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Simulation Study on Single-shaft Parallel Hybrid Electric Bus

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Abstract

Hybrid electric bus uses internal combustion engine (ICE) and electrical power and it has the advantages of stronger power, lower fuel consumption and emissions and so on. In this paper, a single-shaft parallel hybrid electric bus model including vehicle dynamics system, motor system, engine system, battery system, clutch and energy management system is established. And a control strategy based on logic gate torque distribution is designed. Simulation results of different modes verify effectiveness of model.

Keywords: Hybrid electric vehicle, control strategy, simulation, Simulink

1 Modeling of single-shaft parallel hybrid electric bus

Hybrid electric bus uses internal combustion engine (ICE) and electrical power and it has the advantages of stronger power, lower fuel consumption and emissions and so on. The structure of single-shaft parallel hybrid electric bus is shown in Figure 1. The engine and the motor are on the same shaft, and the clutch is located between them. The clutch is used to pass or cut off the torque of the engine to the motor, so as to realize the motor, the engine work alone or work at the same time. The output shaft of the motor is connected with the main reducer, and the torque is transmitted to the wheel through the rear axle. The energy management system is used to manage the operating states of the engine, motor and clutch.

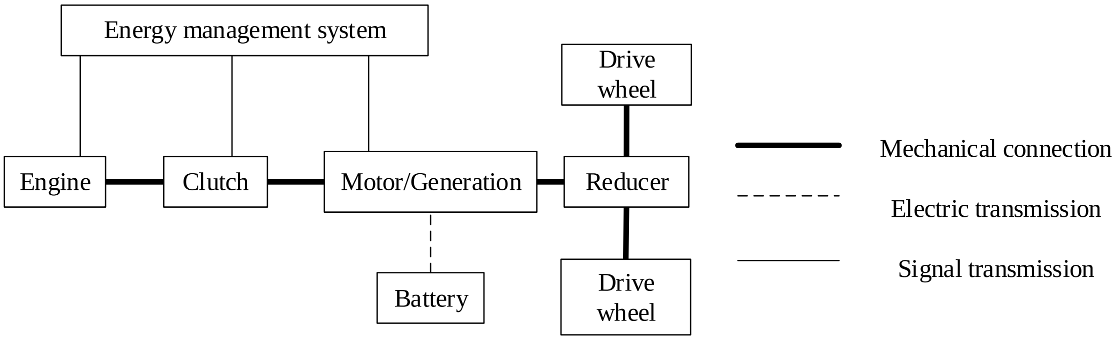

Figure 1: The structure diagram of single-shaft parallel hybridbus

2 Energy Management Strategy

The control strategy of hybrid electric bus is the key part of the whole vehicle design. According to the actual operating characteristics of city bus, the single-shaft parallel hybrid electric bus mainly operate on five working modes: pure electric mode, pure engine mode, light load generation mode, hybrid mode and regenerative braking mode. In this paper, in order to meet the vehicle torque demand and improve the fuel economy, the torque distribution control strategy based on logic threshold value are designed. Then according to different working modes torque distribution rules are developed.

The operating pattern of HEV is determined by vehicle state, battery status and vehicle demand torque. The distribution rule of the driving torque can be divided into the following six situations.

