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Testing and Evaluation of Parallel-Connected DC/DC Converters with Digital Load Sharing Control in High power EV Systems

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Abstract:

In Electric Vehicle (EV) applications, especially in high voltage platforms like commercial EV's the need for efficient low power distribution is becoming critical for optimal power system performance. In such cases the selection of DCDC converters are difficult to serve enough power to low voltage system. It may end up in overdesigning of the aggregate and results in energy efficiency reduction of Powertrain. To meet increasing power demands and ensure system redundancy, multiple DC/DC converters are often connected in parallel.

Parallel operation of DC/DC converters presents a practical solution to address these demands by offering enhanced power handling, system redundancy, improved thermal management and thereby improving energy efficiency. The effective digital load sharing control is essential to ensure balanced current distribution and to prevent overloading of individual units.

The aim is to validate both the performance and reliability of the digital load sharing algorithm under real-world EV conditions. Comprehensive testing and evaluation of parallel-connected DC/DC converters equipped with a digital load distribution mechanism. The scope includes functional validation, dynamic load response, current sharing accuracy, thermal performance, and communication behaviour under both nominal and stressed operating conditions.

The key advantages observed with parallel operation include:

- Increased system power capacity without requiring a single oversized converter
- Redundancy and improved fault tolerance, as failure in one unit does not lead to complete power loss
- Improved thermal distribution, allowing individual units to operate at lower thermal stress levels

The results confirm that with effective control strategies, parallel DC/DC converter architectures significantly enhance the robustness and efficiency of high-power EV power distribution systems.

Keywords: Commercial EV, DCDC converters, Parallel operation, digital load distribution, Power Electronics, Load Sharing Control.

Introduction:

Modern electric vehicles are rapidly transitioning to high-voltage, high-power configurations to achieve greater range, performance, and energy efficiency. In this context, power electronic subsystems such as DC/DC converters play a crucial role in power distribution, voltage regulation, and subsystem interoperability. A single converter approach often encounters issues like thermal overloading, lack of redundancy, and limited scalability. Thus, deploying parallel-connected converters with digital coordination has become a viable solution. This paper investigates the design and validation of such a configuration specifically for high-power EV applications.

2. Background and Motivation:

Conventional single-stage DC/DC converters are prone to inefficiencies under peak load conditions. Furthermore, the absence of redundancy can compromise overall system availability. Parallel operation addresses these concerns by distributing current across multiple modules, thereby improving thermal distribution and system reliability. However, achieving effective current sharing and fault management requires sophisticated digital control strategies. This research is driven by the need to establish a dependable, test-validated framework for parallel converter operation in EVs.

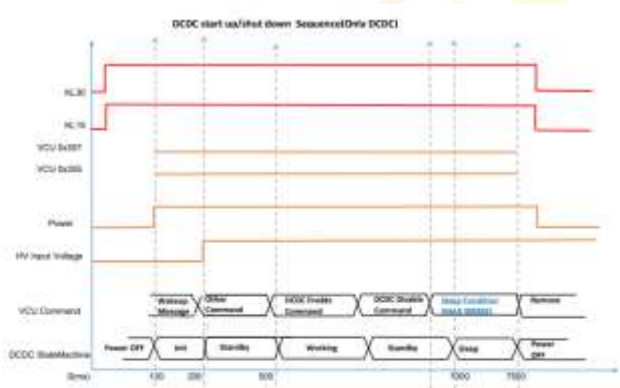
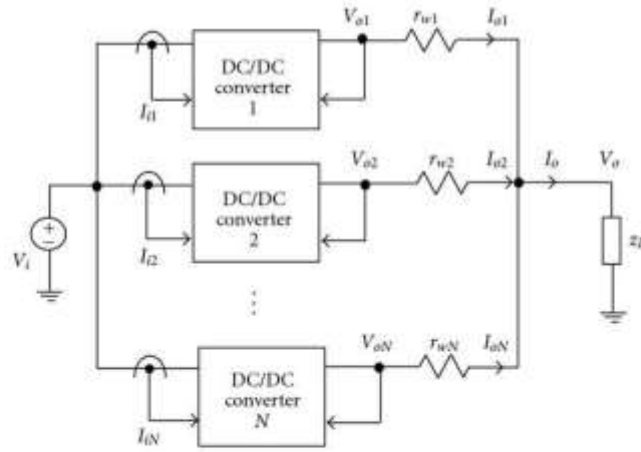


