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Power Supply Distribution System for Calorimeters at the LHC beyond the nominal luminosity

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This paper investigates the use of switching converters for the power supply distribution network in the ATLAS experiment when the Large Hadron Collider (LHC) will be upgraded beyond the nominal luminosity. Due to the highly hostile environment the converters must operate in, all the main aspects are considered in the investigation, from the selection of the switching converter topologies to the thermal analysis of components and PCBs, with attention to reliability issues of power devices subject to ionizing radiations. The analysis focuses on the particular, but crucial, case of the power supplies for calorimeters, though several outcomes of research can profitably be applied to other detectors like muons

Summary

The planned increase of instrumentation sensitivity in the ATLAS experiment of the Large Hadron Collider (LHC), at CERN, calls for a thorough re-design of the power distribution system's architecture. The increase of the radiation background and the requirements of new front-end electronics that will characterize the future LHC luminosity upgrade are indeed incompatible with the current capability of the distribution system in use. One of the considered alternatives involves the development of a distributed power supply network, where point of load converters is to be deployed at the very heart of the detectors. Electronic devices and equipment must face a highly hostile environment, basically for the very high background of both charged and neutral particles and for the presence of a non negligible magnetic field up to 1k Gauss , thus opening a severe tolerance issue for component selection and system design.

The presented investigation proposes a new power supply distribution network for the electronic circuits of the ATLAS Liquid Argon (LAr) calorimeters, which consists of a main isolated dc-dc converter with multiple outputs (ranging from -7V to +11V) followed by many distributed low drop-out (LDO) regulators supplying different analogue and digital loads. In this proposal, a single 12VDC (or other suitable intermediate voltage value) bus is considered, which is fed by an isolated dc-dc resonant converter with redundancy characteristic. The dc bus is distributed to the electronic front-end and read-out boards, where Point of Load (POL) converters are implemented for voltage adaptation and regulation. The resonant topology chosen for the main converter features low switch voltage stress, thus decreasing the sensitivity of power devices to ionizing radiations, and soft-switching operation, with corresponding reduction of overall losses and generated electromagnetic noise (EMI). A modular approach is adopted in order to improve the overall reliability by providing a certain degree of redundancy. Power devices from different manufactures have been tested using gamma irradiation (total ionizing dose effects, TIDs) at different biasing conditions, so as to select the best candidates for the given application.

As far as the POL converters are concerned, the proposed solution makes use of high step-down ratio topologies operating at high frequency. The high step-down ratio is motivated by the need of pushing the dc bus voltage to the highest possible value so as to increase the power capability of the distribution system, the current being limited by dc bus cabling. As far as the switching frequency is concerned, besides standard solutions working at hundreds of kHz suitable for the specific application, also very high-frequency (in the MHz range) solutions are investigated, with the aim of developing coreless conversion stages, applicable also at the core of ATLAS experiment (pixel sensors), where the high stationary magnetic field prevents the adoption of any magnetic material.

Besides the converter analysis and design, the investigation includes the study of the thermal behavior of both power stages, beginning from the development of suitable thermal models for the power devices and ending with the assessment of the overall system thermal performance, including PCBs and chassis. For the main converter, a liquid cooling system has been designed, and tested by of simulation, using the same specifications of the actual converter housing.

Together with the aforementioned analysis, the final paper will include experimental measurements taken on the final demonstrators of main converter and POL converters.

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