1. If V<20km/h and SOC>40%, at this time is the pure electric working mode, the engine demand torque is $T_{ice}^{*} = 0$, the motor demand torque is equal to the vehicle running demand torque (according to the pedal signal), that is $T_{m}^{*} = T_{ref}$.
2. If V<20km/h and the battery needs recharging, the motor can't be used as the source of driving torque, the engine starts to work. When the engine is in low efficiency working range, so the engine doesn't provide charging torque to the motor, power system work in pure engine mode, the engine demand torque is $T_{ice}^{*} = T_{ref}$, the motor demand torque is $T_{m}^{*} = 0$.
3. If V>20km/h, $T_{ref} < T_{ice\_max}$ and SOC>40%, then the power system works in the pure engine mode, the torque provided by the engine can meet the needs of vehicle driving, the motor doesn't need work to provide torque, the engine demand torque is $T_{ice}^{*} = T_{ref}$, the motor demand torque is $T_{m}^{*} = 0$.
4. If V>20km/h, $T_{ref} < T_{ice\_max}$ and the battery needs recharging, at this time the power system work in light load generation mode, the torque of the engine can not only satisfy the traffic demand, also can drive the motor acts as a generator to charge the battery, the demand torque of the engine is $T_{ice}^{*} = T_{ref} + T_{batt}$, the demand torque of the motor is $T_{m}^{*} = T_{ice} - T_{ref}$.
5. If V>20km/h, $T_{ice\_max} > T_{ref}$ and SOC>40%, the power system work in hybrid mode, the torque of the engine is not enough to satisfy the traffic demand, so the motor works to provide torque, the engine demand torque is equal to the current maximum torque, which is $T_{ice}^{*} = T_{ice\_max}$, the demand torque of the motor is $T_{m}^{*} = T_{ref} - T_{ice}$.
6. If V>20km/h, $T_{ice\_max} < T_{ref}$ and the battery needs recharging, the power system work in pure engine mode, the motor stops working, the power system work in the engine direct drive mode, the demand torque of the engine is $T_{ice}^{*} = T_{ice\_\max}$, the demand torque of the motor is $T_{m}^{*} = 0$.

In the braking process of hybrid electric bus, there are 3 kinds of braking modes: regenerative braking, hybrid braking and mechanical braking. If the SOC<80%, the speed is higher than 5km/h and the braking strength is less than 0.7, the regenerative braking is taken as the priority brake. If the motor maximum torque in the current speed meet the conditions of $T_{m\_\max} > T_{ref}$, means that the motor can provide sufficient braking force, so only the regenerative braking works. At this time, $T_{m}^{*}{=}T_{ref}$ and $T_{mech}^{*} = 0$. If $T_{m}^{*}{<}T_{ref}$, the braking mode is hybrid braking. In order to achieve maximum energy recovery, should make the motor work at the maximum torque, namely, $T_{m}^{*}{=}T_{m\_\max}$, $T_{mech}^{*}{=}T_{ref} - T_{m}$.

Energy management strategy of single-shaft parallel hybrid electric bus is shown in Figure 2.

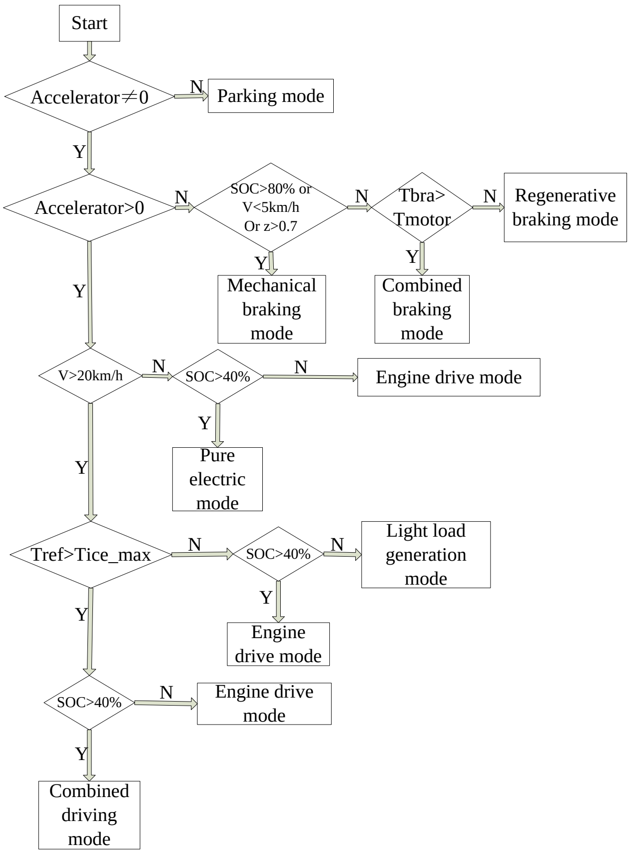

Figure 2: Energy Management Strategy of single-shaft parallel hybridbus

3 Simulation Results

3.1 Simulation parameters

The parameters of single-shaft parallel hybrid electric bus are shown in Tab.1.

