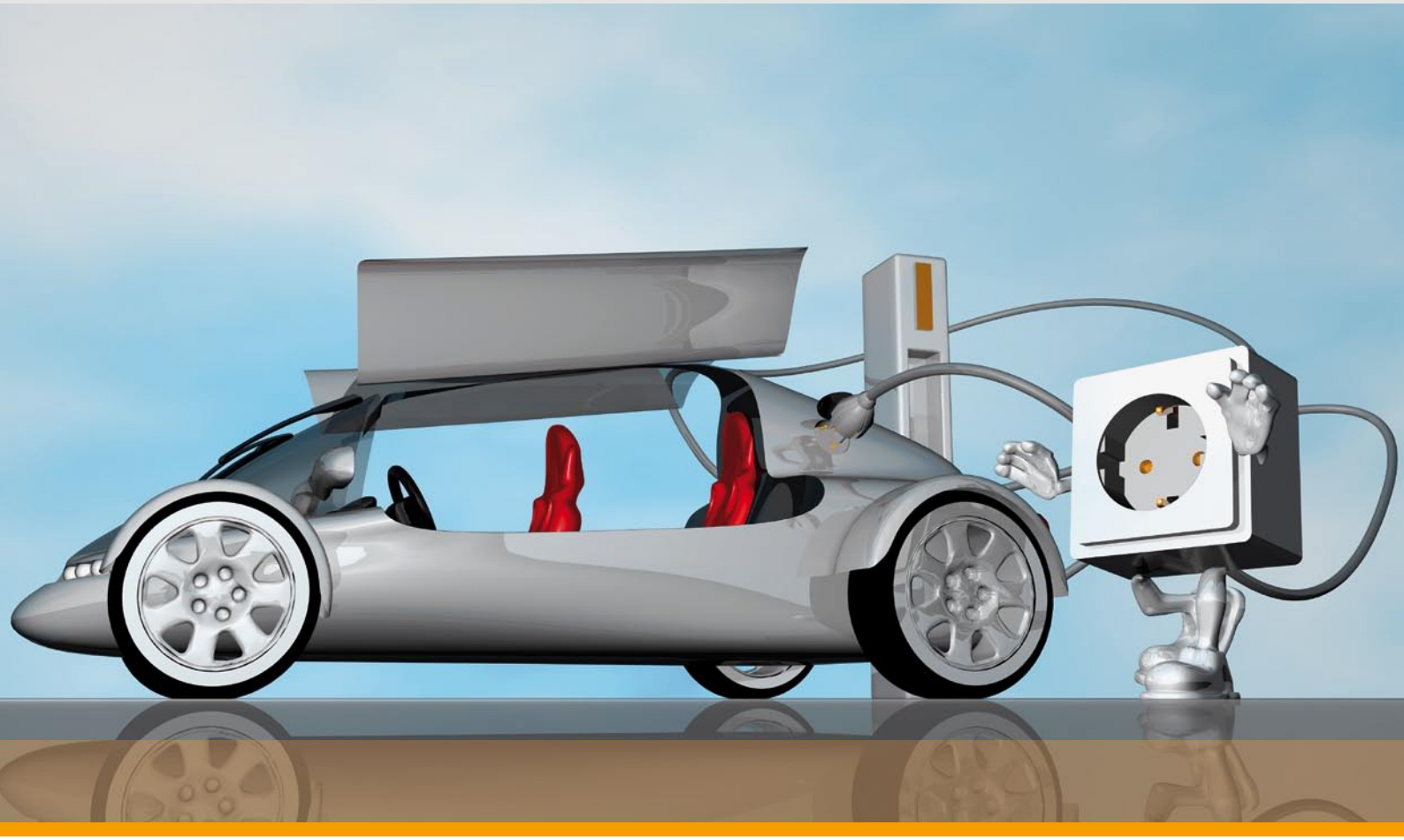

Insulation Monitoring in High Voltage Systems for Hybrid and Electric Vehicles

As a consequence of recent developments in electric drives in vehicle manufacture there are new aspects to be addressed in the protection of individuals and systems. The battery voltages used at DC 120 V to DC 1000 V are way beyond protective extra low voltage. For this reason it is necessary to monitor the level of insulation of the high voltage system in relation to vehicle earth. With continuous high impedance monitoring using an A-Isometer iso-F1 manufactured by Bender, possible high touch voltages and leakage currents can be recognised at an early stage.

