Whitepaper HV System Simulation
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System Simulation according to ZVEI Guideline

Thermal Optimization of HV Harnesses

A ZVEI guideline describes a standardized, cross-manufacturer cross-vendor format for exchanging parameters of electro-thermal component models for system simulation of the vehicle high voltage system. This methodology helps to reduce connector size and weight, wire cross-section and development times.

While first-generation electric drives are still being incorporated into existing vehicle platforms in small numbers, current-generation electric vehicles (EVs) are being built around the electric drive as the central element. To establish electromobility on a broad scale in the market, purchase price and range are the decisive factors. With higher range requirements the increased installation space and weight of the HV battery is a particular concern.

The resulting increase in acquisition costs for end customers currently requires subsidies to be able to offer entry-level prices comparable to those of internal combustion engines (ICEs). The top priority of the entire automotive industry must therefore be to end dependence on subsidies as quickly as possible. The levers are to reduce battery costs (out-of-scope here) and exploit the much lower complexity of the e-drive train compared to that of a comparable ICE. This will reduce development and material costs. The methodology described in this whitepaper discusses how the ZVEI guideline contributes to these objectives by realizing potential savings in development time, material cross-sections, weight and installation space through the design of the HV harness using standardized system simulation.

Product Development Process

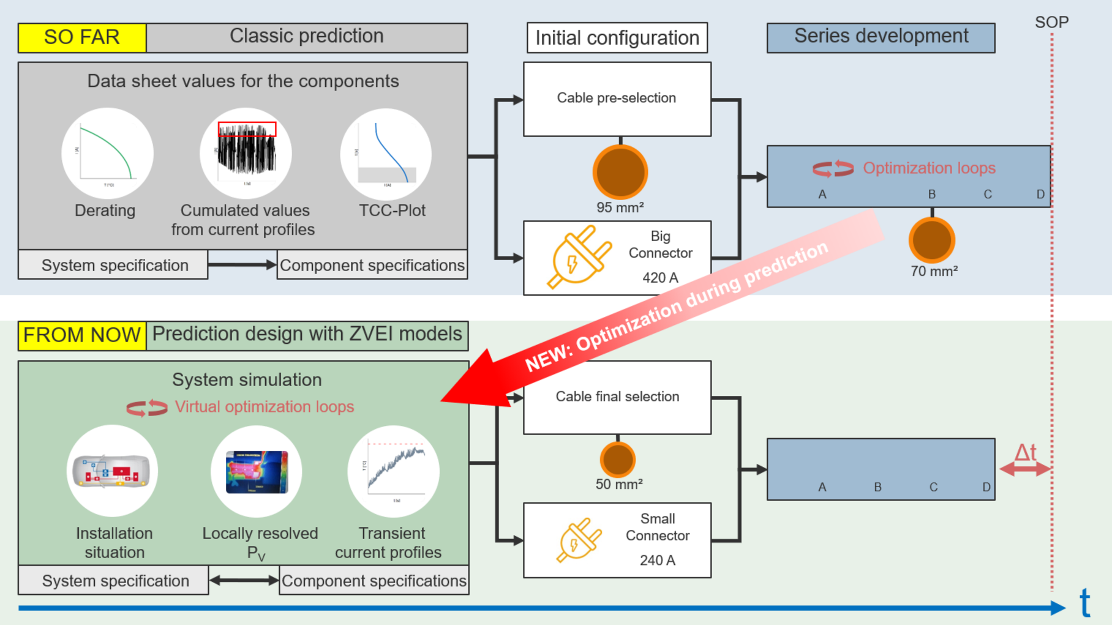


Figure 1: Optimization of the product development process by prediction with ZVEI models

The advantages of system simulation become clear when looking at the existing product development process (Fig. 1, above), which is divided into three phases. In the preliminary design phase, the system and component specifications are prepared. Depending on the design basis , the initial configuration is determined. This includes, among others, the choice of connectors and meter goods. Based on this pre-selection, series development begins in the typical development phases A to D, ending with the start of production (SOP). In this example, connectors of the HVS® series with 420 A (HVS®420) and 240 A (HVS®240) rated current are analysed. In the following, the approach established in the automotive industry is contrasted with the future methodology using thermal networks according to ZVEI guidelines (Fig. 1, bottom). These are surrogate models of individual components whose interconnection in the overall system environment describes the electro-thermal properties of the HV harness.

