Speed and SOC Planning-based Control Strategy for Hybrid Electric Vehicle

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Speed and SOC Planning-based Control Strategy for Hybrid Electric Vehicle

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Abstract. For solving the problem of low engine fuel economy caused by the low average driving speed in the running process of the hybrid power city bus, a control strategy based on the speed and the state of charge (SOC) rule extraction is proposed for hybrid electric vehicle (HEV) in this paper. Combining different vehicle speeds and battery SOC feedback to find the best fuel economy engine and motor status based on the traditional power-based control strategy, and to enable the battery pack to prolong life. The control strategy model is built in MATLAB/SIMULINK software in order to verify the effectiveness of the control strategy, and imported into the Cruise software to carry out co-simulation with the built vehicle power system model. The simulation results show that the proposed control strategy has good working condition adaptability compared with other rule based control strategies and the balance control of SOC is within 5%. It is shown that the design of the hybrid electric bus control strategy not only improves the fuel economy of the engine, but also prolongs the battery life.

1. Introduction

With the improvement of living standards, the per capita ownership of traditional fuel vehicles is increasing gradually. However, the emission of automobile exhaust has caused serious environmental pollution. Based on the existing industrial foundation, HEV and electric vehicles have become one of the best solutions at this stage, Plug-in hybrid vehicle have the advantages of ordinary hybrid and pure electric vehicles, and the state regulations that the production of a plug-in hybrid vehicle will be subsidized by at least a 50 Km[1]. When the battery power is sufficient, the electric mode runs; when the battery power is insufficient, the general hybrid mode is adopted.

As the core of the control system, the energy management control strategy of HEV can be divided into rule-based and optimization-based control strategy, and the rule based control strategy is widely used because of its simplicity. Cordiner et al. propose a control strategy to optimize the power consumption stage [2]. Capata et al. establish the four stage control strategy on the basis of the original charge depleting-charge sustaining control strategy [3]. Wang proposes a multi-stage and multi-objective control strategy based on the vehicle's different state of charge and power requirements [4]. Padmarajan et al. set the control strategy with the target mileage and battery SOC to select the best way to use electric energy [5]. Lin based on the state planning of power battery charge state, the control strategy of hybrid vehicle is formulated, and the balance of SOC is realized by using the torque allocation method referring to the SOC trajectory [6]. The above control strategy is mainly aimed at the planning control strategy of the battery SOC, but little consideration is given to the excessive charge and discharge of the power battery which will reduce its service life. For HEV, a control strategy that accords with its working conditions is formulated.

In order to improve the fuel economy of the whole vehicle and prolong the service life of the power battery, the energy management control strategy based on the battery SOC and the driving speed planning is put forward. So that make the engine and motor and battery pack work in the best condition.

2. Speed & SOC Planning-based Control Strategy

2.1. Topology Structure of Hybrid Power Transmission System

The power system structure of HEV is mainly divided into four types: series, parallel, parallel-series and power split. Although power split hybrid power occupies a dominant position in the passenger car market, the parallel-series hybrid power is widely used in the commercial bus field because of its simple configuration and adaptation to the characteristics of various complex conditions [7]. The power system mainly includes engine, battery, Integrated Starter and Generator (ISG), driving motor and motor controller shown in Figure 1.

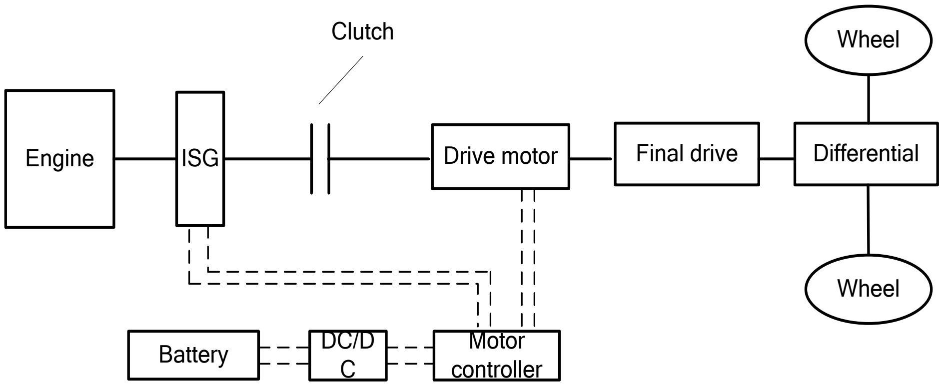

Figure 1. Topology diagram of hybrid power transmission system.

