Use of CAE-Methods to analyse the influence of new electrical systems behaviour on tomorrow’s 42V PowerNet

Authors Christian Amsel, Ralf Schoenen, Institut für Kraftfahrwesen, Aachen
Bernd Frielingsdorf, Ford Werke AG, Cologne

1. Introduction

The demand for more electric power in vehicles is mainly driven by:

- Substitution of mechanical systems with electrical systems: e.g. EPAS (Electric Power Assisted Steering), Electric Water Pump, Active Chassis Controls, ESP, ABS, X-by-Wire
- Increasing customer comfort demands: Interior Comfort (Warm/Cold), Infotainment/Multimedia
- New Legal Requirements: Emissions, Safety, Fuel Consumption
- New Powertrain Technologies: Hybrid Engine Concepts, Electromechanical Valvetrain

This will lead to dual voltage architectures supplying power on 42V and/or 14V. Different components, architectures and concepts are currently under development in the automotive industry. Even for conventional automotive electrical systems based on a 14V architecture, more and more electrical consumers are controlled by means of energy management algorithms. Depending on drive conditions, battery charge conditions, customer usage profiles and demands these algorithms will prioritise and supply power to the various electrical consumers.

The engineering task of sizing the appropriate power supply system is getting more complex: select the correct alternator size, performance characteristics and battery size, develop robust control algorithms, fulfil various customer requirements, meet cost and weight and timing targets.

To be able to assess different concepts, architectures and control strategies early in the development cycle, CAE methods (Computer Aided Engineering) – especially modelling and simulation – are becoming mandatory.
This paper will discuss the usage of modelling and simulation techniques during the development of a PTC (Positive Temperature Coefficient) heater system and its integration into the electrical distribution system.

2. Simulation in Development Processes

The number of electrical systems will increase more and more in the future. This development also means an increasing complexity of the electrical distribution system (EDS). In the past there were lots of consumers in the EDS steered manually or by time variables. Nowadays there are more components with an intelligent control. Intelligent control systems are expected to be implemented in most of the new systems. This means an increasing number of operating conditions as well as more dependencies between the consumers.

The interaction of all systems will not be tested sufficiently because of the number of systems and the complexity of each system itself. All systems in the vehicle have to interact perfectly to enable all safety relevant systems when needed, and also to enable as much of the comfort driven systems as possible.

Simulation techniques make the development and testing of new strategies possible. The software tool Saber by Avant! has become the most important tool worldwide for this development area.

Building up an simulation structure for the testing of new electrical power distribution systems and the combined control strategies consists of the basic systems for energy supply and storage and the loads themselves. There are lots of varieties depending on the driver, the vehicle, the surroundings, the climate and so on.

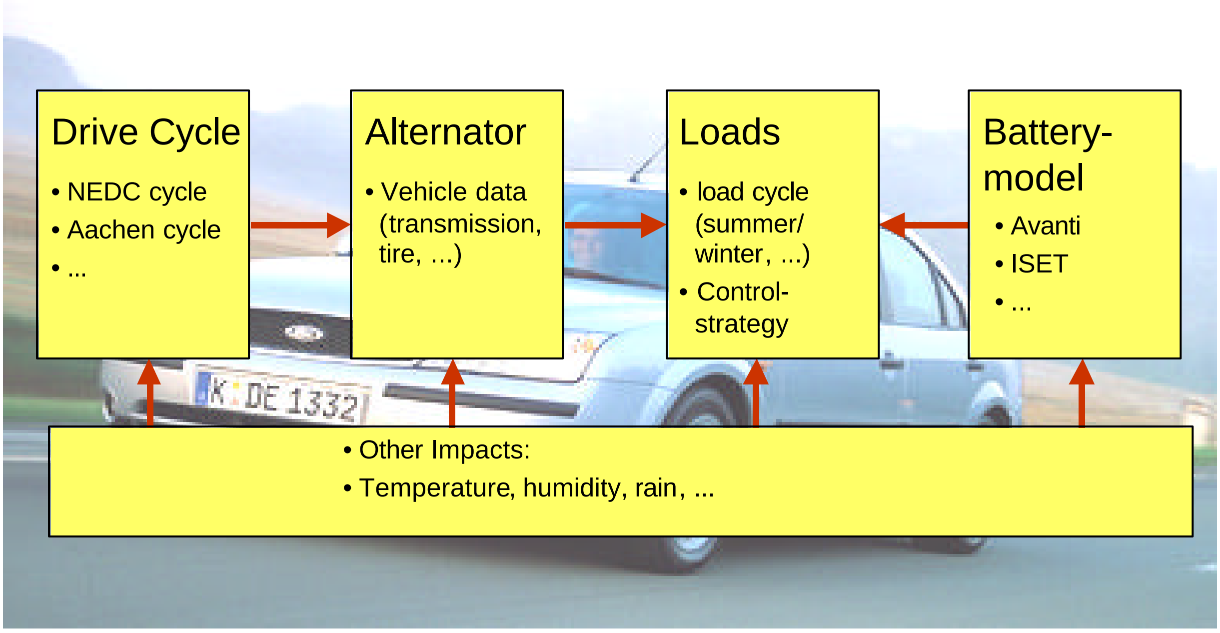


Fig. 2-1: Dependencies and Varieties for Electrical Distribution System Simulation

To narrow down the numbers of the degree of freedom and to minimize the external influences the use of profiles is usual. These profiles have been used for many years concerning drive-cycles. In today’s vehicles there are many different loads and the vehicle equipment varies from model to model. This makes the introduction of a standardized electrical load-cycle very difficult but nowadays each OEM uses its own cycle.

