Dynamic Vehicle Electrical System Simulation

____ The degree of electrification in vehicles is rising constantly: New driving dynamics and assistance systems work together with actuators that draw their power from the vehicle electrical system. However, such high-current consumers, with their peak currents, can place enormous demands of a completely new magnitude on the vehicle electrical system. The result: It is no longer possible to ensure the safe functioning of the vehicle without dynamic simulation of the vehicle electrical system.

By Niklas Guder

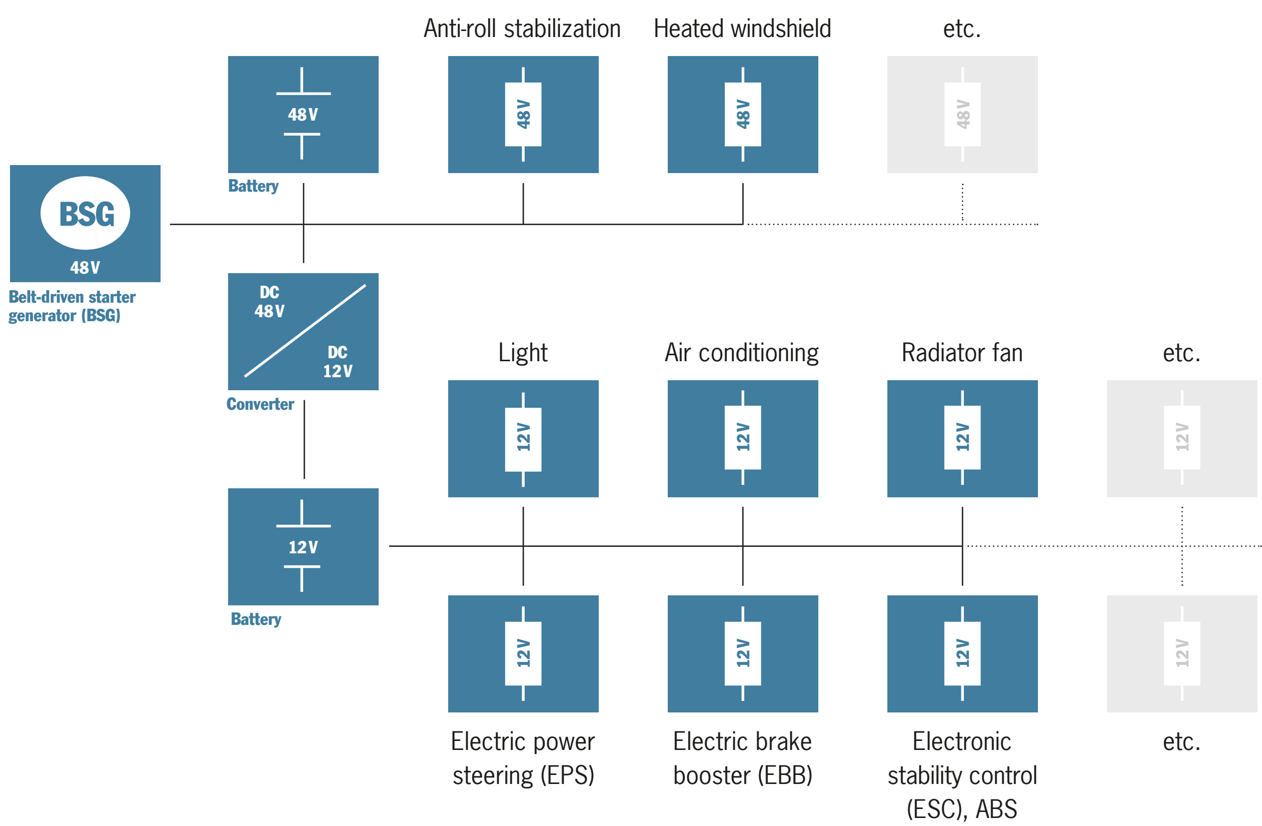

Figure 1: Vehicle electrical system with two different voltage levels

The low-voltage vehicle electrical system: central nervous system of the vehicle

Developments of recent years have clearly demonstrated that the low-voltage vehicle electrical system (12-volt vehicle electrical system) is becoming increasingly important. With increasing electrification, the demand for energy and performance rises steadily. The days in which the generator had to power just a few components, such as the main energy consumer—light—are long gone. (The colloquial name for an alternator in German—"light machine"– highlights this history.) Vehicles today include ever more driver assistance systems and chassis systems designed to enhance comfort, driving dynamics and safety. This includes functions such as the stability program, automatic anti-roll stabilization, and electrically-powered front and rear-axle steering.

