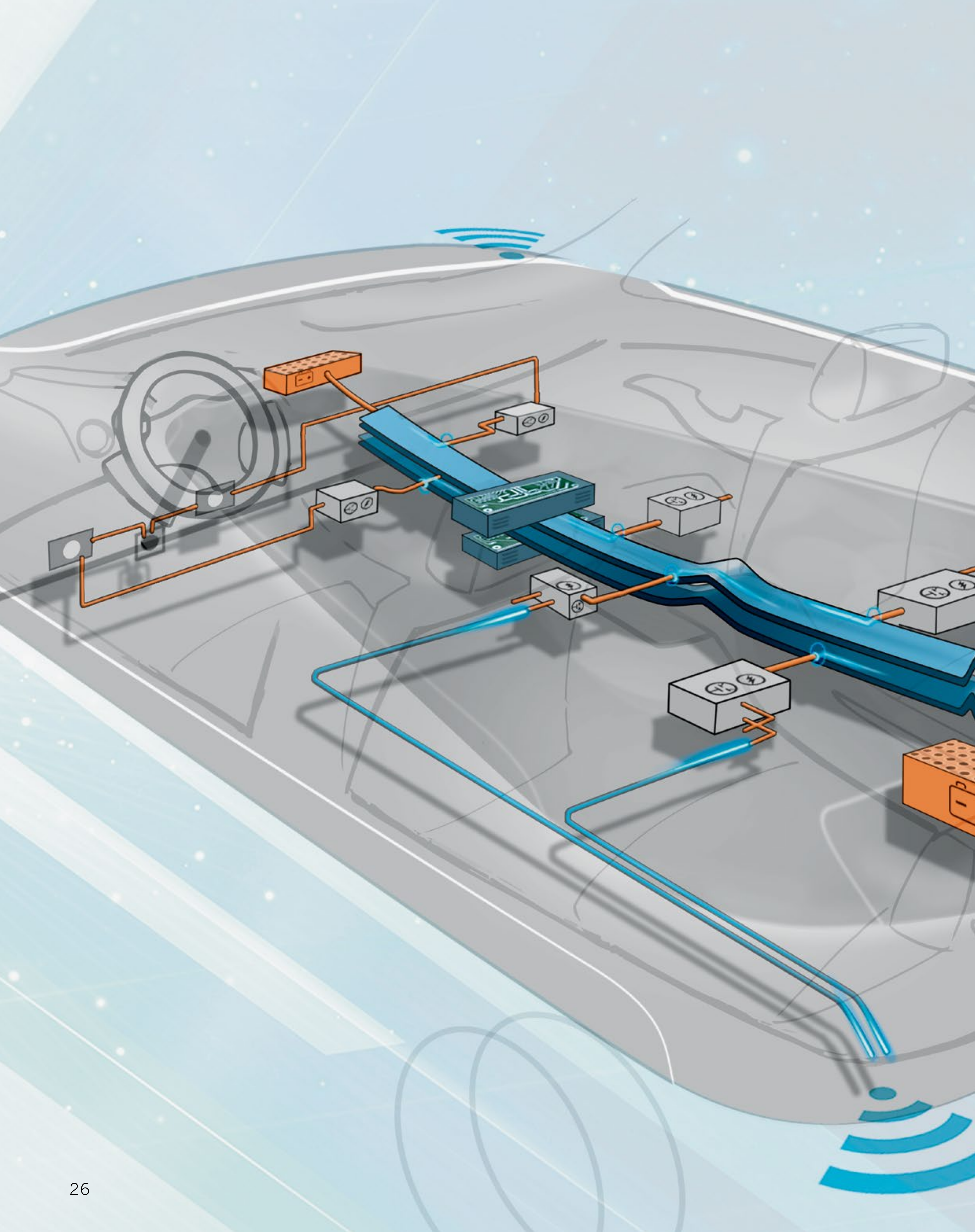
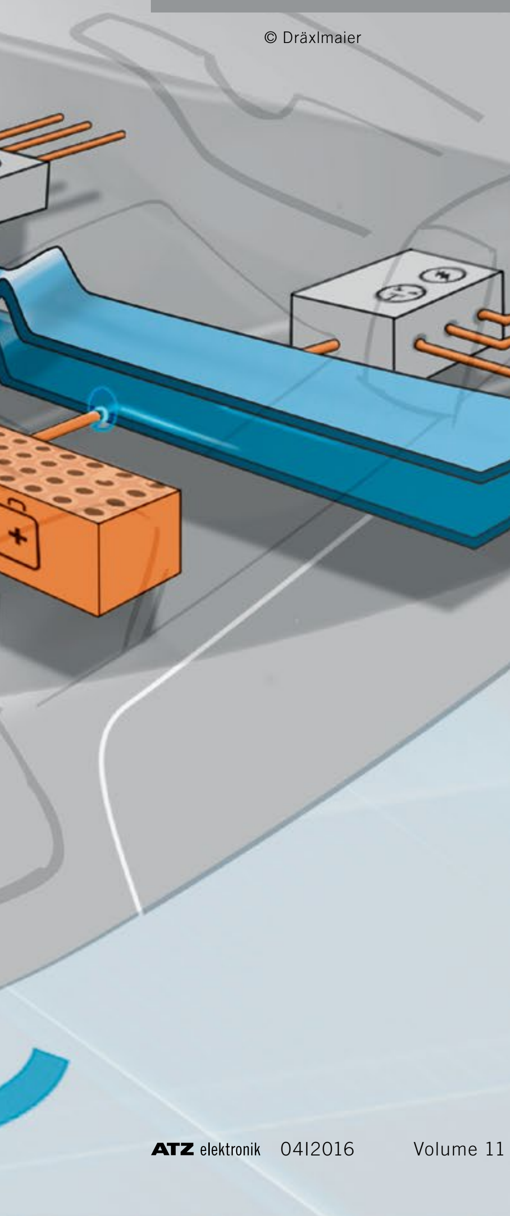


