2022-01-0691 Published 29 Mar 2022

Development of Next Generation Fuel Cell Bus: Investigation of Configuration Impact and Control Strategy Development

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Citation: Zhang, Y., Blades, L., Early, J., Cunningham, G. et al., "Development of Next Generation Fuel Cell Bus: Investigation of Configuration Impact and Control Strategy Development," SAE Technical Paper 2022-01-0691, 2022, doi:10.4271/2022-01-0691.

Received: 20 Jan 2022 Revised: 20 Jan 2022 Accepted: 09 Jan 2022

Abstract

The emergence of fuel cell powertrains has opened up new pathways to net-zero greenhouse gas emissions across a number of sectors, including public transport. However, while these technologies are gaining momentum, they are mostly still in their infancy with a range of fundamental challenges which still need to be addressed. The typical configuration deployed in bus applications requires integration with other fast-response power sources, e.g., battery and/or ultra-capacitor, to effectively manage power delivery. However, implementation of such hybrid energy storage systems (ESSs) complicates the design and control of the vehicle powertrains. In this work, a concept fuel cell bus vehicle powertrain configuration has been constructed first using Matlab/Simulink which can be used to explore the impact of various ESS hybridization strategies, and their effectiveness in power management. Three variants have been studied: [I] fuel cell + battery; [II] fuel cell + ultra-capacitor and [III] fuel cell + battery + ultra-capacitor. A unified global energy management strategy (EMS) based on dynamic programming (DP) has been developed and deployed in the simulated bus powertrain models to understand the practicalities of the three EMS configurations, and the potential advantages and constraints associated with each, offering guide for practical EMS development. Using an explicit equivalent consumption minimization strategy (eECMS), tailored EMSs are developed for three configurations which optimize the power split between the available power sources in real time, and the enhanced performance are achieved benchmarked against other energy management solutions in the compare study. Comparison of results manifests great advantage of the novel instant EMSs in energy consumption saving.

Introduction

The appearing conflict between urban population explosion, economic upheaval and environmental pollution must all be finely balanced in order to achieve a more sustainable society. Acceleration to net zero greenhouse gas emissions (GHGs) is a critical strategic action within the auto industry [1], targeting at carbon neutrality through popularizing e-mobility [2]. Hydrogen energy-dependent fuel-cell vehicles (FCVs), one of several promising electric vehicle (EV) technologies, have demonstrated real potential to transition from low emission electric transport towards next-generation net-zero transportation [3]. Unlike other power sources, e.g., lithium battery, ultra-capacitor, etc., fuel cell presents special physicochemical properties, requiring meticulous design on fuel cell powertrain configurations and energy management strategies (EMSs) [4].

The special electrochemistry-based energy generation leads to a slower response of fuel cell to instantly fluctuating driving requirements. To ensure drivability and protect fuel cell lifetime, it is preferred to integrate fuel cell with other power sources, such as battery and ultra-capacitor, in FCVs [5]. By fully exploiting fast-response capabilities of the high-power density power sources, fuel cell can only operate in stable conditions in most of time. The most representative FCV configurations include: [I] fuel cell + battery (C1), [II] fuel cell + ultra-capacitor (C2) and [III] fuel cell + battery + ultra-capacitor (C3). The integration of multiple power sources in FCVs complexes the powertrain configurations, and increases difficulty in control strategy design. To resilient development new-generation FCVs, it is necessary to have a clear understand impact from multiple power sources integration on FCV performance.

