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A Study on Optimizing SHEV Components Specifications and Control Parameter Values for the Reduction of Fuel Consumption by Using a Genetic Algorithm

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Abstract

For a series hybrid electric vehicle (SHEV), the electric motor is responsible for driving the wheels, while the engine drives the only generator to provide electricity. SHEVs set a control strategy to make the engine run near the fixed operating point with high thermal efficiency, thereby effectively reducing fuel consumption. The powertrain system of HEV is more complex than that of a conventional drive system using only an internal combustion engine, and it is time-consuming to obtain the optimal components specification values and control parameters. Therefore, automatic optimization methods are required nowadays. We used Genetic Algorithm (GA) as the optimization method and optimize powertrain specifications and control parameter values to reduce fuel consumption. The results show that it is an effective optimization method. In this research, we use a SHEV model constructed in MATLAB/Simulink and optimize the motor maximum torque, the capacity of the battery, and the control parameter values for starting and stopping the engine. Then, the degree of influence of each optimized parameter on the fuel consumption is analyzed. The components which have high sensitivity on fuel consumption are the battery capacity, the motor maximum torque and thresholds value for engine stop. As a result of optimization by GA, fuel consumption was reduced by 1.1% compared to the baseline. We are also verifying whether manual calibration of parameters or GA is the more efficient method. Manual calibration of parameters means setting all possible combinations of parameters, calculating the fuel consumption value for each combination and finding the minimum value. As it shows in the result, optimization can be achieved in less time with GA.

Introduction

Due to the increase in car ownership and serious environmental pollution, electric vehicles and hybrid vehicles has received more and more attention. Hybrid electric vehicles uses the engine, motor and battery as a hybrid power assembly, which also sets a control strategy to make the engine run in the area of operating points with high thermal efficiency, thereby effectively reducing fuel consumption and exhaust emissions. Because the various components of the hybrid powertrain system have nonlinear and interfering relationships, the various parameters should be optimized at the same time to achieve the optimization of the control parameters [1].

The control strategies of hybrid vehicles are mainly divided into two categories: offline control strategies and online control strategies [2]. Offline control strategies mainly include: linear programming, dynamic programming [3], genetic algorithm, and particle swarm optimization. Online control strategies mainly include: rule-based control strategy [4, 5] and online optimization-based strategies.

Online control strategies are now widely used in real-time control of vehicles. Offline control strategies cannot be used in real-time control systems because they require advance knowledge of the driving route for global optimization and are computationally intensive, but they can be used in the development process. GA do not need to provide gradient information, and overall convergence to the optimal solution can be achieved by iterations of random variation and

FIGURE 26 The flow of manual combination of component parameters and control parameters to optimize fuel consumption.

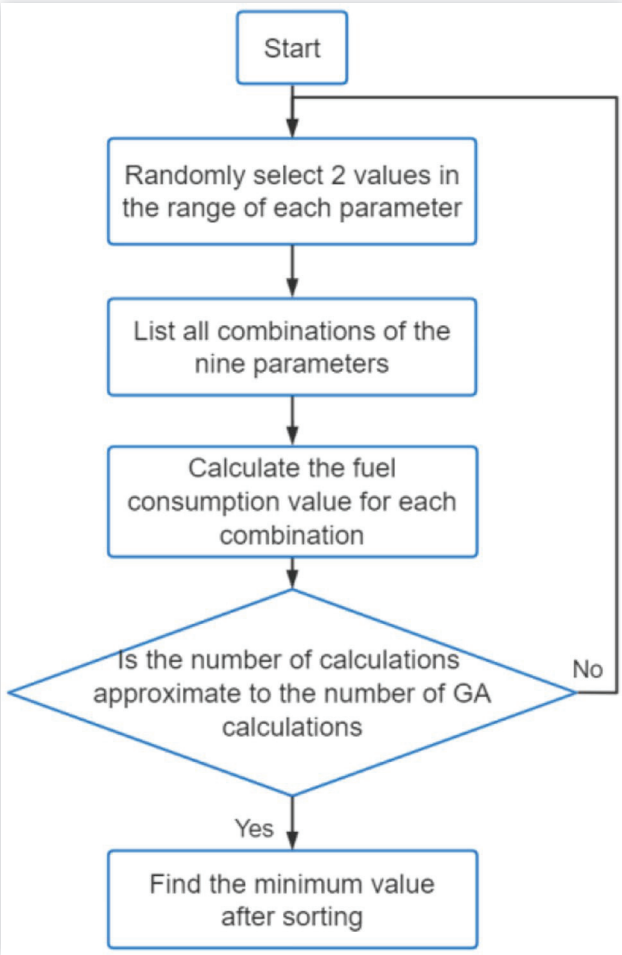

FIGURE 27 Six times of calculation process of the manual method.

