

*EVS25*  
*Shenzhen, China, Nov 5-9, 2010*

## **Approach of a Predictive, Cybernetic Power Distribution Management**

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### **Abstract**

In recent years the trend of an increasing electrification was observable in automotive engineering. That yields an increase in both the total power and the short-term power peaks. Because of the high currents, it is becoming difficult to guarantee voltage stability in the 12 V power net and the danger of voltage instability increases.

This paper deals with the development of a holistic system approach in order to actively balance the power distribution in the vehicles power net. In contrast to other solutions, the system is doing without additional components and topological modifications. However, the mobile environment makes some demands to the power distribution management system like the short resources, lack of fast real-time communication, or the complex power distribution topology of the wiring harness.

Within this work it is pointed out that a cybernetic approach is well-suited to the application in vehicles. Transferring the ideas of other cybernetic management systems, for instance in business administration, to a vehicle's energy and power management results in principles as the detachment of object and steering layer, the introduction of a hierarchy, the principle of subsidiarity, and the development of an interaction interface between the system and its environment.

By using these principles, the complex power distribution management task can be managed by lean and efficient systems well-suited for the application in vehicles.

*Keywords: power distribution management, voltage stability, power net, cybernetics, holistic system approach*

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## **1 Introduction**

In the last years, more and more components in vehicles were electrified. New electrical systems are developed to improve both the safety and comfort of the passengers and the car's driving performance. In addition, an increasing number of previously mechanically driven components are now electrically driven in order to decouple the component from the rotation speed and to reduce fuel consumption.

As the electric power demand increases, so do the load peaks of the electric power net. Loads like electrical power steering, chassis control systems or engine cooling fans with more than 1 kW peak power are installed in the 12 V power net.

Because of the high power and, consequently, currents, it is becoming difficult to guarantee voltage stability in the 12 V power net and the danger of voltage instability increases [1–4]. For example, in a luxury class vehicle the continuous power of heating in winter, air conditioning

in summer, electronic control units (ECUs), sensors, and consumer electronics can be more than 600 W. If this load is augmented by electric chassis control systems within a driving phase with low velocity and alternator power, voltage drops will be inevitable [2].

Fig. 1 presents the voltages, measured in a slalom driving maneuver. Resulting by fast steering interventions, a few systems showing high peak power like electric power steering or dynamic stability control are simultaneously activated and therefore particularly high power peaks occur in the whole system. As a result, the voltage at the load collapses to about 7 V. Voltages at such a low level may lead to failures like flickering of lights, a malfunction of the navigation system or even the reset of an ECU. Therefore it is both a customer and a safety relevant issue.

In order to guarantee the proper functioning of all electrical components, a stable voltage supply has to be realized. There are a few approaches improving the current situation: The easiest method is to boost the dimensioning of battery and wiring harness, but this causes additional costs, weight, and installation space, of course.

The stability problem is reduced by assembling additional power supply or optimizing existing components in various publications. Capacitive energy storages, like electric double layer capacitors, are used in [3] and [5] to increase the peak power capability of the power net. Another approach is to analyze the electric loads [6, 7] or to control the speed of the internal combustion engine [4].

## 2 Goals

The aim of this paper is developing a holistic system approach in order to actively balance the power distribution in the vehicle's power net. In contrast to the solutions mentioned above, here a system should be developed that is doing without additional components and topological modifications. The stabilizing effect is only achieved by controlling the power distribution in the entire power net and using the power reserves of the power net's components. For example, some loads can be switched off noneffectively for a short time to absorb high power peaks. Likewise, sometimes it is possible to reschedule distribution of electric power so as to balance the supply and demand of power and hence guarantee stability.