Table 1: The parameters of Vehicle

Performance of vehicle	Amount	Performance parameter	Engine	Motor
mass/kg	18000			
CG height from ground/m	1.2	rated power/kw	-	100
Distance from CG to front axle/m	3.9	maximum power/kw	146	135
Distance from CG to rear axle/Nm	2.2	rated torque/Nm	-	1364
Frontal area /m^2	7.6	maximum torque /Nm	710	2100
Drag coefficient	0.61	maximum speed/rpm	3000	3000
final drive ratio	6.2	speed @ rated power/rpm	2500	700
Effective rolling radius/m	0.455			

3.2 Simulation results

The initial battery' SOC is set to 40.29% and the accelerator pedal signal is set up as shown in Figure 3. Simulation results of vehicle speed, battery's SOC, clutch signal, motor waveforms, engine waveforms and torque distribution waveforms are shown in Figure 4-9.

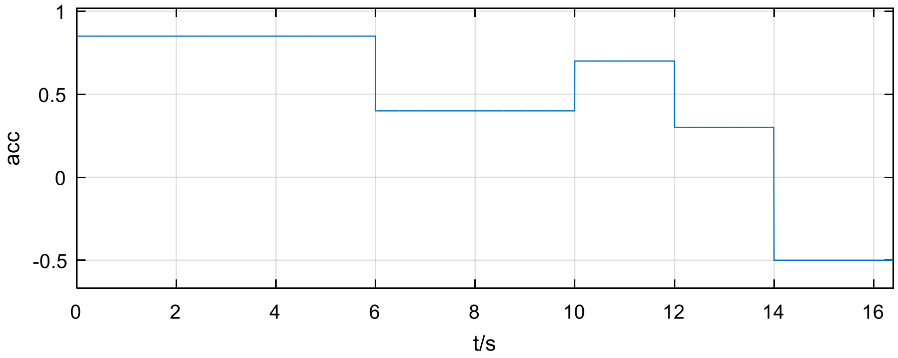

Figure 3: Accelerator pedal signal

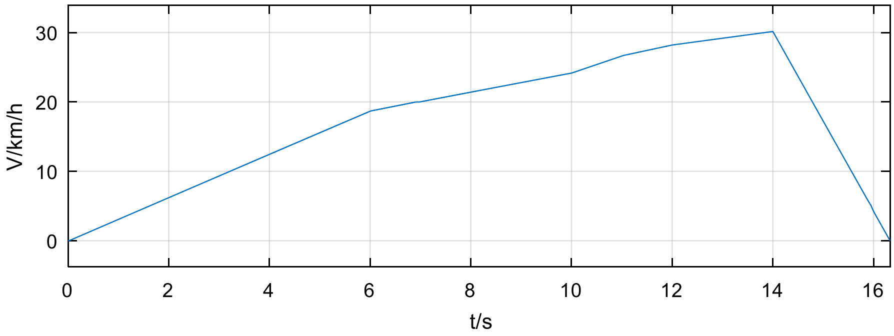

Figure 4: Speed

