Topology Considerations in Hybrid Electric Vehicle Powertrain Architecture Design

by

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ABSTRACT

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Optimal system architecture (topology or configuration) design has been a challenging design problem because of its combinatorial nature. Parametric optimization studies make design decisions assuming a given architecture but there has been no general methodology that addresses design decisions on the system architecture itself. The electrification of vehicles with the introduction of mechatronic devices such as motors and generators to vehicle powertrains has drawn renewed attention to the automotive powertrain architecture optimization problem. Hybrid Electric Vehicle (HEV) powertrains allow various architecture alternatives created by connecting the internal combustion engine, motor/generators and the output shaft in different ways through planetary gear systems. Addition of clutches to HEV powertrains allows changing the connection arrangement (configuration) among the powertrain components during the vehicle operation. Architectures with this capability are referred to as multi-mode architectures while architectures with fixed configurations are referred to as single-mode architectures. Design decisions made on both the powertrain's component sizes and its configuration have significant impact on the fuel economy and vehicle performance. System architecture optimization requires designing the configuration and sizing si-

multaneously. Additionally, evaluation of an HEV architecture design depends on a power management (control) strategy that distributes the power demand to the engine and motor/generators. Including this control problem increases the complexity of the HEV architecture design problem. Methodologies developed specifically for HEV powertrain architecture design work only when the problem size is significantly reduced by eliminating many architecture design candidates or target only a small portion of the design space of architecture alternatives.

This dissertation focuses on a general methodology to make design decisions on HEV powertrain architecture and component sizes. The representation of the architecture design problem is critical to solving this problem. A new general representation framework capable of describing all architecture alternatives is introduced. Using the representation, all feasible configurations are generated to create a new design space of feasible configurations only. These configurations are used to create single- and multi-mode HEV architectures. The architecture design alternatives are evaluated based on fuel economy, vehicle performance and complexity. Three types of design problems are formulated: (i) single-mode architecture design for given component sizes (ii) multi-mode architecture design for given component sizes (iii) architecture design combining the configuration and sizing. Solution strategies for all three types of design problems are developed. The high complexity of the resulting optimization problem does not allow us to claim true optimality rigorously; therefore, the terms "promising" or "near-optimal" are more accurate in characterizing the results of the optimization studies. Case study results show that different architectures must be designed for different applications. The case studies designing architectures for some available vehicles from the market find the architectures already implemented in these vehicles under some design constraints. Alternative architectures that improve these designs under different design constraints are also demonstrated. Architectures for a new application that is not available in the market are also designed.