PAPER • OPEN ACCESS

Modelling of regenerative braking system for electric bus

To cite this article: M Islameka *et al* 2019 *J. Phys.: Conf. Ser.* **1402** 044054

Modelling of regenerative braking system for electric bus

M Islameka*, E Leksono and B Yuliarto

Engineering Physics Program, Faculty of Industrial Technology, Institut Teknologi Bandung, Ganesha Street No. 10, Bandung 40132, Indonesia

*methaislameka@students.itb.ac.id

Abstract. Regenerative braking is a way to harvest electric energy from braking mechanism which usually implemented in electric vehicles. Braking strategies are required to maximize the use of regenerative braking systems. This research aims to design a regenerative braking model for a medium-sized electric bus. Measurements of latitude, longitude, elevation, and speed were firstly conducted by using GPS-based OsmAnd Android application. Transjakarta Corridor 1 (Kota-Blok M) was used for a test track with a distance of 14 km. Besides using data from measurements using GPS, WLTP (Worldwide Harmonised Light Vehicle Test Procedure) data is also used for comparison. This study produced a braking strategy model that considers aerodynamic, rolling, and grade resistances as well as electrical component specifications of the electric bus. The model design is then compared to the existing serial and parallel strategy. With the design of this system, the regenerative braking model can harvest more energy which increases the mileage of the electric bus.

1. Introduction

The use of gas fuel in Transjakarta is done to get a cleaner environment compared to the use of diesel fuel as the main fuel. Over time, there is one alternative source of energy that can be chosen to replace gas fuel. The energy source is a battery. Using a battery will help get a cleaner environment because it does not produce exhaust gas from fuel emissions. However, the distance that can be passed by an electric vehicle is still limited with the capacity of the battery used [1]. Charging stations that are not yet available as much as gas stations also add the concerns of potential users of electric vehicles or commonly referred to as range anxiety. This started researchers to conduct research on battery management systems and how to add electricity to batteries from other systems. One of them is regenerative braking.

Regenerative braking is a way that can be used to convert kinetic energy when braking becomes electrical energy to be added to the battery. The advantage of the regenerative braking system is that there is no need to add any component other than adding a control system to the vehicle. Control system unit change the motor into a generator during braking or deceleration. Furthermore, recharging during braking does not increase battery degradation [2]. In consequence, regenerative braking will function better when the vehicle passes urban traffic [3]. Traffic conditions on the arterial road can be used to replenish energy. Because regenerative braking does not provide enough braking force for emergency conditions or has to stop quickly, electric vehicles usually still use mechanical braking for emergencies [4].

Thus, braking strategies are required to maximize the use of regenerative braking systems. Several braking strategies have been proposed as in [5] showing that the proposed ECO model produces the best recoverable energy. While on [6] shows that the serial control strategy actually generates better than parallel and nonregenerative braking. In this paper, the braking strategy is made to get the maximum recoverable energy with a rear wheel drive medium-sized electric bus.

2. Experimental method

This section explains how data were collected, mathematical formulas to get the amount of energy needed by the medium-sized electric bus, and explanation about the braking strategy.

2.1. Data collection

Measurements of distance, speed, and elevation were conducted by using GPS-based OsmAnd Android application [7]. The step time of collected GPS data was 1 s. Transjakarta Corridor 1 (Kota-Blok M) was used for the test track. The distance is about 14 km with travel time nearly an hour. Data were collected in the afternoon on Monday, so the average speed is around 15 km/h. Besides using data from measurements using GPS, WLTP (Worldwide Harmonised Light Vehicle Test Procedure) data is also used for comparison.

2.2. Mathematical formulation

The proposed braking strategy model considers aerodynamic, rolling, and grade resistances as well as electrical component specifications of the electric bus.