Some of these functions, or rather their components, require huge amounts of power in short bursts because they need to respond quickly. These components are also referred to as high-current consumers. The electricity of these interacting chassis components can quickly lead to peak loads of over 200 A.

Ideally, the generator supplies more power than is needed to cover the base load for the air conditioning, heated windshield and lights. This excess energy is fed into the battery. This ensures that after the drive, the battery has enough power for the next time the car is started. This is referred to as a positive energy balance.

If the demand for energy in the vehicle electrical system rises faster than the generator can adjust for (the control rate for generators is a few hundred ampere-seconds, while chassis components require a current of several thousand ampere-seconds), a power shortage occurs and the voltage in the vehicle electrical system sinks. The battery now supplies the extra power required, provided that it is able to do so. In some circumstances, such as low temperatures, it can happen that it is no longer sufficient to meet the dynamic requirements. Its ability to supply power diminishes and the internal resistance rises, which also results in higher internal losses. The vehicle electrical system voltage thus sinks below the permissible limit. Depending on the voltage value, the vehicle control system reacts with various measures; the limits can vary by vehicle class. Figure 2 provides an example of the distribution of the voltage limit values. Below 13 V, unpleasant effects such as fan noise and flickering lights may be noticeable for the driver.

Multi-voltage vehicle electrical systems increase the power, but also the complexity

With the introduction of hybrid drive systems, new voltage networks with two voltage levels were developed. For vehicles with high-voltage batteries for the drive power, a DC-to-DC converter takes over the task of supplying power for the low-voltage side rather than the generator. It transforms the higher voltage in the vehicle electrical system to the desired voltage of the low-voltage side. In contrast to the generator, a DC-to-DC converter can control a current with tens of thousands of ampere-seconds and thus handle the power requirements of the high-current components. ›

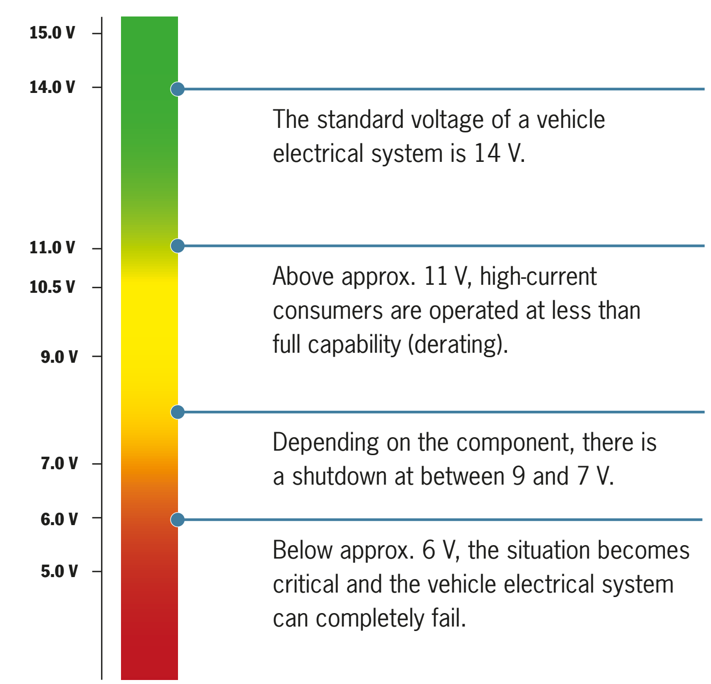

Figure 2: Voltage limits for high-current consumers

Rising energy demands in the vehicle electrical system also result in higher fuel consumption. Major efforts are undertaken to reduce this to the greatest extent possible. In this context, the conventional storage technologies used in the high-voltage realm, such as lithium-ion batteries or electric double-layer capacitors, are increasingly interesting for the low-voltage context due to their high efficiency and thus lower losses. These storage technologies can also recuperate, for example, braking energy in the low-voltage area.

The efficiency of components can also be improved through the variation of the electrical quantities. For a required amount of power, a higher voltage can allow a lower current (since current, in contrast to voltage, goes into the loss calculation squared, a doubling of the current means a quadrupling of the losses). Another advantage is that cables with smaller diameters can be used, which in turn results in weight savings. This has a positive effect on fuel consumption. The power loss that has to be dissipated in the form of heat, which often causes problems, would also be somewhat lower.

