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Title

"A Comprehensive Methodology for the Development of Electrified Powertrain Solutions for off-road Applications"

Summary

The remarkable benefits highlighted by electrified powertrains in on-road vehicle applications have also attracted the interest of Non-Road Mobile Machinery (NRMM) manufacturers, which aims to develop a new generation of products with higher performance and, at the same time, with a reduced environmental impact. Nevertheless, hybrid NRMMs pose additional challenges in the design process since they contain a wide variety of configurations, each designed for specific and diverse tasks.

In such a framework, this thesis presents a comprehensive methodology to support the development of hybrid electric powertrain solutions for NRMM applications. The proposed approach considers all the main aspects of the design process, from the selection of the most suitable architecture, to the preliminary sizing of the components and it also includes the definition of the Energy Management System (EMS).

Its effectiveness is proved using, as a test case, a Skid Steer Loader (SSL) since such an application can be very challenging due to the high number of tasks it must perform. As a matter of fact, a crucial difference between NRMMs and on-road vehicles is the higher complexity of defining a limited set of meaningful duty cycles that reflects the real working conditions of the machine. Therefore, to tackle this task for the SSL, a combination of experimental tests and multi-physics models was used. The targets and the constraints identified in this preliminary phase of the work were then used to numerically assess the performance of different powertrain architectures. To have a fair comparison a global optimization algorithm, such as the Dynamic Programming (DP), was used for Energy Management Strategy. This stage of the process allows exploring electrification potential of both the traction system and the working hydraulic as well as assessing the impact of the component size and technology on the overall vehicle performance.

For EMS design, the proposed methodology takes advantage of innovative techniques, such as Reinforcement Learning (RL), as its capability of self-learning the optimal control law through a direct interaction with the environment can play a crucial role in maximizing

the hybrid powertrain performance. More specifically, a Soft Actor-Critic (SAC) algorithm is trained on a real-world duty cycle, and applied to a parallel hybrid SSL designed in the previous stages of the process.

The proposed methodology provides a robust framework for developing optimized hybrid powertrain solutions for off-road machinery. More specifically, the different hybrid architectures demonstrated a 10-30% in fuel economy improvement. However, achieving the higher end of this benefit will require a significant effort and machine redesign. Meanwhile, both RL and RB strategies performed within 2% of the global optimum provided by DP, suggesting that the EMS is relatively insensitive to the specific application.