On-board Power Supply From Evolution to Revolution

Future driver assistance systems and the advancing electrification of the drivetrain are visible signs of the considerable innovation pressure which the automobile and therefore the supplier industry is under. During the process of the search for innovative product approaches and concepts, the question of how far previous basic requirements for the on-board power supply and dimensioning principles against the background of functional safety have to be reapplied is increasingly being asked. In the past, the answer was provided by the component level, but in the future, knowledge of interferences and retroactive effects in the overall system will be necessary. Only a deep-reaching expertise right along the “storage, distributing, backing up” system can provide the foundation for developing and implementing revolutionary approaches to implementation of the on-board power supply of the future.



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MORE VARIETY IS THE ONLY CONSTANT

The ever-increasing spread throughout vehicle classes from established automobile manufacturers has been observed for a long time now. Since continuous growth efforts and requirements in addition to lucrative margins by now also require the use of niches, there is a spread between a basic variation with a low level of fittings right up to an effectively full-fitting premium version, even in the B segment. In the physical on-board power supply sector the reaction to the considerable increase in complexity with an extension of the conventional structures is reactive but without conceptually implementing new architectures and topologies in basic terms.

The introduction of additional voltage levels, 48 V and HV, for the “partial” electrification results and an extension of the “on-board power supply variation spread” in an extra dimension which, in turn, reflects the complexity of the on-board power supply. The required separate routing of 12 V and 48 V is one example which can be stated.

The electrification of the drive results in the necessity to save weight and to handle the available energy efficiently. Even in the case of an electric vehicle

