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THE INFLUENCE OF NARX CONTROL PARAMETERS ON THE FUEL EFFICIENCY IMPROVEMENT OF A HYDRAULIC HYBRID POWERTRAIN SYSTEM

KEYWORDS: hydraulic hybrid powertrain, internal combustion engines, machine learning, dynamic programming

Remarkable research efforts are needed to minimize the fuel consumption and the transportation sector's environmental impact to sustain energy conservation efforts. The main objective of the study presented in this paper has been to analyze and assess the performance of a nonlinear autoregressive neural network with exogenous inputs (NARX) for controlling a parallel hydraulic hybrid powertrain system of a transit bus. A simulation model of the vehicle has been calibrated using analyzed data obtained during an experiment conducted in real-world traffic conditions. A Dynamic Programming optimization procedure has then been applied to the calibrated powertrain model and an optimal configuration that minimizes fuel consumption has been selected. The NARX has been trained using the optimal control data obtained by the Dynamic Programming optimization of the load distribution between the ICE and the hydraulic powertrain system. Several NARX configurations involving a different number of hidden layers and exogenous input and feedback delay line samples have been trained and subsequently tested in the hydraulic hybrid powertrain system simulation. It has been shown that considerable fuel savings on the order of 30% could be achieved by implementing such a system.

Rising fuel prices and increasing awareness of environmental issues place greater emphasis on the quest for solutions that improve vehicle fuel economy and reduce harmful emissions. The main objective of the study presented in this paper is to analyze and assess the performance of a NARX model for controlling a parallel hydraulic hybrid powertrain system. An experiment has been conducted on a transit bus circulating in real traffic and occupancy conditions to obtain the real driving cycle and perform the calibration of the hybrid powertrain system simulation model. Dynamic Programming (DP) has been used to derive the optimal load distribution between the hydraulic pump/motor and the internal combustion engine to minimize fuel consumption. This set of optimal data has then been used in a Machine Learning (ML) framework to derive an implementable control law for the hybrid propulsion system. For exogenous inputs of the NARX, a vector of 4 variables in total have been used – the instantaneous vehicle speed, the driveshaft torque as a representative of the actual powertrain load, the hydraulic machine normalized load and the hydro-pneumatic accumulator gas pressure. Different configurations of the network have been tested in order to find the one that will yield the closest performance to the reference control law obtained using the DP method. Various

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combinations of values for the number of Hidden Layers (HL), the number of neurons per layer (LS), Input and Feedback Delay (ID/FD) samples have been tested.

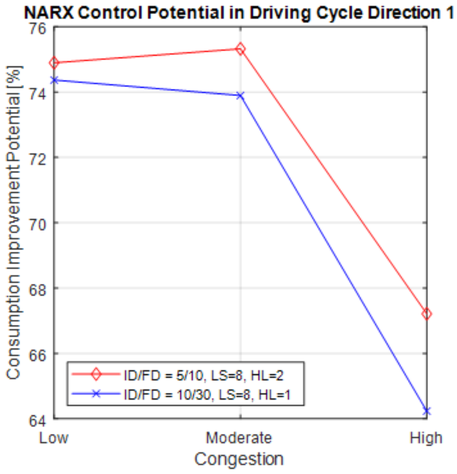

Figure 1. Relative fuel consumption comparison for the driving cycles in direction 1.

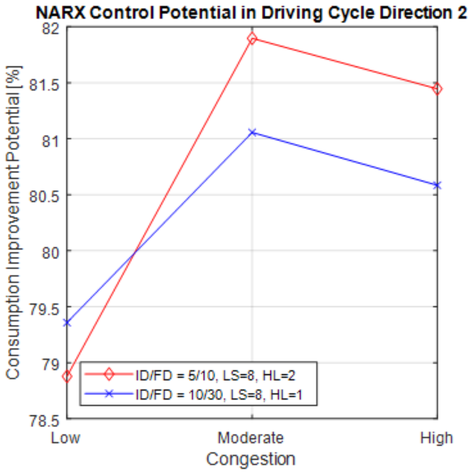

Figure 2. Relative fuel consumption comparison for the driving cycles in direction 2.

The consumption improvement potential, defined as the ratio of the realized fuel consumption decrease and the value of the optimally achievable fuel savings (using DP) is shown in figures 1 and 2 for both driving cycle directions and all congestion states. The proposed implementable control algorithm yields good performance. At least 67% of the potential fuel savings can be achieved by using the NARX control in the most congested driving conditions in direction 1. In the most favorable case, 82% of the maximally achievable fuel consumption reduction can be accomplished by using the suboptimal, implementable control algorithm. The newly trained NARX achieves better fuel economy than the previously tested one (with one hidden layer and increased ID and FD values) in all cases except for the low congestion state in direction 2. In direction 1, the difference between the two ANNs range from 0.5% in low to 3% in high congestion state. In driving cycle direction 2, the difference in the consumption improvement potential is -0.5% in low congestion state and reaches 0.8% in moderate and high congestion.
An implementable, artificial neural network-based control algorithm has been devised to control the load distribution in a parallel, hydraulic hybrid powertrain system for a transit bus. By using a NARX ANN, over 80% of the ultimate fuel consumption improvement potential obtained using a non-implementable optimization algorithm can be achieved.

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