This article was published in the German magazine "elektronik industrie", issue 1/2-2005

Paradigm change for frequency converters

Shunts instead of current transformers

The enormous task of replacing current transformers in frequency converters with shunts could only be accomplished through a joint effort. *elektronik industrie* introduces the shunt module solution that was developed by Isabellenhütte, Semikron and Siemens A&D, and that represents a completely new approach in current measurement in large converters.

For low ratings, current measurement in converters is normally done using low-impedance shunts, whereas current transformers are almost exclusively used today in the case of large converters with ratings ranging between 50 and 500 kW. Disadvantages of this solution include high costs and, above all, a large construction volume. A shunt solution for large converters offers the following advantages over alternative solutions:

It:
- is cost-effective (when considering the entire system),
- is space-saving, and it
- offers high accuracy.

For the new frequency converter series in the range of approximately 100 kW, Siemens AG relies on the shunt solution for current measurement in the output phases. It was developed in cooperation with Isabellenhütte, a well-known manufacturer of precision resistors, and Semikron, an important supplier of high-performance electronics that developed the housing for the shunt module.

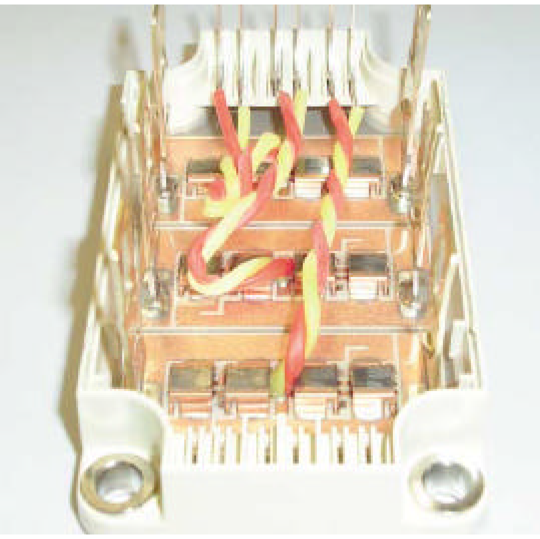

Figure 1: Shunt module for use in large converters of Siemens AG. It was developed in cooperation with Isabellenhütte (shunts) and Semikron (module housing).

Requirements for a shunt solution

A shunt solution must fulfil the following requirements:

- very low temperature dependency over a large temperature range (low TC and low curvature of the R(T) curve)
- high long-term stability
- low thermoelectric voltage
- high pulse power rating
- high overall power rating (3+11 watts for 150 A/phase and R = 0.5 mO)
- high ambient temperature
- low inductivity
- automatic assembly option
- small design, and
- low costs.

The converter manufacturer, who certainly had a lot of convincing to do internally, could not fulfil all of those requirements alone. The know-how of the mentioned companies was required here, each of them being a specialist in their field.

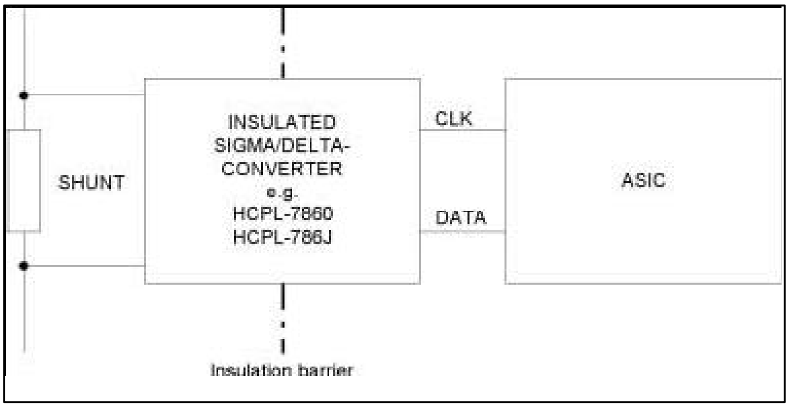

Figure 2: Block diagram/principle sketch of the current measurement using a shunt.

