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**Predictability of the Behavior of Power
Distribution Components
in Power Conversion Applications**

Predictability of the Behavior of Power Distribution Components in Power Conversion Applications

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1. Introduction

As more testing options are available at the development stage, the behavior of current distribution, using laminated busbars in high power applications, is becoming increasingly predictable. The described methodology reduces converter development time and results in contained product costs.

2. Overview of testing possibilities on laminated busbars.

Laminated busbars, used mostly to interconnect active standard components in power conversion applications, are custom designed, making it difficult to predict their behavior. Until now, testing the design of a laminated busbar was performed only when the application was completely assembled in a prototype converter. Subsequently this prototype was submitted to extensive testing of all electrical and mechanical parameters. Design flaws were oftentimes detected very late in the process, resulting in cost and development time overruns. To eliminate this risk, design parameters of the laminated busbars were increased, in turn, resulting in a costly and over-designed solution.

By applying advanced testing on the laminated busbar design before it is integrated into the application, this custom-designed component can be validated and approved very early on in the design process. This validation not only will ensure a better thermal/electrical/mechanical design, but also will provide the most cost-effective solution – eliminating all risks as early as possible, even before any parts are delivered.

Possible testing includes:

- Accelerated aging in climatic chambers
- Electrical Reliability of the insulation system: detection of partial discharges
- Behaviour of the busbar in case of a short circuit of one of the components
- Thermal behaviour of the busbar (self-heating)
- Inductivity of the busbar

- Mechanical fit by the use of 3D modeling

By applying the above design validation techniques to laminated busbars, customers can be ensured of receiving reliable and optimally designed components for their applications from the first sample. As a result, the risks of running into design problems during the qualification of the power conversion product are minimized while at the same time total product costs are contained. Indirectly the final product will also be optimized in weight and thermal behavior. In the past, inductance problems oftentimes had to be solved with snubber networks to protect the power electronics, resulting in thermal dissipation in the application and added cost.

A complete set of “testing and validation” techniques on the laminated busbars is now available for those components isolated from their final application. The detection of hotspots and the analysis of thermal behavior have been made easier. This results in power electronic applications that can be developed faster, cheaper, cooler and lighter, and that will be more reliable in years to come.

Where software modeling of semiconductors is already well developed (we have seen the successful introduction of FEA-techniques to simulate complex processes), the complexity and diversity of laminated busbars are extremely difficult to predict by calculations alone. This encourages today’s designers to take a more practical approach in the design validation of laminated busbars, and to adopt the set of testing techniques mentioned above that will result in predictable and reproducible designs.

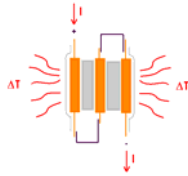
In the following sections, we will show how a potential hotspot was detected during the design static self-heating test. Without this technique, the problem would have been difficult to isolate in the complete (Is the word “complete” necessary?) inverter because the heat would have been spread over several components. An example of design optimization for inductance also will be shown.

3. Simulating dynamical electrical heating of a laminated busbar by static self-heating.

The law of Joule states that any electrical energy (P), added to a system, will be transformed into thermal energy (Q).

$$Q \approx P \cdot t = U \cdot I \cdot t = I^2 \cdot U \cdot t$$

$$Q \approx \Delta T \approx I^2$$



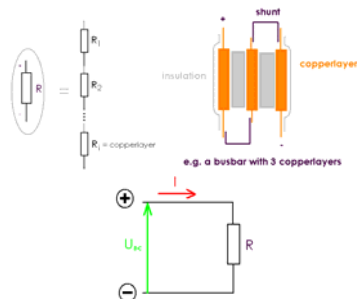
Specifically for a busbar, this means: current flowing through a busbar will heat up its body. (What body?)

For this type of test, a DC current corresponding to the maximum AC current in the application is typically used. This is a worst-case analysis since the average current is usually lower, depending on the duty cycle of the alternating current.

In this test setup, a direct current source was used.



