Energy optimization tool for mild hybrid vehicles with thermal constraints

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A mild hybrid vehicle is a conventional vehicle with a small electric motor and battery pack added as to increase its efficiency. When adding a second source of energy on-board there is a need of an Energy Management System (EMS) that utilizes these two sources in order to gain most benefit. At Volvo Car Group, the current EMS is non-predictive. One idea of making the EMS better is to make it predictive, using future route information to plan the battery use. A replacement of the current EMS with a predictive optimization tool is thus explored.

I. Theory

Two optimization algorithms are used in the overall optimization tool developed in this thesis. The first one reads the data about the considered route ahead and calculates a globally optimum solution to the battery use throughout the drive cycle utilizing convex optimization. The output from this algorithm are two trajectories, one for the state of charge (SoC) of the battery, and the second for the thermal state of the battery.

A real-time controller then reads the output trajectories and compares these with the real-time states of the battery. The errors of the states are used to alter how aggressive the vehicle is to be with the battery. This is achieved by controlling the adjoint states in an Equivalent Consumption Minimization Strategy (ECMS). Simply put, the virtual cost of electrochemical energy is altered, and thus how the battery is used.

Furthermore, the input information about the route ahead to the optimization tool is to be sparsed as the tool is to be run on many vehicles simultaneously, calling for a reduction in calculation and quantity of data used.

As it is not guaranteed that the entire route ahead can be predicted, and also in order to further decrease the magnitude of data that is considered, the results of the optimization tool acting on receding horizon data is studied as well.

II. Results

The performance of the optimization tool, in terms of fuel consumption throughout considered drive cycles, is highly dependent on how coarsely segmented the input information about the future route is. With less future information the prediction of the future power demand is worse, resulting in less efficient battery use. Figure 1 shows the battery SoC for three different controllers. The non-predictive Baseline controller causes the battery SoC to saturate at SoC_{max} before the recuperation phase ends, resulting in a sub-optimal use of the battery. The BN controller corresponds to using the output convex optimization SoC trajectory in the Baseline controller. The PIDC controller is one of the PID-controllers explored in this thesis for altering the adjoint states in the ECMS formulation for determining instantaneous power-split. As can be seen, the battery is drained before the large regeneration phase, allowing for a higher degree of utilization of the on-board battery and a reduction in fuel consumption.

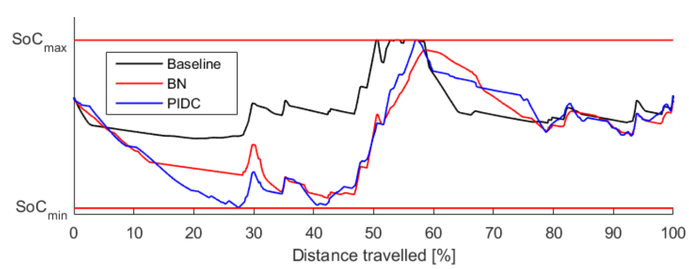

Fig. 1. Resulting SoC trajectories, BN is the Baseline controller using future route information, PIDC is a PID-controller implementation utilizing ECMS.