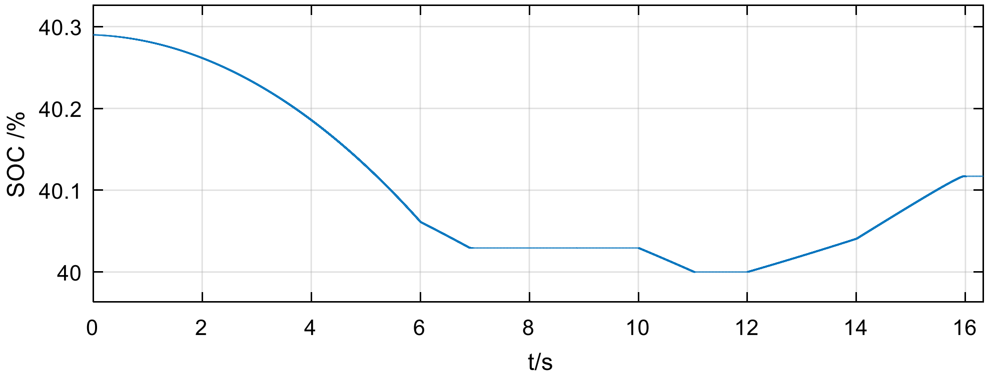

Figure 5: SOC of the battery

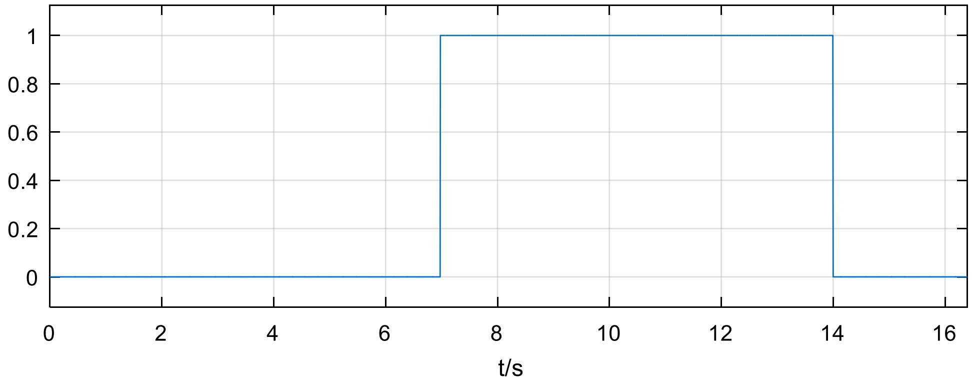

Figure 6: Control single for clutch

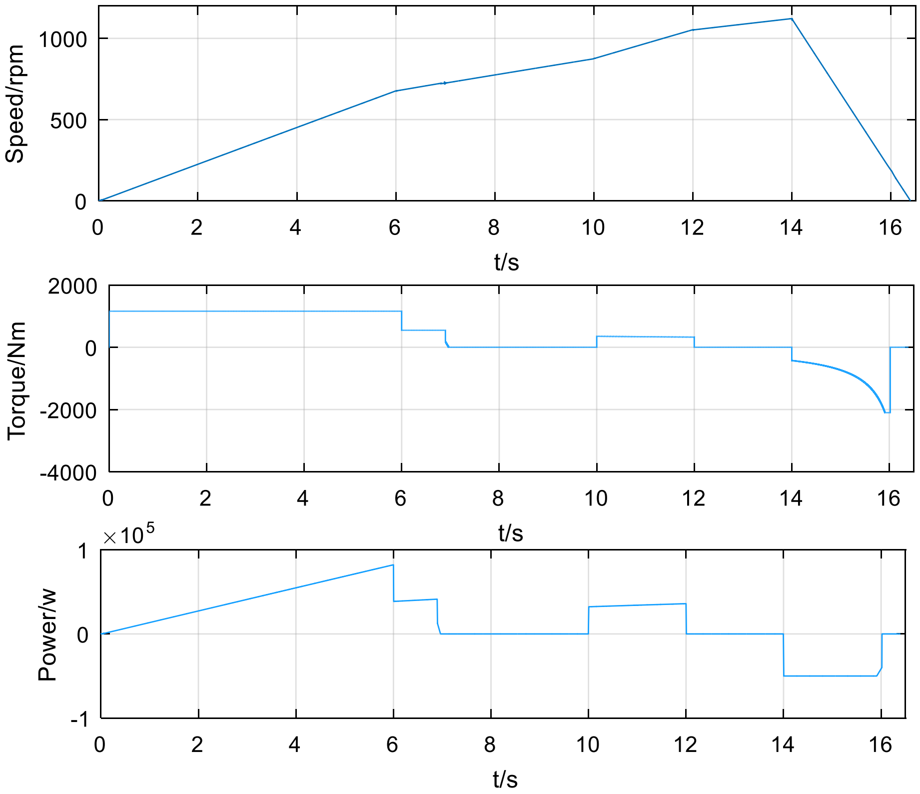

Figure 7: The curves of motor

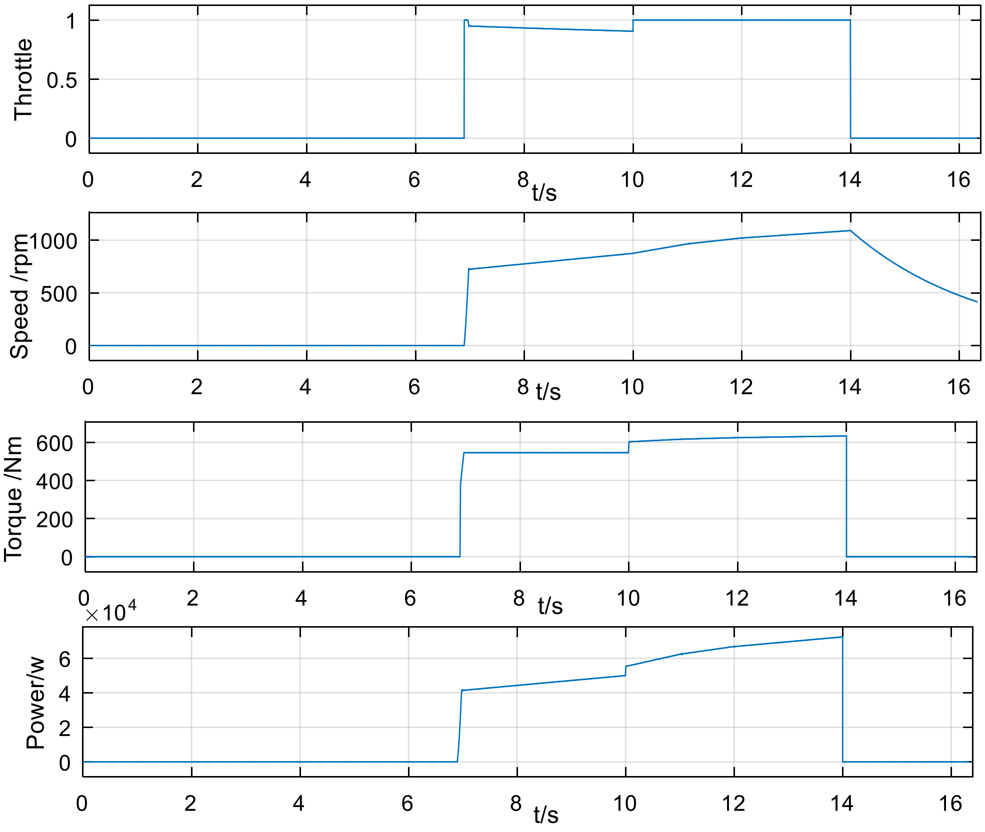

Figure 8: The curves of engine

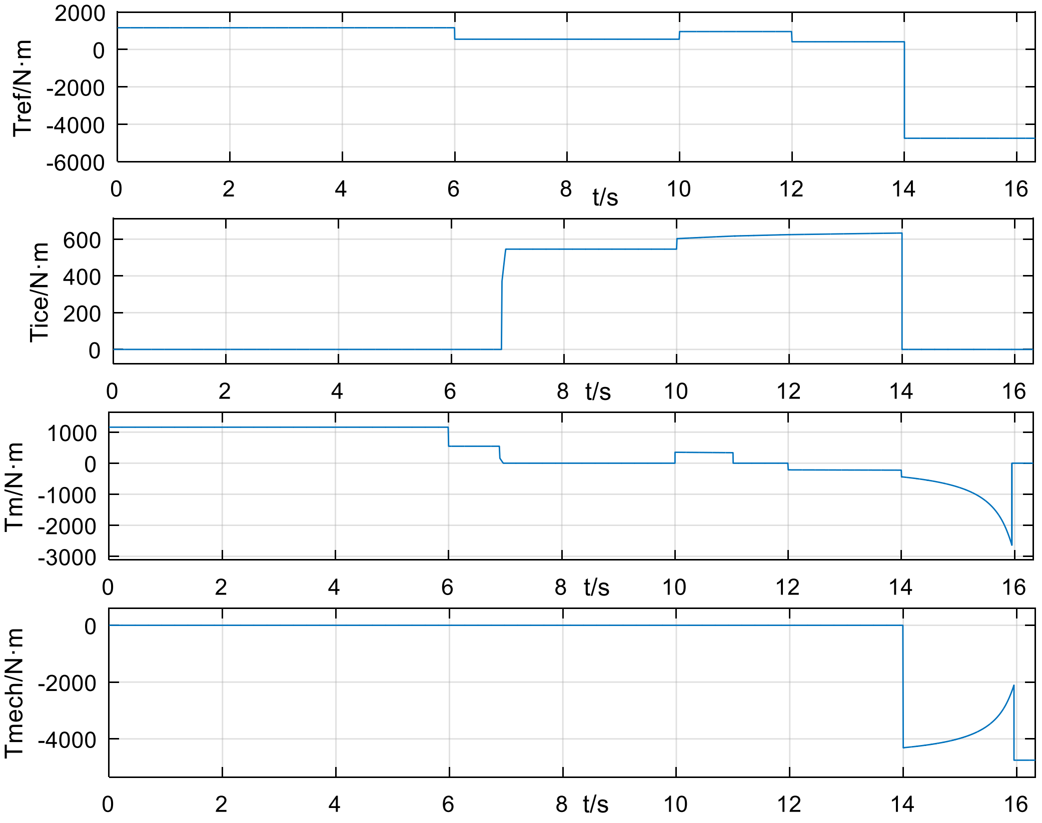

Figure 9: The curves of torque distribution

During (0, 6.9s), the system is in pure electric mode. The car starting at t=0s, the accelerator pedal signal is 85%. Then the speed accelerates from zero and SOC decreases from 40.29%. As the engine does not provide torque, driving torque of the vehicle are only provided by the motor. The vehicle accelerates to 20km/h at 6.9s.

During (6.9s, 10s), the system is in pure engine mode. The acceleration signal is maintained at 40%, the car continues to accelerate, and battery's SOC remains unchanged. The motor does not work. The clutch is combined and driving torque is all provided by the engine.