Fig 1: DC -DC start-up/shut down sequence

System Architecture:

The experimental platform comprises the following elements:

- Two identical 5 kW isolated DC/DC converters
- Common high-voltage input rail (700 VDC nominal)
- Low-voltage output rail (400 VDC)
- CAN-based master-slave digital load sharing control
- Integrated thermal, current, and voltage monitoring



- Programmable electronic load for performance evaluation

The following diagram illustrates the high-level system architecture:

Figure 2: Circuit diagram showing two parallel-connected isolated DC/DC converters receiving input from a common 700 VDC high-voltage bus and delivering power to a shared 400 VDC low-voltage bus. The converters are digitally coordinated using a CAN network connected to a master controller. Each converter includes current and temperature sensors feeding back to the controller. A programmable load is attached at the output to simulate vehicle subsystems.

This architecture enables modularity, load scalability, and active fault compensation, making it suitable for both centralized and distributed EV power systems.

4. Digital Load Sharing Control: The converters are coordinated through a CAN-based digital communication framework. A master controller continuously monitors the current output of each converter using Hall-effect sensors and adjusts their respective PWM signals to maintain balanced load sharing. The algorithm is designed to achieve current sharing accuracy within ±3% and includes failover mechanisms in case of controller or converter malfunction. Additionally, over-temperature and over-current protection thresholds are enforced for safe operation.

5. Testing Methodology:

A comprehensive testing matrix was developed to validate system robustness and performance. The following test cases were executed:

- **Steady-State Load Tests:** Conducted at 80% and 100% rated capacity to assess baseline performance.
- **Dynamic Load Response:** Simulated load steps from 20% to 100% to evaluate transient behavior.
- **Fault Simulation:** One converter was deliberately disabled to observe system resilience and fault compensation.
- **Thermal Cycling:** Prolonged operation under full load to examine thermal hotspot.

Fig 2: Parallel connected DCDC converter

Test equipment included:

- Oscilloscopes with isolated differential probes
- High-precision current transducers
- Infrared thermal imaging camera
- CAN bus logger for control diagnostics

6. Results and Analysis:

- **Current Sharing Accuracy:** Maintained within 2.3% deviation during steady and transient conditions.
- **Fault Tolerance:** Remaining converter seamlessly transitioned to full load with minimal voltage sag (<2%).
- **Thermal Performance:** Average heat sink temperature was 15% lower than a single converter under similar conditions.
- **System Efficiency:** Measured at 95.2% under nominal load with negligible variation during dynamic transitions.
- **Communication Stability:** CAN-based synchronization achieved consistent control loop update rates within 10 ms.

7. Discussion: The integration of digital load sharing significantly enhances the performance and reliability of parallel DC/DC systems. By leveraging real-time feedback and adaptive control, the architecture mitigates the typical challenges of current imbalance and thermal concentration. Moreover, fault simulation confirms that the system can maintain operational continuity with minimal performance degradation. These findings are critical for applications requiring uninterrupted power delivery and modular expansion.

8. Conclusion: This research validates the feasibility and advantages of using parallel-connected DC/DC converters with digital load sharing control in high-power EV applications. The proposed system demonstrates superior load handling, thermal management, and fault resilience. Future developments will focus on integrating this framework with vehicle control units (VCUs), extending to higher numbers of converters, and validating the setup in full-vehicle environments.

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Keywords: DC/DC converter, parallel connection, electric vehicle, digital control, load sharing, fault tolerance, thermal performance