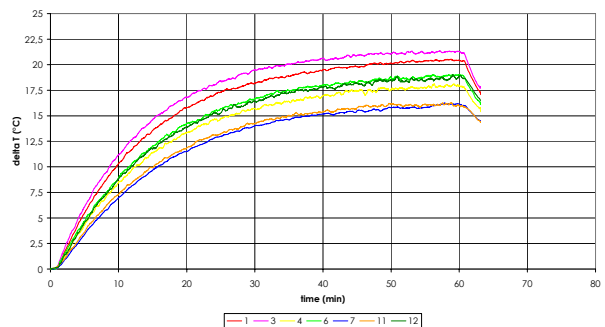
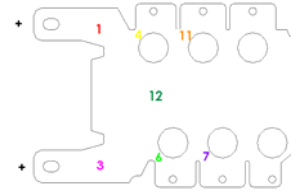
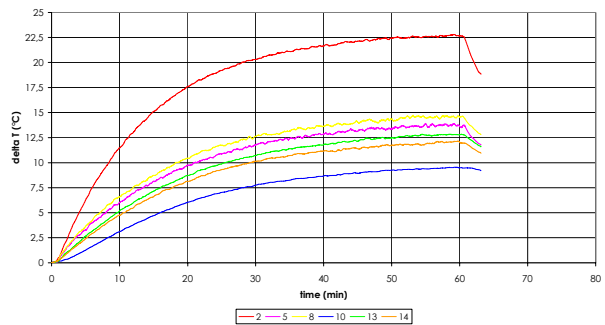
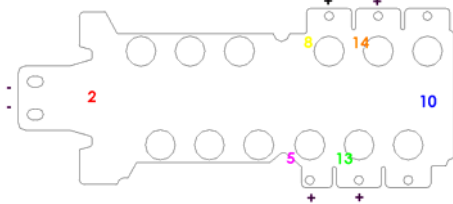
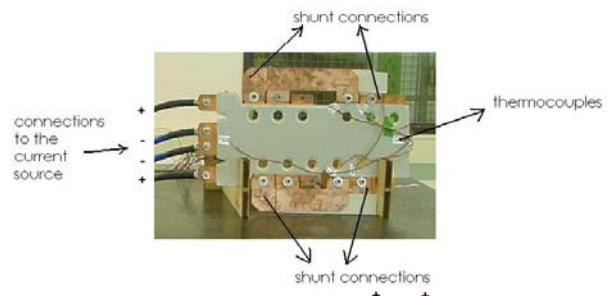
Each conductor of the busbar is used as a resistance in the electrical circuit. (Is resistance the right word?) By way of shunts between the layers, a series of resistances in a circuit together with our current source are built.



A data-recording device using 14 thermocouples measures static self-heating. Thermocouples are placed on critical spots along the busbar. The system is left running until the heating up of the busbar has stabilized (~60-80 minutes).

The following output was obtained:

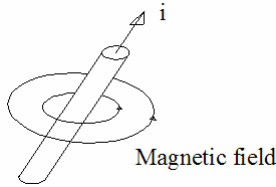
Current 600 A_{DC}



It is clear that spot 2 heats up the fastest since it is nearest to the entrance of the current. Because this busbar setup has 4 shunts, each carrying 150 A, the temperature will be much lower in the neighborhood of these shunts.

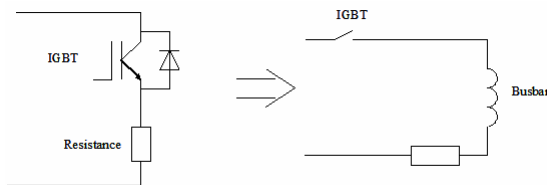
4. Measuring inductivity of laminated busbars to determine optimum design configuration.

Any current flowing through a conductor is inducing a magnetic field or any conductor in a magnetic field induces a current.



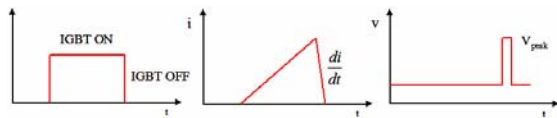
Inductivity is the amount of magnetic field that is stored in a conductor.

The following electrical model is used when comparing the behavior of an IGBT with a switch:



Whenever the IGBT is turned off, the inductive part of the system tries to keep the current because of the magnetic field remaining in the conductor.

This phenomenon induces a peak in the system, causing overvoltage, which may destroy the IGBT.



In an application of 600 VDC at 600A: [1]

With an inductivity of ~200nH, a peak of 1000V is obtained, with an additional 400V.

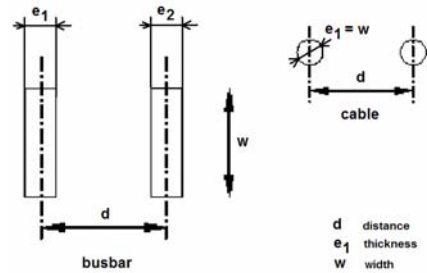
In reducing the inductivity to ~72 nH, a peak of 750 V is obtained, with only an additional 150V.

This example shows that the inductivity must be kept as low as possible to avoid problems with overvoltage.

The shape of the conductor – whether it is flat or circular – and the distance between the conductors - are of major importance for the inductivity.

Inductivity per conductor length is:

$$l = \frac{\mu}{w} \left(d + \frac{e_1}{3} + \frac{e_2}{3} \right) \left[\frac{H}{m} \right]$$



If the same copper section (100 mm²) and the distance between the two setups are identical (3 mm), the following results are obtained:

$$L_{\text{cable}} = 74 \text{ nH}$$

$$L_{\text{busbar}} = 10 \text{ nH}$$

It is clear that using a flat conductor results in a lower inductivity value, and thus a lower overvoltage. This is why busbars are important as power distributors.

