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Energy Assessment of the Electric Powertrain System of a Formula Student Electric Race Car

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Abstract

While the shift to vehicle electrification plays a pivotal role in governments' targets towards carbon neutrality, there exists certain technical challenges that need to be addressed. The motorsport car industry is also affected by this policy with the electric cars being included in the formula SAE and formula E competitions as one of the main categories. Moreover, there is a gap in the literature in energy assessment of the electric powertrain used in Formula SAE (FSAE) and Formula Student (FS) cars. In this paper, a Formula Student electric car powertrain was designed as a case study for energy analysis. The proposed electric powertrain is equipped with a four-wheel drive system. The vehicle was modelled in AVL CRUISE M software using technical and measured lab data as input parameters. Simulations were run in a transient driving cycle for a real circuit layout used in previous SAE competitions. The results of this study showed that, at maximum speed, the battery pack voltage and current reaches 600V and 112A, respectively. In addition, approximately 320.84Wh electrical energy of the battery was consumed in one lap of the circuit (1.1 km). Furthermore, the transient results are presented to indicate the final battery state of charge, voltage fade and current fluctuations in the electric propulsion system. Finally, the electric motors dynamic power and efficiency is presented and analyzed.

Introduction

The vehicles in the global transportation systems are one of the main sources of greenhouse gas (GHG) emissions contributing to climate change and global warming [1, 2]. Reduction of GHG emissions produced by the sector is believed to positively impact the global GHG levels. One of the main solutions for this matter, is electrification of the vehicles [3, 4].

The recent agreements requiring all vehicles to be electric from 2050 in the UK and other similar requirements around the world, have incentivized the automotive industry to speed up the electrification of their offerings. This movement is also further intensified due to the shortage of gasoline and diesel sources especially in the European countries [5] contributing to the uptake of battery electric and hybrid electric vehicles [6, 7]. The electrification is not just restricted to the vehicles on the roads, but also applied to the formula one cars [8].

The Formula Student competition originated from the Formula SAE competition held in the United States in the 1980s [9], is a student design competition in which open-wheel formula racing cars are designed, manufactured, and raced in a controlled environment. The competition is divided into static and dynamic events, the former evaluates engineering design, costs, and business case, whereas the latter tests the vehicles on dynamic conditions such as straight line acceleration and endurance, where vehicles must complete a 22km course in the shortest amount of time. Currently, the competition has more than a thousand teams worldwide and twenty competitions around the world.

One of the major objectives of the Formula Student competition is to prepare students for the challenges of the industry [9, 10]. In this sense, there has been a shift from Internal Combustion Engines (ICE) powertrains towards Electric Vehicles (EV). This trend has gained increasing worldwide attention since the electric vehicle category was created, in 2008, for the Formula Student competition in the United Kingdom (FSUK). Since 2012 it has been united into a single class where both ICE and EV compete together.

There are a few articles published in powertrain design and analysis of the electric formula student cars using numerical software packages. These studies include both the energy recovery in electric formula student cars [11], and the impacts of employment of different control strategies for controlling battery parameters such as SOC [12]. Henao-Muñoz et al [11] have developed a braking strategy for a formula student car for increasing the energy recovered by regenerative braking. The electric car powertrain was simulated in a real racetrack to assess the performance of the novel brake system strategy on the regenerative braking performance. The simulation was performed using MATLAB Simulink software. The

FIGURE 9 The electric motor efficiency variations in different times during the driving cycle

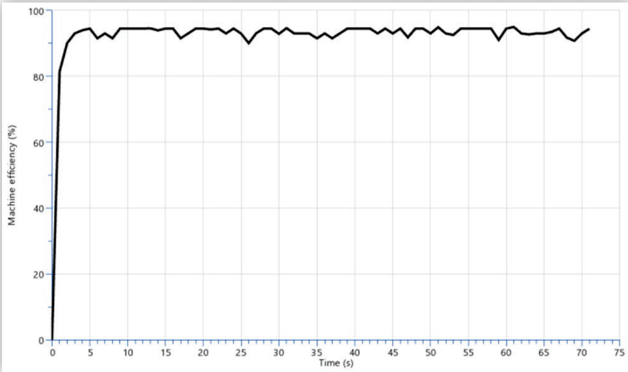
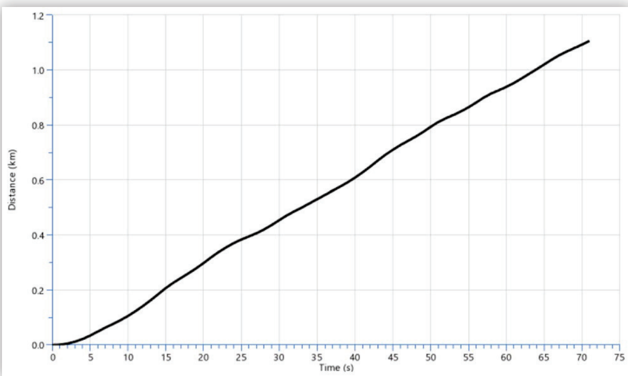