This is why efforts are under way to switch from a 12 V vehicle electrical system to a 48 V vehicle electrical system. As this transition needs to be carried over to the series production process and there are currently few components with a sufficiently long history of experience to draw on, this is associated with significant development work and costs. Thus initially, the transition to a 48 V vehicle electrical system will proceed step by step. It makes sense to start by integrating high-current consumers such as the power steering into the 48 V vehicle electrical system since they generally benefit from higher efficiency and less waste heat. The vehicle electrical systems of different voltage levels then need to be connected, however.

The variety of different functions, components and voltage levels has significantly increased the degree of freedom in designing vehicle electrical systems. To identify all critical paths in functions, components and environmental conditions at an early stage of development, it is essential to analyze the respective target system in advance. In view of the ever-increasing complexity of such systems, it is no longer possible to do so without simulating the components, the environment and the impact of the interactions of the components with each other. The high temporal resolution required for the analysis of voltage behavior in the vehicle electrical system with active driver assistance systems requires transient models (physical modeling). With the results of this analysis in hand, development times and costs can be reduced.

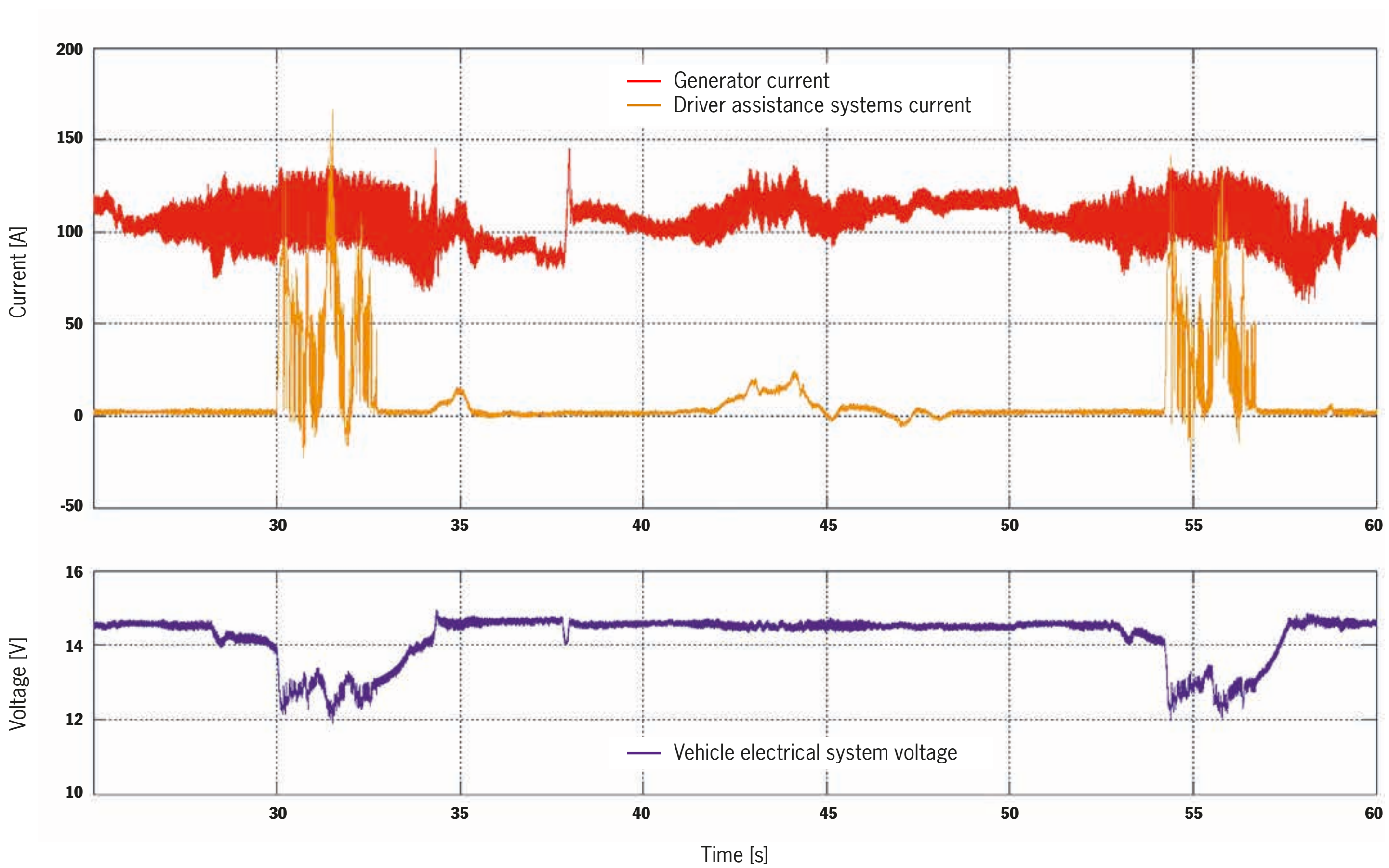

Figure 3: Example of the superimposed power demand of high-current consumers (ESC, EPS, etc.) in the maneuver "braked double lane change"

