

Summary

The current situation about air quality all around the world is pushing governments to ratify stricter and stricter regulations on pollutant emissions from the different fields of activity of the human kind. As reported from worldwide independent organizations, ground vehicles and manufacturing activities play a big role on the overall pollutants production. In the transportation field, several improvements have been introduced in the last years to meet these regulations as demonstrated by the emissions comparison between modern cars and older ones. These improvements highlighted a big gap with another group of vehicles: Non Road Mobile Machineries or NRMM. These machines are mainly used in commercial and industrial activities and are equipped with bigger and more robust Diesel engines which however are not so clean as demonstrated by a large number of research activities. Up to now OEM Diesel engine manufacturers for off-road applications mainly focused the attention on limiting the amount of pollutants by using gas after-treatment systems. However, recently stricter regulations pushed them and working machines manufacturers towards the evaluations of alternative ways to reduce the emissions of their vehicles. Vehicle electrification demonstrated in the automotive field how the overall performance of a vehicle can be improved reducing the amount of pollutant emissions. This process is slowing involving also working machines although very few applications are already available as commercial products.

This work wants to focus the attention on the electrification process that is involving the NRMM field to understand what are the main challenges that are preventing the wide diffusion of this technology on these machines. Chapter 1 proposes an analysis of the actual EU legislation on vehicles pollutant emissions which aim to meet international Air Quality agreements. In this scenario the role of the electrification is to improve performance of traditional engines in hybrid solutions or to replace them when possible. Chapter 2 focuses the analysis on the electrification process that is currently involving the field of working machines. The main solutions proposed in the three major working fields (Construction, Handling and Agriculture) are reviewed to highlight the different design strategies required for the electrification of existing architectures as well as for the design of new machines.

Although full electric and hybrid solutions are well consolidated in the automotive field, the actual state of the art of energy storage systems prevents the widespread adoption of this type of architecture for working machines. Chapter 3 analyses the different energy storage technologies available today, focusing the attention on the battery-based ones. Among several chemistries, Lithium-Ion based cells represent today the most promising solutions for powering electric vehicles. However, their performance must be continuously monitored to keep them working in well defined limits Safe Operating Area. To improve the understanding of this technology and prepare the

modelling base for the architecture proposed in the next chapters, a modelling and characterization activity was performed on a prismatic Li-Ion cell. The cell model obtained was then used in the battery pack model presented in Chapter 4. Here, starting from the general overview of the current situation given in the previous chapters, the design of a hybrid working machines was explored. Given the strong experience and history of the research group in the field of agricultural machineries, the vehicle considered as case study for this work was an orchard tractor. Since no standard working cycles are prescribed in the literature for orchard tractors (and in general there is still a gap in defining standard working cycle in each sector of working machines) an extensive measurement activity during on field operations was performed to determine its working scenarios and load conditions. From this data, a hybrid architecture was designed and simulated on a numerical model which allowed to replicate the same conditions. The main goal of the design process presented in this chapter was to think about a hybrid solution which could impact as less as possible on the actual architecture of the current vehicle. Performance of the traditional architecture were compared to those obtained with the proposed hybrid one both in terms of peak power capabilities and daily work capabilities. The hybrid solution was equipped with a downsized Diesel engine to improve the overall emissions performance of the system. The electric system of the model was powered using the numerical model of a lithium ion cell studied and characterized with an extensive experimental activity, presented in Chapter 3. The control system of the hybrid architecture was developed with the same design approach: the system should be easily integrated on an existing architecture. Thus, a Master-Slave control strategy was developed in order to pair the control strategy of the electric system to the actual control architecture of the Diesel engine. To optimize the amount of electric energy used due to the downsized engine a Load observer function modulated the intervention of the electric system according to the actual engine load. Finally, Chapter 5 describes how the proposed architecture was developed and implemented both at mechanical and control level in a Hardware-In-the-Loop bench. The proposed configuration allowed to test the architecture both in terms of mechanical and electrical performance. The control architecture was developed on the bench both in terms of hardware and software which was deployed on an automotive like control unit. One of the goals of the proposed HIL bench configuration was to validate the control strategy previously simulated using loading scenarios modelled and derived from the analysis performed in Chapter 4. The specific management software developed for this bench allowed to test both the traditional architecture and the hybrid one on the same bench in such a way that the same loading conditions could be applied to the two of them. Thus, the tests aimed to prove the feasibility of a plug and play solution both in terms of hardware components and management strategies.