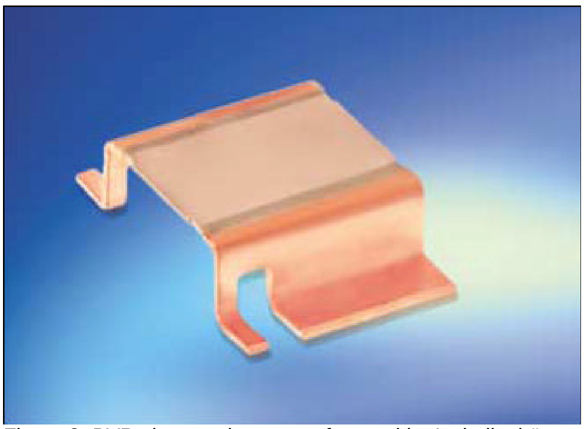

Figure 3: BVR shunt resistor manufactured by Isabellenhütte, made from ISA®-Ohm insulating material.

System considerations

Figure 2 depicts the principle of current measurement using a shunt. The voltage drop at the shunt is converted in the sigma-delta converter into a serial data flow and is transmitted optically or magnetically over an insulation distance. The serial data flow is then integrated in a digital ASIC. Respectively one shunt (or several parallel shunts) as well as a sigma-delta converter are required for every output phase to be measured. The comparable solution using a current transformer would require, for every phase, the current transformer itself, an AD converter, and also an ASIC.

Above mentioned requirements could only be fulfilled through parallel connection of up to four precision SMD resistors, type BVR (**Figure 3**), manufactured by Isabellenhütte. Another important point to be considered when designing the system was the availability of sigma-delta converters HCPL-7860 and HCPL-786J by Agilent, which are galvanically separated by integrated optocouplers. The transformer directly converts the voltage drop at the shunt into a 10-MHz data flow, which can then be processed in a digital control electronic unit.

Arranged like this, the following values could be achieved:

- resolution: 12 bit for an integration time of 62.5 µs
- offset error over the entire operating temperature range < 0.15 %
- amplification error over the entire operating temperature range < 0.9 %
- linearity error < 0.14 %

This solution is thus suitable even for the area of highly precise machine tool drives.

From a system point of view, this solution offers another decisive advantage. For the components used, the serial data flow of 10 MHz is sufficiently high-frequent to implement reliable short circuit or earthing monitoring in the ASIC to protect IGBTs. UCE control, which dates back to the time of bipolar transistors, is thus no longer required.

Due to the high resolution of the sigma-delta converter, a voltage drop at the shunt of approximately 100 mV under nominal conditions is sufficient to ensure the desired quality of the actual value of the current.

Modular technology required for high currents

The measuring currents required for the converters are considerably higher than 150 A per phase. Due to the heating that was to be expected, the measuring resistors could no longer be implemented on a standard printed circuit. For this case of operation, it was therefore necessary to use an already known and well-tried technique, namely modular technology. Apart from the high currents, it was important to maintain air gaps and creepage distances for 1200-V applications and for 1700-V applications, as well as insulation of the current-carrying potentials to earth, or the cooling element, as well as to observe a max. sense inductivity to safeguard against any distortion of the measured value caused by the module.

The Multitrans housing used by Semikron, which had originally been developed for the use as IGBT module (with base plate and ceramic insulation) fulfils the above requirements.

It offers the following advantages:

- 3 phases are provided in one housing
- UL listed
- compliance with the required air gaps and creepage distances
- insulation of non-insulated parts to base plate by Al2O3 ceramic
- connection height at same level as standard IGBT modules (30 mm)
- compliance with thermal fatigue resistance and resistance to slow load alternations, as for standard modules
- contacting of main connections by bolted fastening to increase ampacity
- contacting of the Sense connections by blade terminals
- compliance with required Sense inductivity (Lsense < 0.4 nH)
- shunt element equipment flexibility to achieve required variance.

Due to the selected structural design, it is possible to improve thermal resistance of the individual shunt element from 10 kW to approximately 3.5 kW, thus considerably increasing power dissipation. This is done by connecting the soldering foot of the element via the DCB ceramic and the copper base plate to the cooling element.

The element is consequently not cooled by ambient air, but rather primarily through thermal conduction into the defined heat sink of the system. As the materials used in the module are selected for a range of application up to 150 °C, the max. operating temperature for the shunt itself is specified here at 150 °C instead of 105° C (FR 4 printed circuit material).