However, the mobile environment makes some demands on the power distribution management

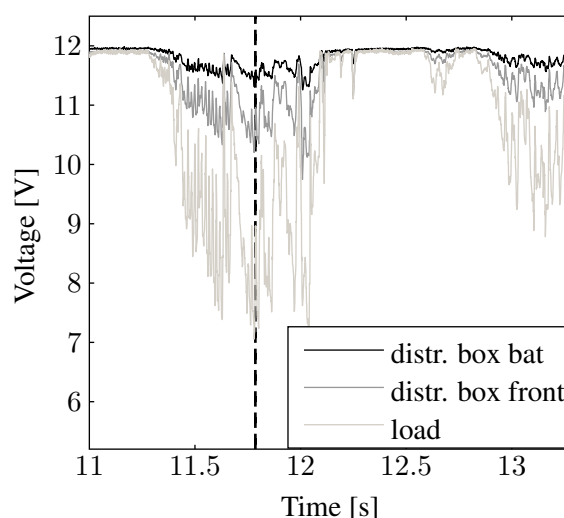


Figure 1: Cut-out of the slalom driving maneuver with measurements at the battery distribution box (distr. bat.), the distribution box in the front driver floor (distr. front), and one load (EPS). The voltage drop can be seen at all measuring points. The dashed line marks the time of evaluation of Fig. 2.

system. This paper points out that a cybernetic approach is well-suited to the application in vehicles.

## 3 State of the art

In essence, today's power management systems in vehicle's electric power nets are characterized by the voltage level and the battery current.

Electric power nets in vehicles were evolved over decades. The main developments were the communication interface of the alternator and an (intelligent) battery sensor. The processing of the newly gained data like the battery's current, voltage, and temperature as well as information from the attached electric loads enabled the intentional control of the power net's voltage and caused the necessity for a functional management of these values.

Until now, the function architecture of the management systems is mainly flat and showing only a loose interconnection between the sub-systems. For example, quite prevalent power management functions are using offline optimized rules like dropping electric loads according to the requirement of a priority table. In newer publications, a double-stage power management consisting of a master and several clients is introduced [8].

## 4 Challenges

However, the development of a holistic power distribution management system which is well-suited for its application in vehicles poses some challenges, which have to be mastered.

### 4.1 Resources

Basic requirement on all mobile devices and systems is the saving of resources in the vehicle such as processing time and memory usage or finally weight, installation space and costs.

Hence, comparing it to other power management systems (e.g. of a production line) there is a serious difference, which will influence the system's design very much.

### 4.2 Requirements of the time

The research on voltage stability done in [9] and [10] clearly shows that the most critical voltage drops occur if a high base load meets with the high power peaks for example of driver assistance systems (see Fig. 1).

Assuming that real-time systems will not be applied in vehicles on a large scale within the next years, a reaction of the power management in exactly the moment of these power peaks is always too late.

Therefore methods have to be found that enable preparing and conditioning of the power net's components in sufficient time.

For this it is necessary to continuously observe driver, vehicle, and environment and check for probable critical situations.

### 4.3 Local distribution

The vertical dashed line in Fig. 1 marks a moment of the global load peak in the slalom driving maneuver. Fig. 2 presents the analysis of the different voltages within the power distribution net at exactly that moment. It can be seen, that all components lying between the battery's positive terminal and the load cause a fall of voltage of total 4.4 V. So do the wires and even the car body between the negative terminal of the load and the battery (1.0 V).

Reverse, this means that the loads are differently affected of the subvoltage depending on their location to the electric power net.

Hence, it is imperative that a power distribution management system takes the local power supply and demand into account. Current systems using a simple priority table and dropping the less prioritized loads may be ineffective.

