Short-Circuit Tests of High-Performance Traction Batteries Using Non-Linear Current Sensors

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Abstract

Qualifying the circuit breakers and fuses of high-power traction batteries requires the ability to measure currents in the range of a few kiloamps. It also calls for the ability to measure currents of a few amps precisely and with high dynamics. This report introduces a specially developed non-linear current sensor (NLCS) and explains measurement and analysis using the Genesis HighSpeed data recorders.

1 Introduction

To be able to meet the increasing performance requirements in electromobility while maintaining a small overall size, the voltages of the battery systems used are increased. This means higher safety requirements, for example, to be able to control the high short-circuit currents that occur in the event of a fault and to interrupt them safely. Moreover, special circuit breakers are being developed and optimized for this purpose. Since these components are highly relevant to the safety of an electric vehicle, they must be tested very carefully under all possible conditions of use. Apart from the current that needs to be interrupted, the operating temperatures, air pressure (use in mountains), and inductance in the circuit are of high importance. A special test stand was developed at the Aschaffenburg University of Applied Sciences to allow for testing of the influence of these parameters. It uses testing and measuring equipment from HBK. In particular, the functionality of the Perception analysis software was used to increase the accuracy of the measurement and automate the analysis processes.

The special challenge in the metrological tests of circuit breakers is to enable the measurement of the high short-circuit current in the order of 10kA and to determine the safe disconnection immediately after the circuit has been interrupted. This requires an accurate current measurement in the range of 1 A. To meet these measurement requirements, the test stand of Aschaffenburg University of Applied Sciences uses an NLCS non-linear current sensor.

2 Linear Current Measurement

Linear current sensors, such as shunt resistors or compensation current transformers, are used in electrical measurement technology due to their high accuracy [1].

While measuring the current using a shunt, the voltage drop in a low-impedance resistor is measured and Ohm's law is applied to derive the current flow. The accuracy of the shunt measurement depends on the precision of the resistance value, the design principle, and, in particular, on the properties of the measuring amplifier. Safe galvanic isolation is of great importance here. HBK's ISOBE isolation systems are particularly well-suited to this purpose [2]. Although they have high accuracy, high bandwidth, and a resolution of the input signal of 14 bits, they can only achieve a resolution of 1.8 A with a linear current sensor with a measuring range of 30 kA. With this resolution, it is not possible to determine without a doubt whether an isolating device has safely interrupted the circuit.

3 Non-Linear Current Sensors

To be able to benefit from the good properties of the ISOBE amplifiers in this measuring task, an NLCS non-linear current sensor was specially developed to detect currents that cover a range of several decades. This NCLS consists of a diode resistor network designed for a maximum current of 30 kA.

The current–voltage characteristic of the NLCS used is shown in Figure 1. To be able to display the entire measuring range, the current is shown on a logarithmic scale. This characteristic curve can be approximately described by

$$i \approx I_0 \cdot e^{\frac{u}{U_0}}$$

[3], where I_0 and U_O are parameters that describe the NCLS and can be determined from the characteristic curve of the sensor in Figure 1. If the quantization for the voltage measurement has the value U_q, there is a relative error due to the quantization during the current measurement

$$\frac{\Delta i}{i} \approx \frac{U_q}{U_0} = konst.$$

This relative error due to the quantization during the current measurement is, therefore, independent of the magnitude of the current. This equation clearly shows that non-linear sensors offer the possibility to precisely acquire the measuring signals over an extremely large measuring range.

