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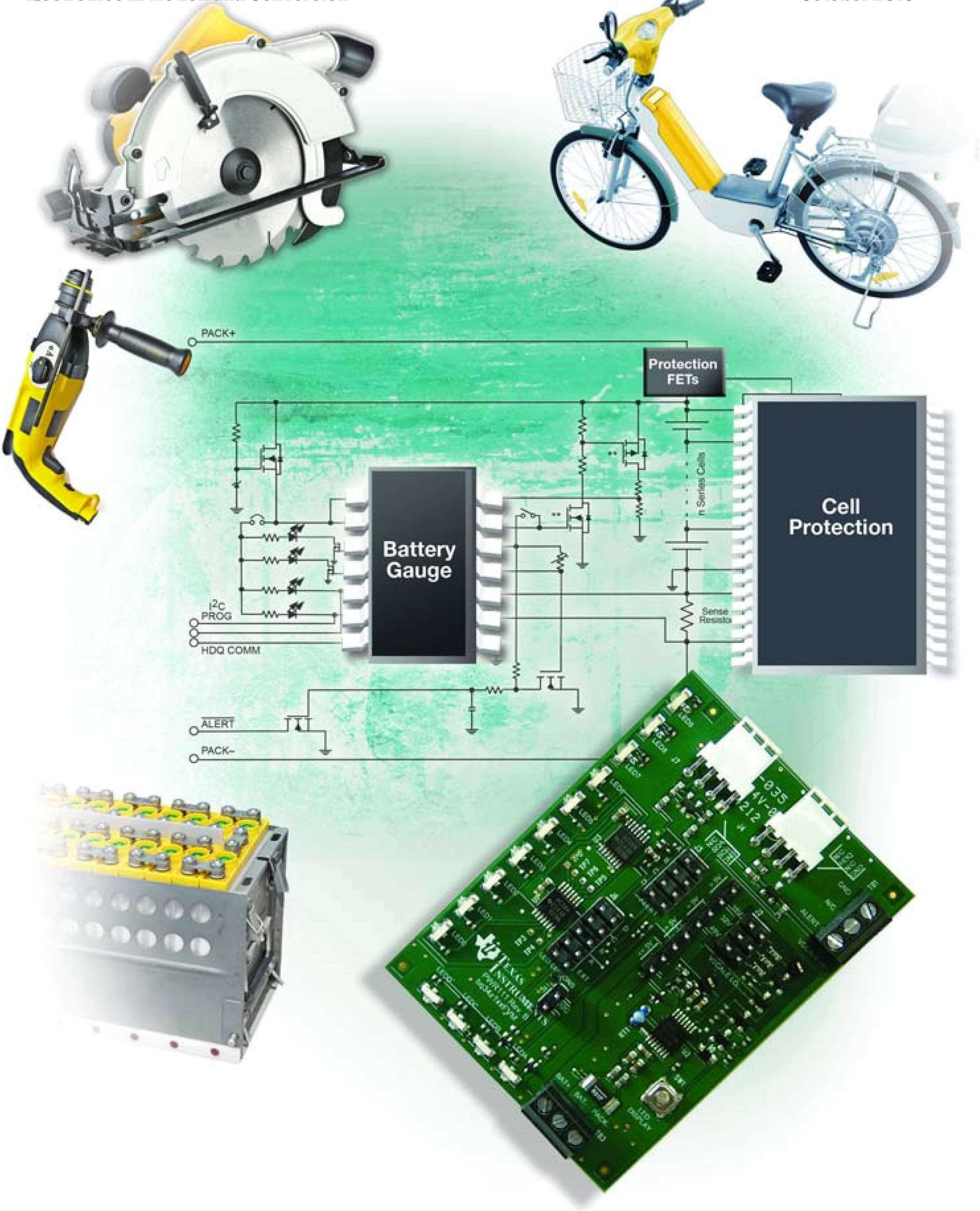

Multiphysics simulation for designing laminated busbars

Improvement of IGBT characteristics switching at higher frequencies has been a decisive factor in the development of smaller, more efficient power electronics converters. Today, the lowest possible system inductance is paramount to push today's state-of-the-art converters to their peak performance.

