

REDSEL

Redundant & Efficient DC/DC System for Electromobility

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Projektbeschreibung

Die steigende Nachfrage und die ständig aktualisierten gesetzliche Vorgaben zur Einhaltung der CO₂-Emissionen haben verschiedene Erstausrüster dazu veranlasst, wichtige Aspekte Energieverteilung innerhalb eines Elektrofahrzeugs neu zu überdenken. Ein einheitlicher Ansatz für die Energieversorgung nicht nur der Elektromotoren, sondern aller Teilsysteme eines Fahrzeugs, hat sich jedoch nicht herauskristallisiert.

Diese Situation wird zusätzlich den enormen Anstieg der Leistungsanforderungen und der Systemzuverlässigkeit zukünftiger Fahrzeugflotten verstärkt. Hatten Fahrzeuge mit Verbrennungskraftmotor bisher einen Leistungsbedarf zwischen 600 W und 3 kW, so erwartet man für zukünftige Fahrzeuge auf Grund von zusätzlichen Funktionen (autonomes Fahren) einen Leistungsbedarf von deutlich mehr als 3 kW. Es ist offensichtlich, dass eine 5- bis 20-fache Steigerung die Komplexität des Niederspannungs-Bordnetzes enorm belastet.

Diese zusätzlichen Anforderungen wirken sich negativ auf die Energieeffizienz, aber vor allem auf die Zuverlässigkeit der EVs aus, die bei AMoD-Systemen als kritisch angesehen werden könnte, und wodurch neue, zuverlässigere Architekturen erforderlich werden.

Der Forschungsschwerpunkt dieses Projekts liegt auf der Untersuchung neuartiger Konzepte und Architekturen für eine sichere, zuverlässige und effiziente Energieverteilung in elektromobilen Hochspannungs-Niederspannungs-Bordnetzen. Im Rahmen der industriellen Forschung ist es das Ziel dieses Projekts, Konzepte für sichere, zuverlässige und effiziente Niederspannungs-Bordnetzsysteme zu untersuchen und zu bewerten, technische Komponenten des Stromversorgungssystems zu entwickeln und diese in Form eines Demonstrators zusammenzuführen.

Dieses Ziel beinhaltet folgende Schritte:

- Entwicklung einer neuartigen HV-zu-NV-Bordnetzarchitektur mit Blick auf hohe Verfügbarkeit und redundante Systemversorgung.
- Eine hohe Verfügbarkeit erfordert einen Leistungselektronikwandler mit mehreren Eingängen - es ist geplant, ein magnetisches Integrationskonzept zu verwenden, anstatt die Anzahl der Module zu erhöhen, wodurch Größe und Gewicht des Leistungsmoduls reduziert werden können. Die weitere Integration verschiedener Komponenten und Funktionen wird

ebenfalls untersucht.

- Redundanz erfordert eine sichere Abschaltfunktion - ein neues Systemkonzept, bei dem Halbleiterschalter anstelle von mechanischen Relais verwendet werden, wodurch Größe und Gewicht weiter reduziert werden.

Die Konzepte werden für spezifische Einsatzbedingungen evaluiert, für die Anwendung, die höchste Zuverlässigkeit bei der Versorgung aller kritischen Fahrzeugkomponenten erfordert - sicherheitsrelevante oder lang genutzte Fahrzeuge.

Vorgeschlagene Realisierungen werden nach den Kriterien Zuverlässigkeit und Effizienz bewertet, wobei der Kompromiss zwischen Zuverlässigkeit und zusätzlicher Größe und Gewicht berücksichtigt wird. Darüber hinaus wird ein Vergleich auch darüber Aufschluss geben, ob ein Konzept das Potenzial hat, die Niederspannungsbatterie zu ersetzen, wodurch weiter Gewicht reduziert und die Gesamteffizienz der Elektrofahrzeuge verbessert werden kann.

Abstract

According to the data from Credit Suisse Global Auto Research team, production of the Electric Vehicles (EVs) is expected to rise from 11% in 2020 to 62% in 2030, come to a head at 63 million vehicles worldwide. As EVs are moved from niche to mainstream, governments and municipalities are trying to find sustainable ways of transportation that can match mobility needs and reduce environmental harm. Autonomous Mobility-on-Demand (AMoD) systems hold promise as a future mobility concept in urban environments, composed out of fleet of robotic, self-driving vehicles co-exist in the existing infrastructure, in a more efficient way. Soon to follow up are applications in the fields of agriculture, industry, airport and railway, as the price of implementation will be reduced, enabling return of investment in reasonable amount of time.

