bar applications, given its low resistance characteristics and cost. Aluminum may also be specified when weight is a factor. Other materials sometimes specified for mechanical characteristics are brass, beryllium copper and phosphor bronze. The accepted value for current carrying capacity of copper is 5A/mm^2. To determine the cross-sectional area (in mm^2) required to carry the steady state current, divide the steady state current of the DC bus by 5A/mm^2. Copper has a current carrying capacity of 5A/mm^2 and will have a temperature rise of 20°C above ambient temperature.

The proper selection of dielectric material will ensure the lowest mutual inductance in the laminated structure. A common misconception by designers in laying out a laminated structure is that a very thick dielectric is needed to meet their voltage requirement. The laminated structure has materials in a sandwich; designers need to allow sufficient insulation overlap beyond the edges of the conductor to eliminate arcing between the conductors (commonly known as creepage/clearance distance). The voltage requirement will establish the creepage/clearance distance best suited for the laminated bus bar. Should the conductor plates be joined by laminating, the designer should consider if the laminated bus bar should have: 1. Open edges, 2. A molded edge seal, 3. Epoxy-edge filling, or 4. a Glastic Border.

Once the conductor size and insulation is specified, the designer must determine 1: how to distribute power in and out of the IGBT module and, 2: what the physical layout will look like. Synergies between bus bars and heatsinks exist. Once the electronic design is set, thereby defining the heat generated by each IGBT, the cooling device and the bus bars are the first passives to be selected. The heatsink answers the thermal needs but also serves as a base frame for the converter main power switch. Furthermore, the heatsink thermal performance combined with the thermal dissipation of each power semiconductor will draw the converter layout thus the bus bar design.

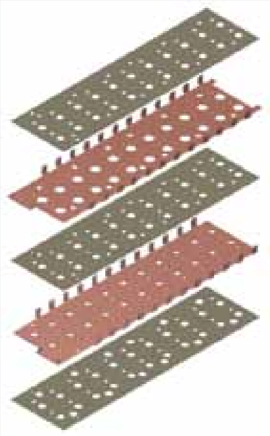

Figure 4: *(Left photo) Distribution bus bar for wind mill application. (Right photo) Solar Inverter bus bar.*

Various connection techniques may be used to interconnect the IGBT module with the laminated bus bar. Once the DC conductor plates are laminated into an assembly, the assembler may simply place conductive bushings/spacers under the contact surfaces of the bus bar to the IGBT tabs. The different height potentials required for the bushing/spacers may cause an assembler to place the wrong bushing/spacer in the inverter during assembly. The solution to this potential problem is the use of embossments and soldered-in bushings. By having the needed contact surfaces incorporated into the laminated bus bar, the designer ensures the proper connections to the IGBT tabs while maintaining a low voltage drop contact. The DC bus conductors can be effectively embossed to two times the material thickness. The embossment can be slotted if different IGBT terminal spacings are required. The current carrying capacity of the embossment is reduced when the conductor material is stretched beyond two conductor thickness. The soldered-in bushings can extend down and/or up to accommodate the creepage barrier on some IGBT modules and to interconnect driver circuits and snubber boards. The use of a tab with slotted holes can also be used to interconnect IGBT modules with built-in creepage barriers. However, the mutual inductance will increase when the DC plates are separated.

The designer will also need to determine whether a modular or system approach is needed for the laminated bus bar design. A modular bus bar will contain individual laminated bus bars for each phase leg of the inverter.

In today's design-for-manufacturability environment, manufacturing cost come into play when systems are laid out by design engineers. 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 of the components in a power system into a single structure which contributes to cost effectiveness and efficiency. The physical shape of the bus itself requires less space than traditional power distribution components due to the fact that a wide flat conductor is capable of carrying the same amount of current as a bulky wire harness. Reliability is another aspect that is enhanced by this modular approach to power distribution. This is a result of the smaller component as well all terminations being rigidly in place and labeled within the structure. This design reduces the likelihood of installation errors and subsequent failures because there are much fewer components and wires to worry about installing.

In conclusion, we still have to keep in mind that size and weight matter. Smaller size leads to lower parasitic inductance therefore lower watt dissipation, permitting higher converter operating frequency thus lowering the size of the capacitor and inductor passive components. The Mersen cooling, bus bar, and fuse bundle offer is helping our customers achieve this goal. Our high thermal performance heatsinks combined with our bus bar design capabilities will help shrink the size of the cooling plate, thus the bus bar and ultimately the converter. Once again, a passive components specialist like Mersen brings a lot of added value to the converter designer if integrated in the project at the early stage.

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ADDITIONAL RESOURCES

- Power Electronics Note 4: Innovative Solution to Connect Stator Main Windings in Rotating Machines via Circular Laminated Bus Bars (TT-PEN4)
- Power Electronics Note 5: Multiphysics Simulation for Designing Laminated Bus Bars (TT-PEN5)

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