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Introduction

Improvement of IGBT switching characteristics at higher frequencies has been a decisive factor in the development of smaller, more efficient power electronics converters. Today, the lowest possible system inductance is paramount to push state-of-the-art converters to their peak performance.

Laminated bus bars are a response to this goal. High switching frequencies will result in significant commutation losses if stray inductance is not kept at very low levels. Mutual inductances can be minimized by thinning and bringing conductors as close together as possible. Furthermore, laminated bus bar helps to incorporate all components of a power module into a single structure, which will contribute to cost effectiveness and efficiency. Converters will be more compact, as well as faster and easier to assemble, resulting in an optimal design for manufacturability (DFM). As well, the bus bars will eliminate the likelihood of installation errors. Compared to the traditional cable, bus bar will improve heat dissipation and keep the converter cooler while carrying the same level of current. Overall, laminated bus bars offer a great deal of benefits to the power electronics converter design engineers, especially if their design is integrated in the early stage of the project.

MERSEN (formerly ELDRE) is a specialist of custom designed bus bars with over 60 years of technical expertise. Historically, products were developed based on hand calculations, and a comprehensive know-how. However, as designs are becoming increasingly more complex, analytic calculations become impossible to solve, especially from the thermal point of view. To shorten time to market, while maintaining top quality and controlled costs i.e. the right material and/or thickness for the application addressed, thermal simulations are becoming a deciding tool when developing a custom laminated bus bar.

Why use simulation?

The most reliable way to make sure that a bus bar respects its specifications is to build a prototype and test it in operating conditions. But as reassuring this solution would seem, it also present several drawbacks. The metal cutting and surface finishing are unique to each design. The tools used to bend some intricate shaped products have to be tailor-made. The insulating material layers have to be specially crafted for the tested geometry. The matrix used to laminate the assembly has to be tailor-made as well… All those adding costs cause the global price to increase for a bus bar that might not be validated by the tests.

Building a prototype is also time consuming, due to the number of various specialized operations involved, and can sometimes be incompatible with the client deadline. Once the prototype has been finalized, running the test itself is not so easy, especially as the worst case scenario has to be investigated. High temperature, complex or high current electrical client conditions might not be easy to recreate. Oversized constructions do not fit in a typical environmental chamber. The test can therefore turn out expensive and add unnecessary study time.

That's why simulation is a handy tool to boost development processes. By adding pre-test steps in the conception phase, design flaws can be spotted and eliminated before going through the prototype manufacturing process. Overheating areas or overly thick plates are not always clear to determine by calculations.

Computer generated temperature maps are very appealing and easy to understand: "a picture is worth 1000 words". It is more encouraging for the client to get preliminary tests results before ordering a prototype, and to have a back and forth exchange to adjust its initial design. However, simulation is not meant to replace tests entirely. The quality of the calculated results is only as good as the input data and understanding of underlying physics.

Simulation process

Mersen is using COMSOL Multiphysics, a finite element software. Finite element method is based on iteratively solving equations locally until reaching whole stability. One of its main strong points is that it can be used to solve partial derivative equations modelling different physics simultaneously.

COMSOL is structured as a modular platform, with a basic version addressing typical physical phenomenons such as structural mechanics, heat transfers, electric currents, laminar fluid mechanics, acoustic, etc... More specialized (and optional) modules range from corrosion study to plasma physics. This tool is used by both study engineers and researchers, and the underlying equations can be controlled to an in-depth level.

- Most simulations start with a 3D geometry model provided by the client, usually in the form of a .stp file. If necessary, the design is modified, for clearance or creepage distance for example, or if the thickness of the conductive material is obviously not adapted. Some time, several possible geometries are investigated.

- As it was said earlier, the physical equations are solved locally. To be able to take into account the geometry, we have to divide spatial domains (or surfaces in the case of a 2 D problem) into small meshes, for whose knots we will calculate the value of each studied variable at each iteration (in the case of a stationary study) and each time (in the case of a transient study).

An adapted mesh is mandatory, as a too coarse mesh might hinder the convergence of the simulation, and as the number of elements and knots is limited by the system memory and computing capacities. In COMSOL the mesh is built automatically, depending of the physics used in the model. However, in the case of laminated bus bars, this operation can sometimes be problematic, because we are dealing with very thin and wide layers, not counting drawing mistakes. Redrawing parts and de-featuring the original model is often necessary to get an exploitable mesh.