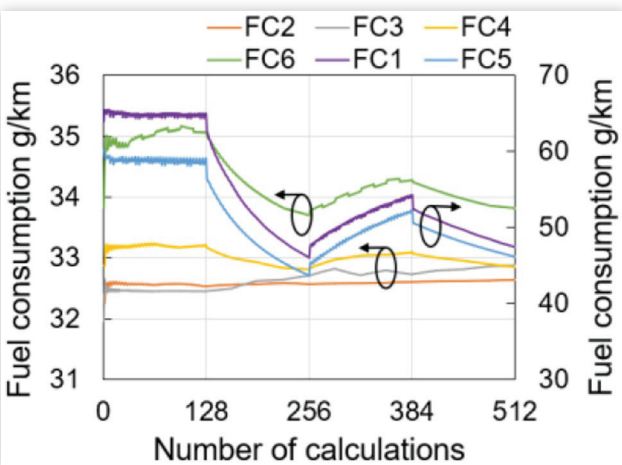

TABLE 10 Compare the optimization efficiency between GA and the manual method.

Optimized parameters	Optimal solution of GA	Optimal solution of manual method
Calculation number	3350	3584
Total calculation time h	12.34	30.35
Time used for one calculation s	13.26	30.49
Optimized result g/km	30.61	31.95
R g/(km•s)	0.03	-0.03

Summary/Conclusion

In this study, the parameters used for optimization are divided into two main categories: component parameters and control parameters. The component parameters include the battery capacity and the motor maximum torque. The control parameters include the engine start thresholds and the engine stop thresholds. These parameters affecting the engine start/stop of a SHEV are optimized using GA with fuel consumption as the objective function. The fuel consumption when driving WLTC is calculated by simulation using the vehicle model.

Finally, the fuel consumption is reduced by 1.1% by changing the constraints of the parameters. However, the 1.1% optimization result is based on WLTC cycles and remains to be verified for other test cycles and real-world driving cycles. After that, the analysis of the effect of parameters on fuel consumption is completed. As a result of analyzing the influence of parameters on fuel consumption, the more influential parameters are the battery capacity, the maximum torque of electric motor and the engine stop thresholds.

Finally, we also discussed the efficiency of GA optimization. In comparison to the manual method of combining parameters, GA can derive the parameters in a shorter time to reduce fuel consumption. Although GA is an offline optimization method, it is necessary to consider how to reduce the computational load of GA and improve the optimization speed in future research.

References

1. Sarvaiya, S., Ganesh, S., and Xu, B., "Comparative Analysis of Hybrid Vehicle Energy Management Strategies with Optimization of Fuel Economy and Battery Life," *Energy* 228 (2021): 120604, doi:10.1016/j.energy.2021.120604.
2. Enang, W. and Bannister, C., "Modelling and Control of Hybrid Electric Vehicles (A Comprehensive Review)," *Renewable and Sustainable Energy Reviews* 74 (2017): 1210-1239, doi:10.1016/j.rser.2017.01.075.
3. Zhu, D., Pritchard, E., Dadam, S.R., Kumar, V. et al., "Optimization of Rule-Based Energy Management Strategies for Hybrid Vehicles Using Dynamic Programming," *Combustion Engines* 184, no. 1 (2021): 3-10, doi:10.19206/CE-131967.