To ensure a maximum of flexibility with simulation strategies it is necessary for the simulation architecture to be built up of the following exchangeable and variable modules to investigate the EDS dimensioning:

- Drive-Cycle,
- Alternator,
- Load-Cycle
- Control Strategy,
- Type of Battery.

To give a short overview of drive cycles Fig. 2-2 shows two of the cycles used in simulation. On the left side there is an example of the NEDC-Cycle (Northern Europe Drive Cycle) and on the right side the Aachen-City-Cycle which is not an industrial standard.

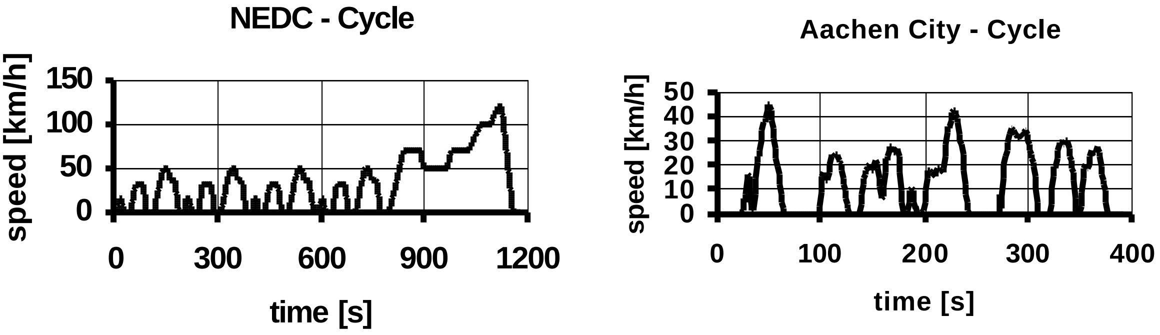


Fig. 2-2: Different Drive-Cycles Used for Simulation

If it is the aim of the simulation to show systems behaviour over a longer time period, it is usually enough to model the single system components just with its average behaviour. This avoids a high expenditure to create very complex and detailed models. Testing of new electrical distribution system concepts with new system components is sometimes possible within only a few hours.

In this thesis we will describe the integration of a new high-load-consumer, the PTC heating device, into an existing electrical distribution system. As a second step the integration into a dual PowerNet will be done and evaluated.

The following formulations of questions must be answered:

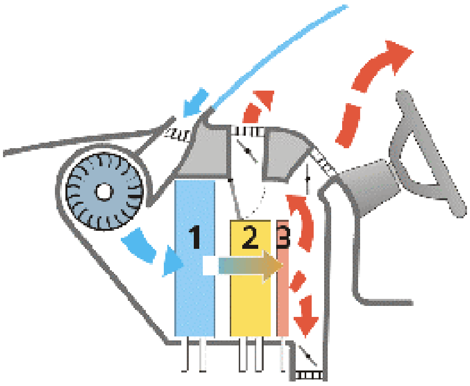
- Assessment of different alternators (14V) by a comparison of the alternator performance of several versions,
- Influence of the PTC heating device on the electrical distribution system,
- Evaluation and optimision of the control strategy,
- Rating whether a power management strategy is necessary,

- Rating of the use of the PTC device in a dual voltage electrical distribution system.

As already stated, the systems to be simulated must be described sufficiently. As to the high-power consumer supplementary heating device the simulation is divided up into two main areas. There is an electrical and a control area. The electrical area has to be modelled in a way that gives a realistic view of the electrical behaviour of the components. The control area encircles all necessary functionalities of the electronic control unit and its algorithms.

3. Supplemental Heating Systems

Growing efficiency of modern Diesel engines and also Gasoline engines require supplemental heating devices to guarantee interior heating comfort. There are different technologies available to more quickly achieve a pleasant interior climate during cold start and warm up scenarios in Winter. Fuel fired heaters burn fuel to provide heat for the interior. Glow plug systems use electric energy to heat up the water in the cooling system.



1	Evaporator
2	Heater Core
3	PTC Heater Unit

Fig. 3-1: PTC Heater Unit and Fitting in the Vehicle

More advanced systems use PTC elements to heat up the air directly after the heater core before it flows into the interior compartment. A PTC thermistor is a thermally sensitive semiconductor resistor. The resistance value rises sharply with increasing temperature above a defined reference temperature. Several of these semiconductor resistors are assembled to a PTC heater unit. Total electrical power consumption for PTC heater units are in the range of 1kW to 2kW depending on the size of the interior compartment. The PTC unit is normally split into 3-4 smaller (300W - 400W) elements which can be controlled separately by either PWM or relays. This is necessary to apply a more flexible control strategy and to prevent load dumps and EMC problems caused by the high currents being switched.

Due to the high electric power required by these components, they have a considerable influence on the sizing and behaviour of the power supply system. Alternator size and control strategy have to be selected to supply enough power to fulfil the heating performance requirements.