2.2. Construction of Control Strategy Based on Speed and SOC Planning

Based on the torque control strategy, combined with the vehicle speed and the SOC state of the power battery, a control strategy based on vehicle speed and SOC planning is formulated. Because the bus running speed is in the middle and low speed period most of the time, the best working mode can be designed according to the different speed range, and the best efficient working interval of the power battery is at 40%~60%, which can combine the demand power of the whole vehicle. The specific hybrid power control strategy is designed, and V_{min} shows the speed when the engine starts at the lowest speed when the hybrid drive is driven when the speed is in the 0~V_{min}, the whole vehicle is in a pure electric running mode. The V_{max} indicates the corresponding motor speed when the engine is driven by the engine, and the P indicates the demand power in the driving process, and the SOC_{min} indicates the minimum value of the power charge state of the power battery. The specific control strategy for vehicle driving is shown in Table 1 below.

Table 1. Control strategy of hybrid power bus

Vehicle speed	Power	SOC	
		$SOC<SOC_{min}$	$SOC>SOC_{min}$
$V<V_{min}$	$P_{min}<P<P_{max}$	Extended range mode	Motor drive
$V_{min}<V<V_{max}$	$P<P_{min}$	Vehicle charging	Motor drive
	$P_{min}<P<P_{max}$	Vehicle charging	Engine drive
	$P>P_{max}$	Vehicle charging	Joint drive
$V>V_{max}$	$P_{min}<P<P_{max}$	Engine drive	Engine drive

2.3. The Working Mode of Hybrid Power System

The switching of the working mode of the hybrid bus is as follows: the power demand of the vehicle controller according to the current driver's operation, such as the acquisition of the acceleration pedal signal or the brake pedal signal, then calculates the corresponding demand torque, and combines the current working mode of the current demand of the power state of the power battery shown in Figure 2. According to the current speed signal and the power demand signal, the current mode of the output is judged by the power state of the battery.

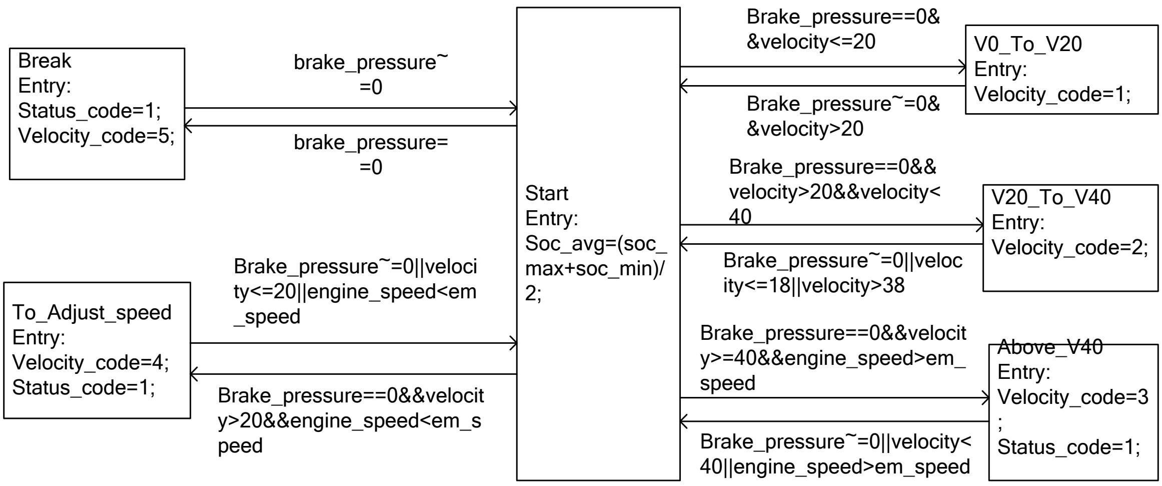

Figure 2. Stateflow working pattern judgment diagram.