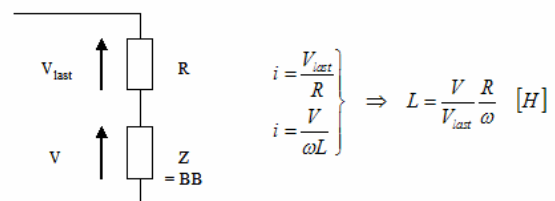
The advantage of laminated busbars in comparison with stacked busbars can be explained using the same formula. Laminated busbars keep the distance between the conductors as close as possible. If we compare:

$$L_{\text{stacked busbar}} (d=3\text{mm}) = 10 \text{ nH}$$

$$L_{\text{laminated busbar}} (d=1\text{mm}) = 6 \text{ nH}$$

The method to determine Inductivity (developed by Rogers NV in cooperation with the University Gent)[2] is based on following:

An electrical circuit is made by placing a well-defined resistance in series with a busbar.



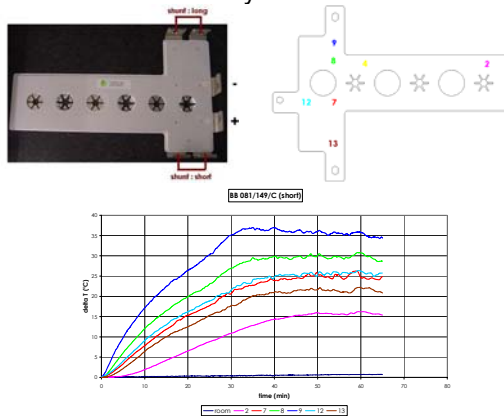
This measuring technique uses neither IGBTs nor capacitors. The measurement is performed at high frequencies (10 MHz) so that the impedance of the busbar is dominated by inductivity.

Since inductivity of busbars has extreme low values (<50 nH), it is difficult to obtain accurate values. However, we are confident about the magnitude and are able to compare different configurations in order to define the optimum design criteria.

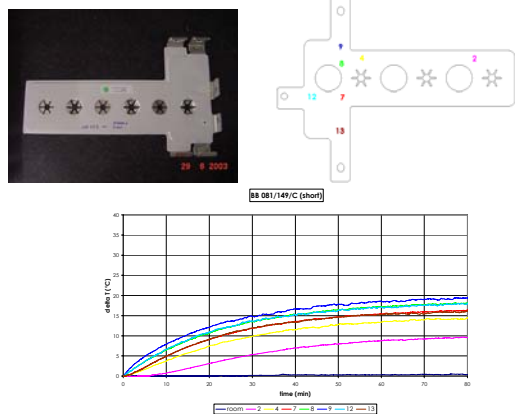
5. Example: Design of a laminated busbar for a traction inverter

Concerning static self-heating:

A new prototype busbar was tested for static self-heating during the design phase. A hotspot was soon discovered, located at one of the tabs, due to a reduced contact surface. As a result, the static self-heating reached 45°C, where in this case only 25°C is allowed.



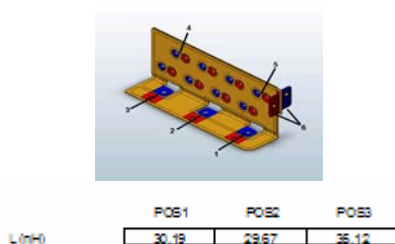
A detailed look on this specific spot, located at the short shunt, resulted in an optimization of the mechanical design of this specific tab.



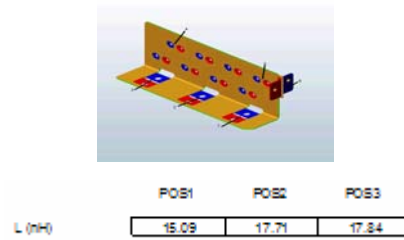
The new prototype now shows static self-heating of 20°C, which is far below the 25°C requested.

Concerning inductivity:

Inductivity was evaluated for a new prototype. In the first approach, standard mechanical techniques were used to design the specific busbar. This gave following results:



A second design tried to keep the conductors on top of each other as long as possible. This resulted in following busbar and inductivity results:



Just by adapting the design of this particular busbar, we reduced the inductivity of the busbar by ~50%. Knowing that low inductivity is one of the advantages, this step was a major improvement for the busbar.

6. Conclusion

From the above examples, it is easy to understand the added value the described testing and validation techniques are bringing to the designer of power conversion systems. The laminated busbar, which is a critical component in the application, can be optimized separately before it is delivered to the customer and mounted in the converter. The combination of the various techniques described in this paper, supplemented by others mentioned above as well, yields a better performing product that fits into the final design from the first time. It virtually eliminates the risk on cost and time overruns, providing designers with the confidence they need to develop better products for their markets.

- [1] M. Chiadò Caponet, F. Profumo, R.W De Doncker, "Low Stray Inductance Bus Bar Design and Construction for Good EMC Performance in Power Electronic Circuit", PECS, June 2000, Galway Ireland.
- [2] Prof. dr. ir. Alex Van Den Bossche, "Beschrijving van een meetopstelling voor het meten van zelfinducties <math>< 1\mu\text{H}</math>", ELMAPE, April 1997, Gent, Belgium.

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