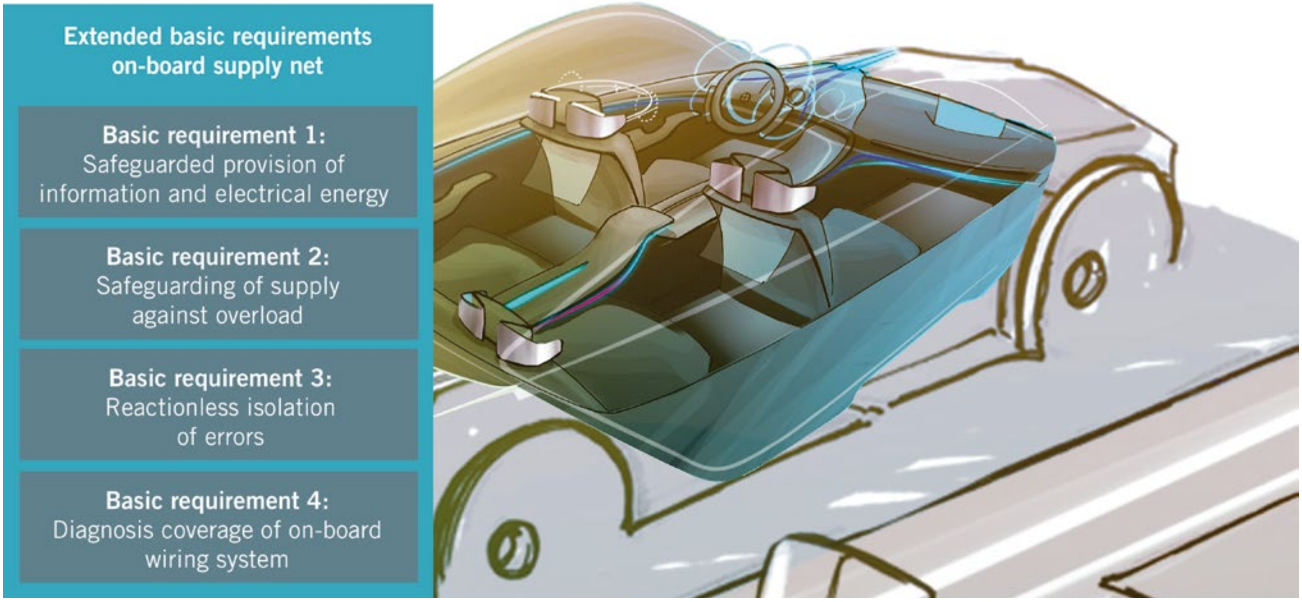

FIGURE 1 Extended basic requirements for the on-board power supply systems of the future (© Dräxlmaier)

(battery electric vehicle) with a powerful 85 kWh battery, the energy transported is less by up to a factor of 5 in comparison with the conventional vehicle with a combustion motor. The consumption required by the electrical auxiliary equipment such as heating or air conditioning, in addition to losses in the on-board power supply network, therefore significantly reduces the vehicle range.

A further dimension in the "on-board power supply network variation range" is currently caused by the implementation of highly-automated up to completely autonomous driving functions with their new requirements with regard to functional safety. This is because the energy supply network from the transition from "Fail Safe" to the available and relevant "Fail Operational" must be directly included in the safety consideration of an (electronic) function. The system architecture of on-board power supply systems must be highly developed right at the very introduction of highly automated driving features. In the future, this could mean the end for the nicely encapsulated individual life of the electric system both technically and organisationally, at least if one wants to achieve efficient and needs-based solutions with regard to costs and development efforts.

NEW BASIC REQUIREMENTS

Against the background of the new features, especially the highly automated or autonomous driving, the basic requirements for on-board power supply systems are to be questioned in the following way, **FIGURE 1**. All in all, storage, distributing and backing up will have to fulfil these basic requirements in the future. To simplify matters, the term "on-board power supply" refers to the physical harness plus storage, converter and power distribution centers.

The well-known basic requirements on the on-board power supply require two top level fundamental premises: Basic requirement number one says, that the on-board power supplyshould supply the functions with information and electrical energy. Base requirement number two demands, that the on-board power supplyis protected against overload that can lead to exothermic reactions.

There are now two newbasic requirements on top of the known basic

Fuse blow 80-A maxi

Δt	Min.	Type [A]	Max.
10,000	90	100	110
1000	95	105	115
100	100	115	140
10	120	170	230
1	170	270	370
0,1	280	700	1100
0.01 ...			

*

Loop impedance

Impedance battery + main distribution [mΩ]
18
15
12
11
10
10

=

Voltage drop [V]

Δt	Min.	Type [V]	Max.
10,000	1.62	1.8	1.98
1000	1.425	1.575	1.725
100	1.2	1.38	1.68
10	1.32	1.87	2.53
1	1.7	2.7	3.7
0.1	2.8	7	11
0.01 ...			