3. Modelling and Simulation of Control Strategy

3.1. Parameter Selection of Hybrid Power Vehicle

In the simulation of vehicle control strategy, vehicle basic parameters, engine parameters, main reducer parameters and so on should be provided. The power of the vehicle is calculated according to the maximum speed, the maximum climbing requirement and the acceleration time, and the power of the motor is calculated with the different energy management strategies [8]. The power selection of the power battery pack is related to the motor to meet the power demand of the motor [9].

$$P_{max1} = \frac{v_{max}}{3600n_t}\left(m \cdot g \cdot f + \frac{C_D \cdot A \cdot v_{max}^2}{21.25}\right) \tag{1}$$

where, v_{max} is the highest speed for the best pure electric driving; η_t is the transmission efficiency for the power system; f is the rolling resistance coefficient; C_D is the air drag coefficient.

$$P_{max2} = \frac{v_i}{3600n_t}\left(m \cdot g \cdot f\cos\alpha + m \cdot g \cdot \sin\alpha + \frac{C_D \cdot A \cdot v_i^2}{21.25}\right) \tag{2}$$

where, v_i is the speed for a car to climb at a certain speed; A is the Frontal area.

$$P_{max3} = \frac{v_i}{3600}\left(m \cdot g \cdot f + \frac{C_D \cdot A \cdot v_i^2}{21.25} + \delta \cdot m \cdot \frac{dv_i}{dt}\right) \tag{3}$$

where, δ is the car rotating mass rotation factor.

$$P_e \geq \max\{P_{max1}, P_{max2}, P_{max3}\} \tag{4}$$

where, P_e is the rated power of the drive motor and must meet the requirements of the car's maximum speed, acceleration time, and climbability.

$$P_{b\_max} \geq \frac{P_{m\_peak}}{n_b n_{m\_peak}} \tag{5}$$

where, P_{b_max} is the maximum power that can be provided for the power battery pack; P_{m_peak} is the peak power of the motor; η_b is the efficiency of the power battery pack; and η_{m_peak} is the efficiency of the motor at the maximum power.

Table 2. Basic parameters of the vehicle.

Parameters	Value
Curb weight /kg	12500
Full weight /kg	18000
Frontal area/m^2	7.5
Drag coefficient	0.65
Rolling resistance coefficient	0.018
Engine power/kW	147
ISG power/ kW	80
Drive motor power/ kW	144
Battery capacity / (kW h ·V^{-1})	12.96/460

3.2. Establishing the Simulink Model of Control Strategy

The dynamic and fuel economical simulation of the SOC control strategy based on speed and power battery group is designed. First, a hybrid control strategy model is built in Simulink to deal with the signals transmitted from the Cruise software. According to the current speed signal and SOC signal, Simulink determines the working mode of the next step, establishes the Stateflow driving model judgment model, and then carries out the engine and motor torque distribution in the drive execution model.