Owing to the geometry, temperature distribution varies considerably when there is a load between base and centre of the shunt element. This causes significant stress on the soldered connection when alternating loads are present, which come closest to reality. This was also shown by the results obtained during alternating load tests with the BVS shunt series, in the case of which length adjustment in the element itself is almost impossible. In that case, a defect in the soldered connection occurs for a load in the nominal point already after 120’000 cycles. When using the BVR shunt series and significantly increasing the distance of the actual shunt element from the solder joint in order to make the specified linear extension possible for the system, alternating loads of far more than 1’000’000 cycles in the operating point were achieved.

Another important point is the design of the layout of the DCB in order almost to eliminate the influence of the copper on the temperature coefficient of the module through optimal direction of current. This is important insofar as the influence of the temperature drift on the measurement itself cannot be eliminated. Through optimised layout, it was possible to achieve the required value of TC < 40 ppm/K for all variants.

At Siemens A&D, printed circuit resistors are used up to 60 A (accordingly 6 W/phase), Econo shunt modules are used up to 100 A (= 10 W/phase), and the Multitrans modules manufactured by Semikron are used up to 200 A (= 20 W/phase).

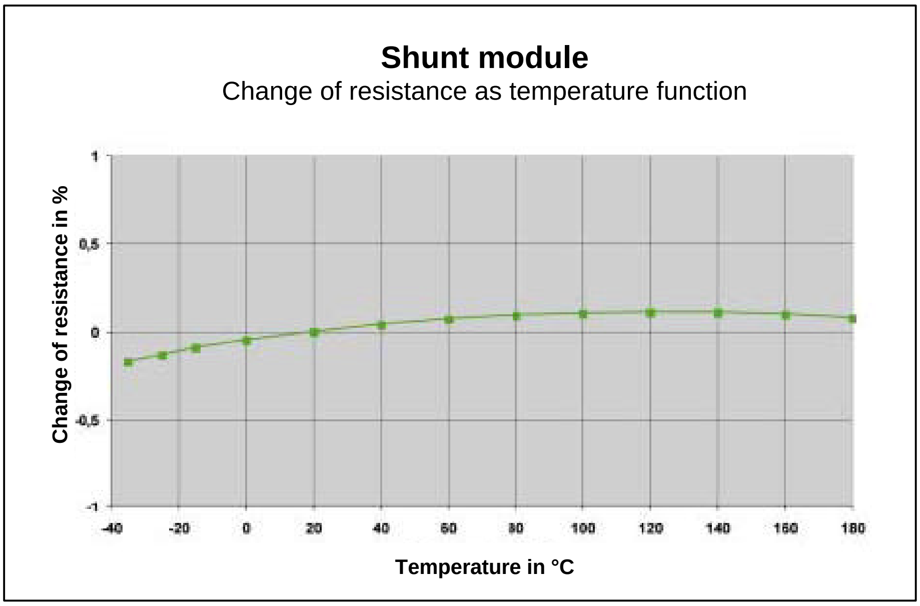

Figure 4: Change of resistance of shunt module as temperature function

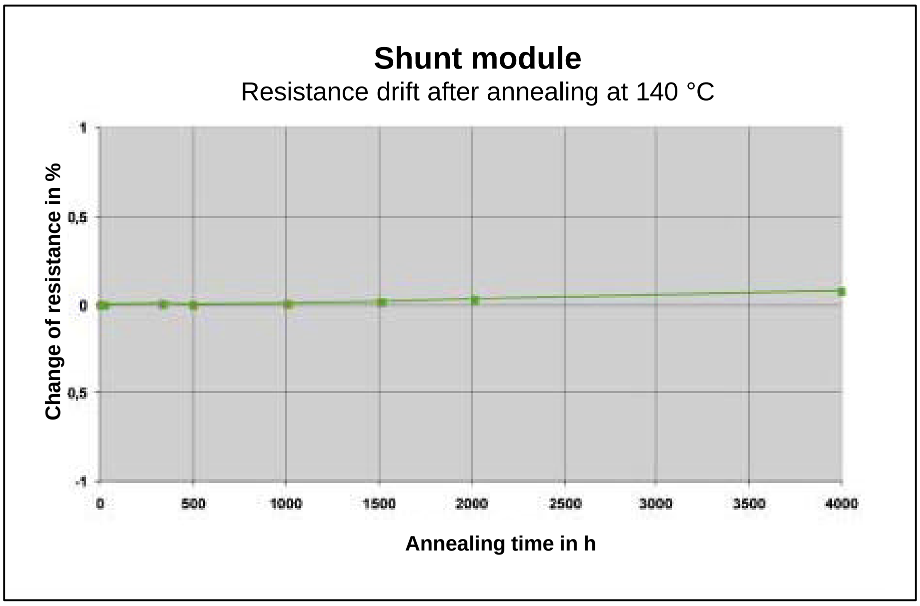

Figure 5: Resistance drift of shunt module after annealing at 140 °C.