4. Zhu, D. and Pritchard, E., "NCSU Year Three Final Technical Report," SAE Technical Paper 2014-01-2907 (2014). https://doi.org/10.4271/2014-01-2907.
5. Kumar, V., Zhu, D., and Dadam, S., "Intelligent Auxiliary Battery Control - A Connected Approach," SAE Technical Paper 2021-01-1248 (2021), doi:10.4271/2021-01-1248.
6. Sivanandam, S.N. and Deepa, S.N., *Introduction to Genetic Algorithms* (Berlin Heidelberg: Springer-Verlag, 2008), 9-11, ISBN:978-3-540-73189-4
7. Runcai, W., Ren, H., Jianbo, Y., and Chunhua, H., "Parameter Optimization of a PSHEV Based on Genetic Algorithm," *China Mechanical Engineering* 24, no. 18 (2013): 2544-2549, doi:10.3969/j.issn.1004-132X.2013.14.026.
8. Hasanzadeh, A., Asaei, B., and Emadi, A., "Optimum Design of Series Hybrid Electric Buses by Genetic Algorithm," in *Proceedings of the IEEE International Symposium on Industrial Electronics, ISIE 2005*, pp. 1465-1470, 2005, doi:10.1109/ISIE.2005.1529148.
9. Eckert, J.J., Corrêa, F.C., Bertoti, E., Yamashita, R.Y. et al., "Powertrain Optimization to Improve Vehicle Performance and Fuel Consumption," in: *Mechanisms and Machine Science*. Vol. 54, (Cham: Springer, 2017), doi:10.1007/978-3-319-67567-1_49.
10. The United Nations Economic Commission for Europe, UNECE Global technical regulation No. 15, May 2014.
11. Ministry of Economy, Trade, and Industry, "Manual for Models Compliant with Plant Model I/F Guidelines for Automobile Development (Fuel Efficiency Model for Series Hybrid Vehicles) (ver. 1.0) (in Japanese)," *Environmental Partnership Council*, accessed March, 2021, https://epc.or.jp/fund_dept/sim_foundation/2020model.
12. Yamagishi, T., Shingyouchi, H., Yamaguchi, K., Mizushima, N. et al., "A Novel Integrated Series Hybrid Electric Vehicle Model Reveals Possibilities for Reducing Fuel Consumption and Improving Exhaust Gas Purification Performance," SAE Technical Paper 2021-01-1244 (2021), doi:10.4271/2021-01-1.
13. Liu, W., *Hybrid Electric Vehicle System Modeling and Control* (Chichester, West Sussex, UK; Hoboken, NJ, USA: Wiley, 2017), ISBN:ISBN 978-1-119-27932-7
14. Borthakur, S., and Subramanian, S., "Parameter Matching and Optimization of a Series Hybrid Electric Vehicle Powertrain System," in *ASME 2016 International Mechanical Engineering Congress and Exposition*, 2016, doi:10.1115/IMECE2016-66312.
15. Hassanat, A., Almohammadi, K., Alkafaween, E., Abunawas, E. et al., "Choosing Mutation and Crossover Ratios for Genetic Algorithms—A Review with a New Dynamic Approach," *Information* 10, no. 12 (2019): 390, doi:10.3390/info10120390.
16. MATLAB, "Genetic Algorithms," accessed April 2021, https://jp.mathworks.com/discovery/genetic-algorithm.html.
17. Honda Motor Co., Ltd., "Fit Hybrid (in Japanese)," accessed February 2021, https://www.honda.co.jp/auto-recycle/pdf/li_ion_fit.pdf.
18. Honda Motor Co., Ltd., "Odyssey Hybrid (in Japanese)," accessed February 2021, https://www.honda.co.jp/auto-recycle/pdf/li_ion_odyssey.pdf.
19. Honda Motor Co., Ltd., "Step Wagon Spada Hybrid (in Japanese)," accessed February, 2021, https://www.honda.co.jp/auto-recycle/pdf/li_ion_stepwagon.pdf.
20. Honda Motor Co., Ltd., "Insight Hybrid (in Japanese)," accessed February, 2021, https://www.honda.co.jp/auto-recycle/pdf/li_ion_insight.pdf.
21. Honda Motor Co., Ltd., "Accord Hybrid (in Japanese)," accessed February 2021, https://www.honda.co.jp/auto-recycle/pdf/li_ion_accord.pdf.
22. Honda Motor Co., Ltd., "Legend Hybrid (in Japanese)," accessed February 2021, https://www.honda.co.jp/auto-recycle/pdf/li_ion_legend.pdf.
23. Honda Motor Co., Ltd., "Freed Hybrid (in Japanese)," accessed February 2021, https://www.honda.co.jp/auto-recycle/pdf/li_ion_freed.pdf.
24. Toyota Motor Corporation, "HV Battery Collection and Recycling Manual (in Japanese)," accessed February 2021, https://global.toyota/pages/global_toyota/sustainability/esg/challenge2050/Challenge5/proper-disposal/hv_detachable_priusalpha40w.pdf.
25. Suzuki Motor Corporation, "Removal manual (in Japanese)," accessed February 2021, https://www.suzuki.co.jp/about/csr/recycle/traders/pdf/TORIHAZUSI_MANUAL_MH44S_MK42S_MR41S_MA36S_FF21S_ZCZD53S_MN71S.pdf.

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Definitions/Abbreviations

GA - Genetic Algorithm

$T_{ENG}^{(t)}$ - Engine total torque at time t Nm

$T_{(\theta,\omega)}$ - Engine torque calculated by map Nm

T_{ENG} - Engine torque calculated by generator torque Nm

$\omega_{ENG}^{t_n}$ - Engine speed rad/s

I_{FW} - Inertia moment of engine flywheel kgm^2

t_n - Time s

V_{MG} - Generator voltage V

V_{EM} - Motor voltage V

$\kappa\omega$ - Back EMF constant V/(m/s)

T_{MG} - Generator torque Nm

η_{MG} - Generator efficiency

η_{EM} - Motor efficiency

κ_τ - Torque constant