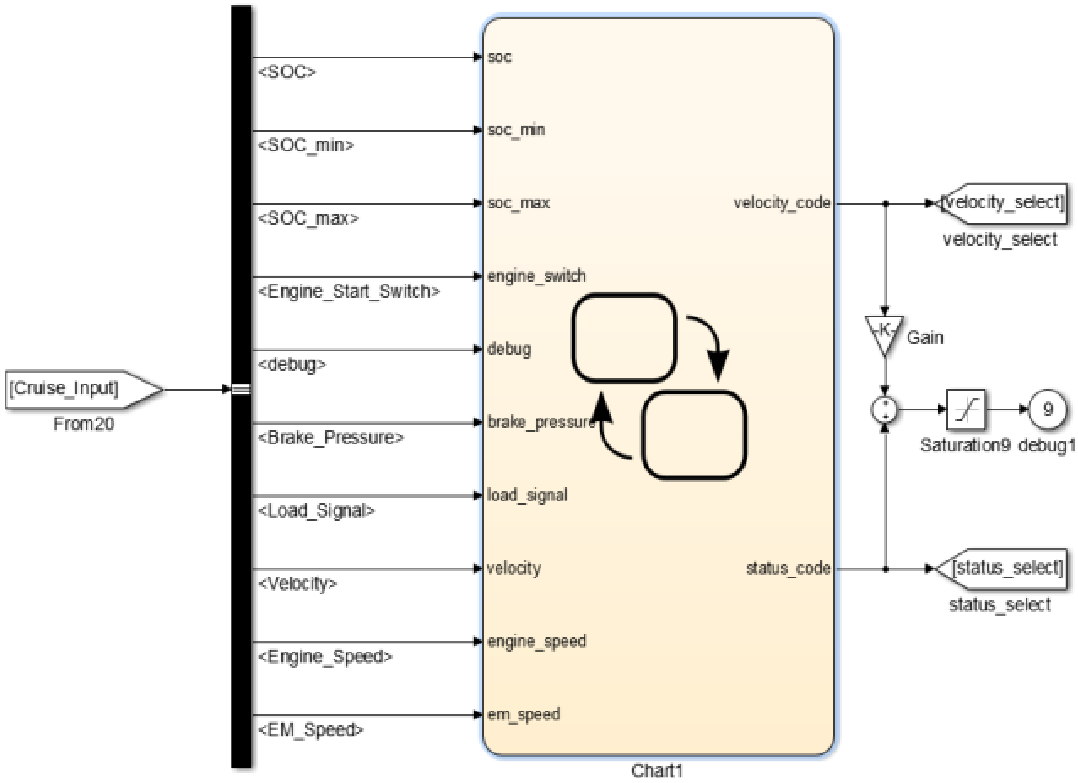

Figure 3. Diagram of stateflow pattern output.

