

Investigation into Low Inductance Bus Structures to Reduce Voltage Overshoot in High Density Inverters

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Abstract:

High power density designs (kW/cm^3) are a fundamental requirement to meet the challenging performance, size, reliability, efficiency, and cost goals of the automotive power system market. PEM (Power Electronics Module) engineers are using faster IGBTs that enable higher frequency designs facilitating these goals. Selection of the optimal bus structure is critical as there is little room for waste in the connections to minimize inductance and to achieve optimal power density. Recent availability of annular or "ring" capacitors with higher current carrying capability and lower temperatures creates an opportunity to explore new bus options.

Summary:

It is important to note that a series of innovations has led to substantial advancements in Inverter Performance and Size. Recent availability of annular or "Ring" Capacitors is a key enabler for a low inductance symmetrical bus structure because the capacitors require short connections and have high current handling capability. In addition, ring capacitor connection systems allow for direct connection of the capacitor to the heat sinks thus achieving lower temperatures (see Fig 1).

In a symmetrical bus design, the IGBTs are connected in a coaxial fashion to a symmetrical bus plate and coordinated with the ring capacitor. The symmetry here offers two interesting advantages. The first is the shortest possible connections hence the lowest inductance. Designed the right way using short connections and arranged in a coaxial pattern, inductance will be negligible. The second advantage is compact size gained from a tighter design.

The net result is an inverter design with significantly reduced voltage overshoot and switching losses. More importantly, there is potential for a higher safety margin to the semiconductors assuming the same ratings. IGBTs will be operating well within the specified voltage rating leading to reduced failures and longer life. A new opportunity may also present itself in that lower voltage IGBTs may now be applied that can reduce conduction losses.

Two different bus designs are shown in Figures 1 and 2 below. Figure 1 shows a traditional bus structure design utilizing capacitors arranged in a multi-can or array form factor. Figure 2 is a symmetrical bus structure design utilizing ring capacitors. Figures 3, 4, and 5 show additional ways of optimizing the connection structure.

Two important measurements are being considered when evaluating these two designs. Temperature rise in the capacitors and voltage overshoot in the IGBTs at shut off. An example of the type of data being created during this investigation is shown in temperature rise data in Fig 6. One important learned lesson learned to be discussed is that the ring capacitor designs

enable very specific calculations on bus inductance versus the estimates used for traditional bus structures. Also, data presented will show that there were no indications that once designed and tooled, a symmetrical design would be at any cost premium compared to the traditional design.

Once a design has been optimized to improve voltage overshoot and bus inductance, it is important to understand how the heat generated from the IGBT die and connections may affect the capacitor and ultimately the reliability of the system. In order to see such effect, SBE has developed temperature profiling tools which can be iterated with design changes and external conditions. We will present this data to show the impact on the capacitor and what the reliability implications would be. Figures 7, 8, and 9 are representative examples from an existing project.

Conclusion:

The result of this analysis gives the inverter designer the ability to optimize the design, increase power density, and reduce snubber, capacitor and cooling costs. Newly available tools will provide the data to show that the reliability of the IGBTs and Capacitors will not be compromised.