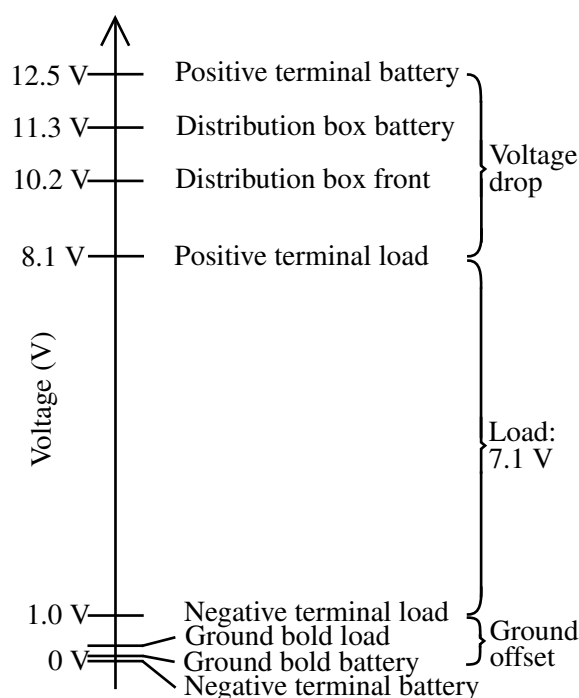


Figure 2: Voltages at different measurement points at the power peak at  $t = 11.8$  s of the slalom driving maneuver in Fig. 1. There is a voltage fall about 4.4 V within wirings, fuses, and distribution boxes. Further losses occur in the return conductor, for instance grounding bolts and car body. The resulting voltage at the terminals of the load is only 7.1 V.

For instance, the cut-off of a 40 A load enhances the voltage at the same distribution box about nearly 0.4 V [9]. The influence on other places in the power net is only 0.2 V and less.

For that reason an optimized power distribution management system has to consider not only the global supply and demand of electric power but also the local distribution and the location of the power net's components and their interactions.

### 4.4 Complexity

The power net of today's vehicles is a quite complex structure. Beginning from the power distribution box at the battery, the wiring harness branches out into several subnets and via other distribution boxes to the electric loads.

In a luxury class vehicle more than 80 ECUs can be built in [3, 11]—distributed over the entire car body. The cumulated length of all wires is about several kilometers and the wiring harness is one of the most expensive and the heaviest electric component in the vehicle [12].

In compliance with the above mentioned fact that there is no sole voltage in the power net, many

voltages and currents have to be monitored and a multitude of ECUs has to be controlled.

This shows the necessity of methods which can master and reduce the complexity in order to create a system being suitable to mobile application. Furthermore, on the input side of the power distribution management system a similar problem is recognizable: In luxury class vehicles up to 200 sensors and other information sources like navigation systems, the internet and in future vehicles also car-to-car and car-to-infrastructure communication are installed. In order to build predictive models based on this raw data, methods which are able to deal with this complexity have to be developed.

#### 4.5 Online adaptability

To fit the power distribution management system to the different driving scenarios it is necessary to trim the target value according to the respective situation. For example, in some scenarios the absolute stability of the voltage is essential, in different situations it is most important to save energy and smaller voltage fluctuations are tolerable.

Therefore there should be an adaptive control strategy that can be configured online without modifying the total system and thereby complicating the car's development process.

### 5 Cybernetics

Cybernetics is "the art of steermanship" [13] and an multidisciplinary science founded by the mathematician Norbert Wiener in 1948 [14]. Based on biological systems the cybernetic approach deals with complex systems, their reactions, and their (predictive) control (it is "the study of control and communication in the animal and the machine" [15]).

Mastering the complexity is one main focus besides a methodical system analysis, the interrelationship between the components and the strategic control to the point of adaptive and self-regulating systems [16]. The interaction of system and its environment is of particular importance.

Today, cybernetic ideas found their way into computer science, games theory, engineering, psychology, sociology, and many more.

## 6 Transfer to a power management system

The work of Fredmund Malik demonstrates how a management (in business administration) has to be arranged cybernetically [17, 18]. Transferring this and other cybernetic theory to a vehicle's energy and power management, the following principles are most notably important:

- Detachment of object and management layer
- Introduction of a hierarchy and recursive definition
- Principle of subsidiarity
- Interaction between the system and its environment
- Fuzzy modeling
- Reduction of the complexity by abstraction and data compaction

In the following these principles and their application on power management systems is amplified in more detail.

### 6.1 Detachment of object and management layer

To achieve a proper system design a functional detachment of the different components is necessary. So there is a distinct separation of object and management layer in the implementation of the power management system. Considering the lowest system layer, objects are components and can be classified into three clusters: storages like the battery, sources like the alternator and loads like the ECUs or actors of driver assistance systems. The task of the management layer is to control the co-operation of the subordinated objects (Fig. 4). That doesn't mean that there are closed-loop transfer functions for every component in terms of cybernetics the management layer only generates control targets based on its control strategy and the characteristic number. These control targets are realized by the objects (see section 6.3).

