Electric vehicle with sliding mode control super-twisting control strategy

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Abstract: The braking system is the crucial part in vehicle system. The main purpose of braking system is to slow down or stop the moving vehicle. The regenerative braking system (RBS) designed to recapture more energy during braking. The electric vehicle dynamic model was design using Matlab/Simulink. Sliding mode controller with super-twisting (SMCST) was designed to avoid overcharging and improved the batteries’ SOC. Conventional sliding mode control (SMC) shows convergence within the desire level of accuracy, in which chattering is the main issue related to destructive phenomenon. SMCST intentionally to eliminate chattering with high accuracy. The results from the simulation show that the super-twisting control strategy offers higher regeneration efficiency.

Keywords: Electric vehicle, Regenerative braking system (RBS), Sliding mode control.

1. Introduction

In general, brakes are applied to stop the motion of moving object. In automobile field, the conventional braking system absorbs the kinetic energy by friction. There are some shortages brought by friction brake such as high price, short energy, and lost in the form of heat energy due to friction losses. During braking, the momentum of vehicle absorbed and to reaccelerate the vehicle, momentum have to redeveloped that consume more power from and engine thus may lead to wastage of energy. Based on Newton’s Second Law, an inertial force created in the opposite direction during the acceleration and deceleration of an object [1]. Therefore, in this project, regenerative braking system was proposed to overcome this issue.

The RBS technology is growing drastically an as alternative method to save energy instead of using traditional method that run on fossil fuel. Besides that, the traditional braking cause energy wastage since it produces undesirable heat during braking. Therefore, RBS purposely invented to overcome these advantages [2]. By implement the regenerative braking system (RBS), it able to reduce the fuel consumption and environment pollution [3][4]. Electric vehicles have huge attention for alternate to conventional internal combustion engine (ICE) vehicles. Regenerative braking is the most suitable a to improve the driving mileage.

2. Vehicle Dynamics Model

Vehicle dynamics describe vehicle behaviour based on the general principles of mechanics. The vehicle resistance includes rolling resistance of tires, aerodynamic drag and grading resistance.

Drag resistance
A vehicle traveling at a particular speed in air encounters a force resisting its motion. This force is
known as aerodynamic drag. It mainly based on shape drag and skin friction [5].

Shape drag: During motion of the vehicle, two zone of pressure will created. The pressure at in front of the vehicle is high while low pressure at the back. Skin friction results when the air closes to the moving vehicle, the speed of air almost equivalent to the speed of the vehicle. While the air far from the vehicle remains still.

\[ F_o = \frac{1}{2} C_d \rho v_r^2 \]  

(1)

Rotational resistance
Due to elastic structure of the wheel in front of the wheel contact centre, a resistance force against the rotational movement of the tire occurs.

\[ F_f = C_r mg \cos \alpha \]  

(2)

Gradient Resistance
Gradient resistance appears when vehicles moving on a sloping road. Whether the vehicle goes up or down the slope, its weight produces a component which always directed downward direction.

\[ F_i = mg \sin \alpha \]  

(3)

Inertia Resistance
One of the vital features of EV is the ability to recover the kinetic braking energy. A regenerative braking system recaptured and stores the kinetic energy during braking in a reusable manner. Two parameters that consist in regenerative braking control are regenerative braking scale coefficient and lowest regenerative braking speed. Regenerative braking scale coefficient describes the ratio of regenerative braking torque and total braking torque which range between 0 to 1 [6].

Regenerative Braking
When brake pedal is applied in RBS, the motor functioning as generator, then transfer the kinetic energy to electricity to store into batteries or capacitors, exerting regenerative braking torque on the axle and charged the vehicle batteries that purposely to drive the system [7]. The Advanced Simulator (ADVISOR) as shown in figure 1 can be used to model the complete vehicle.

![Electric vehicle ADVISOR model](image)

Figure 1. Electric vehicle ADVISOR model

The ADVISOR braking force strategy is speed sensitive type. The braking force distribution coefficient of motor as shown in figure 2 increase correspondingly as the vehicle speed increasing. ADVISOR is a vehicle simulator that able to simulate conventional, hybrid, electric and fuel cell vehicles. It uses drive train components in order to estimate fuel economy and emission. Basically,
there are about 30 different drive cycles and various test procedures can be used to assess the fuel economy and emission under numerous test conditions [8].

This software is used in order to simulate and analyse the regenerative braking control strategy. The simulation SMC results are compared with the ADVISOR braking strategy. In order to recycle more energy during regenerative braking, the braking using SMCST are designed.

![Figure 2. The braking force distribution strategy](image)

The speed graph of driving cycle was used to study the vehicle driving pattern. NEDC is the New European Driving Cycle condition. This driving cycle represent urban driving scenario with frequent stops at average speed 34 km/h. Figure 3 below shows the NEDC driving cycle.