Classic Prediction for the Selection of Connectors and Cables

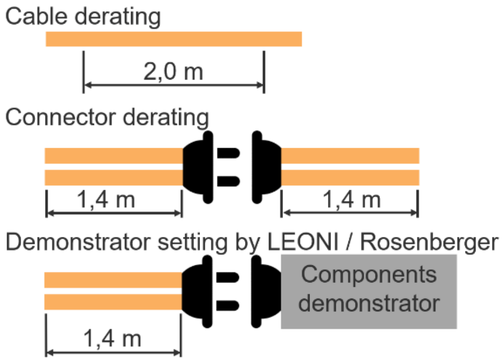


Figure 2: Cable and connector derating according to DIN 60512-5 and demonstrator setup

The classic procedure for selecting connectors and meter goods is carried out in standardized setups (Fig. 2) by means of derating curves according to DIN 60512-5 and current-time diagrams, so-called TCC plots (Time Current Characteristics), which are currently not defined in any generally applicable standard. A derating curve describes the current capacity of a component as a function of the ambient temperature. The resulting current-carrying capacity is multiplied by 0.8 in accordance with the standard to cover, for example, measurement uncertainties and specimen scatter. Aging effects are not mentioned in this standard.

In TCC plots, the time until the limit temperature is reached is given for one-time current-pulse loads. For current-carrying HV contacts and cables, this is often 180 °C, depending on the material. Here, too, the safety factor 0.8 is usually applied to the current. The key parameter is the ambient temperature. TCC plots are also used to evaluate current profiles. For this purpose, the current profile of the load is divided into current intervals (Fig. 3, left) and broken down into equivalent individual loads. The duration of individual current pulses in each interval is cumulated along the current profile. Thus, the equivalent total duration of the load per current interval is obtained. The upper interval limit is taken as the current. The equivalent individual loads were plotted as crosses by current and equivalent duration in the TCC plot (Fig. 3 right). The load capacity curve of the components (curves in the TCC plot) must lie above these individual loads. With this design, the permissible maximum load is not exceeded.

In the example, the accumulated individual values of the profile lie between the 70- and 95-mm² curves of the cables and between HVS®240 and HVS®420. According to classical prediction, HVS®420 with 95 mm² cable cross-section is recommended.

Possibly, by loading transient current profiles on test specimens, the cable cross-section can be reduced to 70 mm² in the sample phases of series development. However, boundary conditions of the system environment such as heat sinks cannot be evaluated with this approach. The cross-sections of the components are therefore not designed to the limit. Shield currents are not taken into account although they can reduce the current carrying capacity.