The types of vehicle electrical system simulation

If the "vehicle electrical system" is to be analyzed through simulation, the type and complexity of the models depends on the issues to be examined. Models can be of a static nature. That means that the respective components are represented in their static operating states such as the map of a generator. On the other hand, models can be of a physical nature if they represent the dynamics, i.e. the transition from a static state into other states, of the elements. The difference is not only in the precision, the effort required and the necessary parameters, but also in the execution of the simulation. In some cases, combining the two types of modeling is appropriate. Whether a simulation with the vehicle electrical system environment or an isolated vehicle electrical system simulation is preferable, and which components should be calculated at which respective temporal resolutions, always depends on the particular task at hand. Porsche Engineering analyzes vehicle electrical systems in accordance with customer requirements and has the expertise to generate the appropriate model for every stage of vehicle development.

Different ways of creating models

Depending on the stage of development of the vehicle, the available information about the components and systems varies and so, consequently, do the simulation models. Nevertheless, even before beginning the construction of the first prototypes, substantial decisions regarding the voltage behavior of the vehicle electrical system must be made as changes later in the process can result in major costs. There are various ways of dealing with a lack of important data. For previously used components, there may already be existing models that can be used instead. If this is not the case, models can be created on the basis of existing or calculated component parameters derived through measurements.

If it is a new component and the potential suppliers are known, preliminary data can be requested from them. The supplier may even provide an encapsulated model of its component. If, for example, the power requirements of an electric brake booster (EBB) at different voltage levels is known, the simulation processes these parameters in the calculation of the vehicle electrical system model. If the suppliers are not known, comparable components and their models can be applied with appropriate adjustments. The respective component experts are involved in the process at every stage. With their expertise, it is also possible to develop the right test cycle to determine the maximum current load, for instance during a braked lane change.

Energy balance as the basis for vehicle electrical system assurance

The first step is establishing energy balance. This involves a simulation with the target components in a particular cycle, for example urban traffic under conditions as they would occur in a real vehicle. Multiple minutes are simulated with models that generally have a temporal resolution of a few milliseconds to seconds. The results show whether the energy in the battery after the drive is still sufficient to start the vehicle again. If that is not the case, the components are modified in their performance and another simulation is carried out.

This type of observation, however, is not sufficient to ensure the proper functioning of the vehicle electrical system. The high-current consumers among the driver assistance systems require a low current on average, but often manifest extremely high dynamic peaks when in action. In dynamic analysis, the overall time period examined is in the second range and the models have a temporal resolution of a few microseconds. An example of the manifestation of the superimposed currents of various high-current consumers is shown in figure 3.

Dynamic analysis using the example of a DC-to-DC converter

New safety regulations demand that the vehicle remains functional until it comes to a standstill even if it is only being powered by a generator, DC-to-DC converter or battery. Therefore one simulation case is to assume that the battery is defective and only the DC-to-DC converter is supplying energy. In the first step, the simulation is conducted with the target components (see figure 4 on page 42). A braked lane change ("evasive maneuver for animal") is used as a test cycle. The characteristic units that describe a DC-to-DC converter include its rated power (in the example 2 kW), its supply and output voltage range, the temperature range in which it may be operated, and its behavior above the rated current. ›

