Research Journal of Applied Sciences, Engineering and Technology 7(6): 1120-1124, 2014
DOI:10.19026/rjaset.7.368
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 24, 2013 Accepted: March 14, 2013 Published: February 15, 2014

Research Article

Simulation of the Control Strategy for an Electric Bus with Motorized Wheels

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Abstract: This study aims to simulate the running state of the bus as real as possible and verify the correctness of electric bus control system that is developing, which is good for reducing the development cycle and cost for enterprise. The vehicle dynamics model is built and the actual vehicle driving condition is simulated in AMESim and the vehicle control strategy is established in Simulink. The co-simulation platform is used to simulate the actual running state of the bus with the action of the control system, which provides the reference for subsequent real vehicle test.

Keywords: Co-simulation, control strategy, electric bus

INTRODUCTION

Under the pressure of both environment protection and energy conservation, the development of EVs (Electric Vehicles) has been taken on an accelerated pace all over the world (Cao *et al*., 2004). As the representative of the modern EVs, motorized wheels have more advantages. The mechanical differential is removed in the EVMW (Electric Vehicle with Motorized Wheels) and the control system of vehicle must provide the electric differential function during the vehicle driving on uneven road or cornering condition (Lee *et al*., 2000; Jin *et al*., 2007). The driving speed/torque on the driving wheels are independent of each other, the distribution of driving force is different from the traditional mechanical transmission. For the unique characteristics of the EVs, it requires different control Strategies from traditional vehicles (Sakai *et al*., 1999; Jin *et al*., 2011; Esmailzadeh *et al*., 2001).

There are many control models of EVs, most of them based on the overall control of a single motor and its' dynamics control and recovery of braking energy only for uniaxial (Liao *et al*., 2008; Omatu *et al*., 2009). They cannot play the performance and use energy effectively.

In this study, we build a control system model in Simulink for the electric bus with motorized wheels. The control model of EBMW (Electric Bus with Motorized Wheels) is built in Simulink and each wheel is controlled independently. It can use motor to control the bus dynamics and the braking energy of each wheel can be recovered efficiently. The vehicle model is built in AMESim and co-simulated with Simulink. It is used to simulate the dynamic performance of the electric bus with motorized wheels.

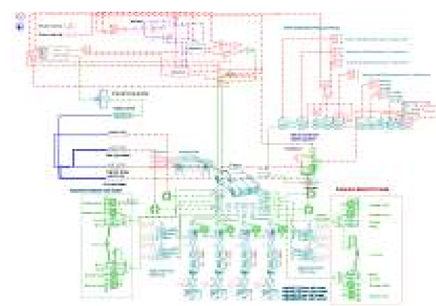

Fig. 1: Vehicle dynamics model in AMESim

ESTABLISH OF THE VEHICLE DYNAMICS MODEL

In this study, the electric bus is driving by the rear motorized wheels. The model is shown in Fig. 1.

The vehicle model is based on the 15 DOF vehicle model in AMESim, includes Car Body, Suspension model, Wheel model, Steering system, Braking system, Motor model and Battery model. Motor model in AMESim is shown in Fig. 2, vehicle parameters are shown in Table 1.

THE ELECTRIC BUS CONTROL STRATEGY

The control strategy of the electric bus is built in Simulink, including Control Mode Recognition model and Controller Working Mode model. The controller has 7 modes that are Forward-Drive, Forward-Glide, Backup-Drive, Backup-Glide, Forward-Brake, Backup-Brake and default mode.