### 6.2 Introduction of a hierarchy and recursive definition

Vehicles' power nets, of course, are more complicated than the example with source, generator,

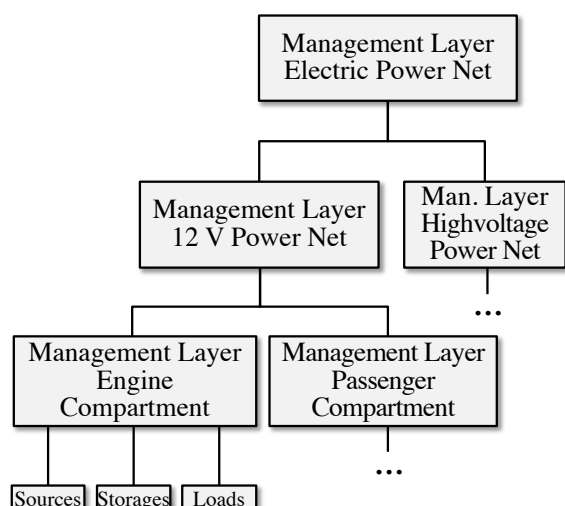


Figure 3: Hierarchy within the electric power net. Below the total electric management level, there are single management levels for the different voltage levels. Again below are the subnets and lowest the objects like sources, storages and loads.

and loads mentioned above. Many dozen components are connected in the complex topology of the wiring harness and coupled into subnets, for instance by a fuse and distribution box.

According to the principles of cybernetics there shall not be only one management layer knowing all system states and controlling everything but there should be a management layer on each level coordinating the functionally subordinated objects.

Consequently, there is already more than one level in the 12 V power net by itself as figured out in Fig. 3. Thinking about the entire energy flow in the vehicle it results in a multistage hierarchy:

Total energy management level (all energy forms in the entire vehicle) Energy domain management level (e.g. electric energy, mechanical energy, thermal energy ...) Voltage level management level (e.g. high-voltage power net, 12 V power net ...) Subnet management level (e.g. distribution box engine compartment) Objects (e.g. sources, storages, loads)

Each management level seems as an object to the next higher management level as shows in Fig. 4. By a clean recursive definition there is only one standardized interface between object and management layer no matter if a component or a subnet reports its status. Likewise the control targets are standardized.

Using that hierarchical architecture controlling even complex systems becomes possible. By the abstraction of characteristic numbers of the

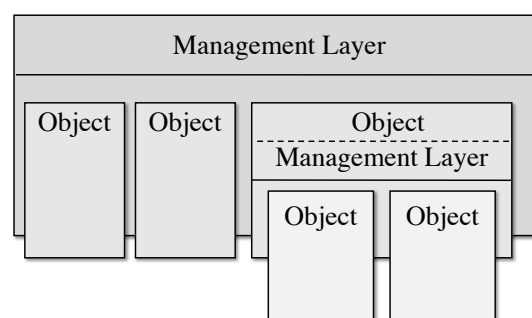


Figure 4: In cybernetic systems there is a distinct separation of object and management layer. Each management layer (e.g. a subnet) can function as an object in the next higher object level. According to the principle of subsidiarity, every management task is performed by the lowest competent level.

physical principles any energy forms may be included.

### 6.3 Principle of subsidiarity

Subsidiarity is the organizing principle that a central authority should have to perform only those tasks which cannot be fulfilled effectively at a more local level [19].

The lack of high-speed real-time communication makes a central control impossible, yet. Using the subsidiarity principle all components try to attain the control target in the scope of their possibilities. In the next higher level, every subnet tries to attain the control target given by the 12 V power net's management layer and so on.

Reverse, the objects report their characteristic numbers only to the next management layer. By avoiding a level-crossing control, a robust system is created without requiring much communication capacity. Furthermore each management layer has to process a manageable quantity of characteristic numbers.