4. The Simulation Area of the PTC Heating Device

The architecture of the simulation is divided into two main areas to characterize the influence of high-power consumers. The electrical level has to be equal to real systems behaviour. The control level has to be combined with the electrical level in such a way that the functionality of an electronic control unit (ECU) is built up in a realistic manner. The PTC heating device, split into three elements of equal size, is driven via relays. They are described in the electric level, driven by the control level.

Alternator

The alternator, which is part of the electrical system is modelled as an average model. An average model is a simplified physical model for long term simulations. It offers current depending on the engine speed. The engine speed is given by one of the drive cycles.

On the other side of the alternator provides power to the PTC elements and a predefined current source is reflecting the other loads in the car.

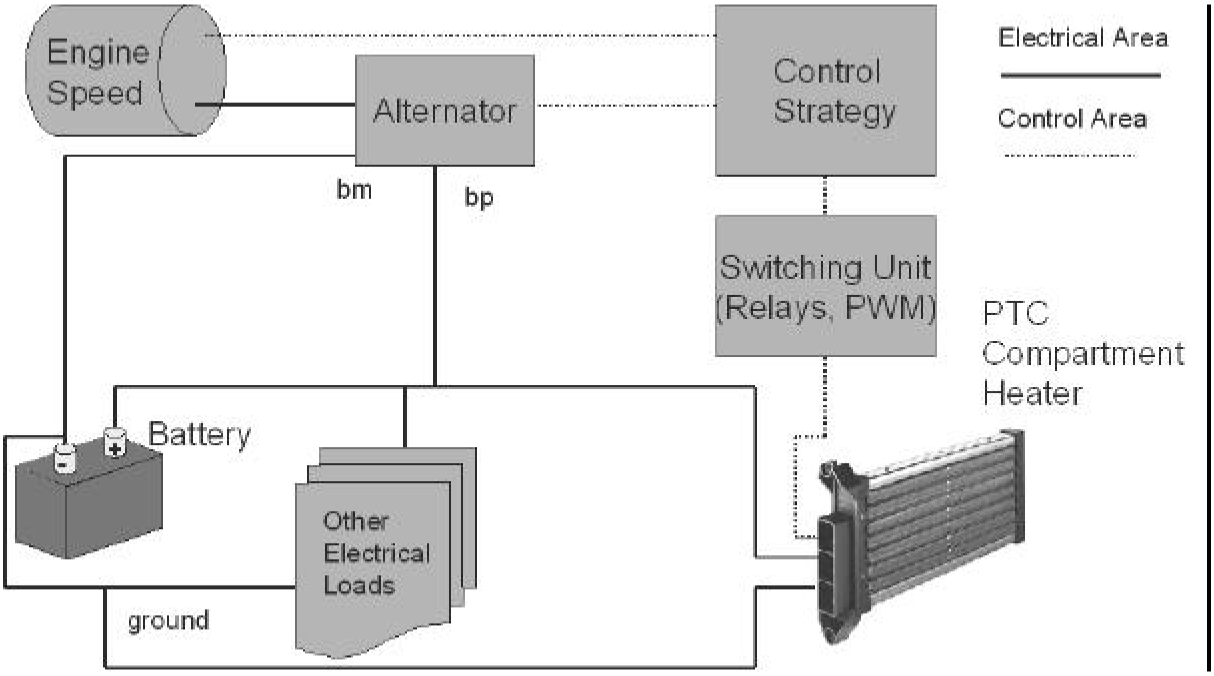


Fig. 4-1: System Schematic for a PTC Heating Device

Control Strategy

The control strategy of the PTC devices is implemented in the control level. The electronic control unit controls the relays in the electrical level to switch the PTC elements on and off. The first strategy was delivered by the supplier and could be improved.

Control of the PTC device is dependant on the engine speed, the alternator current, the load-cycle representing the rest of the electrical distribution system, the predefined control strategy and the PTC device itself.

Battery Model

To simulate the behaviour of a lead-acid battery the standard model of Avant! was used. Detailed comparisons with measured results of battery suppliers show, that the battery model is sufficient for simulations without any high current charge/discharge conditions (e.g. starting).

Simulation of the Rest of the Electrical Distribution System

The choice of an appropriate electrical load cycle scenario is very important. There are no standardised city cycles or motorway cycles available. But, when looking at the alternator performance, it is necessary to have a look at worst-case scenarios. This would be a city cycle in winter time with many loads turned on and with low speed. Therefore it is nowadays necessary that the OEM defines the basic loads and the number of loads being switched on and off during the cycle. The time when the loads are switched is also important.

In the 14V electrical distribution system a load-cycle is used which was measured during tests with an existing vehicle. It is still possible to use other cycles from simulations, but they often do not have dynamic switching behaviour.
Different approaches are possible to consider the other electrical loads: define a profile of the activated loads over time to drive a current source (sink); measure the electrical load during a typical city cycle and use this data to drive a current source (sink) in the model.

5. Modeling a PTC Heating Device

Building up the model was done in close contact to Catem and Visteon as manufacturer and supplier of PTC heating devices.

How a PTC heating device is constructed shows Fig. 5-1. The radiator elements are heated by PTC thermistors and air is passing through. The forced airflow is regulated by the blower.