References

1. Bonsu, N.O., "Towards a Circular and Low-Carbon Economy: Insights from the Transitioning to Electric Vehicles and Net Zero Economy," *Journal of Cleaner Production* 256 (2020): 120659.
2. Albrecht, M., Nilsson, M., and Åkerman, J., "Nordic Power Road Map 2050: Strategic Choices Towards Carbon Neutrality. D4. 2. R Policy and Institutional Review Electric Vehicles (EV)," 2012.
3. Ehsani, M., Gao, Y., Longo, S., and Ebrahimi, K.M., *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, (CRC Press, 2018)
4. Hu, Z., Li, J., Xu, L., Song, Z. et al., "Multi-Objective Energy Management Optimization and Parameter Sizing for Proton Exchange Membrane Hybrid Fuel Cell Vehicles," *Energy Conversion and Management* 129 (2016): 108-121.
5. Sulaiman, N., Hannan, M.A., Mohamed, A., Ker, P.J. et al., "Optimization of Energy Management System for Fuel-Cell Hybrid Electric Vehicles: Issues and Recommendations," *Applied Energy* 228 (2018): 2061-2079.
6. Schell, A., Peng, H., Tran, D., Stamos, E. et al., "Modelling and Control Strategy Development for Fuel Cell Electric Vehicles," *Annual Reviews in Control* 29, no. 1 (2005): 159-168.
7. Geng, C., Jin, X., and Zhang, X., "Simulation Research on a Novel Control Strategy for Fuel Cell Extended-Range Vehicles," *International Journal of Hydrogen Energy* 44, no. 1 (2019): 408-420.
8. Sun, H., Fu, Z., Tao, F., Zhu, L. et al., "Data-Driven Reinforcement-Learning-Based Hierarchical Energy Management Strategy for Fuel Cell/Battery/Ultracapacitor Hybrid Electric Vehicles," *Journal of Power Sources* 455 (2020): 227964.
9. Wang, Y., Advani, S.G., and Prasad, A.K., "A Comparison of Rule-Based and Model Predictive Controller-Based Power Management Strategies for Fuel Cell/Battery Hybrid Vehicles Considering Degradation," *International Journal of Hydrogen Energy* 45, no. 58 (2020): 33948-33956.
10. Hemi, H., Ghouili, J., and Cheriti, A., "A Real Time Fuzzy Logic Power Management Strategy for a Fuel Cell Vehicle," *Energy Conversion and Management* 80 (2014): 63-70.
11. 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.
12. Li, H., Ravey, A., N'Diaye, A., and Djerdir, A., "A Novel Equivalent Consumption Minimization Strategy for Hybrid Electric Vehicle Powered by Fuel Cell, Battery and Supercapacitor," *Journal of Power Sources* 395 (2018): 262-270.
13. Quan, S., Wang, Y.X., Xiao, X., He, H. et al., "Real-Time Energy Management for Fuel Cell Electric Vehicle Using Speed Prediction-Based Model Predictive Control Considering Performance Degradation," *Applied Energy* 304 (2021): 117845.
14. Reddy, N.P., Pasdeloup, D., Zadeh, M.K., and Skjetne, R., "An Intelligent Power and Energy Management System for Fuel Cell/Battery Hybrid Electric Vehicle Using Reinforcement Learning," in *2019 IEEE Transportation Electrification Conference and Expo (ITEC)*, 2019, 1-6, IEEE.
15. Musardo, C., Rizzoni, G., Guezennec, Y., and Staccia, B., "A-ECMS: An adaptive Algorithm for Hybrid Electric Vehicle Energy Management," *European Journal of Control* 11, no. 4-5 (2005): 509-524.
16. Lei, Z., Qin, D., Hou, L., Peng, J. et al., "An Adaptive Equivalent Consumption Minimization Strategy for Plug-In Hybrid Electric Vehicles Based on Traffic Information," *Energy* 190 (2020): 116409.
17. Paganelli, G., Tateno, M., Brahma, A., Rizzoni, G. et al., "Control Development for a Hybrid-Electric Sport-Utility Vehicle: Strategy, Implementation and Field Test Results," in *Proceedings of the 2001 American Control Conference (Cat. No. 01CH37148)*, vol. 6, 2001, 5064-5069, IEEE.
18. Mirjalili, S. and Lewis, A., "The Whale Optimization Algorithm," *Advances in Engineering Software* 95 (2016): 51-67.

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Acknowledgments

This work is supported by the Innovate UK and Wrightbus.

ISSN 0148-7191