Fuel savings of plug-in hybrid electric vehicles (PHEV) strongly rely on the energy management strategy (EMS) deployed onboard. For current commercialized PHEVs, EMS are of rule-based type, configured to operate the vehicle in electric (EV) mode over a predefined all-electric range, then in Charge Sustaining (CS) mode. Hence, they are designed to optimize the powertrain efficiency at each instant of time and not over the entire given driving schedule. The objective of this study is to assess fuel consumption of current PHEV rule-based EMS, case study of the Toyota Prius plug-in; and investigate fuel saving enhancements for an optimized rule-based EMS, based on the prior knowledge of the scheduled route, using Dynamic Programming (DP) routine for global optimization over the scheduled route.

A PHEV model of the Prius power-split powertrain has been carried out in Matlab/Simulink environment. A rule-based EMS, emulating the real vehicle performance and energy consumption has been calibrated and validated from on-road measurements: the Prius starts with all-electric mode until the battery is sufficiently depleted, then the control switches to CS mode, strongly similar to the conventional self-sustaining hybrid Prius.

In order to optimize the existing EMS over the given driving schedule, the DP optimization routine was applied to the model, assuming the prior knowledge of the scheduled route. Though fuel saving improvements were identified over the tested cycles, DP showed limitations preventing its implementation for real-time vehicle operation. Therefore, DP results were used to generate new operating laws for the powertrain components aimed at optimizing the rule-based EMS.

In this paper, the optimized rule-based EMS is presented, based on the DP routine and relying on the prior knowledge of the scheduled route. The main amendment in the optimized EMS consists in modifying the engine threshold as function of the scheduled route distance; consequently, operating the engine more frequently in the all-electric range, and therefore, conserving more electrical energy.
in the battery for later use at the end of the trip. Another amendment consists in operating the engine at higher power rate once switched on. This turns to ensure higher engine efficiency and recharge the battery if power provided by the engine exceeds the load. Furthermore, the change of the control sequence from EV/CS modes in the existing EMS to CD over the entire scheduled route with the optimized EMS showed additional fuel saving potential. Fuel consumption results are presented over repeated NEDC drive cycles, up to 100 km.


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**Methodology for Modeling and Energy Management Control of a Parallel Hybrid Powertrain on Recurrent Routes Using Energetic Macroscopic Representation**

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This paper presents the methodology to design and optimize a predictive Rule-Based Energy Management Strategy (RB EMS) for real-time control applications, intended to minimize the fuel consumption on a recurrent route, e.g. the daily work-home commute.

The optimization process takes into consideration the desired trip profile, selected by the driver on the vehicle onboard GPS and linked to a traffic management system. A basic RB EMS, emulating the vehicle performance and energy consumption is first set using on-road measurement data logging. As a second step, the dynamic programming optimization routine is applied to the vehicle model, assuming a repeated NEDC cycle as the scheduled route. Obtained results of the powertrain
components behavior under optimal control are evaluated and used to update the operating energy management rules of the basic controller. Finally, an optimized RB-controller is proposed by coupling between the dynamic programming and the basic RB-controller, followed by an evaluation of the energy consumption and powertrain efficiency resulting from the three investigated control strategies of a mass-production parallel hybrid vehicle (Peugeot 308). The powertrain is modeled using the energetic macroscopic representation.

**Paper:** To be sent for publication.