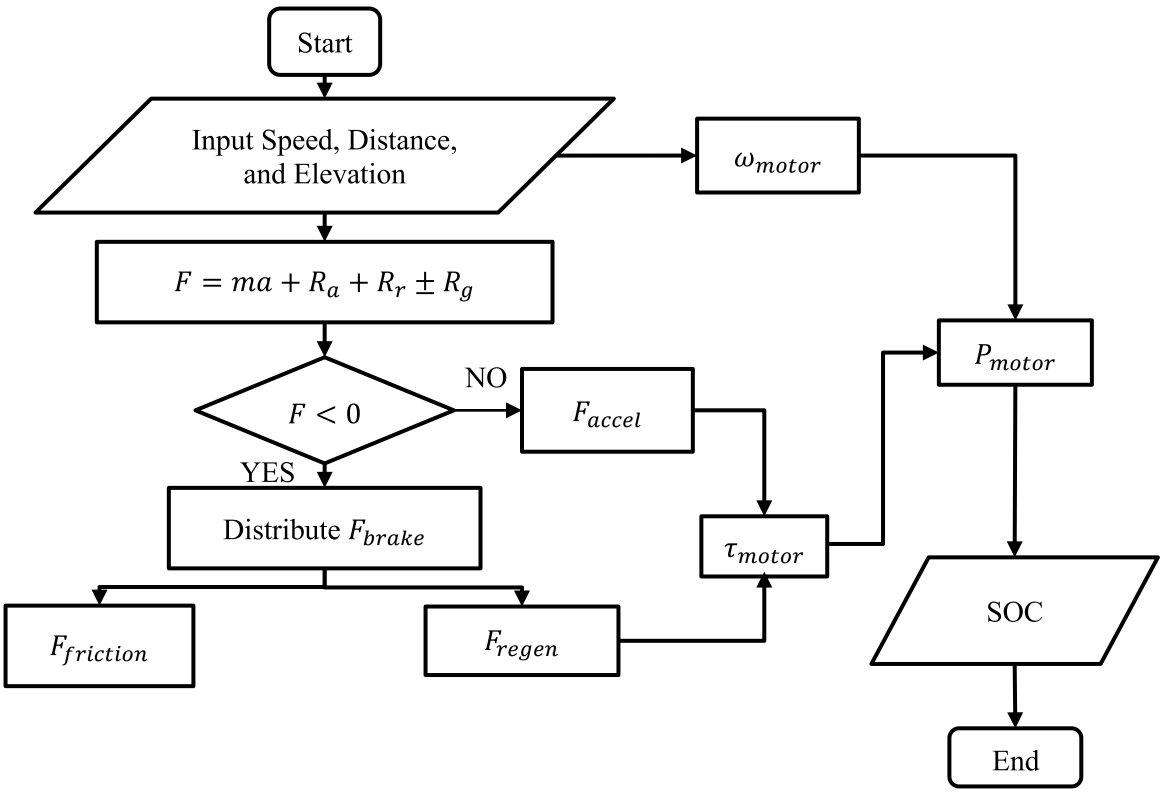

Figure 1. Energy flowing.

Forces acting on a moving vehicle can be calculated as follows,

$$F = ma + R_a + R_{rl} + R_g \tag{1}$$

Where R_a is aerodynamic resistance, R_{rl} is rolling resistance, and R_g is grade resistance.

Table 1. Electric bus parameters.

Description	Symbol	Value	Unit
Vehicle Mass	m	5285.282	kg
Air Density	ρ	1.275	kg/m^3
Aerodynamic Drag Coefficient	C_d	0.6	-
Frontal Area	A_f	6.993	m^2
Wheel Radius	r	0.4	m
Total Gear Ratio	G	6.1	-

Aerodynamic resistance calculations are as follows,

$$R_a = \frac{1}{2}\rho C_d A_f v^2 \tag{2}$$

Where ρ, C_d dan A_f are available in Table 1. While rolling resistance is calculated as follows,

$$R_{rl} = f_{rl}W \tag{3}$$

Where W is the weight of the electric bus and f_{rl} can be calculated by [8],

$$f_{rl} = 0.01\left(1 + \frac{v}{147}\right) \tag{4}$$

Whereas R_g can be calculated by,

$$R_g = W \sin\theta \tag{5}$$

Where sin θ can be determined based on elevation and distance data retrieval from GPS.