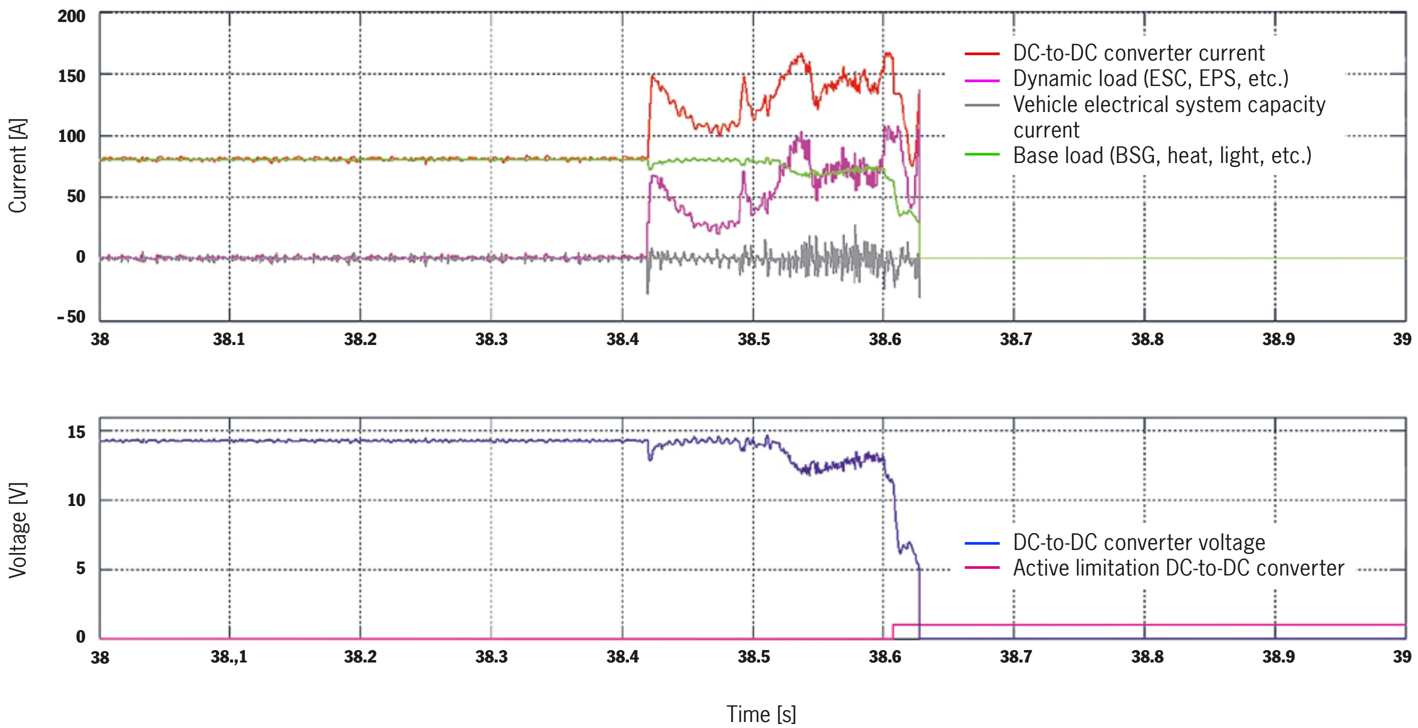

Figure 4: Current profile in the vehicle electrical system with a 2-kW DC-to-DC converter in case of total failure during braked lane change ("evasive maneuver for animal")