1 Introduction

There is no doubt as to the need to monitor the insulation level of high voltage systems in electrically assisted or completely electrically powered vehicles. However, the battery management systems produced in the past only incorporated very simple, so-called passive methods of measurement. High value resistors were connected alternately to the positive or negative wire with more or less intelligence. The leakage currents produced by the battery voltage were then evaluated using Kirchhoff's laws and an insulation resistance calculated. In1885 this method of measurement has been developed by Siemens & Halske and became known as the "Three Voltmeter Method". Experience has shown that it is excellently suited to use in static permanently installed DC systems in mining.

In case of electrically powered vehicles, on the other hand, engineers are faced with several problems on the usage of this method which can be solved by so-called active methods of measurement, such as continuous high-voltage monitoring using the Bender A-Isometer iso-F1, **Figure 1**:

- It is only possible to locate asymmetrical faults. An evenly moistened connector, for instance, would however generate a symmetrical fault.
- A measurement through the inverter is not possible. As a consequence, drive trains and recuperation generators and, as a result, a large portion of the high voltage system remain unmonitored.
- High voltage gradients are caused by acceleration or braking. These gradients cause the majority of simplistic insulation monitoring systems to "give up" while the vehicle is in operation, that means that there is no monitoring during the trip, a situation that is imperative to avoid.

2 Unearthed (IT) Systems – Industrial Application for the Vehicle

As already described, the "Three Voltmeter Method" is a very old and proven measuring method that was used at the

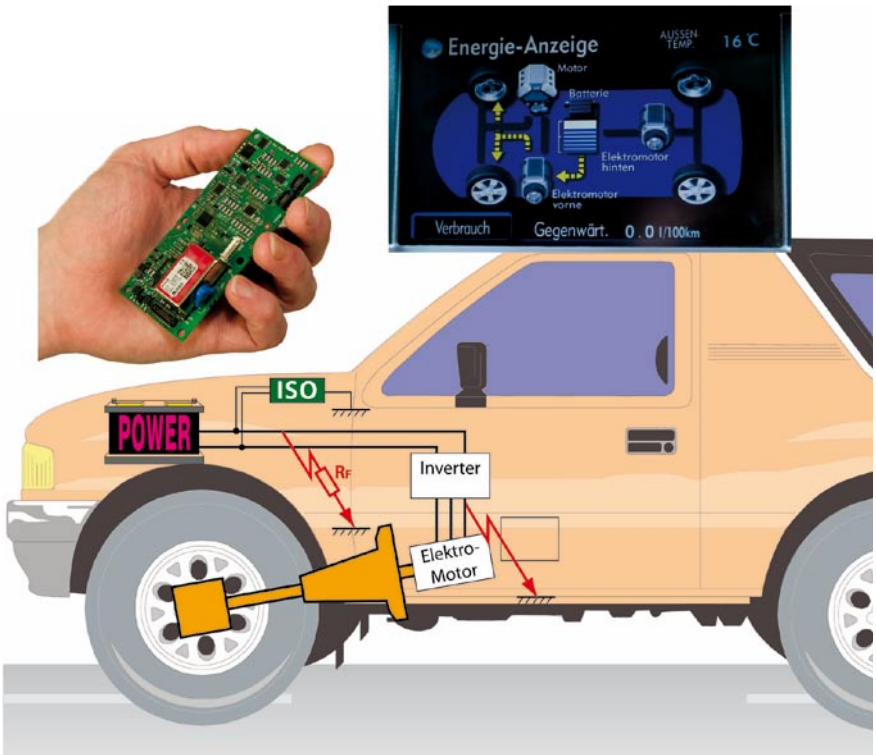

Figure 1: Application of the insulation monitoring device for unearthed DC systems (IT systems) in electric and hybrid vehicles: monitors the entire drive system, protects against electrical accidents and reduces the fire risk

The Author

Dipl.-Ing. Holger Potdevin is Key Account Manager OEM at Dipl.- Ing. W. Bender GmbH & Co. KG in Grünberg (Germany).

start of isolated power supply systems, the so-called unearthed (IT) systems. These IT systems were and are used due to the specific property that the first (insulation) fault in the DC system cannot generate any leakage current. This is because there is no connection between the active conductors and the equipotential bonding. The outcome is significantly increased availability of this supply system: It is not necessary to shut down the supply in the event of a fault, it is sufficient to detect and signal this insulation fault. However the supply should only continue to be operated as long as absolutely necessary and, after shut down, the fault located and rectified by a specialist.

To be able to use the term IT system, the following applies: the protective conductor must be intentionally earthed. In the case of an electrically powered vehicle, the earthing is, however, undefined and, if present at all, heavily dependent on the weather. An earth cable cannot be used for obvious reasons. In this application, it would therefore be better to talk of protective separation (with permanently connected loads) than of an IT system. However the advantage is the same: It is not necessary to shut down the drive on the occurrence of a first fault. In some circumstances a shut down could place the occupants of the vehicle at great risk.