2.3. *Braking strategy*

The braking strategies i.e. the existing serial, parallel [9] and ECO-models [5] are using for comparison. The comparison between those three strategies shows that ECO braking strategy generates more energy than two others. Novel braking strategy based on ECO braking strategy is then proposed. Braking strategy is also adjusted to rear wheel drive medium-sized electric bus.

Maximum regenerative braking can be used only as much as the maximum torque motor available [10]. The division of 60% and 40% is based on maximum force braking distribution. The value of maximum force braking on the front and rear axles is based on the ideal force braking distribution. The center of gravity of the bus is assumed to be at the midpoint of the vehicle. 40% of the rear braking force is divided into two, for regenerative braking with maximum torque motor and the rest using a friction brake.

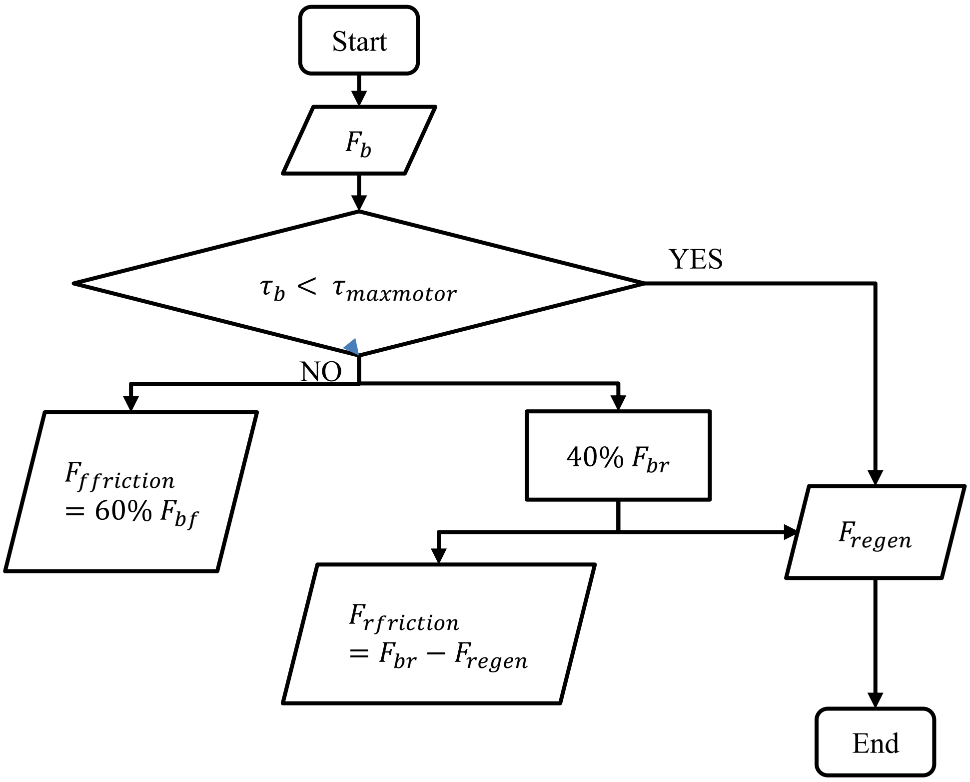

Figure 2. Block diagram representation of proposed braking strategy.

3. Results and discussion

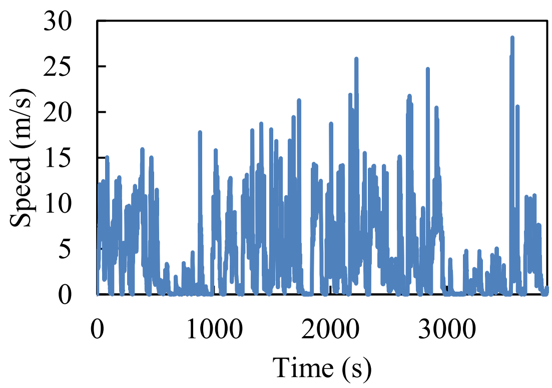

Figure 3. Kota-Blok M driving cycle.