FIGURE 2 Matrix for calculation of the relative voltage drop in battery and main supply during hard short-circuit behind an 80-A maxi-fuse (© Dräxlmaier)

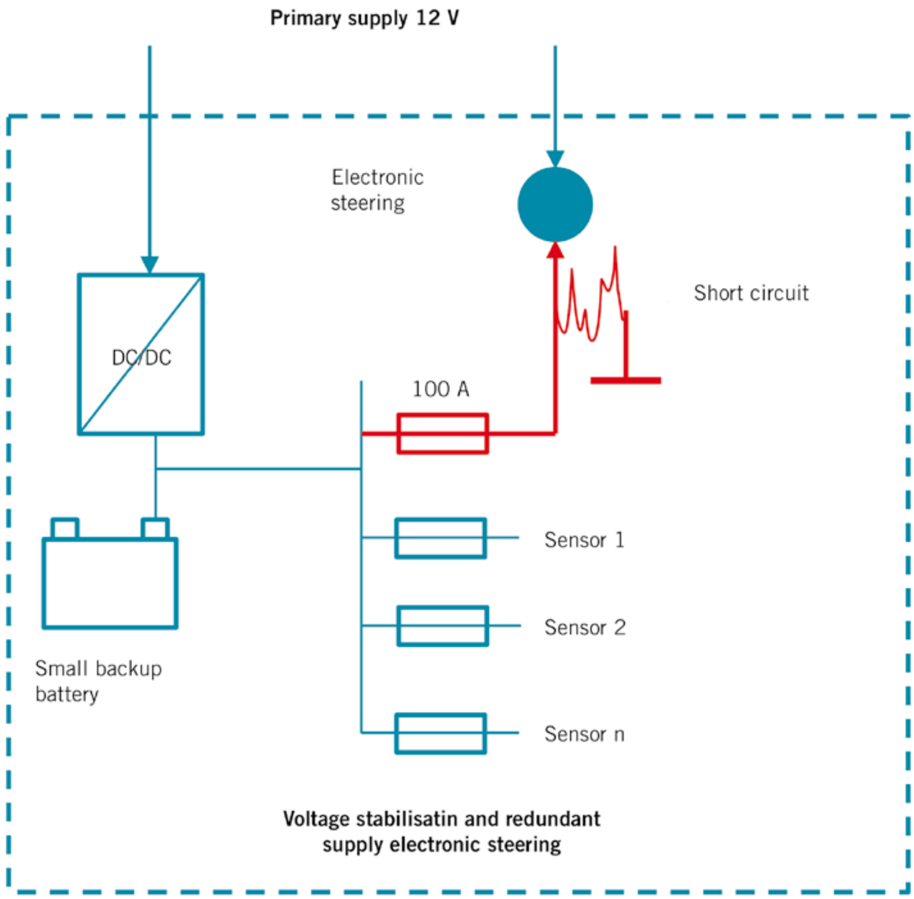

FIGURE 3 The 100-A fuse cannot isolate the short-circuit on the secondary steering system supply without reactions; sensors 1 to n fail simultaneously (© Dräxlmaier)

requirements, and we will be dealing with those in detail here. This third basic requirement states that errors must be isolated without interaction (interference-free in acc. w. ISO 26262) in the on-board power supply network.

Or, in other words: A fault at any location in the on-board power supply net, must with reference to the safety goals, be non-interactive and separated so that the safety relevant functions are not impaired. It must also be ensured that an error in a non-safety relevant function (for example short-circuiting of a PTC auxiliary heater) does not have any retroactive effects on the highly-automated or autonomous driving functions.

A fourth basic requirement has now been added: Not only for the electronic function, but also for the on-board power supply net of the vehicle, a diagnostic coverage must be provided, referring to the ASIL classification of the function to be supplied, because a failure of the energy supply for fail-operational functions of highly automated driving leads directly to a violation of the safety goals.

Against the background of these new basic requirements, which are related directly to the safety objectives of the highly available on-board power supply, the question now arises as to what extent conventional on-board power supply solutions can meet this extended catalogue of basic requirements.

THE FUSE IS AN OVER-SIMPLIFIED SOLUTION

The fuse, which has been used as standard so far for protection of wires in the on-board power supply net affects all four basic requirements. Triggering too early (for example due to ageing) affects basic requirement 1, in other words safeguarding of the constant supply availability, triggering too late affects basic requirement 2, protection against thermal incidents. Up to now the relationship to basic requirement three, freedom of interference, has been paid little attention: **FIGURE 2** shows the characteristics and the effects of a short-circuit in the form of a matrix in order to clarify the above context, the example shows the effect on an 80-A maxi-fuse: In **FIGURE 2** it can be seen that voltage drops in the supply wiring system of between 7 and 11 V can occur due to the thermal inertia of the fuse for 100 ms. This type of voltage drop at the main supply level has considerable repercussions. As a result all voltage sensitive consumers will fail at the same time, unless they have a redundant supply from a secondary source and the voltage drop in the primary supply is decoupled from the primary supply by an additional and rapid switching element (Mosfet), **FIGURE 3**.

