Development of a Comprehensive 0-1D Powertrain and Vehicle Model for the Analysis of an Innovative 48 V Mild-Hybrid Diesel Passenger Car

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The demanding CO_2 targets are pushing the development of cost-effective solutions for the improvement of the efficiency of the powertrains. The electrification of the powertrain increases the complexity of the vehicle and the impact of the calibration activity that are required for the optimization of vehicle performance as fuel consumption and pollutant emissions. To manage this complexity, numerical simulation can play a fundamental role in evaluating innovative technologies, seeking the trade-off among conflicting objectives, scaling the number of tests at a minimal cost with respect to the experimental activity.

The aim of this work is to develop a methodology that integrates the detailed modelling of each powertrain subsystem in a high-level framework, that is a comprehensive powertrain and vehicle model of a 48V Mild Hybrid Vehicle. This comprehensive vehicle model, bringing together a 1D fast running model engine, a 1D aftertreatment model, a 1D cooling circuit model, a 0D electric motor and battery model as well as a virtual electronic control unit, aims to be a virtual test rig for the investigation of the impact of the electrification in terms of vehicle transient performance, fuel consumption and tailpipe pollutant emissions.

More in detail, in Ch.2, the case study is presented: a EURO 6 passenger car equipped with a 1.6 L 4-cylinder diesel is chosen for the analysis. The electrification is provided by the adoption of a 48V Belt Starter Generator (BSG) and a Li-Ion battery pack. A 48V electric catalyst placed upstream the Diesel Oxidation Catalyst and a 48V electric supercharger downstream the main turbocharger, integrate the equipment of the investigated Mild Hybrid Vehicle.

In Ch.3 the development and the validation of the comprehensive vehicle model is presented. Using a commercially available software, GT-SUITE, a predictive combustion model was calibrated and validated on different combustion mode to test the model accuracy with different injection strategies. A Fast Running Model (FRM) engine was validated in steady state and transient time to boost operations showing a satisfactory agreement with the experimental data from General Motors Global Propulsion System.

The comprehensive vehicle model, featuring the FRM engine with predictive combustion, the cooling circuit and the aftertreatment system, when driven along a WLTC driving cycle, performed closely to the vehicle on the roller bench in terms of fuel consumption, engine-out and tailpipe emissions. After the introduction of the 48V electric system, the impact of electrification on the engine thermal state and on the 48V battery state of charge was compared with the experimental data showing a noteworthy correspondence of the results.

Using the comprehensive powertrain and vehicle model as virtual test rig, in Ch.4, the optimal calibration of the Energy Management Strategy, which showed a beneficial impact on the concurrent reduction of fuel consumption and nitrogen oxides emissions, was chosen. The analysis of the introduction of an electric catalyst demonstrated the advantages of this technologies in terms of tailpipe nitrogen oxides emissions reduction with a limited increase in fuel consumption, in several type approval and real driving emissions driving cycles. Moreover, the 48V hybridization with BSG and the adoption of the electric Supercharger, showed that the electrification remarkably reduces the elasticity time of the vehicle, on different elasticity test in fixed gear.

Finally, in order to take advantage of the detailed modelling of the powertrain, a virtual calibration methodology, with the aim to investigate in depth the effects of innovative technologies on engine combustion and on vehicle fuel consumption and nitrogen oxides emissions, is proposed. The control parameters of the engine featuring, separately, Injection Rate Shaping, an innovative injector, the electric supercharger as auxiliary boosting system and Variable Valve Actuation were optimized on several Key Points. After the update of the calibration maps, driving cycle simulations of the innovative powertrains were performed showing benefits in fuel consumption and nitrogen oxides tailpipe emissions.