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DOCTOR OF ENGINEERING SCIENCES

of **Mustapha Al Sakka**

The public defense will take place on **Thursday 2nd May 2024 at 4:30 pm**

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DESIGN AND CONTROL OF FAULT-TOLERANT MULTIPORT DRIVES FOR MULTI-MOTOR SYSTEMS

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Abstract of the PhD research

In recent times, full vehicle electrification and autonomous driving have become top trends in the automotive industry as a way of facing the tightening requirements of low transport emissions and the growing demand for automation, autonomous driving, and high performance. This transformation is enabled by the employment of X-by-wire (XBW) technologies. In XBW systems, mechanical systems are replaced by electric actuators to perform the various vehicular functions such as traction, braking, steering and suspension, bringing performance improvements, and allowing for automation and implementation of new technologies and active safety systems. These systems are crucial for proper operation and for the safety and comfort of the driving experience. Hence, it is important that they are fault-tolerant, reliable, and safe, allowing for their commercialization and mass deployment. Consequently, a conservative yet costly approach of mechanical backup or parallel redundancy is often employed. For vehicles, where safety, cost and available space are relevant issues, it is desirable to develop fault-tolerant, cost-effective, and compact solutions.

XBW systems in vehicles comprise multiple actuators (one per axle or one per corner), which are typically electric motor drives. Electric motor drives are composed of a power converter, motor, controller, and feedback sensors, and generally are less reliable than mechanical systems. Particularly, the power converter is the least reliable part, thus development of fault-tolerant power converters is especially important. Furthermore, multi-motor systems pose challenges concerning coordinated control, cost, reliability, and available space. The multiport configuration combines multiple inverters into one system enabling the possibility of using reduced switch-count (RSC) topologies and sharing various components (DC-link, heatsink, controller, sensors, redundant components, fault-diagnostic and protection circuitry), both of which lead to a reduction in cost and size, and improvements in reliability. These characteristics could be exploited to realize fault-tolerant motor drives that meet the requirements of automotive XBW applications.

The goal of this PhD research is to design, implement, and validate multiport fault-tolerant multi-motor drive solutions for automotive XBW systems. The research lays ground for and verifies solutions that could be employed for the realization of cost-effective and compact designs. The dissertation starts by a review of research works and commercial systems employing XBW technology in vehicles, showing the prevalence of multi-motor systems and the need for developing effective solutions. Following, a thorough state-of-the art review, assessment, and comparison of RSC topologies and fault-tolerant inverter strategies is carried out. The result of which is the identification of three suitable solutions that present benefits over the conventional topology. The first one combines conventional inverters that share a redundant leg (LRI-1), in the second one a single inverter leg is shared between all motors (SL), the third topology reconfigures from a conventional inverter into a shared-leg inverter (C-SL) when a fault occurs (only applicable for dual-motor systems). A 6 kW fault-tolerant dual-motor prototype capable of testing all proposed topologies is then designed and built, and the performance of the topologies is experimentally assessed and validated. Additionally, since both solutions based on the shared-leg concept suffer from voltage limitations, a PI-based field-weakening control scheme is developed and validated that considers the state of the two motors and simultaneously acts on both of them. Finally, taking advantage of the multiport configuration, a recently developed system-level short-circuit diagnostic method known as stray voltage capture (SVC) is also implemented. The challenges of adapting the SVC method for a multiphase drive are tackled and a fault localization algorithm is developed and experimentally validated. With the implemented short-circuit diagnostic method, the fault-tolerant control of the proposed solutions is validated under real short-circuit conditions.