

## MODELING AND MODEL PREDICTIVE CONTROL FOR HYBRID ELECTRIC VEHICLES

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**ABSTRACT**—This paper builds up a typical model of a parallel hybrid electric vehicle and develops model predictive controllers for this model to control the speeds and torques for fast clutch engagement with high driving comfort and low jerk. Some modified algorithms for model predictive controllers are studied to improve their ability to track the desired speed setpoints, subject to input and output constraints.

**KEY WORDS** : Vehicle modeling, Model predictive control, Speed tracking setpoints

### 1. INTRODUCTION

Hybrid electric vehicles (HEVs) are combined hybrid and electric vehicles that combine the best features of internal combustion engines (ICEs) and electric motors (EMs). HEVs can be divided into two main groups: serial and parallel hybrids. In the serial hybrid, the primary power source (ICE) is not mechanically linked to the powertrain, but it is used to provide electrical power to a battery. The secondary power source (EM) can then draw the energy from the battery to run the vehicle. In the parallel hybrid, both power sources are independently installed so that they can run the vehicle either individually or together. Most commonly, the ICE and EM and gearbox are coupled by automatically controlled clutches. For electric driving at low speeds, the clutch between the ICE and the EM is open, and only the EM propels the vehicle. At high speeds, the clutch is closed, and the ICE is activated and runs the vehicle while the EM is turned off. At very high speeds or under very heavy loads, the EM can also be automatically turned on to join with the ICE to propel the vehicle.

The motivation behind using the Model Predictive Control (MPC) method in this work is the ability of MPC to solve optimization problems online with both linear and nonlinear systems. MPC refers to a class of algorithms that compute a sequence of input variables to optimize the future behavior of the output variables. One of the superiorities of MPC is its ability to deal with constraints within open-loop optimal control problems. Finding the solution for general constrained nonlinear models over an infinite prediction horizon is impractical because numerical

methods to solve these problems can only be formulated in a finite horizon length to find a real-time numerical solution. For this reason, only a finite moving horizon regulator is considered, in which the optimization problem is performed over a finite prediction horizon and the cost of prediction after the end of the horizon is approximated by a terminal penalty. To ensure the stability within a finite prediction horizon, most Nonlinear Model Predictive Control (NMPC) schemes use a terminal region constraint at the end of the prediction horizon in (Rawlings, 2000; Morari and Lee, 1999; Mayne, 1993). A particular NMPC scheme using a terminal region constraint, namely, a quasi-infinite horizon that guarantees asymptotic closed-loop stability with input constraints, was presented in (Minh and Afzulpurkar, 2006). However, the nonlinear systems then have both input and output constraints, and difficulties arise from the failure to satisfy the output constraints due to constraints on input. Therefore, a new NMPC scheme without a terminal region constraint is developed in (Minh and Afzulpurkar, 2006) using softened output constraints. A Robust Model Predictive Control (RMPC) that guarantees stability in the presence of model uncertainty using Linear Matrix Inequalities (LMIs) subject to input and output saturated constraints was presented in (Minh and Afzulpurkar, 2005a). In this novel RMPC, the controller softens the output constraints as penalty terms are added into the objective function. These terms maintain the output violation at low values until a constrained solution is returned.

When there are too many input and output constraints, the control system may not be able to meet all of the desired outputs. Because the MPC regulator is designed for an online implementation, any infeasible solution of the optimization problem cannot be tolerated. To guarantee system stability, the traditional MPC methods delete one or

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