The next step is very important: defining the physics involved.

In the case of our thermal simulations, we are aiming to prevent the bus bars from reaching high temperature caused by joule heating, for example 105°C being the typical PET limit or a limit set by the end customer.

The current distribution is determined according to client specifications. The easiest way to model it is to calculate currents RMS values and to treat them as direct currents. With this approach, we can set a stationary model of current repartition. When currents gets more complex, especially in the case of currents of different frequencies going through different inputs or outputs, a transient model is required to account accurately for the fact that currents of different frequencies doesn't add up directly. The electrical phenomenon time scale being different than heat transfers time scale, a transient study has to be conducted to calculate the current density map before the stationary heat transfers study.

Current density leads to heating. Cooling is usually accounted for by three phenomenons. The first is conduction, and is done by solving the heat equation. The second is radiative heat transfers calculated from Stephan-Boltzmann law. Plastic is radiating much more than oxidized metal, which is radiating more than polished metal. The third is convection and is less straightforward.

Furthermore, simulating a complete air volume with fluid mechanics is possible, but memory and computing power can be expensive. Meshing the air is again very difficult, as the air mesh has to be continuous with the bus bar mesh. The finite element method is also not the best to solve this kind of problem. The best way to address it swiftly is usually to calculate mean heat transfer coefficient depending on temperature, based on the client operating conditions.

However, fluid mechanics is used in the case of water-cooled bus bars, by modelling laminar water flows in the pipes. Conduction means a water cooled bus bar will take the heat away from the circuit.

Of course, well defined material properties and current condition are paramount to run an accurate simulation. Simulation can, in fact, vary significantly, depending on environmental conditions (temperature, pressure, etc.), the metallic alloys and dielectric materials (PET, Nomex, Kapton, etc.) used. To achieve an accurate simulation will require clear understanding of the final application.

Examples

As we saw earlier, the thermal simulations can be used in a numerous situations. The earlier the simulation is integrated to a project the better, see example fig-1 and fig-2. Numerical calculation can also intervene later in the product life time. For example, to determine causes for product failure, or to study if a given design could be used for another application and/or higher current rating and/or surrounding temperature conditions. The main goal is to validate if the proposed design meets the client specifications. High current density zones can be spotted with little calculation, but evaluating the temperature reached by the bus bar is much more difficult.

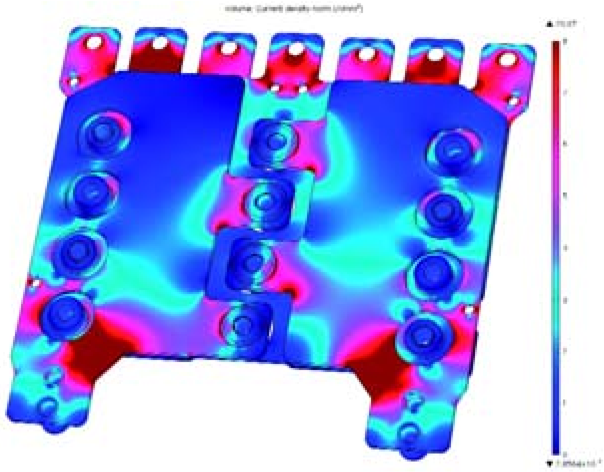

Figure 1: Simulation is integrated to a project

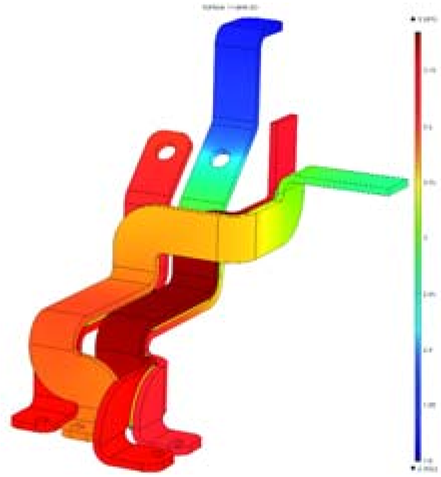

Figure 2: Simulation is integrated to a project

The client is usually not a bus bar specialist so adjustments can also be proposed to reduce heat that exceeds allowable temperature rise. Propositions such as: increasing cross sectional thickness as well as increasing the conductor width in high current density areas. As shown in fig-3 a design change will help removing hot stop on bus bar. Conversely, if the bus bar has been designed with too much caution, a cheaper and thinner version can be studied to offer a more attractive price.