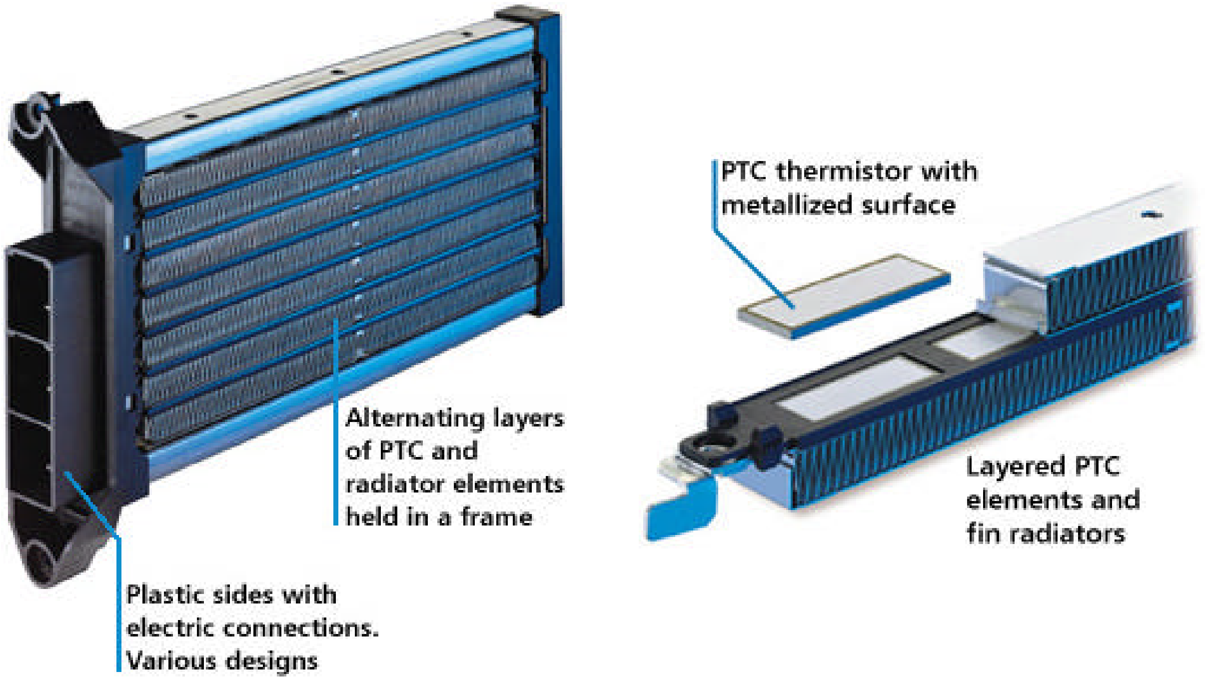
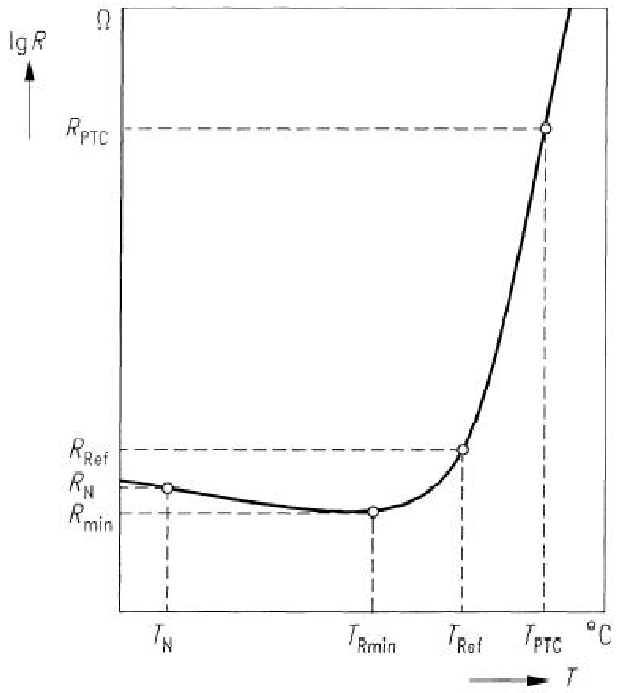


Fig. 5-1: Electric PTC Compartment Heater - Eltronic L [Catem]

A PTC thermistor is a thermally sensitive semiconductor resistor. Its resistance value rises sharply with an increasing temperature after a defined temperature (reference temperature) has been exceeded. The very high positive temperature coefficient (PTC) has given the PTC thermistor its name.



R_N	PTC thermistor nominal resistance (resistance value at T_N = 25°C)
R_{min}	Minimum resistance (resistance value at T_{Rmin})
T_{Rmin}	Temperature at R_{min} (start of positive temperature coefficient a)
R_{ref}	Reference resistance (resistance value at T_{Rref})
T_{Rref}	Reference temperature (start of steep rise in resistance)
R_{PTC}	random resistance in steep area
T_{PTC}	Temperature at R_{PTC}

Fig. 5-2: Typical Resistance Temperature Curve of a PTC Thermistor

As soon as current flows through the PTC heater the element warms up by electrical dissipation until a steady state is reached and the PTC element has reached its working temperature. Warming up of the PTC elements is depending on the electrical power inside the element und can be calculated in the following way:

$$P(t) = U(t) \cdot I(t) = \frac{U^2(t)}{R(T,t)} = d \cdot (T - T_A) + C_{th} \cdot \frac{dT}{dt}$$

P(t)	electrical Power
U(t)	present Voltage at PTC
I(t)	present Current at PTC
d	heat dissipation of PTC
T	present temperature of PTC
T_A	ambient temperature
C_{th}	heat capacity of PTC
dT/dt	change of temperature over time

Influences on PTC elements

The current over time curve of a PTC heater is depending on the forced air flow through the heating device. The forced air flow is controlled by the driver via the blower intensity. The worst case is on the highest blower switch position. This case is investigated first by means of the simulation. It is fundamentally possible to change the blowing fan switch position during the simulation.