However, to establish such a system at least the most important components must have a local intelligence that allows conducting cybernetic functions.

A big advantage is that hot plug-in is enabled and the design of the management system is independent from the vehicle's customized configuration.

### 6.4 Interaction between the system and its environment

For cybernetic purposes every system consists of the system and its environment, as illustrated in Fig. 5. The interaction occurs at the system's



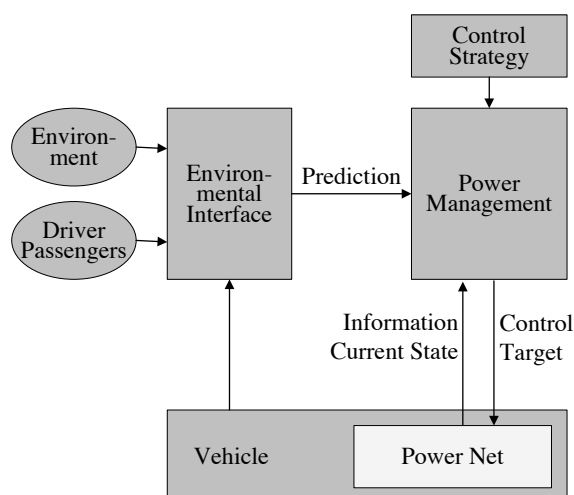


Figure 5: Each cybernetic system consists on the system itself and an environment. In this schematic representation both are coupled by an environmental interaction model.

boundary. In order to supply information about possible external-triggered changes of state, the modeling of the environment is essential. The modeling generalizes the measured data in relation to the assigned problem. So probability and risk of the expected environmental scenarios are evaluated.

Taking the knowledge about critical events into account, this statistically point of view enables predictive functions concerning the management tasks. For example, some driving maneuvers like extreme cornering always activate the electric stability program, which creates a high power demand and, as a consequence of this, a voltage drop. It is now a purpose of the environment model to predict extreme cornering situations enabling the management system to take counteractive measures and to condition the power net in advance.

## 6.5 Fuzzy modeling

The prediction as explained in section 6.4 has to manage some uncertainties of the input data:

A sensor can be broken-down or provide wrong information. Alike, it is possible that two sensors offer different information.

Some power relevant situations are not quantifiable sensors and other input data can only give suggestions.

Human beings as remarkable influence factors can hardly be modeled. Indeed, from the observation of the driver's past behavior his indications for his future behavior can be made. However, a prediction of other users is impossible. That is why

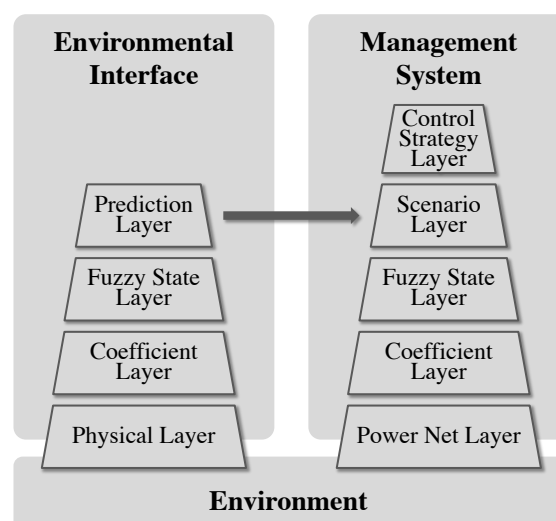


Figure 6: Both environmental interface and management system are divided into abstraction layers. The higher the layer is, the higher is the information density and the degree of abstraction.

a residual inaccuracy is always remaining in the system.

Accepting that it is not possible to develop an accurate environment and prediction model, it seems to be consistent to apply fuzzy modeling. Methods like the theory of Linear Partial Information (LPI) allow making statements even though the available information is not complete [20, 21]. But, of course, the more detailed the existing information is the more accurate becomes the prediction. However, the certainty of the prediction can be rated at any time. The authors made some suggestions how to implement LPI theory in a vehicle's prediction model in [22].