Increase in demand and continuous updated CO₂ emission compliance standards have stimulated different OEMs to reconsider key aspects of how to power the electromobility again, however a harmonized approach for delivering electric power, not only to the motors but to all the subsystems in a vehicle has not emerged. The lack of direction is obviously amplified by the tremendous increase in power requirements and system reliability, as legacy electrical subsystem in combustion engine vehicles operates within power levels between 600W to 3kW. In today's EVs low voltage (LV) on-board power supply exceeds power levels of 3kW, especially when considering power requirements of the autonomous driving systems. It is evident that 5 - 20x increase puts tremendous strain on complexity of the LV on-board power supply system. These demands negatively impact energy efficiency but especially reliability of the EVs, which could be considered critical in AMoD systems, implying need for new architecture designs.

This project research focus is directed towards investigating novel concepts and architectures for safe, reliable & efficient energy distribution in electromobility HV to LV on-board power supply system. Within the framework of industrial research, the aim of this project is to investigate and evaluate concepts for safe, reliable & efficient low voltage (LV) on-board power supply system, develop technical components of the power supply system and bring them together in the form of a demonstrator. This includes:

- Develop novel HV to LV on-board power supply system architecture having in mind high availability & redundant system supply.
- High availability requires multiple-input power electronic converter - a magnetic integration concept is planned to be used instead of increasing the number of the modules, therefore reducing size and weight of the power module. Further integration of different components and functions will be also investigated.
- Redundancy requires a safe disconnect function - a new system concept to use semiconductor switches instead of mechanical relays - further reducing size and weight.

Concepts will be evaluated for specific use conditions, for the application which requires highest reliability supplying all

critical vehicle components – safety relevant or long usage vehicles. Proposed realizations will be evaluated on the merits of reliability and efficiency, bearing in mind the tradeoff between reliability and added size and weight. Additionally, comparison will show if the concept could have potential to replace the low voltage battery, reducing weight and improving overall efficiency of the EVs.

Endberichtkurzfassung

In the REDSEL project, the goals and approaches were pursued consistently in accordance with the original proposal document, with the aim of developing a highly reliable, compact, and efficient HV-to-LV on-board power supply system for future electromobility applications. The project addressed both the system-level architecture and the development of key enabling components required to ensure high availability, redundancy, and functional safety under demanding automotive operating conditions.

A primary objective was the creation of a comprehensive framework for the quantitative estimation and modeling of the reliability of different HV-to-LV on-board power supply system topologies. This framework was established based on the specific implementation of power electronic modules, reliability requirements derived from real operating conditions, and representative mission profile data from automotive applications. Particular attention was given to identifying critical failure mechanisms, evaluating the influence of thermal and electrical stress on component lifetime, and comparing different redundancy concepts from a reliability perspective. This systematic approach enables a quantitative comparison of alternative system architectures and supports the selection of optimized topologies for future high-reliability vehicle platforms.

A second major focus of the project was the development of two critical hardware components for the novel high-availability and redundant power supply system. The first component addresses the requirement for high availability through a redundant and multiple-input power electronic converter. Instead of increasing redundancy by simply adding more converter modules—which would significantly increase system size, complexity, and weight - a magnetic integration concept was developed and implemented. This approach allows multiple power paths to be integrated within a shared magnetic structure, thereby maintaining redundancy while significantly improving power density and reducing the physical footprint of the converter. This represents an important step toward practical automotive integration where installation space and weight are highly constrained.

The second component focused on achieving redundancy through the implementation of a safe disconnect function for fault handling and isolation. Conventional solutions based on mechanical relays were replaced by a newly developed semiconductor-based switching concept. This new approach offers significant advantages in terms of switching speed, reliability, wear-free operation, and compactness. By eliminating mechanical contacts, the system benefits from improved long-term durability and reduced maintenance requirements while simultaneously reducing system volume and weight. This contributes directly to the overall robustness and efficiency of the on-board power supply system.

In parallel to the component development, a novel HV-to-LV on-board power supply system architecture was designed to enable safe, reliable, and efficient energy distribution in electric vehicles. This architecture integrates the redundant converter concept and the semiconductor-based disconnect functionality into a unified system solution optimized for automotive applications. The development process included system simulation, design validation, hardware implementation,

and the realization of a laboratory-scale demonstrator. Special consideration was given to fault tolerance, fail-operational capability, efficiency optimization, and the balance between redundancy and system complexity.

The final project objective consisted of the experimental investigation and validation of the selected system realization using the laboratory-scale demonstrator. Extensive testing was performed to evaluate system performance with respect to efficiency, thermal behavior, fault handling capability, and overall reliability. The experimental results confirmed the technical feasibility of the proposed concepts and demonstrated that high reliability and redundancy can be achieved without excessive penalties in packaging or efficiency.

Overall, the project objectives were successfully achieved as outlined in the proposal document. The REDSEL project provides both a validated system architecture and key technological innovations that contribute significantly to the development of next-generation HV-to-LV power supply systems for electromobility.

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