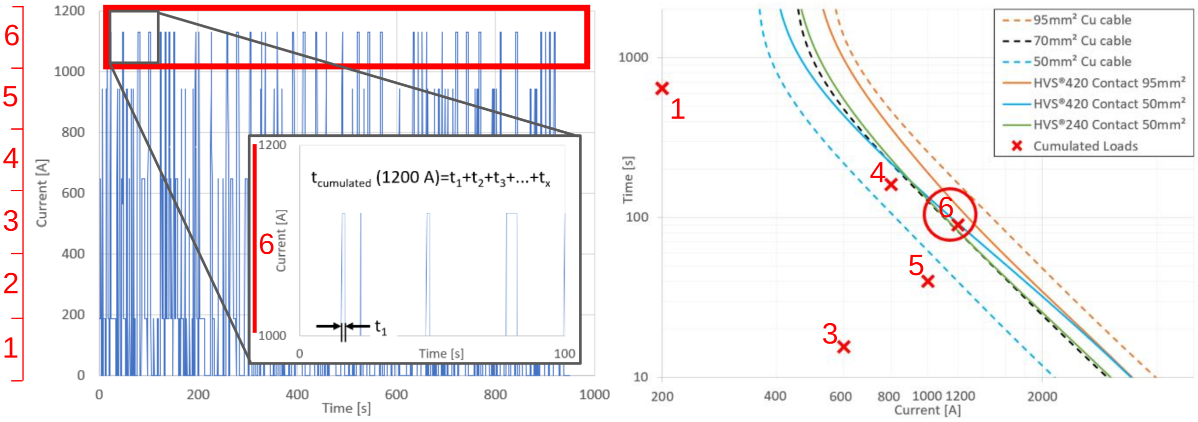


Fig. 3: Dimensioning of components from a current profile (left) by cumulated values in a TCC-Plot (right)

Prediction Design with ZVEI Models

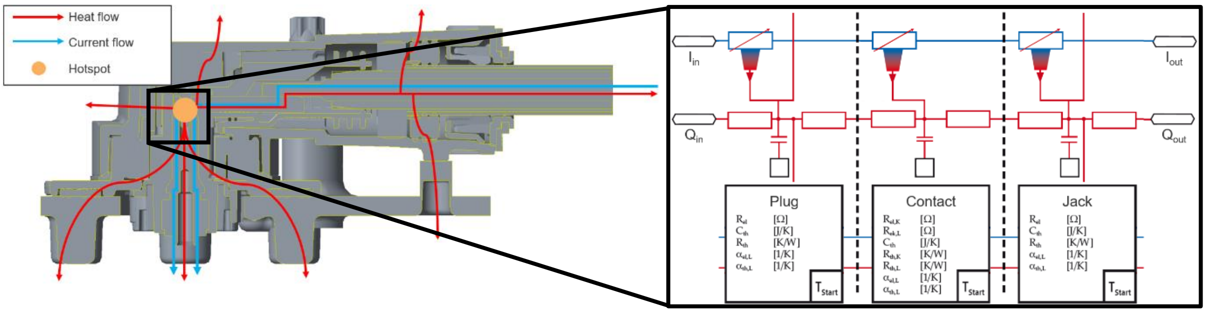


Fig. 4: Sketched current and heat flow of the HVS®420 and equivalent circuit diagram of the contact

In the ZVEI, several OEMs and large numbers of automotive suppliers have collaborated in recent years to publish a standard format for exchanging thermal network parameters in the TLF0101 technical guide. The current flowing in the system (Figure 4, blue path) causes ohmic losses. This heat loss is dissipated thermally (red path). The heat dissipation behaviour can be affected by thermal resistances and heat capacities. In analogy to electrical circuit technology, the heat dissipation behaviour can be modelled by thermal networks.

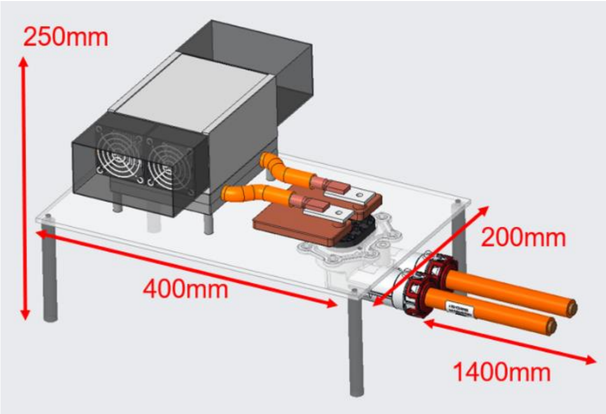
The guideline standardizes the procedure for creating thermal networks and defines the parameters required to describe the component. This allows complete HV systems consisting of cables and connectors to be modelled. In future the aim is to make derived equivalent circuit diagrams available for all components as building blocks for overall thermal models.

To generate the transfer parameters, the thermal network of the component is simplified by combining subcomponents using methods from network theory and thus abstracting them. Details and therefore the know-how of the manufacturers do not have to be disclosed. Verification of the transmitted parameters can be performed using an additionally transmitted test current profile.