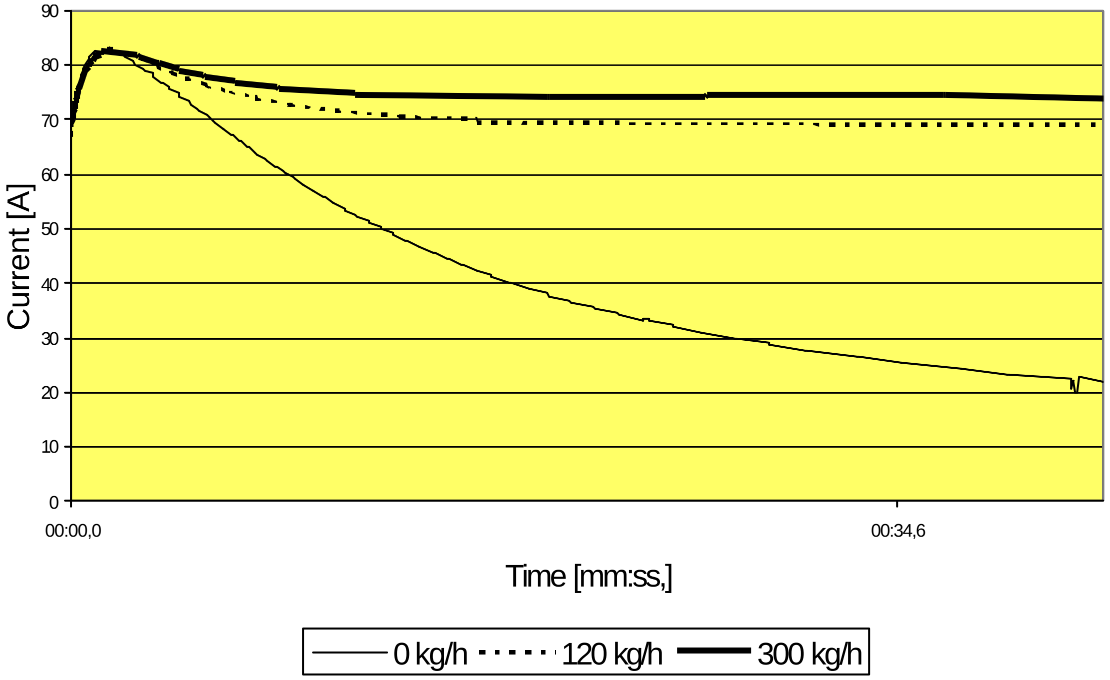


Fig. 5-3: Current over Time for Different Airflows Through a 1000W PTC Element at 0°C

In Fig. 5-3 the current over time curves for a 1000W PTC element at different airflows are shown. The current runs through a maximum (at the lowest PTC resistance) and comes close to the steady state. When looking at these steady states depending on the forced airflow, the curve shown in Fig. 5-4 is resulting.
This is a characteristic behaviour for PTC thermistors.

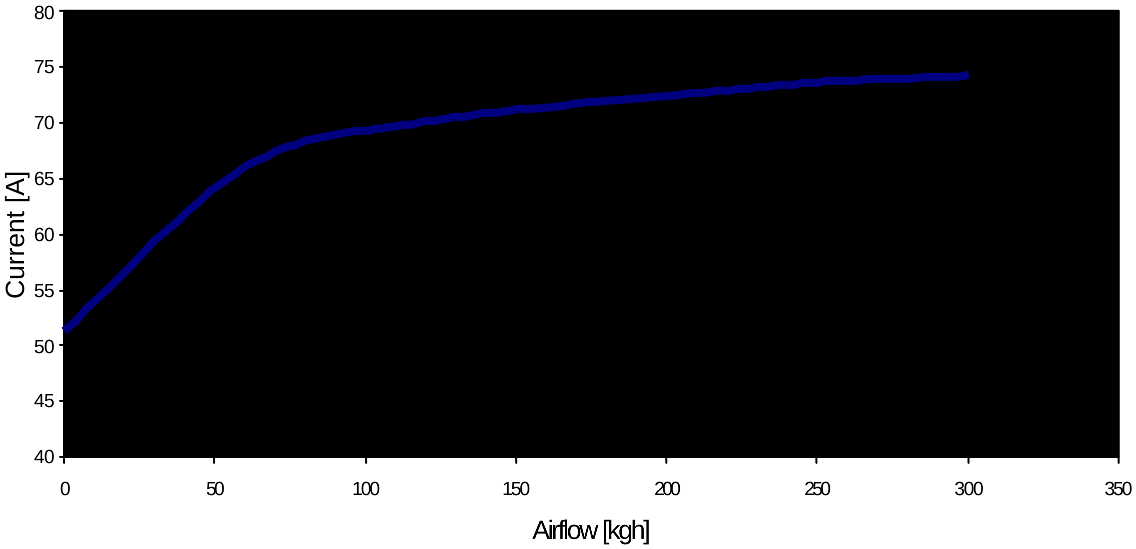


Fig. 5-4: Current over Airflow at T=0°C and U=13V

The simulation of a PTC heating device leads to very realistic results. The divergence from measurement results is shown in Fig. 5-5.