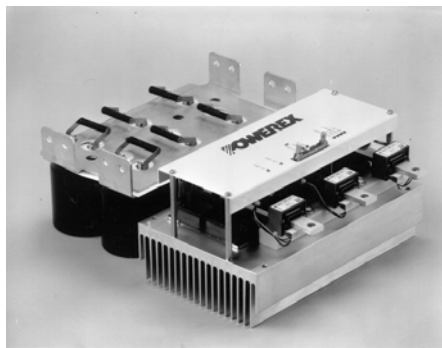


Fig. 1: Traditional Inverter Design

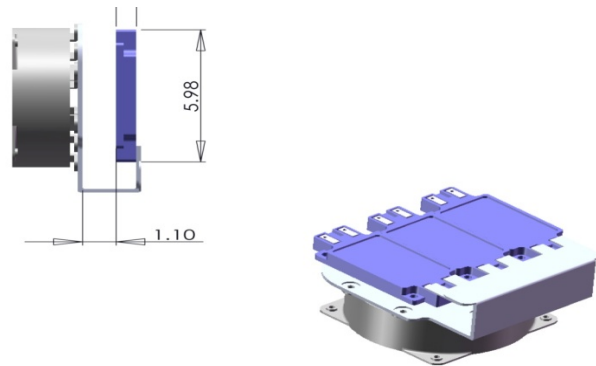


Fig. 2: Stacked Inverter Design

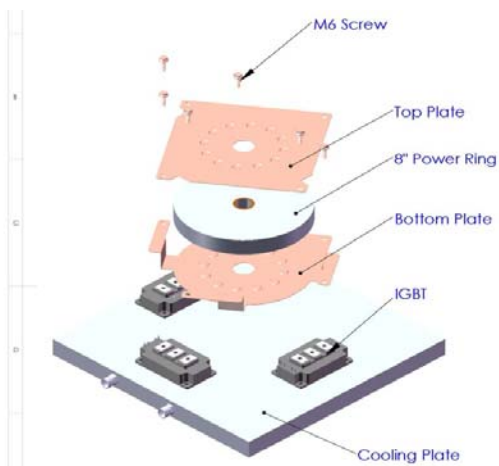


Fig. 3: Orbital Inverter Design

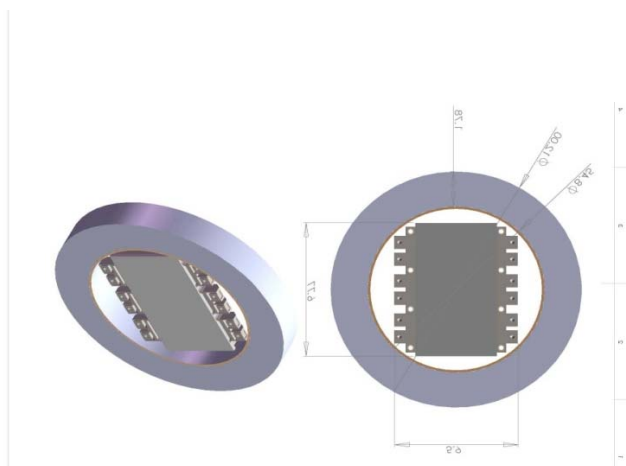


Fig. 4: Center Mount Inverter Design

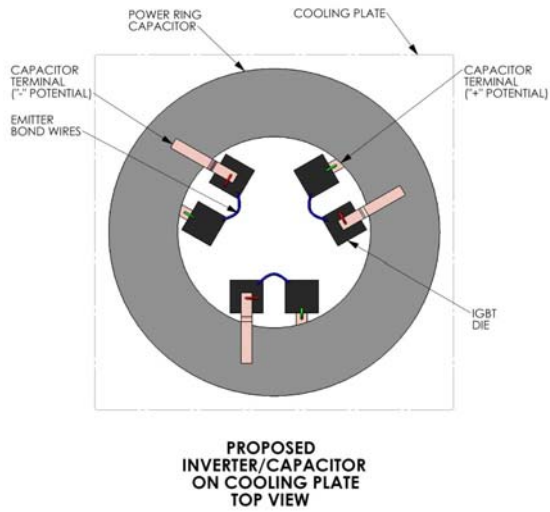


Fig. 5: SBE Patent Application, Nov. 1, 2007

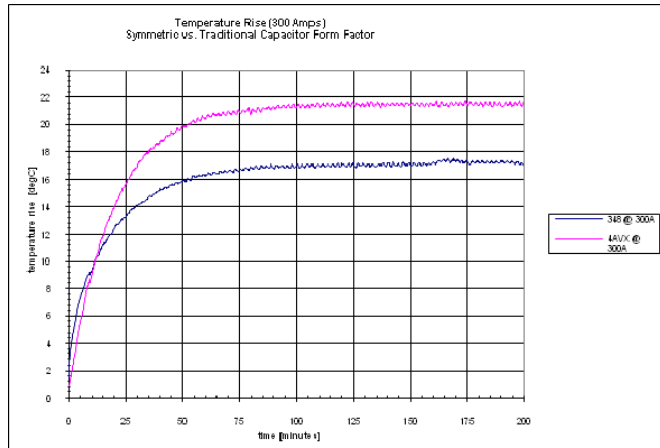


Fig. 6: Temperature Rise at 19.kHz under 300 RMS load

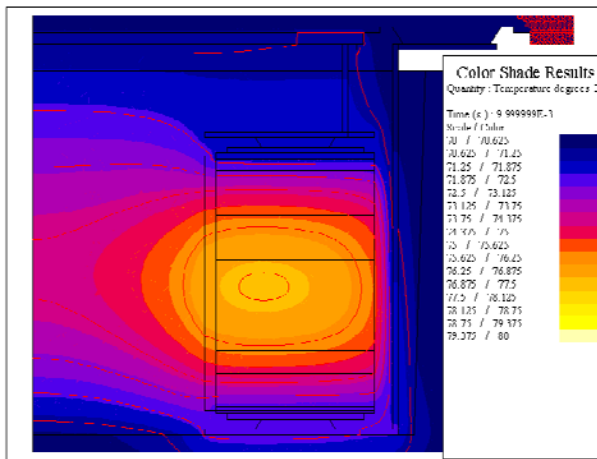


Fig. 7: Thermal Model of example capacitor under 105Arms load

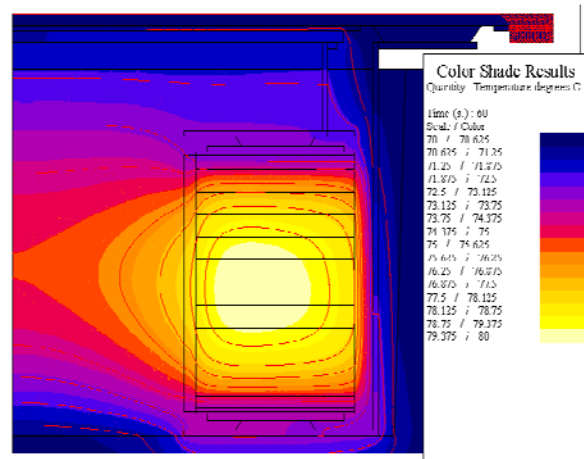


Fig. 8: Thermal Model of 60 sec 210Arms condition