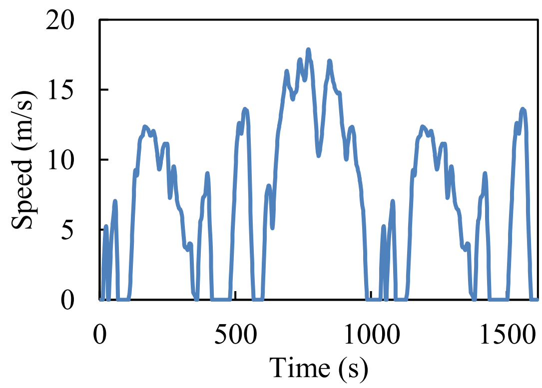

Figure 4. WLTP driving cycle.

Figures 3 and 4 show differences in speed for the driving cycle of Kota-Blok M and WLTP. The total driving cycle of Kota-Blok M is around 1 hour while WLTP is around half an hour. The maximum speed on the Kota-Blok M driving cycle is almost 30 m/s while in WLTP it is almost 20 m/s.

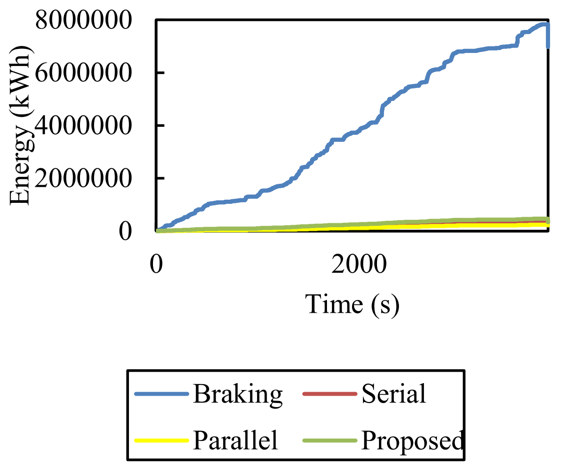

Figure 5. Energy recovery based on Kota-Blok M driving cycle.

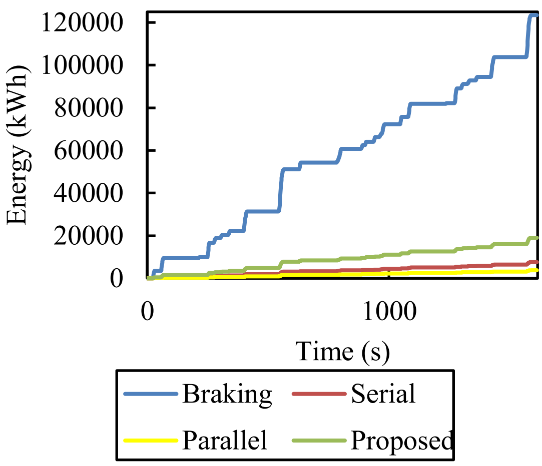

Figure 6. Energy recovery based on WLTP driving cycle.

Figures 5 and 6 show the serial, parallel, proposed energy recovery strategy, and required braking energy. Two driving cycles show that proposed braking strategy based on ECO strategy produces the most energy recovery compared to serial and parallel strategy. Energy recovery produced using the proposed braking strategy is 4.9% for Kota-Blok M driving cycle and 15.4% for WLTP driving cycle. Serial and parallel strategies are 4.6% and 3% respectively for Kota-Blok M driving cycle and 6.16% and 3% respectively for the WLTP driving cycle. WLTP produces more energy recovery cycle than Kota-Blok M driving cycle.

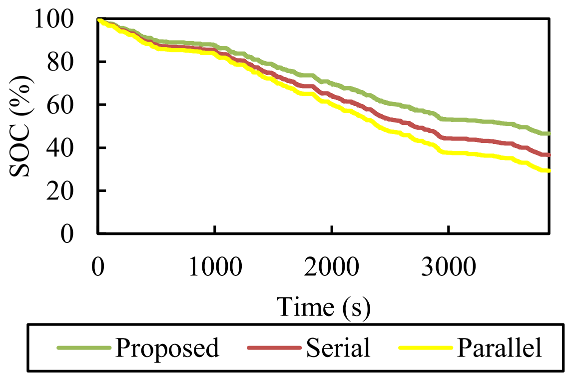

Figure 7. SOC Kota-Blok M driving cycle.