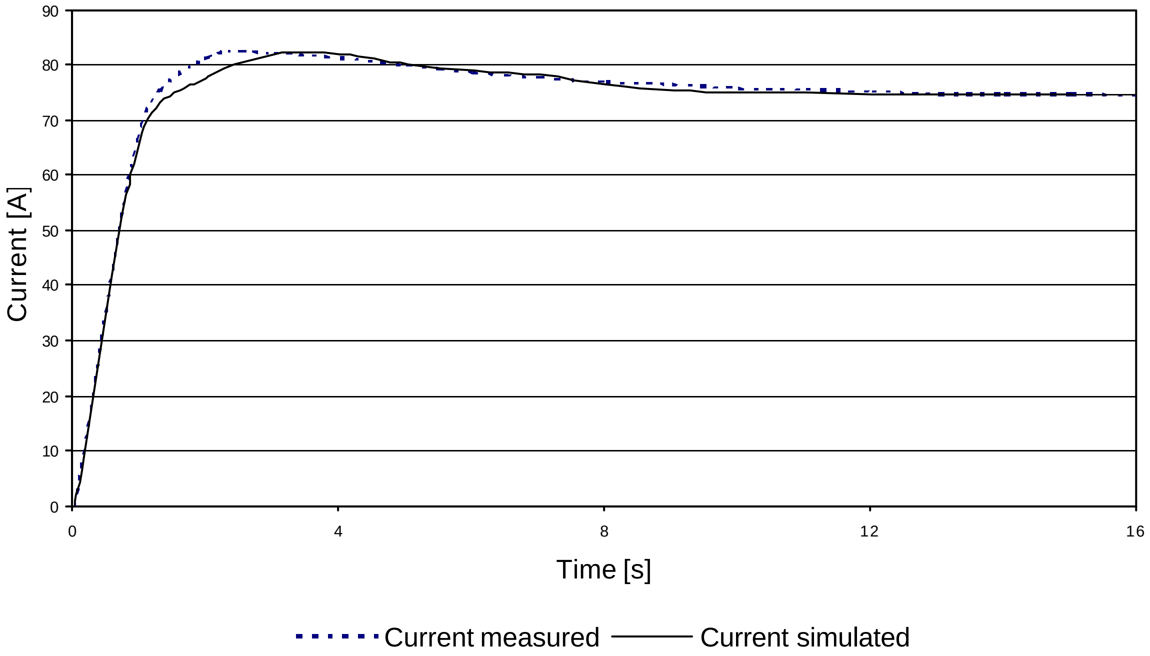


Fig. 5-5: Comparison Between Measured Current and Simulated Current Through a PTC Compartment Heater

The current shown in Fig. 5-5 represents the worst-case at an airflow of 300kg/h and an ambient temperature of 0°C. The airflow of 300kg/h represents the highest blower fan position.

5.1 Simulation of an Electric PTC Compartment Heater in 42V PowerNet

There are no fundamental changes at the PTC heater when moving from a voltage of 14V to 42V. Looking at it from the electric point of view the current flowing is only a third of the current in 14V electrical distribution system. To realise less current through the heating device there has to be a change inside the PTC thermistors themselves. The inner resistance R=U/I rises nine times compared with the 14V electrical distribution system. The electrical construction does not change.

This means that changes at the resistance over temperature curve take place. A comparison between the two electrical distribution system voltages for 1000W PTC compartment heaters is shown in Fig. 5-6.