The prediction accuracy of the simplified transfer models is in the range of the experimental measurement uncertainty. In practice, the results deviate from each other in the single-digit percentage range at 120 °C temperature rise. In the case of the investigated current profile, the deviation at the contact area of the HVS®420 is only one percent.

In the pre-development process, system simulation already enables more precise dimensioning during the preparation of the specifications compared to the classic preliminary design. Taking the installation situation into account, transient current profiles are calculated, and power losses and temperatures analysed with spatial resolution. Thanks to upstream optimization, the development time can be reliably adhered to in the series development phase and, if necessary, reduced. Electro-thermal system responses of the component models can be exchanged independently of the software without having to disclose design details.

Optimization Potential for HV Harnesses



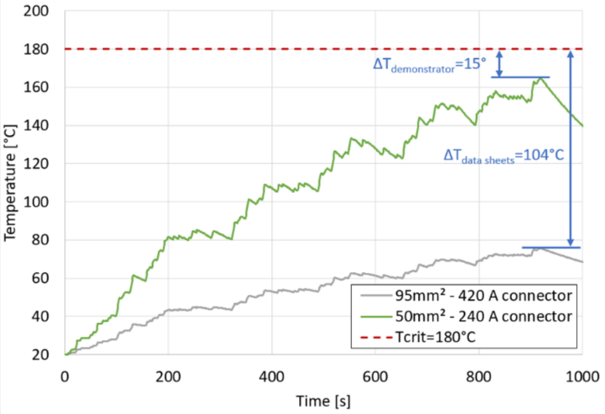
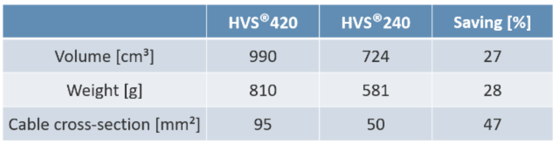


Fig. 5: Demonstrator

Fig. 6: Effect of the genset on the dimensioning

Rosenberger and Leoni have developed a demonstrator to analyse the influence of power units on connector and cable dimensioning (Fig. 5). The aggregate represents a heat sink in the HV harness. Analogous to the procedure described, a thermal network was set up and validated.

In this model, if the transient current profile from Fig. 3 at room temperature is used as an input variable, the influence of the genset becomes apparent. First, the dimensioning according to classical pre-dimensioning was investigated (Fig. 6). The result shows that the maximum temperature in the connector has a considerable reserve with respect to the limit temperature. The harness is clearly designed too conservatively. By successively reducing the cross-section and comparing the connectors, the optimization potential becomes clear. Compared to the classic design, which used an HVS®420 with 95 mm² cable cross-section, the new methodology using the HVS®240 with 50 mm² resulted in a volume and weight saving of almost 30 percent (Table 1). The cable cross-section was reduced by almost 50 percent.



	HVS®420	HVS®240	Saving [%]
Volume [cm³]	990	724	27
Weight [g]	810	581	28
Cable cross-section [mm²]	95	50	47

Table 1: Savings through enhanced dimensioning with ZVEI models

While the thermal description of cables and connectors is defined, this is still a challenge for HV units. However, an analogous approach for the transfer of simplified models by means of parameter sets is already in progress at the ZVEI.

Potential of the ZVEI Approach

The comparison of the two design methods shows the potential of the ZVEI approach. In the example shown of a cooled component, the system simulation enables a cross-section reduction of the cables by almost 50 percent. By applying the new design process, the use of a significantly smaller connector could be recommended, resulting in a reduction of installation volume and weight of the connector by almost 30 percent.

The major advantage lies in the dimensioning of the components well before the start of series development. Application-specific simulation models can be used to calculate the immediate temperature response. The load history is thus taken into account, avoiding the inaccurate accumulation of currents. At the same time, the model exchange according to ZVEI protects the know-how of the cooperating companies and functions independently of software. Once this method is established in the supply chain, it results in shorter development times for long term series development as well as later in subsequent derivatives development. A reduction in development and product costs is possible throughout the entire product development process.

SOURCES

[1] ZVEI, Technischer Leitfaden 0101 – Thermosimulationsmodelle Vers. 1.1, Köln, 2020

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