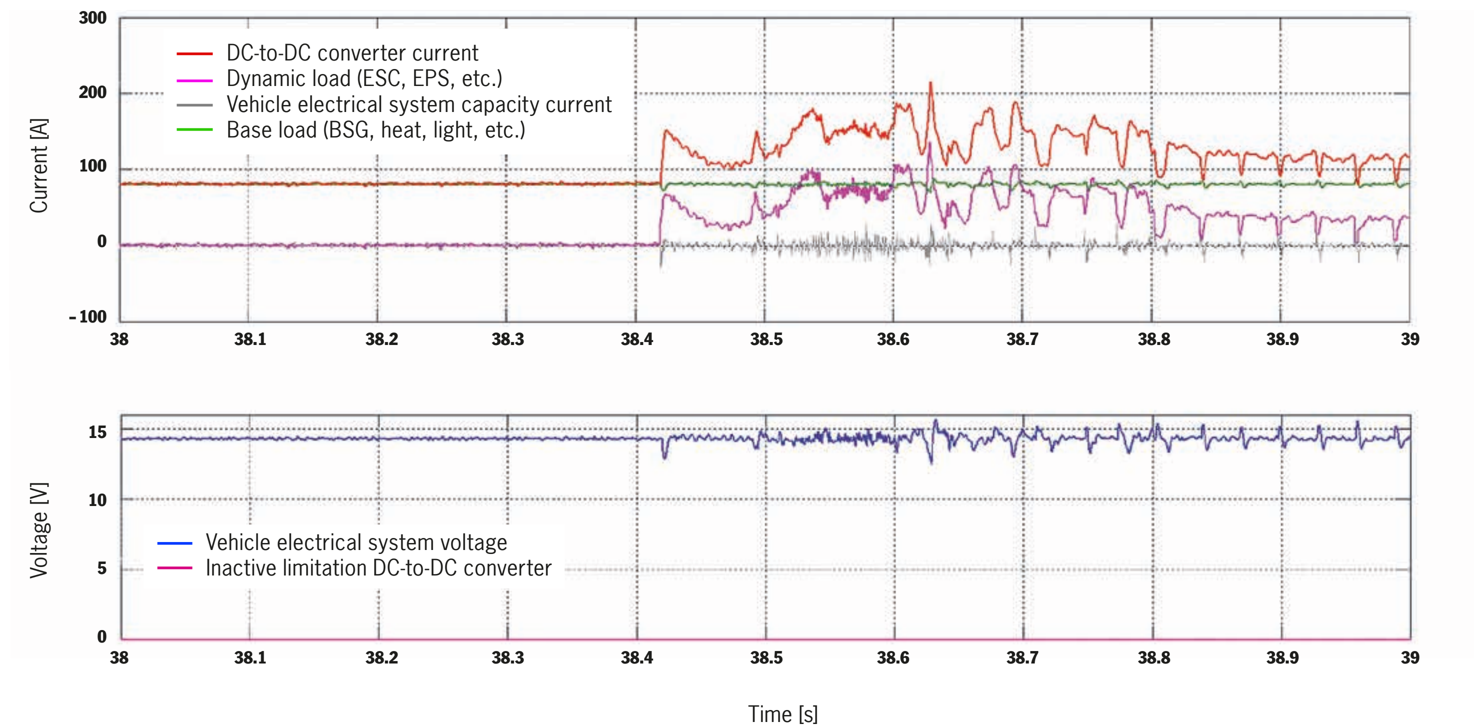

Figure 5: Current profile in the vehicle electrical system with a 3-kW DC-to-DC converter

The task of the converter is to keep the voltage constant at a target value (in the example 14.3 V). If the actual voltage (blue in the example) in the vehicle electrical system deviates from the target voltage, the converter adjusts its output current so that the required voltage is restored. It has the capacity to go into overload temporarily in moments of high power demand, but that means that it is supplying more than its rated current. However, operation above the rated current results in the DC-to-DC converter heating up beyond its permissible range. To prevent thermal damage occurring, after a defined time or above a certain temperature, the current is restricted to the rated value until it dips back below the threshold temperature.

The DC-to-DC converter usually has a capacitor in the form of a condenser in order to stabilize the output current. Together with the wire harness and the internal storage of the control units, there is also a very small storage unit that can serve as a "load buffer." But the voltage in the vehicle electrical system is also influenced by parasitic factors such as cable resistance and inductance, so they need to be taken into account.

The current profile in the simulation is shown in gray. The base load (green), which is comprised of the supply to the control units, switched-on lights and other consumers, amounts to 80 A. Due to the additional dynamic energy demands of the high-current consumers (magenta), a power deficit in the vehicle electrical system is produced. The DC-to-DC converter attempts to compensate the deficit by increasing the current even into the overload range, but cannot supply enough current to raise the voltage to the desired target value. If the voltage now falls below the minimum voltage of the control units, the vehicle electrical system as a whole will shut down. The result: The DC-to-DC converter with an output of two kilowatts is not suitable for this load as the sole supply.

In the next step, the simulation is run with a 3-kW DC-to-DC converter (fig. 5). This fulfills the current requirements and the vehicle electrical system voltage remains at an acceptable level. If supplied by a generator, the result would be different as its control rate is much lower. There the problem is not resolved by increasing the output of the component. The power behavior when consumers are discarded, or stabilization through additional energy stores such as double-layer capacitors, would be potential further lines of examination.

In analyzing the results of this, or indeed any, simulation, it is important to bear the following in mind: It is not only important to devise the model with sufficient model depth and precision for the particular task, but also to know the limits of the model so that it is possible to distinguish the physical and model-specific factors in the analysis.

Conclusion: The rapid development of complex vehicle electrical systems requires simulations

The demand for power is rising constantly due to increasing electrification. Securing the proper functioning of the vehicle electrical system by increasing the output of components such as generators and batteries is no longer possible due to the highly dynamic loads produced by the high-current consumers. At the same time, components from the high-voltage side, such as lithium-ion cells, are increasingly moving into low-voltage vehicle electrical systems. Multi-voltage vehicle electrical systems significantly increase the complexity level yet again. Dynamic analysis and assurance through simulation are therefore an indispensable part of ensuring the reliable design of future vehicle electrical systems. ■