If the reactive effect was previously concerned with a battery backup function, this effect is then increased, if the source for example is a DC/DC converter without large powerful battery in the output circuit, which may be in this case for example, a 12-V supply net fed from a 48-V/12-V DC/DC converter. A DC/DC converter is typically not able to deliver the short circuit current necessary to trigger a large fuse, unless it is oversised with negative cost implication.

It remains to be noted that the conventional fuse of the basic requirement of the non-interactive (interference-free) isolation of faults, at least for high assurance levels, cannot be met. This has considerable influence on possible approaches to architecture of the energy supply system. Concepts with conventional fuses are also poorly positioned regarding basic requirement no. 4, the diagnostic coverage. All known diagnostics are limited to knowing if a fuse has blown or not. Whether a fuse has aged due to impulse loads of whether due to thermal loads the tripping characteristics have shifted and the tripping is close, cannot at the moment be technically diagnosed.

OPEN QUESTIONS

For the conception and dimensioning of the highly available on-board power supply the term “safe operational condition” has considerable meaning. If a component that belongs to a function is only loaded in the safe operating conditions, then it will bring the calculated safety margin during the defined service life corresponding to the requirement without any limitations to its specific performance. If the component is used outside its safe operational condition, partly overloaded, then the degradation

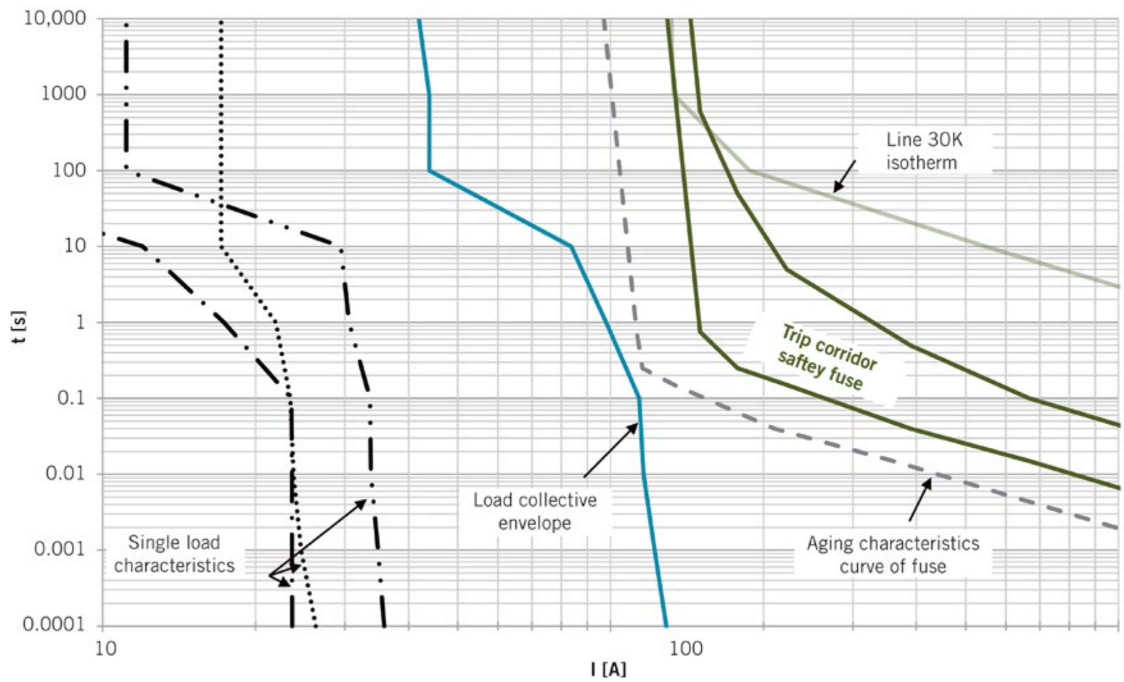

FIGURE 4 Load characteristic of a collective in relation to tripping characteristics of fuses (© Dräxlmaier)

and early destruction is to be expected and thus the loss of availability is predestined. For the availability of the highly automated driving features, it is therefore necessary that the components of this function are only loaded in the safe operational range. As the "fail operational functions" of the physical on-board power supply is part of the action chain of the functional safety (FuSi), this is not allowed to be loaded outside the safe operational range. The task that has to be dealt with when designing a corresponding on-board power supply, is to design components of the on-board power supply net, which can operate in the safe operating range under the possible load profiles and the collective load of the components of the entire system.