FIGURE 10 The distance travelled by the car in different times during the driving cycle



lap. Therefore, the total distance can be traveled by the formula student car based on the conditions of this racetrack is about 22km when the initial SOC of the battery pack equals to 100%.

Conclusions

In this study, the energy analysis of the electric powertrain of a formula student car is performed. The numerical model of the proposed powertrain is developed in AVL CRUISE M software and its performance in one of the standard formula student racetracks is assessed. In addition, the technical input data used in this study is coming from catalogues and the real data extracted in the labs. Moreover, the output parameters from the model are assessed to evaluate compliance with the competition rules. The main conclusions drawn from this paper can be listed as:

- The maximum and minimum voltage of the battery pack equals to approximately 600V and 564V, respectively, and the final SOC of the battery pack reaches 84.6% at the end of the first lap of the proposed racetrack.
- The maximum battery pack discharging power is almost 80kW, and charging power is below 70kW. Moreover, the cumulated energy discharged from the battery pack at the end of the first lap equals to approximately 320.84Wh. Therefore, it can be estimated that, the total energy discharged from the battery pack at the end of 22 laps would be nearly 7058.5Wh.
- The electric motors efficiency equals to 96% at most of the times during the driving cycle.

References

1. Felseghi, R.-A., Carcadea, E., Raboaca, M.S., Trufin, C.N. et al., "Hydrogen Fuel Cell Technology for the Sustainable Future of Stationary Applications," *Energies.* 12, no. 23 (2019): 4593.
2. Abouelkhair, E., Salek, F., and Babaie, M., "Comparative Energy Analysis of the Conventional and Fuel Cell Electric Powertrains for a Medium-Duty Truck," *SAE International Journal of Electrified Vehicles.* 12, no. 1 (2022).
3. Obereigner, G., Shorten, R., Meier, F., Jones, S. et al., "Active Limitation of Tire Wear and Emissions for Electrified Vehicles," SAE Technical Paper 2021-01-0328, 2021, https://doi.org/10.4271/2021-01-0328.
4. Dadam, S., Jentz, R., lenzen, T., and Meissner, H., "Diagnostic Evaluation of Exhaust Gas Recirculation (EGR) System on Gasoline Electric Hybrid Vehicle," SAE Technical Paper 2020-01-0902, 2020, https://doi.org/10.4271/2020-01-0902.
5. 2050 long-term strategy.
6. Kumar, V., Dadam, S.R., Zhu, D., and Mehring, J., "Fuel-Economy Performance Analysis with Exhaust Heat Recovery System on Gasoline Engine," *SAE International Journal of Engines.* 15, no. 03-15-06-0045 (2022).
7. Zhu, D., Pritchard, E., and Dadam, S.R., "Optimization of Rule-Based Energy Management Strategies for Hybrid Vehicles Using Dynamic Programming," *Combustion Engines* 184, no. 1: 3-10.
8. Martellucci, L. and Giannini, M., "Regenerative Braking Experimental Tests and Results for Formula Student Car," *Journal of Transportation Technologies.* 11, no. 1 (2020): 78-89.
9. HISTORY OF FORMULA STUDENT [Available from: https://www.imeche.org/events/formula-student/about-formula-student/history-of-formula-student.
10. Rules and Important documents [Available from: https://www.formulastudent.de/fsg/.
11. Henao-Muñoz, A.C., Pereirinha, P., and Bouscayrol, A., "Regenerative Braking Strategy of a Formula SAE Electric Race Car Using Energetic Macroscopic Representation," *World Electric Vehicle Journal.* 11, no. 2 (2020): 45.
12. Kumar V., Zhu D., Dadam S.R.. Intelligent Auxiliary Battery Control-A Connected Approach. SAE Technical Paper; 2021. Report No.: 0148-7191.
13. Regas, B.I., "Analysis of Different Powertrain Configurations for a Formula Style Electric Racecar," *Universitat Politècnica de Catalunya* (2019).
14. Nguyen, C.T., Walker, P.D., Zhou, S., and Zhang, N., "Optimal Sizing and Energy Management of an Electric