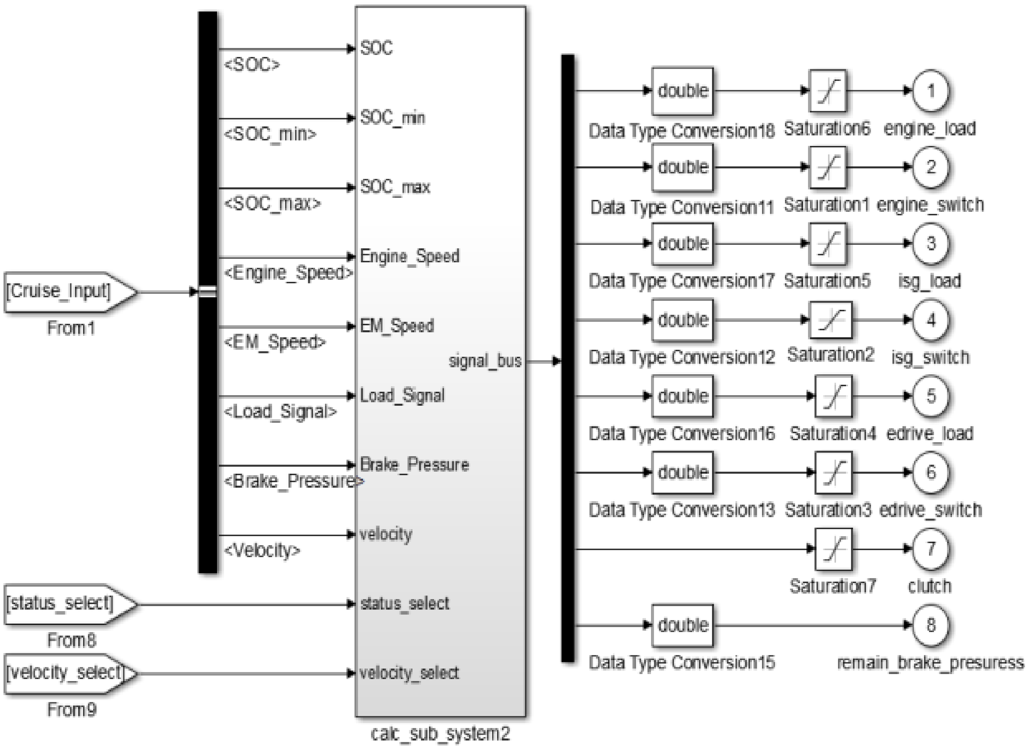

Figure 4. Diagram of drive pattern execution .

3.3. Building a Vehicle Cruise Model and Joint Simulation

The whole vehicle model is built in the Cruise software according to the dynamic requirement of the whole vehicle, and the necessary parameters in each module are input and the connection of mechanical and electrical of the parts are conducted [10]. Communicate through the CAN-BUS, transmit the speed and load of cruise to Simulink, and judge the working mode through the drive calculator in Simulink, and transmit the engine signal and motor signal to the cruise model. The specific process is shown in the following figure 5 and 6.