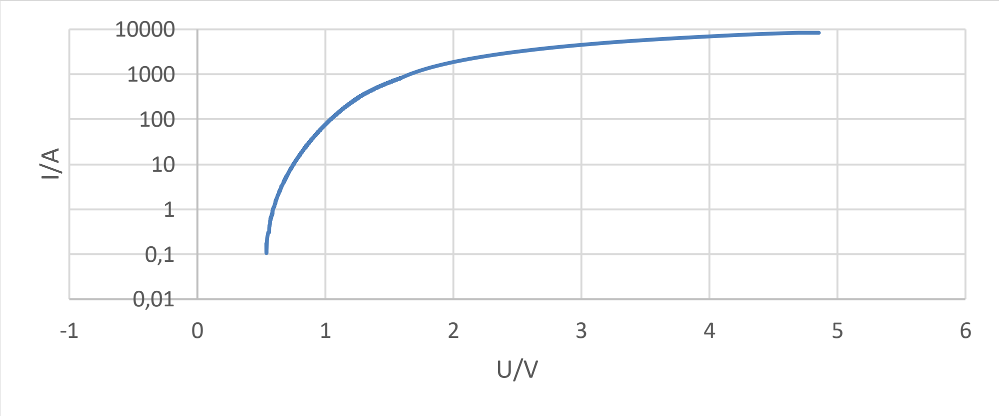

Figure 1: Non-linear characteristic of the NLCS in a current range of 100 mA to 10 kA

This non-linear characteristic of the sensor is stored in the data recorder to derive the current value from the measured voltage. A user-friendly sensor database is embedded in HBK's Perception software [4]. It enables a non-linear sensor characteristic to be taken into account conveniently. The input mask is illustrated in Figure 3. To avoid input errors, it is recommended to add the measured sensor characteristic to the sensor database as a *.csv file.