High requirements for the measuring resistors

The ISA®-Ohm insulation material that is used for the shunt resistors (**Figure 3**) is an alloy that was developed to be used in normal resistors and that has been optimised to fulfil the requirements mentioned above. Progression of the R(T) curve over the temperature is almost linear and highly reproducible (**Figure 4**).

Thermoelectric voltage of the ISA®-Ohm has been adjusted to the Cu environment so that even very small voltages can be analysed and the Peltier and Seebeck effect, which normally causes considerable interference, does not produce any measuring errors. Thorough annealing and special tempering of the material guarantee very good long-term stability (**Figure 5**).

The component is a punched part made of electron-beam welded composite material Cu-ISA®-Ohm-Cu that has been optimised for assembly by soldering on DCB ceramic. Raised Cu connections ensure that unavoidable mechanical extensions due to alternating electrical loads are decoupled from the solder joint.

Simultaneously, the relatively thick Cu connections guarantee good heat transfer from the resistor via the solder joint into the substrate, which has equally good heat-conducting properties, so that it was possible to achieve a very low overall heat resistance of 4.5 kW.

In order to eliminate the influence of the Cu leads on TC and resistance value, a four-conductor geometry was implemented in the component.

Owing to the design as SMD component, cost-efficient, automatic assembly on standard fitting machines is possible, guaranteeing cost efficiency and high safety despite high accuracy and rather comprehensive initial tests.

Module-specific characteristics

Parallel assembly of several resistors in one module has an influence on certain characteristics, such as:

- inductivity
- ampacity
- TC
- long-term stability.

If assembly and layout are not correct, the inherent characteristics of the material and the construction could completely be annihilated because of the negative influences of the layout and the modular design.

Overall inductivity is significantly reduced by connecting several resistors in parallel. The antenna structure that is produced at a resistor by the Sense lines should comprise an as small as possible surface (for instance by conductors that are arranged very close to each other), so that as little voltage as possible is induced in the Sense circuit through the changes in the magnetic field which cannot be prevented.

Due to the high ambient temperature of 150 °C and the required long-term stability, encapsulation is absolutely necessary to protect the connection against oxidation. On the other hand, the resistor will reach a temperature of approximately 200 °C in the hot spot at maximum load, which might impair the encapsulation during long-term use.

The encapsulation height was therefore selected to ensure that the actual resistor area lies open, radiating upward. Through this structure, very high stability over time under alternating loads is guaranteed, even over more than several million alternating loads.

Conclusive remark

Parallel connection of several (in this case four) resistors in four-conductor technology is not possible unless certain provisions are made. This is due to the current distribution on the individual resistors, as well as the temperature dependency of these.

From a physical point of view, the correct solution would be to determine a mean value of all four voltages, which, however, is too expensive and costly in most cases. If, in the simplest case, the voltage drop is only analysed at one resistor, current distribution might slightly differ because of the asymmetric Cu leads resistance to the individual component, which would produce an incorrect resistance value.

What is even worse, however, is the fact that this Cu multiplier resistor changes significantly with temperature, so that current distribution also drifts with temperature. This, in turn, could completely distort the overall TC of the module.

The TC might thus shift by several 100 ppm/K in plus and minus direction. The only way to prevent this is to adapt the layout on the DCB in order to ensure even current distribution. In an optimised condition, the TC of the module corresponds exactly to that of the individual resistor.

COMPACT

Replacing current transformers for current measurement in large converters with shunts represents a completely new approach. It offers the following advantages:

- System costs are low as modern components are used.
- Shunt modules require only little space.
- Use of a sigma-delta converter that combines converter and insulation functions in an 8-terminal housing also saves a lot of space.
- Very high accuracy is achieved.

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