3 Development of the Measurement Technology

As the usage of the IT system is proven and brings immense advantages, this form of installation has become increasingly widespread. The requirements on the monitoring devices have become increasingly complex and technologically more demanding. For decades converters or inverters have been in use with drives and generators in industry. These devices are also installed in the high-availability IT systems.

At the Bender Group very high priority is placed on the development of the latest innovative measurement technology for the protective measures to be installed in the different types of system. As a result, time and again, it has been possible to offer the right measurement solution for insulation monitoring for very recent developments in very early project phases. The experience obtained in the past in the non-automotive sector is today helping to increase the high voltage safety in hybrid and electric vehicles. A short review: One of the first requirements was to monitor pure AC systems. Already in 1939, Walther Bender provided a device-related solution and applied for a patent for this method. With the usage of converter technology, the DC voltage from the DC link circuit could then be superimposed on the measuring signal. This situation made it necessary to change the measuring voltage so that it can be differentiated from the "extraneous DC voltage". It was now possible to correctly detect insulation faults after directly connected rectifiers if a load current flowed through the rectifier valves of 5 to 10 mA in case of insulation faults > 10 kΩ and around 100 mA in case of insulation faults < 10 kΩ. With supply systems of ever increasing physical size, the challenge of increasing system leakage capacitances arose. By using microcontrollers it was, however, possible to adjust automatically to the existing conditions in the electrical system. It was also soon possible to deal with a wide range of different electrical system frequencies and interference by using increasingly intelligent, digital filters.

In vehicles, there is an additional source of interference: the heavily fluctuating mains voltage, Figure 2, that had only been seen previously in industry on pure DC systems. This situation made a further trick necessary: it was necessary to couple together two intelligent measuring systems to obtain the required results, which is now also possible.

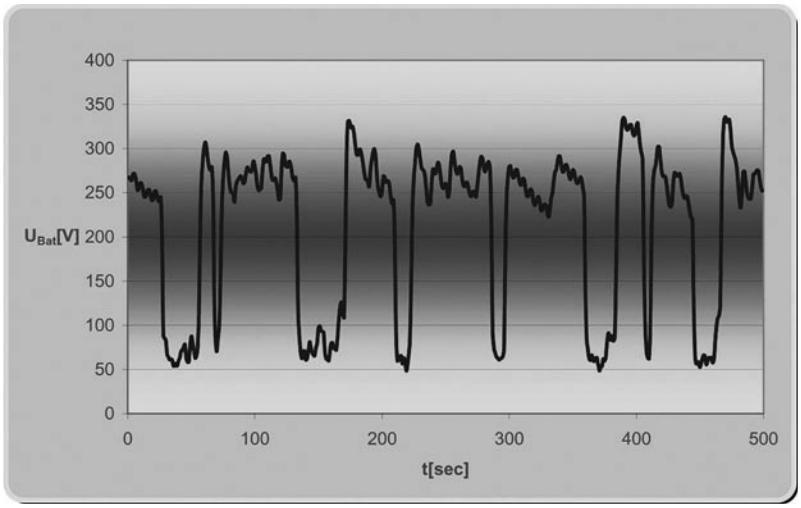

Figure 2: In vehicles, there is an additional source of interference: heavily fluctuating mains voltage. it was necessary to couple together two intelligent measuring systems to obtain the required results.

4 HV Insulation Monitoring – Device-Related Development

In the now almost 70-year history of the Bender Group, the emphasis has been on complete systems for installation in industrial plants. These industrial devices are equipped with easily accessible terminals. They are installed in housings for DIN rail mounting or for installation in panels, have a large control panel with illuminated display and user-orientated menu-based control. In a lot of cases, communication with other components can be realised via a special measuring system bus.

For vehicle manufacture these systems are unfortunately completely unsuitable, as they are too big, have a relatively low internal resistance, a high power demand and are relatively expensive. Over the past years, however, a variety of industrial device solutions have found their way into different vehicle projects. Responsible system developers recognised that monitoring only makes sense when the appropriate measure-

ment technique is applied. Bender is going back to an old development for the high voltage insulation monitoring solutions now required in hybrid and electric vehicles. A small circuit board solution was produced based on a feasibility study for a hybrid application in a military vehicle. This did not include any evaluation intelligence or manual control features, but should withstand the extreme conditions and can be equipped with the latest measurement technique.