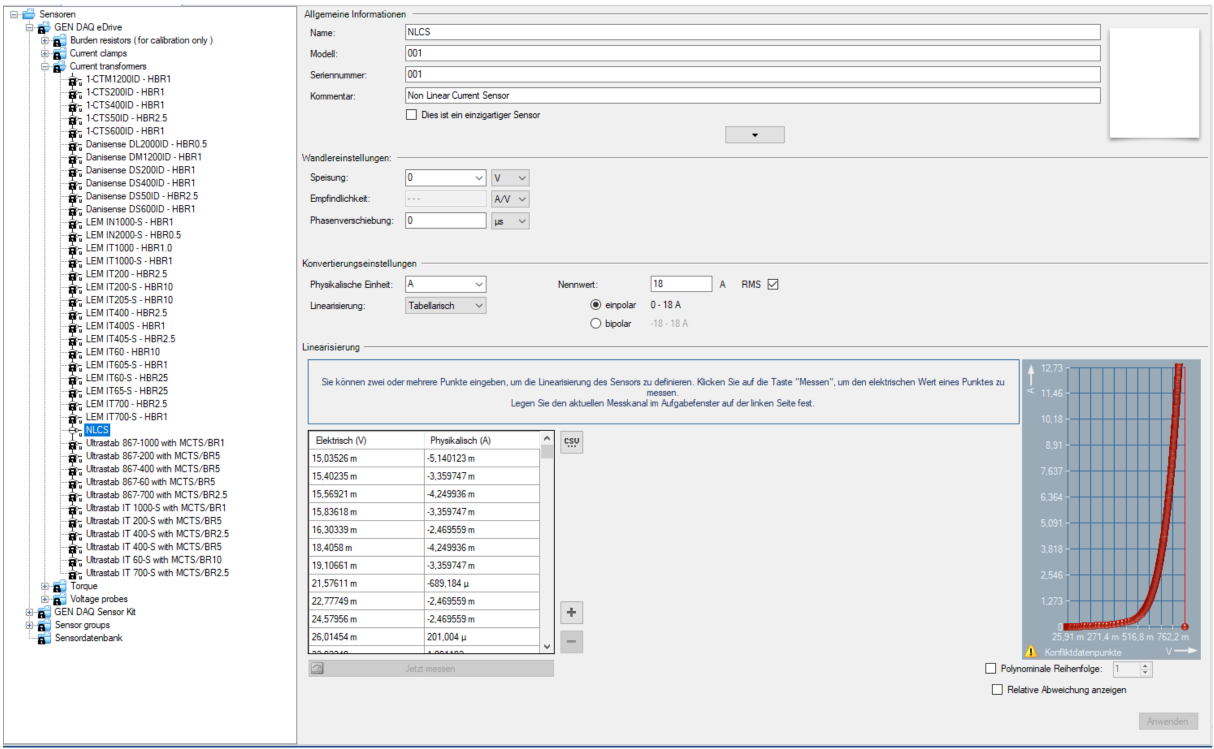

Fig. 2: Screenshot of the input mask of the sensor database in Perception

4 Example of a short-circuit measurement

The test setup as shown in Figure 3 is used to test the safety device of a traction battery The NCLS is installed practically like a shunt in the current path between the HV battery system and safety electronics. The sensor is connected to the ISOBE5600t via a measuring lead. The measurement signal is transmitted to the data recorder via a fiber-optic cable in an electrically isolated manner. A GEN2tB was used in this application [5].

The battery management system (BMS) is responsible for monitoring and protecting a battery system. During normal operation, the BMS determines the state of charge of a traction battery and communicates with the in-vehicle computer. The safety electronics with the circuit breaker, which is meant to disconnect the battery from the on-board power supply in the event of a fault, are also installed here. Further, a short circuit is provoked in the inverter to enable testing of the safety electronics. A short-circuit current then flows, which must be switched off by the safety electronics within a short time with the help of a circuit breaker.

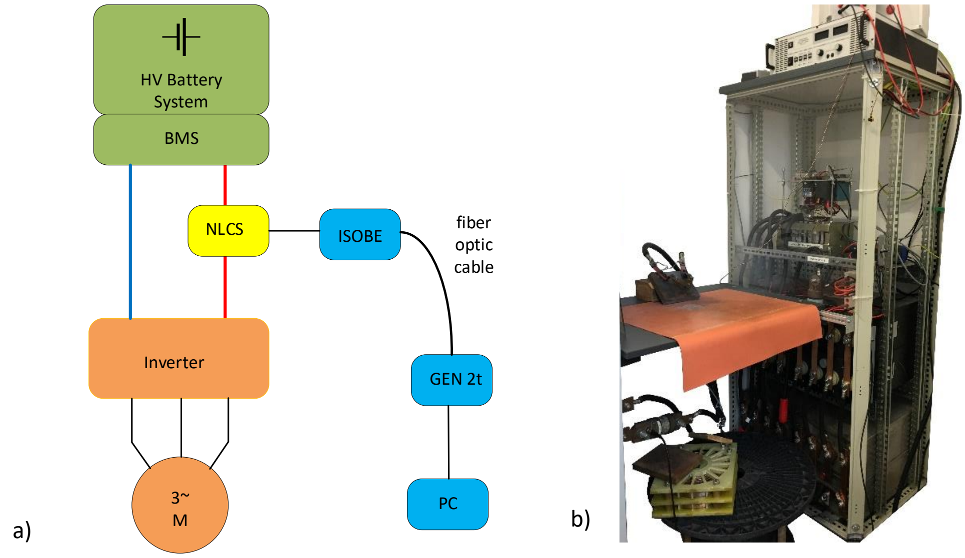

Figure 3: a) Principle of the measurement setup b) Detail of the measurement setup

The gradient of a short-circuit current over time is shown in Figure 4. This short-circuit current reaches a peak value of approx. 12 kA at time t = 4 ms. After the short-circuit current apparently has been interrupted, this current increases again to 4 kA. This behavior is not acceptable for an admissible disconnection. To clearly identify the cause of this error, it must be checked whether the current at t = 5 ms was actually interrupted or whether a small current continues to flow. However, this cannot be achieved because, with a linear converter and a large measuring range, the quantization is too high. Here, the advantages of the non-linear sensor, which have already been explained, come into play.

