CONTROL ORIENTED MODELLING OF A SERIES HYBRID SOLAR VEHICLE

P. Bauer*, Zs. Preitl*,P. Gáspár,Z. Szabó**, J. Bokor****

* Budapest University of Technology and Economics, Dept. Of Transport Automation,
H-1111 Budapest, Bertalan L.u. 2., Hungary
Email: bauer.peter@mail.bme.hu, preitl@sch.bme.hu, bokor@sztaki.hu
** Computer and Automation Research Institute,
H-1518 Budapest, Kende u. 13-17, Hungary

Abstract: Nowadays more and more importance is dedicated to research in the field of alternative vehicles. An option to conventional vehicles, having usually as energy source a fuel tank with gasoline, consists in the so called hybrid electric vehicles (HEVs) which have multiple main energy sources. These energy sources are the conventional fuel tank and a battery, delivering both chemical and electrical energy. This can be completed with a photovoltaic (PV) panel resulting in a hybrid solar vehicle (HSV). HEVs and HSVs can be seen as a transition from conventional vehicles to fully electric vehicles. The paper presents a study on modelling a series HSV. The model can be used for the development of optimal control strategies which minimize the vehicle's fuel consumption. Modelling is solved in two different ways. The first way, which can be used for example in a dynamical programming optimization method, is the application of static maps for all components. The second is the use of basic dynamical relations between the components, from which piecewise affine (PWA) models are generated. Model Predictive Control algorithms can be applied for this type of models.

Keywords: hybrid solar vehicles (HSVs), static maps, dynamical relations, PWA model

1. INTRODUCTION

The paper presents a study on modelling a series HSV. Series HSVs are optimal solutions for urban traffic applications where vehicle starts and stops frequently during a drive cycle. So regenerative braking can be often used which substantially improves the fuel economy of the vehicle. However, a series structure applies fully electric driving, where instantaneous large tractive forces provide good acceleration for the vehicle. The overall structure of series architecture can be seen on figure 1.

The vehicle model can be used for the development of optimal control strategies which minimize the vehicle's fuel consumption. Modelling can be solved in two different ways. The first way is the application of static maps for all components, while the second is the use of dynamical relations between all components and the basic dynamics of each component. The first approach can be used for example in a dynamical programming optimization method, meanwhile the second can be a basis for piecewise affine (PWA) model generation for Model Predictive Control (MPC) problems.

In the first section the specification of all components of the series hybrid driveline is given. The second deals with vehicle modelling using static maps of each component, where their connection is also important. In the next section modelling based on dynamical relations and the generation of PWA models is detailed. Finally a comparison of simulation results for both types of models is performed.

2. COMPONENTS IN A SERIES HYBRID ARCHITECTURE

The architecture of a series hybrid vehicle can be seen in Figure 1.

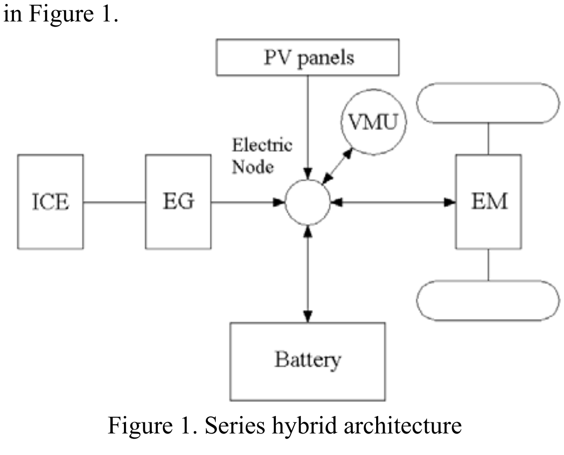

Figure 1. Series hybrid architecture

The main part is the electric motor (EM) which drives the wheels or works as a generator during regenerative braking. The electrical energy for the EM is delivered by the electric generator (EG), the PV panel and battery. The electric generator is in rigid connection with the internal combustion engine (ICE).

These two components have to be considered as an integral part of the vehicle, so power range, working points and efficiencies must be fitted. The internal combustion engine can be a diesel or a gasoline engine. The EM is usually a brushless DC motor which can be used both in motor and generator modes.

PV panels can be used mainly during parking of the vehicle but on open area they are useful supplements for the electric power sources (EG and Battery) in driving too.

The vehicle management unit (VMU) is used for control and coordination of components. When designing the control strategies, one must consider the properties of all the components and the goals of the control application. Usually the main goals are minimum fuel consumption during a trip and battery charge sustaining.

2. COMPONENT MODELLING WITH STATIC MAPS

The main components of a series hybrid vehicle are highly nonlinear, which can be characterized with static maps depicting their possible working points.

Of course this type of modelling does not reflect the dynamical effects in the vehicle. However, if one uses dynamic programming, this makes a search for optimal paths in the space of these points. Static maps are proper and effective solutions to characterize this type of problem.