4.1 Status Quo

As in October 2008 a Formula 1 team approached Bender and asked about a monitoring solution for a "Kers" system, it was possible to provide the first 100 functional models as early as December. Here a circuit board version of an insulation monitoring device according to DIN EN 61557-8 (VDE 0413-8), **Figure 3**, was produced weighing only 50 g and that with a temperature range from -46 °C to 105 °C (even 125 °C for 3 h), extreme resistance to shock and vibration, and very high dielectric strength and EMC immunity, in the majority of cases actually exceeds the requirements for vehicle manufacture. This iso-F1 is now in use in large numbers in a very wide range of electric and hybrid vehicles without any failures or incorrect measurements. Various versions, for example DC nominal voltage up to 800 V with 1 Mohm internal resistance (1 MOhm conductor to protective conductor, 4 Mohm conductor to conductor) or up to 1000 V with R_i = 1.2 MOhm or 4.8 MOhm with supply voltage from 9 to DC 18 V or 10 to DC 36 are already available. Here, it does not play a part what kind of energy store is applied, for example fuel cells such as electric double layer capacitors (EDLC), lead, NiCd, NiMH or Li-ion-batteries. Also the basic design does not play a part – whether fully electrically powered, serial hybrid, parallel hybrid or mild hybrid – for using the measurement technique of iso-F1 this would be no criterion of exclusion.

4.2 Outlook and Recommendations

With its broad "model policy", Bender wants to address automobile manufacturers or suppliers and implement special requirements such as CAN bus on board or the removal of the dedicated DC/DC converter (power supply) as further developments.

A further more complex subject will be the start sequence. Here the issue is to prevent the connection of a "good" component to a "bad" component. This means neither a battery with an insulation fault should be connected to the drive system, nor should a badly insulated drive system be started up. The realisation of this measurement by the time the separate systems start is a major challenge. Here it is important to take into account the requirement from the vehicle manufacturers that the start sequence must be just as quick as for a combustion engine. As a result long measuring times are excluded right from the start. The positioning of the devices in the overall system will also be crucial for the design of the devices. There are many vehicle concepts that integrate the insulation monitoring device in the battery. However, there are also solutions in which monitoring is intended to be undertaken from the inverter, integration in the battery management system is also a common approach.

Within the framework of further development, the undefined construction of the charging stations must also be taken into account. In this respect, it has to be clarified whether the construction should be realised earthed or unearthed via a transformer. It is also important to align the use of protective measures for the charging station with the protective measure for the vehicle. To this end, it is necessary to work out normative fundamentals in the corresponding committees. Through participation in a number of standard committees over many years, Bender has gained the necessary experience and competence to provide assistance in this matter.

5 Conclusion

Experience to date has shown that there exist certain reservations in relation to the subject of electrical protective measures in the high voltage systems in the car. Measurement solutions are sometimes highly simplified with the consequence of an increase in the risk of electrical accidents. With technical solutions tailored to the vehicle market, Bender is making it clear that this is not another problem area for electric mobility that is "insolvable" in the short-term, but that suppliers and automobile manufacturers can make use of proven technology installed in compliance with the standards. The Bender Group is embracing the challenges from the vehicle market. Custom technical solutions adapted to the vehicle concept ensure that electricity in the car can also "be made safe". ■

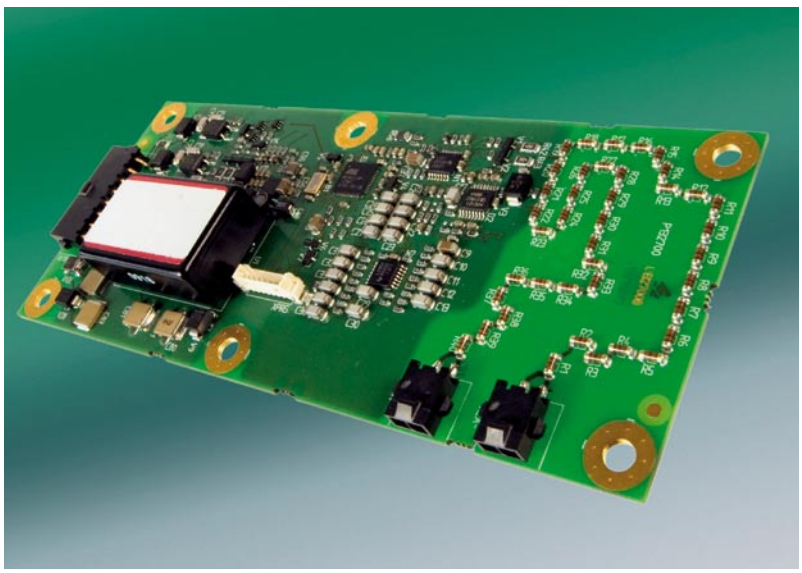

Figure 3: Circuit board version of an insulation monitoring device, weighing 50 g, according DIN EN 61557-8 (VDE 0413-8), with a temperature range of -46 °C to 105 °C (125 °C for 3 h)