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Chevrolet Bolt Electric Vehicle Model Validated with On-the-Road Data and Applied to Estimating the Benefits of a Multi-Speed Gearbox

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Abstract

This paper presents a model for predicting the energy consumption of a 2017 Chevrolet Bolt electric vehicle. The model is validated using 93 measured drive cycles covering in excess of 10,600 kilometres of driving and temperatures from −8 to 32 °C. The mechanical road load acting on the vehicle is calculated via ABC parameters from the publicly available US Environmental Protection Agency (EPA) Annual Certification Data database. The vehicle model includes wheel diameter, gear ratio, rated electric machine torque and power, 12V accessory load based off measurements, measured electric machine efficiency obtained from a publication from General Motors, and modelled inverter efficiency. Assumptions are made regarding gearbox losses as well. To ensure accuracy under real-world conditions, road grade, temperature effects, and heating and cooling energy are included as well. The model predicts an EPA range of 380 km, which is very close to the 383 km rating. Error is typically around ±10% for the experimental drive cycles used for validation. The presented modelling methodology can be applied to any production battery electric vehicle and used to predict the benefits of utilizing multi-speed gearboxes, wideband gap semiconductor inverters, different electric traction machine designs, and other vehicle design changes. The paper includes an extensive comparison of modelled versus measured results, as well as an analysis of the benefits of a multi-speed gearbox for the vehicle, showing an increase of range of 1.3% (5 km) with a two-speed gearbox.

Introduction

Global warming has forced the automotive industry to drastically decrease vehicle emissions towards zero CO_2. Over twenty countries have announced ambitious goals to reduce vehicular greenhouse gas emissions by restricting or even banning the selling of internal combustion engine (ICE) propelled vehicles. For example, the United Kingdom will ban ICE-propelled vehicles in 2030, followed by Japan and China in 2035 [1]. To achieve these challenging targets, automakers such as General Motors (GM) have been heavily investing in vehicle electrification and setting public commitments to offer new global, fully electrified products in a short period. GM, for example, plans to invest 35 billion dollars in expanding its portfolio to 30 new battery electric vehicles (EV) by 2025 [2] and even has a notable plan to produce only zero-emission vehicles by 2035 [3].

Nevertheless, the vehicle powertrain design process is complex. To manage this complexity, a new system development framework is proposed in [4], where model-based design is used to support the system requirements, design, analysis, verification, and validation activities. Thus, this paper presents the performance of a straightforward way to model an electromechanical EV powertrain that incorporates the electric machine, inverter, gearbox and differential, and the mechanical forces acting on the vehicle, including the aero drag force, acceleration force, rolling resistance force, and gravitational incline force. These mechanical forces contrapose the vehicle's movement and are used to calculate the power demand from the high-voltage battery. The model is used to estimate the vehicle energy consumption, predicted electric machine and inverter efficiencies, and the distribution of the system energy. The model is also used to predict the benefits of a two-speed gearbox and its impact on vehicle energy consumption. Other vehicle powertrain configurations can be further incorporated, for instance, wideband gap semiconductor inverters, different electric traction machine designs, and other powertrain changes. The model is based on backwards power losses equations, having as input the required vehicle speed, and is demonstrated for the 2017 Chevrolet Bolt EV as a benchmark.

Vehicle modelling has been extensively detailed in the literature, and various authors have proposed different modelling approaches to predict the power and energy required for a given drive cycle. In [5], the MATLAB/Simulink Powertrain Blockset™ is applied towards the design of a hybrid vehicle drivetrain. In [6], NREL's Advanced Vehicle Simulator, ADVISOR, is used to model a vehicle and create a machine the model. The electromechanical model validation centred on the comparison of the measured and predicted energy consumption. The model demonstrates accuracy for real driving conditions or around ±10% for temperatures from 0 °C to 20 °C, with higher error for temperatures outside of this range. This increased error is likely due to the model not considering tire pressure variation and bearing and gear loss as a function of the outside air temperature, as well as due to lower accuracy heater and air conditioning power measurements. The model is shown to predict the EPA range of the Chevrolet Bolt EV quite well, with an error of just 3 km. Hence, the Chevrolet Bolt EV presented model provides a reasonable estimation of vehicle power and energy consumption for a given drive trip, demonstrating that a relatively simple model can be relied upon when modeling vehicle range.

Following the validation, the single-speed model of the Chevrolet Bolt EV was adapted to include a two-speed gearbox to estimate the potential benefits of such a system. With the two-speed gearbox, the electric machine and inverter combined losses were found to be reduced by 27.5% for the US06 drive cycle, which translates to an average efficiency increase of 2.7%. While this demonstrates the potential of a two-speed traction system, further investigation is needed, including gearbox loss modeling or a co-optimized design of the electric machine, inverter motor controller, battery pack and gearbox.

Future model improvements should aim to reduce the model error for temperatures below 0 °C and higher 20 °C by having more precise vehicle recorded data and accounting for more temperature-dependent loss sources. Most importantly, this paper has confirmed that EV energy consumption can be accurately estimated with relatively straightforward modeling practices, and that the proposed modelling methodology can be applied to evaluate the benefit of proposed changes and improvements to electric drivetrains, including multi-speed gearboxes, as was investigated in this study.

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