The Control Mode Recognition model is built in Stateflow and shown in Fig. 3. Vehicle state is divided into 7 states, Initialization, Power-on, Power-off, Shift,

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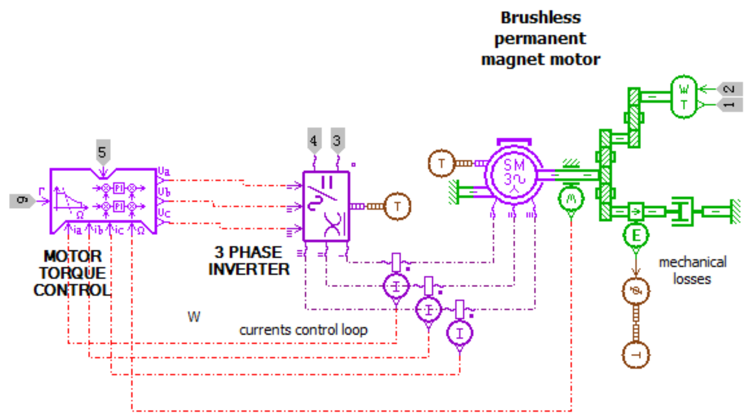

Fig. 2: Motor model in AMESim

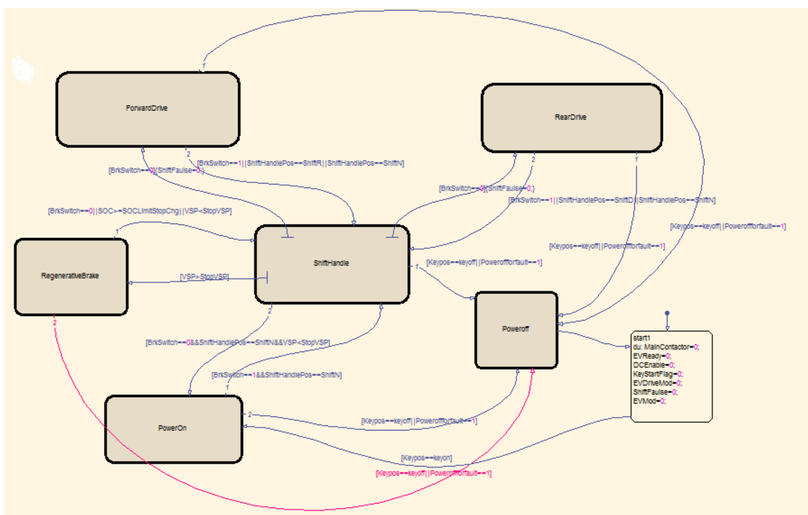

Fig. 3: Control pattern recognition model

Table 1: Vehicle parameters

Parameters		Values
Total mass (kg)		7194
Axle load (kg)	Empty	2485/3071
	full	2744/4450
Rated load quality (kg)		1713
Curb weight (kg)		5481
Calculating mass (kg)		7194
Continuous Torque (N*m)		418
Peak Torque (N*m)		1110
Continuous Power (kw)		70
Peak Power (kw)		140
Motor number		2
Cell voltage (V)		3.2
Capacity (kwh)		76.8
Battery voltage (V)		384

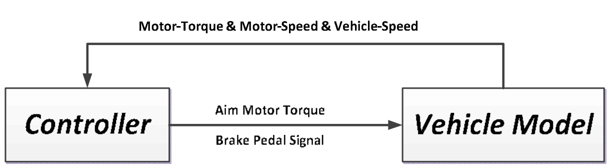

Fig. 4: Co-simulation interface schematic

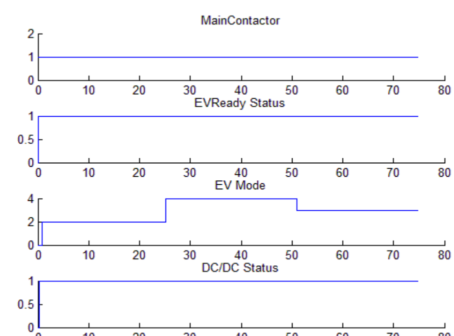

Fig. 5: Controller working state

Forward-Drive, Backup-Drive and Regeneration-Brake. When the key turns to the 'on' position, the control system enters to Power-on state, then the vehicle has different state depending on the operations of the driver.

After building vehicle dynamics model and control system model, they are co-simulated through s-

Function file compiled by AMESim, as shown in Fig. 4. The controller calculates the target torque and the brake pedal signal and sends them to the vehicle. The vehicle model simulates the state of the vehicle and feedback the motor torque, the motor speed and the vehicle speed to the controller.