During (10s, 11s), the system is in hybrid mode. At t=10s, the acceleration pedal signal is increased to 70%, and the speed continues to rise. The vehicle demand torque is greater than the maximum torque that engine can provide, so the engines and motors work simultaneously to drive at this time.

During (11s, 12s), the system is in pure engine mode. At this time, battery stop supply power and the motor doesn't work.

During (12s, 14s), the system is in light load generation mode. The SOC of battery begins to increase. The required torque is less than the maximum torque that the engine can provide. Part of the torque of the engine is used to drive vehicle directly and the other part is supplied to drive the motor that works as a generator to produce current to charge the battery.

During (14s, 16.2s), the system is in regenerative braking mode. The accelerator pedal signal is -50%. The speed begins to decline and the battery's SOC rising when the engine stops working. At this time, the motor acts as a generator. At t=15.59s, the vehicle speed is 5km/h, the regenerative brake stops working and braking torque is supplied only by mechanical brakes and the motor stops working.

4 Conclusion

In this paper, a single-shaft parallel hybrid electric bus model including vehicle dynamics system, motor system, engine system, battery system, clutch and energy management system is established. And its energy management strategy is studied. Simulation results of low speed start mode, acceleration mode, high speed cruise mode, regenerative braking mode and other operation modes verify effectiveness of single-shaft parallel hybrid electric bus model and its energy management strategy.

Acknowledgments

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