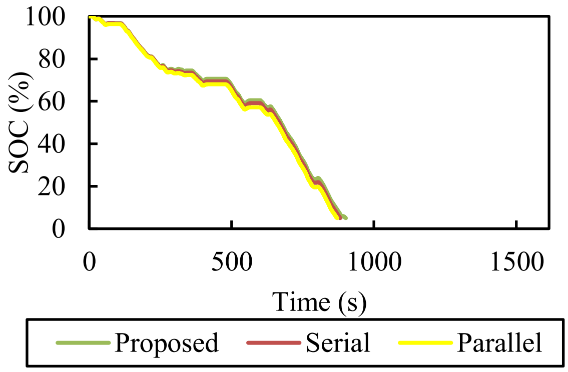

Figure 8. SOC WLTP driving cycle.

Figures 7 and 8 show a decrease in the battery SOC value of each driving cycle. Both driving cycles use batteries with the same parameters. Figure 9 shows that the battery remains around 30%-60% depending on the braking strategy used. Figure 10 shows the battery runs out before the WLTP driving cycle is complete even though the proposed braking strategy has been used.

4. Conclusions

This study observes about energy recovery from the use of braking strategy. Proposed braking strategy is used for Kota-Blok M driving cycle and WLTP driving cycle. Kota-Blok M driving cycle has more deceleration process compared to the WLTP driving cycle. Proposed braking strategy shows that it can recover more energy than the two other strategies in both driving cycles. Distribution of braking force is greater to the regenerative braking system in the proposed braking strategy than the two other strategies. From the simulation results of battery SOC for two driving cycles, the use of regenerative braking is effective in traffic conditions. Future work will try to add more motors as the drive wheel to see if it could add more energy recovery.

Acknowledgments
This paper is funded by USAID through Sustainable Higher Education Research Alliances (SHERA) program with grant number IIE00000078-ITB-1.

References
[1] J Li and Z Zhu 2014 *Battery thermal management systems of electric vehicles*. Division of Vehicle Engineering & Autonomous Systems.
[2] P Keil and A Jossen 2017 Impact of dynamic driving loads and regenerative braking on the aging of lithium-ion batteries in electric vehicles. *Journal of The Electrochemical Society* **164**(13) A3081-92.
[3] C Fiori, K Ahn and H A Rakha 2016 Power-based electric vehicle energy consumption model: Model development and validation. *Applied Energy* **168** 257-68.
[4] S Heydari, P Fajri, M Rasheduzzaman and R Sabzehgar 2019 Maximizing Regenerative Braking Energy Recovery of Electric Vehicles through Dynamic Low-Speed Cutoff Point Detection. *IEEE Transactions on Transportation Electrification*.
[5] B Xiao, H Lu, H Wang, J Ruan and N Zhang 2017 Enhanced regenerative braking strategies for electric vehicles: Dynamic performance and potential analysis. *Energies* **10**(11) 1875.
[6] C Qiu, G Wang, M Meng and Y Shen 2018 A novel control strategy of regenerative braking system for electric vehicles under safety critical driving situations. *Energy* **149** 329-40.
[7] I P Nurprasetio, B A Budiman, K Noersalim and R S Naufal 2017 Pengembangan Metode Rekonstruksi Jalan Berbasis Data Global Positioning System dan Giroskop. *Mesin* **26**(1) 17-28.
[8] F L Mannering and W P Kilareski *Principles of Highway Engineering and Traffic Analysis*. Second.
[9] C Qiu and G Wang 2016 New evaluation methodology of regenerative braking contribution to energy efficiency improvement of electric vehicles *Energy Conversion and Management* **119** 389-98.
[10] S R Tousi, S O Golpayegani and E Sharifian 2016 Anti-lock regenerative braking torque control strategy for electric vehicle. *In 2016 IEEE International Conference on Industrial Technology (ICIT)* 1418-1423 IEEE.