SIMULATION OF NORMAL DRIVING CONDITIONS

To test the accuracy of vehicle control strategy on any conditions completely, three conditions which is Backup Driving after Forward Driving and Braking, Gliding after Forward Driving and Braking after Backup Driving are selected by simulation according to design requirements.

Backup driving after forward driving and braking condition: In this condition, the vehicle drives forward until 25s that it brakes. Then it begins backing-up at 50s. The aim speed of forward driving is 50 km/h, while backup driving is 20 km/h. The controller working state is shown in Fig. 5 and vehicle driving state is shown in Fig. 6.

- **Gliding after Forward Driving Condition:** In this condition, the vehicle drives forward and releases the acceleration pedal at 15s, then the vehicle glides. The controller working state is shown in Fig. 7 and vehicle driving state is shown in Fig. 8.
- **Braking after Backup Driving Condition:** In this condition, the vehicle begins to bake until it stops at 25s in the backup state. The aim speed of backup driving is 20k m/h. The controller working state is shown in Fig. 9 and vehicle driving state is shown in Fig. 10.

SIMULATION OF FAULT CONDITIONS

According to the design requirements, setting two fault conditions, which are Dislocation Shifting and Serious Fault in the driving, verifies whether the vehicle could continue to safe driving or not in the fault conditions.

- **Dislocation shifting condition:** In this condition, the driver shifts to the backup position suddenly when it is driving forward at 15s. This belongs to the dislocation shifting condition. The controller working state is shown in Fig. 11 and vehicle driving state is shown in Fig. 12.

The controller is designed to stop motor torque output and begin gliding at the dislocation shifting condition. As shown in Fig. 12, the motor do not output torque after 15s, the vehicle begins to glide and slows