## 6.6 Reduction of the complexity by abstraction and data compaction

In spite of detaching object and management layer and using the principle of subsidiarity, a huge amount of data will be piled up due to the complexity of the vehicle's power net and the environment.

To achieve a lean and efficient system that is well-suited for vehicle applications it is necessary to reduce the systems complexity.

Therefore, five abstraction layers are established in any management layer. According to the cybernetic principle of reducing the complexity by abstraction data of equal information density are combined in each abstraction layer. Standardized interfaces pass the processed information on the next higher abstraction layer.

In Fig. 6 the five abstraction layers of both the management system and the environmental interface are shown.

### 6.6.1 Abstraction layer 1: Physical layer

On the one hand, the physical layer consists of the power net's components of the object layer. On the other hand, it contains sensors and any information sources.

### 6.6.2 Abstraction layer 2: Coefficient layer

Here, from the raw information characteristic numbers are fused that are relevant for the management task and the prediction, respectively. Thereby fuzzy modeling and the theory of LPI is used.

### 6.6.3 Abstraction layer 3: Fuzzy state layer

In this layer the states of the power net and the environment are modeled. Like in abstraction layer 2, only states that are relevant for the management task are modeled.

### 6.6.4 Abstraction layer 4: Prediction layer and scenario management layer

In case of the environmental interface, the prediction is made in abstraction layer 4. In the management system's hierarchy measures are planned based on the system states of abstraction layer 3 and in accordance with the attitude of the control strategy in abstraction layer 5.

### 6.6.5 Abstraction layer 5: Control strategy layer

In abstraction layer 5 the long-term strategy of the management system is stored. At this point the driver or other systems can influence the management system and its control targets.

In the environmental interface there is no control strategy.

## 7 Conclusion

The cybernetic principles presented in section 6 are well suited to master the challenges given in section 4. The online adaptability is provided by the detachment of object and management layer as well as the architecture of abstraction

layers in each management layer. Thereby the control target can be changed online without endangering the stability of the management system by interference on the lower levels. The strategy's modifications can be triggered either by the driver, or environmental events e.g. a discharged battery, or a self-learning system.

Also, the abstraction layers assist with mastering the existing complexity by the compaction and abstraction of the input data.

The principle of subsidiarity makes sure that each control task is performed by the lowest competent level. In this way, expanded and centralized control structures cannot occur. That saves computing power as well as communication capability.

By the stringent hierarchization, new objects can be easily applied in the power net. If there are suitable communication interfaces, the system enables hot plug-in of new objects.

The principle of subsidiarity provides a local power management by itself. Each difference in supply and demand of power will be balanced on local levels without any superordinate and extensive control. Higher management levels will not be involved until the problems exceed the capability of the local level.

The requirements of the time are met by the prediction that provides early enough information about prospective system states. Using the theory of Linear Partial Information tendencies can be detected very early. Every new piece of information strengthens the prediction and the conditioning of the power net is more ensured.

The principle of subsidiarity makes sure that decisions are fast made on local level and thereby long transmission time is avoided.

All in all, this complex control task can be managed by lean and efficient systems well-suited for the application in vehicles.

## 8 Outlook

In the next steps the cybernetic power distribution management system will be implemented on a rapid prototyping platform (dSPACE Autobox) to demonstrate the abilities of the system. The verification of the system's stability will be an important item. Likewise, it shall be evidenced, that the system gets along with any configuration in any power net topology. For it, a power net test bench is build-up, which is described in detail in [10]. In this test bench any behavior of loads and sources can be reproduced - even future applications or worst cases that are very improbable in reality. The power net's reaction can

be analyzed with plenty of voltage and current sensors. Thereby the improvement compared to an unmanaged system will become visible. Furthermore, the interface between the components and the management system as well as between the management system and the control strategy has to be standardized. Finally, the control strategy has to be developed and optimized.

## Acknowledgments

Represented research and development work is carried out in the project “Energiemanagement III” within the framework of the cooperation CAR@TUM (“Munich Centre of Automotive Research”) between the BMW Group and the Technical University Munich. This particular research was supported by BMW Group Research and Technology. The responsibility for this publication is held by authors only.

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