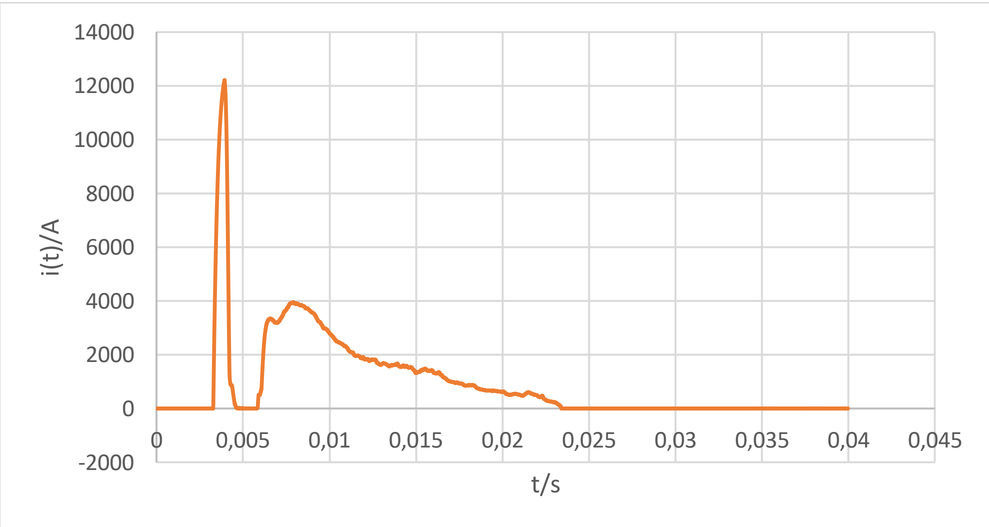

Figure 4: Gradient of the short-circuit current over time measured using a shunt

Figure 5 shows the gradient of the short-circuit current over time at t = 5 ms with a good resolution. When taking the measurement using the shunt, the quantization of the measurement can be clearly recognized. In this case, the coarse quantization and a possible offset error do not permit a reliable statement on whether or not this current has been interrupted. The same operation was recorded with the NLCS. Here, the finer resolution is easy to see. It becomes clear that the current was not interrupted and that the arc was permanently present in the separating element. This insight allows a targeted optimization of the separating element. This example clearly shows that good and accurate testing and measuring equipment allows shorter development times and ultimately reduces overall development effort.

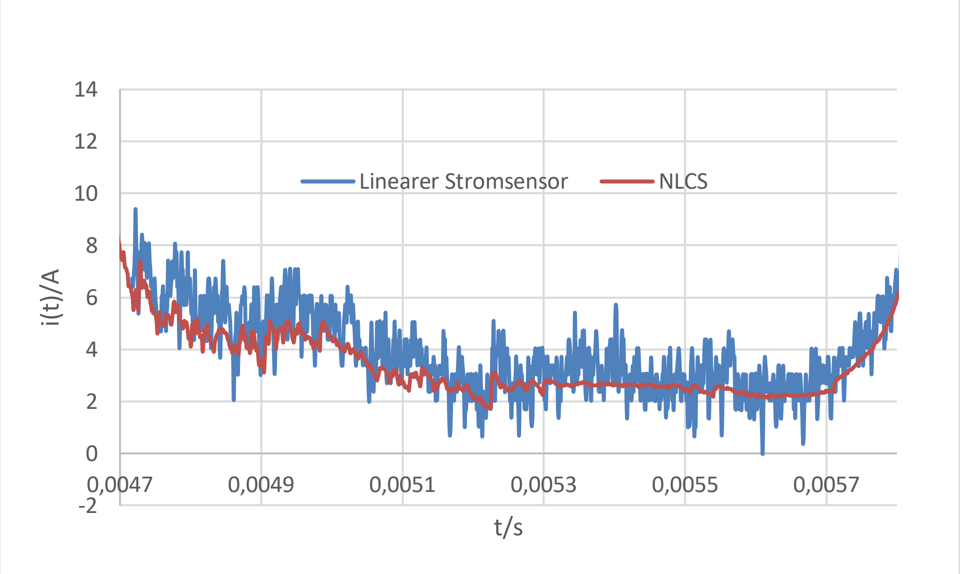

Figure 5: Comparison of the shunt and the NLCS in the lower current measurement range

5 References

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