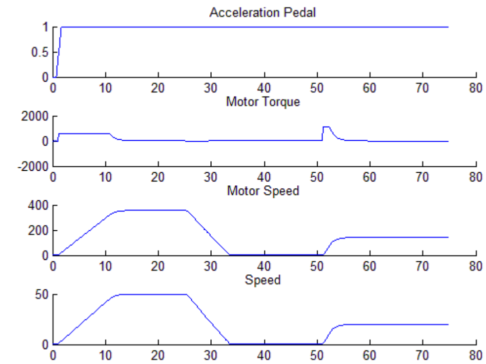

Fig. 6: Vehicle driving state

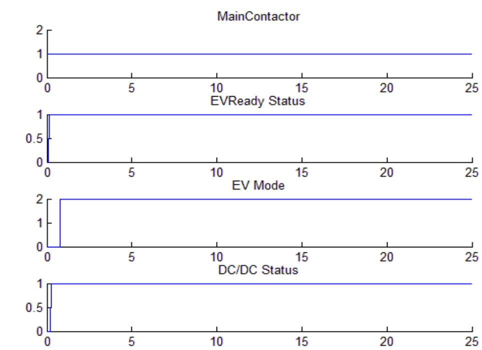

Fig. 7: Controller working state

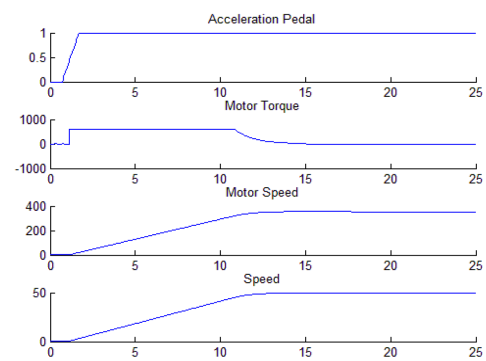

Fig. 8: Vehicle driving state

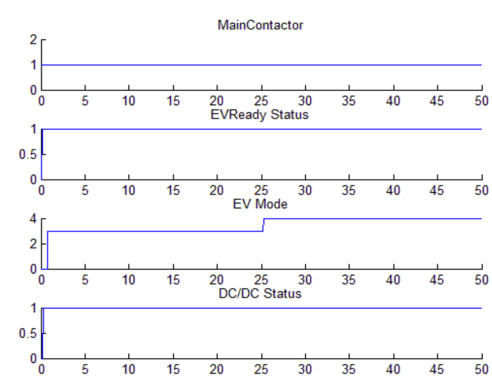

Fig. 9: Controller working state

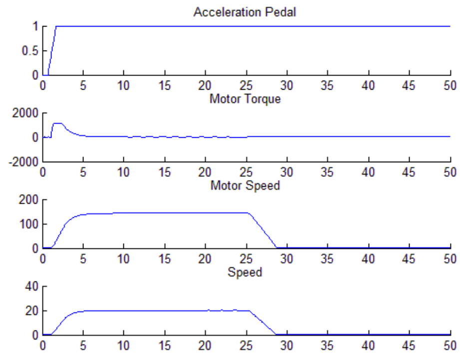

Fig. 10: Vehicle driving state

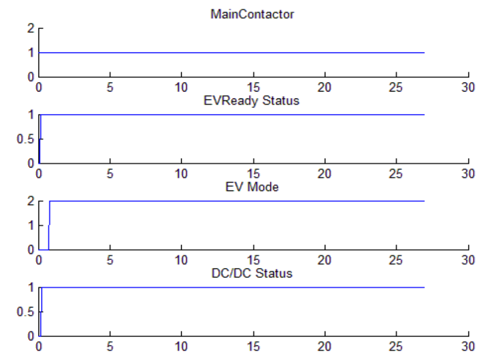

Fig. 11: Controller working state

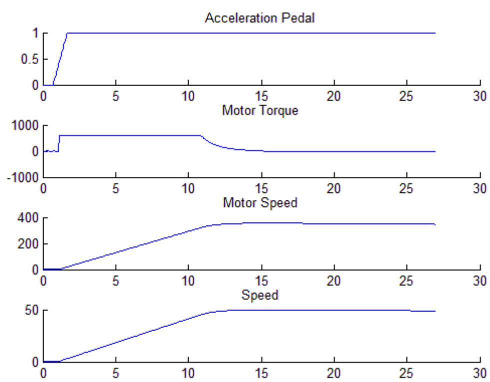

Fig. 12: Vehicle driving state

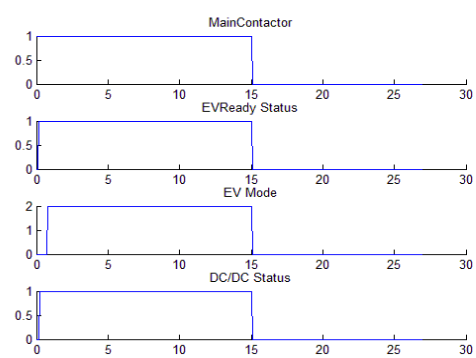

Fig.13: Controller working state

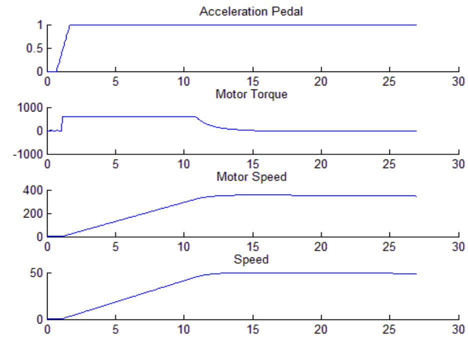

Fig. 14: Vehicle driving state

down. It can be seen that the vehicle drives safely in dislocation shifting condition and controller meets the design requirements at the dislocation shifting processing.

- **Serious fault condition:** In this condition, the high voltage needs to power-off when the vehicle meets serious fault. The controller working state is shown in Fig. 13 and vehicle driving state is shown in Fig. 14.

As shown in Fig. 14, when the vehicle has a serious fault at 15s, the high voltage turns off. The vehicle begins to glide and slows down. It can be seen that the vehicle drives safely in the serious fault condition and controller meets the design requirements at the serious fault processing.

CONCLUSION

A simulation model of electric bus with motorized wheels is built to verify the correctness of the control strategy and the results really reflect the actual state of the vehicle. The results show that the control strategy of electric bus meets the design requirements. It can be used for subsequent real vehicle test.

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