FIGURE 5 Use of busbars and electronic power distribution in Dräxlmaier Smart KSK (© Dräxlmaier)

Although this statement appears obvious, the following questions arise: How can the safe operating range of the components of the on-board power supply system be represented? How can the load profile of a load or a collective load be represented and considering this, be brought to the safe operating range! An example here is the design of the feed to a decentralised small power distributer. With this, the supply path to ten loads is assured. The sum of the fuse values is 210 A. What cross section must the main supply lead to the decentral current distributer need to have?

A conventional design rule is, that the fuse of the main supply line should be 60 % of the sum of the individual fuses. In this case a 125-A fuse is required. The associated main supply lead would then be 25 mm² copper wire. From experience we know that a copper wire of 25 mm² at this point would be significantly oversised, especially since it is associated with too much weight and cost in the on-board power supply. Instead, you can select a 10 mm² copper wire with a 70-A fuse. The suitability of an expert estimated based sizing is then verified by a measurement on the vehicle.

However, this empirical approach leads to a problem: If a separate measurement is made of the individual loads, this does not provide any clear conclusions concerning as to how they overlap in terms of time so that the maximum constructive addition results. If on the other hand the total current of the collective load is measured, it is unlikely that the constructive addition of all loads of the consumer network are really discovered during a measurement run.

The question as to whether the fuse is operated in its safe operating range, with no aging, cannot be satisfactorily answered. A false tripping with the resulting drop of availability or the loss of a safety-relevant consumer cannot be excluded.

It can be summarised firstly that the conventional methodology for the dimensioning of fuses and leads as attestation for the conclusive suitability of the availability of relevant functions is insufficient and secondly the fuse itself has to be highly criticised when it comes to the non-reactive isolation of faults in the on-board power supply.

DETERMINISTIC DESIGN

A deterministic interpretation, for example, the supply of a remote small distributor, assumes reproducible information with regard to the maximum load of the collective load, which arises from the constructive superposition of the individual loads of the distributor.

This task can be solved using the energy envelope of the individual loads in the form of a current-time relationship matrix [1 ms: 35 A; 10 ms: 33 A … 103 s: 11 A]. The energy envelopes, also known as load characteristics, can be derived by filtering the load curve with stepped RMS filtering. The following is to be emphasised: The addition of the load characteristics of the individual loads results in the load characteristic of the collective load. The constructive addition in all impulse durations is given implicitly. This makes the addition of the individual load characteristics for the derivation of the operating range of the collective load.

This important precondition, however, does not apply to an addition of load profiles in the time domain. The addition of all single load profiles in terms of time does not lead to the maximum load profile of the collective load! The condition of a constructive addition is therefore not given, because this would require a variable time shifting and correlation of the signals.

FIGURE 4 shows the derivation of enveloping of the load spectrum by adding up the individual characteristics of the load. The Safe Operating Area of the fuse is in the area on the left of the aging curve of the fuse. For the current time envelope edges on the left, this assumes that the fuse does not age. The selection of the fuse in this example shows the valid dimensioning for the supply line of the distributer. The fuse is not loaded outside its safe operating range, so that no reduction in availability is to be expected due to false tripping.

IMPLEMENTATION OF THE ON-BOARD POWER SUPPLY OF THE FUTURE

For a high-availability system of energy supply the deterministic design is necessary, but not sufficient. Due to the degradation of a load over time the aging curve as shown in **FIGURE 6** can be exceeded. Hence, the importance of diagnostics is immediately obvious for high-availability systems: It should monitor that the loads do not leave the pre-defined Save Operating Area, which presupposes current measurement. Such a diagnostic with a safety concept using fuses does not make any sense from a technological point of view nor from a commercial point of view. At this point the electronic safety concept comes into play, which is beneficial from the diagnostic concept point of view and also aids for configurable fuse characteristics which allow for non-interactive behaviour when interrupting short-circuits.