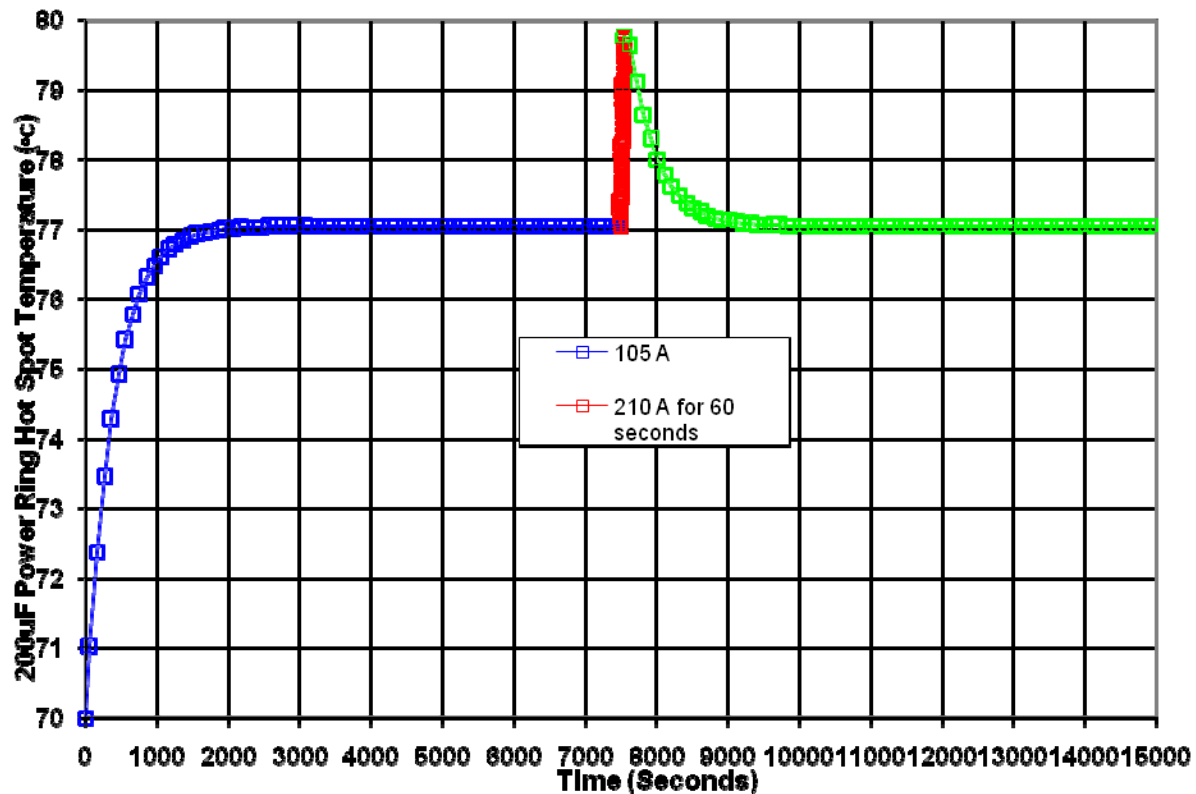


Fig. 9: Thermal profile of an EV drive cycle

Biography:

Mr. Sawyer holds a BSEE from Tufts University and an MBA from Colorado State University. By 1995, Mr. Sawyer was recruited into a Business Leadership role at Emerson Electric Company. He had worldwide responsibility for Product and Business Development for a \$25 Million business unit.

In 2002, Mr. Sawyer purchased SBE Inc. and led the company into sustainability by developing and launching two patented technologies (pulse power and annular ring film capacitors) and broadening SBE's supplier base. SBE recently was awarded a US DoE manufacturing expansion grant to greatly increase the capacity of its ring capacitor production.