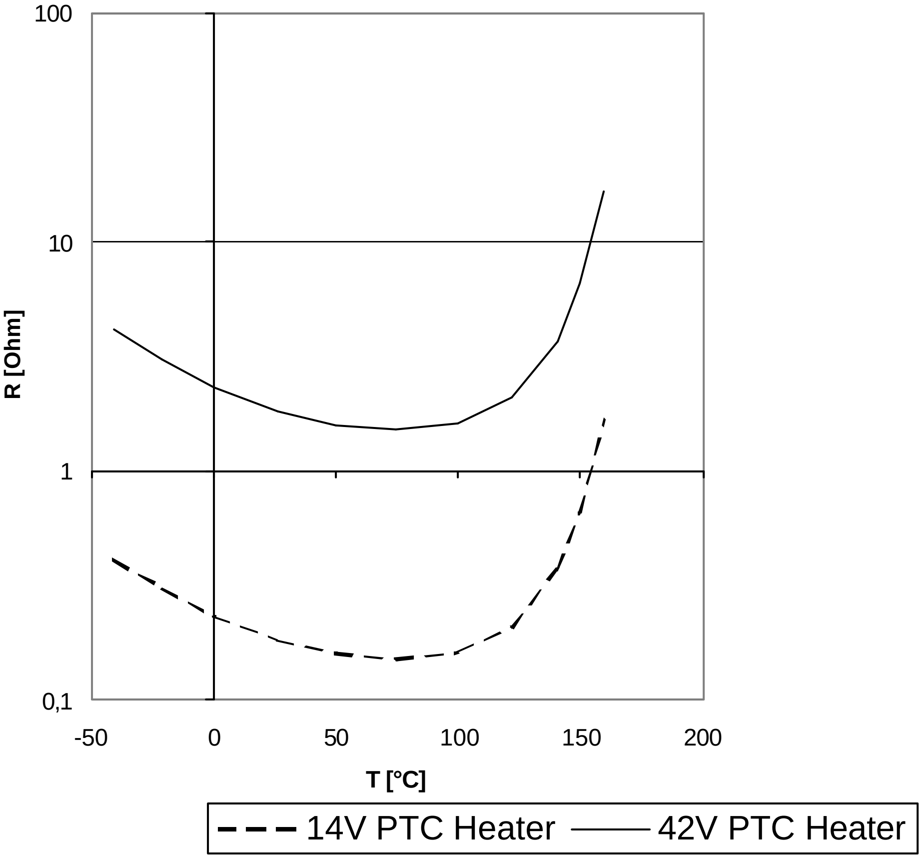


Fig. 5-6: Different Resistances of PTC Heaters for 14V and 42V Applications

6. Results of the simulation in 14V Electrical distribution system

A specification of the OEM may demand a defined temperature $T_{pass.comp.}$ in the passenger compartment within a limited time t_{limit} after starting the engine to fulfill the heating performance requirements. Due to this requirement the power of the PTC element will be calculated and defined (e.g. 1000W). Because of the fact that the PTC element can be activated only if the generator output is high enough, there won't be an on-period of 100% all the time.

The simulation of the 14V EDS has been realized using two alternators of the same model line, one 120A and one 150A type. The first aim of the simulation was to find out if the 120A alternator will provide enough power to supply all loads of the electrical distribution system together with the additional component, the PTC heater.
The simulation will calculate the number of activated PTC elements within a defined period.

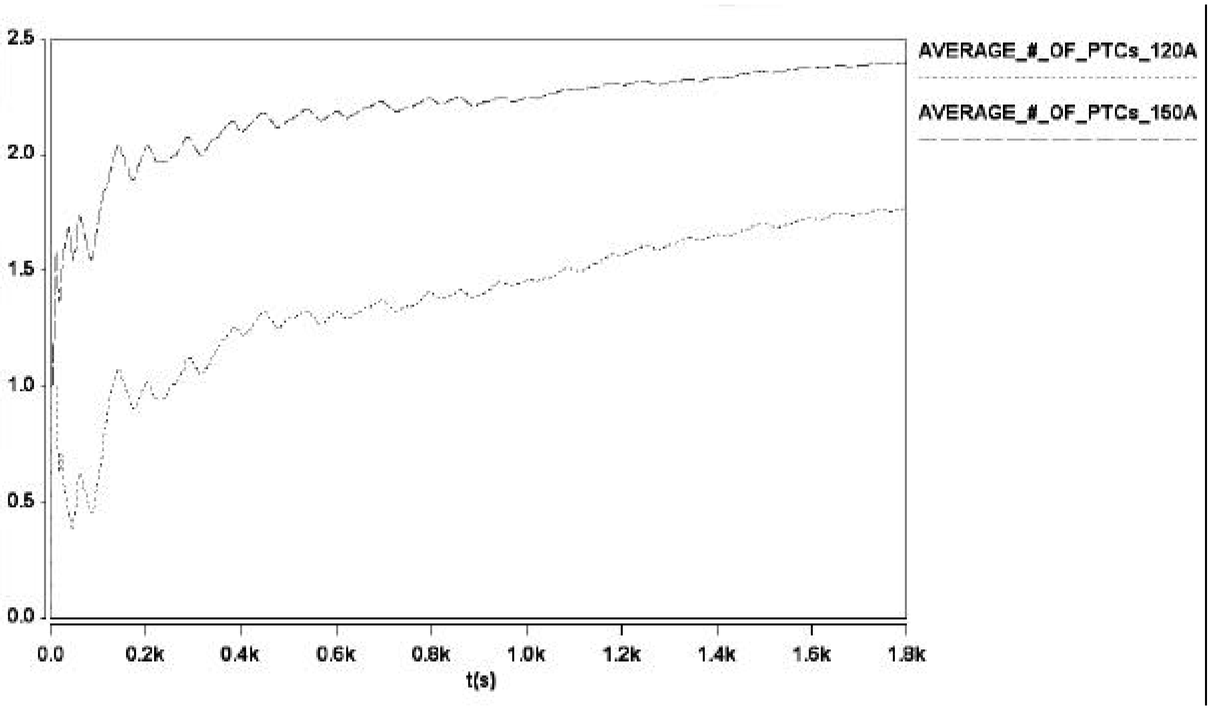


Fig. 6-1: Results of the Simulation With Two Different Alternators

The PTC heating consists of three elements which can be powered separately via a relay control circuit. Three power levels (300W, 650W and 1000W) can be activated in this way.