After the foundations for a high-availability on-board energy system has been described, a view should be made of the “big picture” for the future of an on-board power supply system: Initial concepts from car-makers show how highly automated

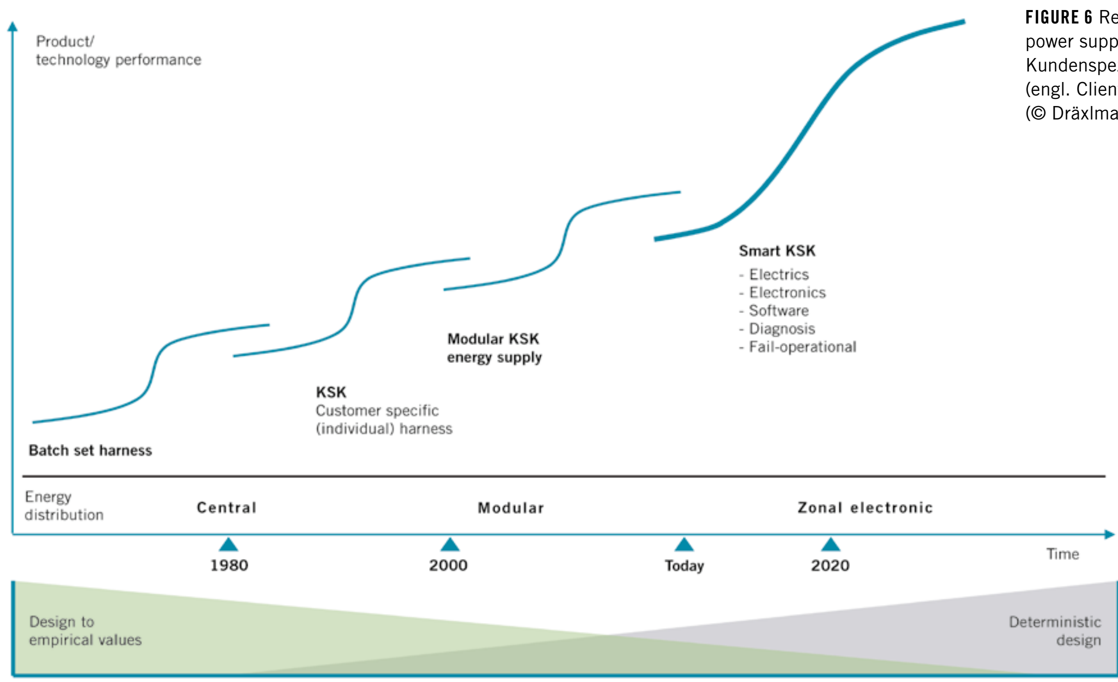

FIGURE 6 Revolutions in on-board power supply design; KSK = Kundenspezifischer Kabelstrang (engl. Client-specific cable harness) (© Dräxlmaier)

driving features and software-driven services on two high performance redundant computer units can be counted on. The two computer units are supplied redundantly, as well as the sensor and actuator functions of the highly automated driving. The leads for the main supply are no longer integrated in the body sill, but in a crash-resistant centre area of the vehicle, **FIGURE 5**. As this point a revolutionary new supply concept from the Dräxlmaier Group comes into play: Two busbars with redundant supply voltages from two sources form the backbone of the electrical and thermic flow in the vehicle. The heat of the computing units can be given up to the busbars and at the same time supply can be drawn. Electronic decentralised power distribution moduls perform the energy flow management and the fusing against overloading or short-circuiting. Fail Operational Functions of the highly automated or autonomous driving are also supplied via two electronic distributors. These take on the task alternately of supplying energy so that the supply can be switched from a faulty busbar to a faultless busbar.

REVOLUTION IN ON-BOARD POWER SUPPLY DESIGN

Variety is the only constant – automotive manufacturers and suppliers will have to abide by these words in the future. The increasing diversity of variants of vehicle models demands that their products be even more flexible. In order not to enter a phase of high complexity, future vehicles with and without automated functions should share a basic architecture. System integrating and at the same time scalable solutions for storage, distributing, backing up and distribution along the complete electrical, electronic, software, diagnostics require defined interfaces in advance. These interfaces must on the one hand support scalability, on the other hand must be able to isolate faults and their effect on the on-board supply system. To meet the new requirements, a profound system approach must be made regarding deterministic design, which is being followed by Dräxlmaier – a real revolution in the on-board power supply network. As a system supplier Dräxlmaier has the competency to actively shape and drive this approach.