ABSTRACT

Multi-objective optimum design of two-motor and two-speed powertrain system for electric vehicles with probabilistic driver model

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Because of the growing worldwide demand for solutions to environmental issues, a major trend observed in the automotive industry has been the change from the internal combustion engine vehicle (ICEV) to the electric vehicle (EV). As the powertrain system constitutes the main configuration difference between an ICEV and EV, it should be carefully designed. In particular, a two-motor and two-speed powertrain system can outperform other powertrain systems in terms of driving requirements, achieving a high dynamic performance and energy efficiency. The key design components of the powertrain system are the motor and transmission; hence, the specifications of these components should be optimized, to improve both performance and efficiency as much as possible. To analyze such requirements, an EV dynamic model, which includes a two-motor and two-speed powertrain system, was developed using a model-based design methodology. This model

consists of driver, powertrain, equivalent vehicle inertia, resistance torque, braking, and battery sub-models. In real-world situations, variations in driver behavior can cause a variation in energy consumption under the same driving conditions. Therefore, an effective driver model, which precisely reflects the driver characteristics, is required to investigate the variation in driver behavior. For realizing this objective, this thesis has employed a driver model that expresses driver behavior using three parameters for the human operator: the aggressivity of driving, the perception of the driver, and the inherent viscosity and inertia of the driver's muscles. Using a probabilistic approach, these parameters were described by probability density functions.

The design parameters for the motors and transmission were defined as the maximum torque of each motor, the torque distribution coefficients between the two motors, and the first and second gear ratios of the transmission. To quantify the performance and efficiency, acceleration time and energy consumption were used as the evaluation criterion, respectively. The results obtained by changing the values of the design parameters show that the specifications of these parameters significantly affect the performance and efficiency of the EV. Therefore, optimizing these parameters is necessary to determine an effective design for the EV powertrain system. Moreover, because of a trade-off between performance and efficiency, a multi-objective optimization method is superior to a single-objective optimization method, for suggesting a variety of design solutions. Accordingly, this thesis formulates a multi-objective optimization problem that minimizes the acceleration time and energy consumption, and that includes dynamic constraints. Because of the large computational effort required to solve the multi-objective optimization problem using the analysis results of the EV model considering the probabilistic driver model, the surrogate models of each objective function were constructed, using an artificial neural network to reduce the computational burden. In addition, by employing an adaptive sampling method, the surrogate models were able to meet the high accuracy requirements of the models, using only a small number of samples to do so. Based on these surrogate models, the multi-objective optimization was performed, and the optimization results provided a Pareto front showing a variety of optimal design solutions that consider both objective functions simultaneously. Through a comparison with the results of a reference design, the superiority of the proposed design was confirmed. Moreover, by comparing the results of the optimal design solutions under both deterministic and probabilistic driver models, the necessity of the probabilistic model was made clear. Finally, comparisons of cost and accuracy between the EV dynamic model and the surrogate model verify the effectiveness of surrogate-based multi-objective optimization.