![Figure 3. NEDC driving cycle pattern](image)

**State of Charge**

The SOC with lower 10% of internal resistance of perform high value and not suitable for charging condition. Thus, the ratio of regenerative apply should be low. When the SOC value in between 10% to 90%, the batteries can be charge with high current and regenerative braking should increase correspondingly. When the SOC value more than 90%, charging current should be decreased to avoid deposit of lion

**Super-twisting Algorithm**

In general, the super-twisting algorithm is similar to second order sliding mode controller purposely to provide finite time and exact convergence in presence of bounded perturbation [9]. The SMCST block diagram as shown in figure 4 and its algorithm as follow;
The sliding mode control strategy was chosen due to its robustness. In addition, SMC improves the chattering phenomenon. A typical form for the sliding surface is the following. The error variables are:

\[ e(t) = x(t) - x_{ref} \]
\[ \dot{e} = x_2(t) \]

(4)

The sliding surface is selected as

\[ \sigma = e(t) + \lambda e(t) \]

(5)

Substituting Equation (4) in Equation (5)

\[ \sigma = x_2(t) + \lambda (x_2(t) - x_{ref}) \]

(6)

The time derivative when $x_1$ is constant

\[ \dot{\sigma}(t) = \dot{x}_2(t) + \lambda \dot{x}_1(t) \]

(7)

Super-twisting Sliding mode controller describe as;

\[ u(t) = -\lambda \sqrt{\sigma} \text{sgn}(\sigma) + \theta \]

(8)

\[ \dot{\theta}(t) = -W \text{sgn}(\sigma) \]

(9)

3. Results

Figure 5 show the SOC trend of NEDC driving cycles between default algorithm and SMCST algorithm. From the result, the SOC final value with SMCST is higher than the default design. The SMCST algorithm decreases slower than default algorithm. This indicates that the SMCST can recover more energy than the control design without SMCST.
According to data in Table 1, the motor ratio efficiency of original control strategy is 0.67, while the SMCST algorithm is 0.84. Next, the SOC ratio of default algorithm is 0.78, and SMCST improved until 0.83. The overall efficiency for default control system is 0.44 and SMCST improve to 0.646.

Table 1: Performance Comparison

|                | Default | SMCST |
|----------------|---------|-------|
| Motor efficiency| 0.67    | 0.84  |
| SOC            | 0.78    | 0.83  |
| Overall efficiency | 0.44    | 0.646 |

4. Conclusion

The electric vehicle with NEDC driving cycle scenario has significant energy saving effect when SMCST algorithm was applied. The simulation results show that the response of new controller is better when compared to default control strategy. As the SMCST improve SOC ratio, thus increase the driving mileage

References

[1] A. Pise and A. Suvarna, “Regenerative Braking For Greener Future,” vol. 9, no. 1, pp. 9–11.
[2] M. K. Yoong, Y. H. Gan, G. D. Gan, C. K. Leong, Z. Y. Phuan, and B. K. C. K. W. Chew, “Studies of Regenerative Braking in Electric Vehicle,” no. November, pp. 40–45, 2010.
[3] A. Caratti, G. Catacchio, C. Gambino, and N. C. Kar, “Development of a Predictive Model for Regenerative Braking System,” 2013.
[4] J. Zhang, Y. Yuan, C. Lv, and Y. Li, “Modeling and Analysis of Regenerative Braking System for Electric Vehicle Based on AMESim,” pp. 1307–1312, 2015.
[5] A. O. Kiyakli and H. Solmaz, “Modeling of an Electric Vehicle with MATLAB / Simulink Modeling of an Electric Vehicle with MATLAB / Simulink,” no. January, 2019.
[6] Z. Zhang, J. Zhou, and Y. Li, “CONTROL PARAMETER ANALYSIS OF REGENERATIVE,” vol. 48, no. 2, pp. 1040–1046, 2013.
[7] Z. Junzhi, L. Xin, C. Shanglou, and Z. Pengjun, “Coordinated control for regenerative braking system,” pp. 1–6, 2008.

[8] L. Chu, M. Shang, Y. Fang, J. Guo, and F. Zhou, “Braking Force Distribution Strategy for HEV Based on Braking Strength,” 2010 Int. Conf. Meas. Technol. Mechatronics Autom., vol. 1, pp. 759–764, 2010.

[9] S. Lee, B. Lee, and S. L. B. L. S. You, “Sliding Mode Control with Super-Twisting Algorithm for Surge Oscillation of Mooring Vessel System,” vol. 24, no. 7, pp. 953–959, 2018.