Applying the NEDC-cycle to the 120A alternator system, only 1.8 PTC elements (average) are switched on during the simulation period of 1800s. This corresponds to an average power of 594W. The performance of the PTC heating doesn't fulfil the heating performance requirements.

The simulation of the 150A alternator of the same model line obtains an average value of 2.4 activated PTC elements. The improvement is about 33% compared to the 120A alternator system.

This example shows that simulation is an appropriate way to analyse and evaluate different concepts and algorithms. Variation of parameters is one way to find an optimised operating strategy of components. Different components represented by different component models can be compared and evaluated by exchanging the models in the simulation area.

7. Simulation of a PTC Heater in a Dual 42V PowerNet

The approach of simulating high-power consumers in a future electrical distribution system is similar to the approach used in the 14V EDS. In each system the architecture must be represented in an appropriate way.

The Institut für Kraftfahrwesen Aachen developed a modular simulation environment which offers the opportunity to simulate dual voltage systems as well as a pure 42V PowerNet.

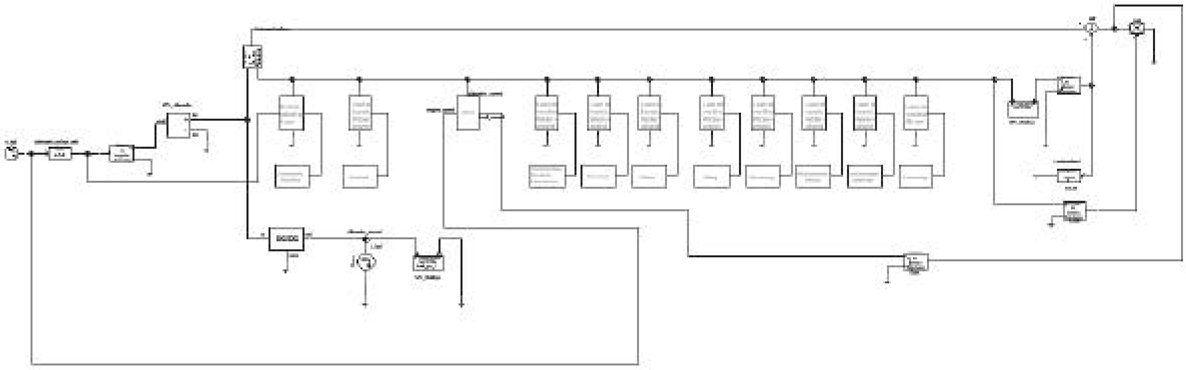


Fig. 7-1: Dual Voltage EDS with DC/DC-Converter and two Batteries

A 42V alternator model as well as a 36V and a 12V battery model represent the basic components in an electrical system which are mandatory. For the alternator the performance must be calculated whereas for each battery the State of Charge has to be determined.

The loads can be simulated with the help of different models. In order to achieve realistic simulation results, a choice of different kinds of load models are available. Each load can be switched on and off individually.

Furthermore measurements can simplify the simulation environment substantially by replacing a number of (complex) simulation models. In this way the development of models for dynamic or high current loads can be accomplished.

The architecture of the dual voltage system is as follows. A defined number of high current loads will be supplied directly by the 42V alternator. The 42V side can be simulated with or without the 36V battery. A DC/DC-Converter supplies the 14V side, which will be buffered by a 12V battery. All electrical loads of the 14V side are based on measurements of the electrical loads during a typical city cycle. This data is used to drive a current source (sink) in the model.

The aim of the simulation is the development and evaluation of different scenarios and architectures. New power management strategies will be tested to obtain an alternator, batteries and converters of minimum size. The PTC model has been converted from 14 to 42V voltage level as already described.

8. Concluding remarks

Simulation methods will become more and more important for the development of future electrical systems. The complexity of each subsystem and the combination of all systems would otherwise be no longer controllable.

The component suppliers must adapt to the demands of the OEMs to use this methodology. Models of each subsystem (alternator, battery, DC/DC-Converter, High current loads) will belong to the scope of the supplier and must be delivered as a kind of technical/requirement specification. Early experiences demonstrate that suppliers don't regard this task as just a duty, but also as a chance to use and to benefit from simulation methods in-house.

Subsystem simulations such as the PTC compartment heater, can easily be adapted to 42V PowerNet simulations if there is a modular simulation structure. Investigations on new systems can easily be performed concerning their behaviour and power management strategies. According to these investigations several aims of power management strategies (reduction of peak loads, positive load balance of the batteries, improvement of the interaction of EDS components) can be analysed and optimised.

9. References

[1] CATEM, Product Presentation Electric PTC Compartment Heater - Eltronic L, Landau 2001.
[2] Fischer, P., Simulation eines 42V Kfz-Bordnetzes, Aachen 2001.
[3] Langenwalter, J., Die Architektur des 42-Volt-Bordnetzes. VDI Nachrichten Konferenz, München 12./13.10.2000.
[4] Schoenen, R., Modellbildung und Simulation einer PTC-Heizung und deren Einfluss auf das elektrische Bordnetz im Kfz, Aachen 2001.
[5] Schöttle, R., Threin, G., Elektrisches Energiebordnetz: Gegenwart und Zukunft. VDI Berichte 1547, Baden-Baden 2000.