The material can also be a decisive factor. Aluminium is cheaper and has a better conductivity / mass ratio than copper. Aluminium is a choice often proposed during quotation. Simulations are perfect to provide precise information to the customer. Having accurate and detailed information on each available solution is extremely valuable when determining a thickness/material couple for a prototype.

As shown in fig-4, we learned earlier, the possibility of using a water-cooled laminated busbar can also be investigated, which can provide an alternative design option. The simulations have been compared to real tests and typical differences of less than 2 K have been measured. More variations can be found for very small bus bars or near electrical connections areas where the kind of wiring chosen for the test has a significant influence on simulated results. A poorly chosen connector can heat the product or conversely act as a heat sink, and not match the simulation.

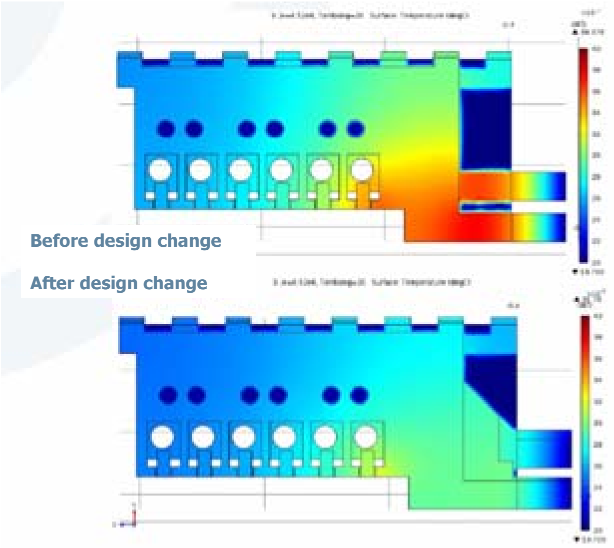

Figure 3: Design change will help removing hot spot

Future development

Thermal simulations are only the beginning. Multiphysics modelling has a wide range of applications. Electromagnetic effects, such as the skin effect, or mutual inductance effects can be modelled and studied for applications implying high frequency/high intensity currents. Information valuable for the customer, such as the stray inductance of the product, can be calculated by Mersen.

Conclusion

We still have to keep in mind that cost, size and weight continue to be primary requirements in the world of power electronic applications. Smaller size leads to lower cost, lower parasitic inductance therefore lower watt dissipation, permitting higher converter operating frequency thus reducing the size of the capacitor and inductor passive components. Mersen thermal simulation offer is significant to support this goal in bus bar design. Our thermal modelling approach has been confirmed through physical measurement. Overall, our method is reliable and able to provide a high level of added value to a client/bus bar producer relation. Also, Mersen thermal bus bar offering will reduce customer product time to market by decreasing drastically the number of necessary prototypes.

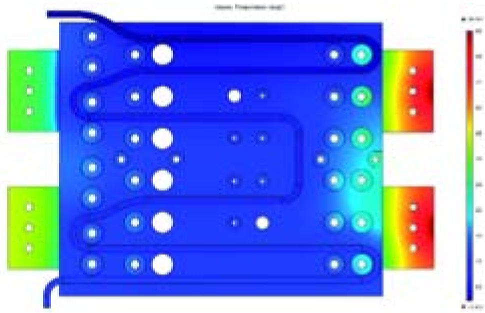

Figure 4: Water-cooled laminated busbar can provide an alternative design option

Mersen cooling, bus bar and fuse bundle offer is helping our customer achieve this goal. Our high thermal performance heat sink combined with our bus bar design capabilities and simulation will help compact the size of the cooling plate thus the bus bar and ultimately the converter. Again, a passive components specialist like Mersen and its newly implemented specification team of engineers brings much added value to the converter design if integrated in the project at an early stage.

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