Simpler components such as batteries can be characterized with basic equations too. Static maps can be generated using these formulas. It is important to properly select the parameters for these maps.

For the electric motor (generator) the electric power input (output), the mechanical power output (input) and the angular velocity are the main parameters. In such way, the characteristics reflect for the efficiency of these components.

For the internal combustion engine the most important parameter is the fuel rate of the engine plotted against the output torque and parameterized with angular velocity. The fuel map of the gasoline engine can be seen in Figure 2.

The static maps of the electric components are transformed in a similar form containing the torque instead of power values.

For control design the static maps of ICE and EG are integrated in one resultant characteristic.

A dynamic programming algorithm can be applied for this model giving a reference global, optimal solution which highly depends on the discretization of the space of working points and the drive cycle used for design. For this system, urban driving schedules are used.

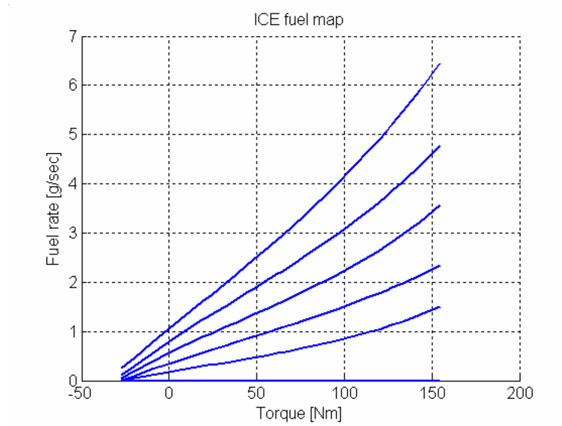

Figure 2. Fuel map of the gasoline engine

All the maps are integrated in a Matlab/Simulink model which is a basic platform for control strategy validation and evaluation.

3. DYNAMICAL MODELLING OF VEHICLE AND COMPONENTS

In this section a more detailed model is presented, this way sophisticated control strategies can be designed using dynamical model. However, the global optimality of dynamic programming solution can not be satisfied.

The vehicle dynamics is only characterized by the longitudinal term according to Newton's second law. Closed form equations are used for the dynamics of simple components such as batteries.

Static maps are integrated in the dynamical equations considering the working points of the components.
After the generation of all the dynamical equations, a highly nonlinear system of equations results. Usually this cannot be used directly for controller design, so we generated state space models connected in a PWA structure. Now, this can be used in MPC design strategies, which try to approach the global optimal solution resulted from dynamic programming.

First continuous time PWA (CT-PWA) models are created and simulated in Matlab/Simulink. The state dynamic equation and output equation of such models is in the following form:

$$\begin{aligned} \dot{x} &= Ax + Bu + f \\ y &= Cx + Du + g \end{aligned} \tag{1}$$

The simulations are used for system behaviour inspection using different driving schedules. Cost functions for control design algorithms are created considering the main properties of system dynamic and control goals of our strategy.

However, model predictive control algorithms use discrete time system models, so the models must be discretized, resulting in the following discrete time PWA (DT-PWA) equations:

$$\begin{aligned} x(k+1) &= A_d x(k) + B_d u(k) + f_d \\ y(k) &= C_d x(k) + D_d u(k) + g_d \end{aligned} \tag{2}$$

Of course simulations are performed comparing the behaviour of CT_PWA and DT_PWA models, which gives satisfactory results as can be seen in Figure 3.

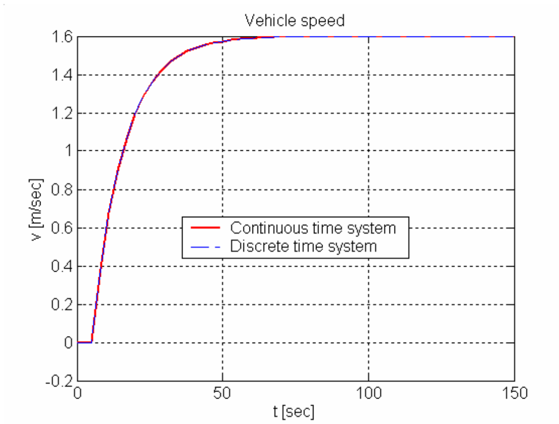

Figure 3. Simulation results from CT_PWA and DT_PWA models using the same input function

4. CONCLUSIONS

In the paper two types of models are set up for a series hybrid solar vehicle, taking into account available control design strategies and control goals.

For dynamic programming, static maps of the vehicle components have to be used as satisfactory solution. Using this type of model, a global optimal control strategy results from calculations, which is discrete not only in time but also in states. The global optimality of solution strongly depends on the discretization of states and time which must be considered in model building.

Another approach is to use a relatively simple dynamic model of the system, characterizing the basic dynamics of the vehicle. CT_PWA and DT_PWA models were built using this approach. The resulting models can be used for control strategy design with MPT methods.

Matlab/Simulink models were also built from all two modelling strategies. These can be used in controller validation, evaluation and simulation.

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