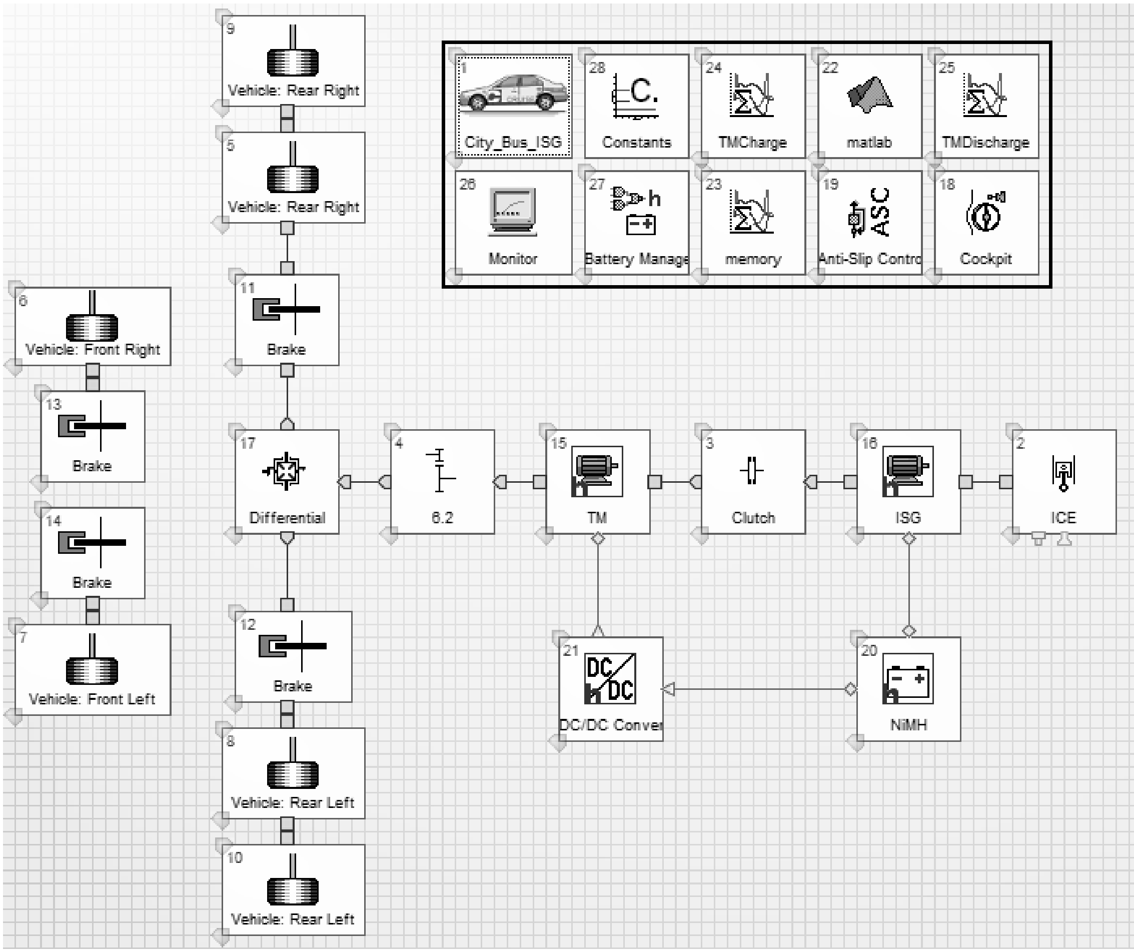

Figure 5. Vehicle mode of Cruise.

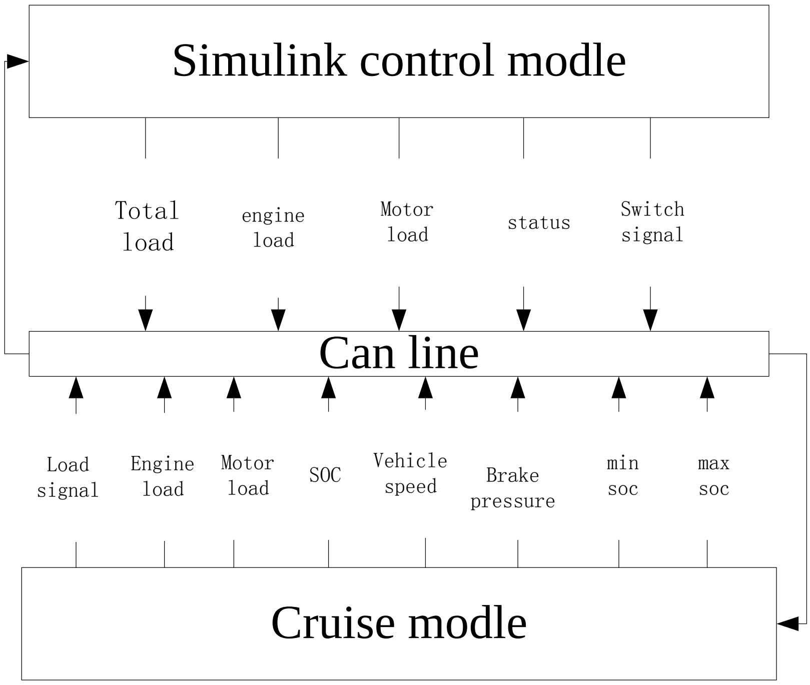

Figure 6. Diagram of joint simulation.

4. Simulation and Result Analysis

4.1. Analysis of Fuel Economy

The fuel economy simulation is carried out in the typical city bus condition (CCBC) in China [11]. According to the control strategy mentioned above, we select electric mode when 0<*V<20km/h*. When *20<V<40km/h*, this is a hybrid driving stage, when *V>40km/h*, the motor torque is taken into account. As the speed increases, the engine is driven independently. The results are shown in the following table.

Table 3. Fuel economy of different control parameters.

V_{min}	V_{max}	Inital SOC (%)	Fuel (L/100Km)	Electric (KW h/100Km)	Total (L/100Km)
40	20	50	20.42	-9.68	17.20
40	20	60	20.01	-7.35	17.56
40	20	70	16.34	5.02	18.02
40	20	80	9.81	26.57	18.67

From the above table, the overall fuel consumption increases with the increase of the initial value of SOC. The main reason is that when the initial value of SOC becomes larger, according to the set control strategy, the driving mode is mostly pure electric working mode and the power consumption of power battery is more, and the less the corresponding braking energy recovery is.

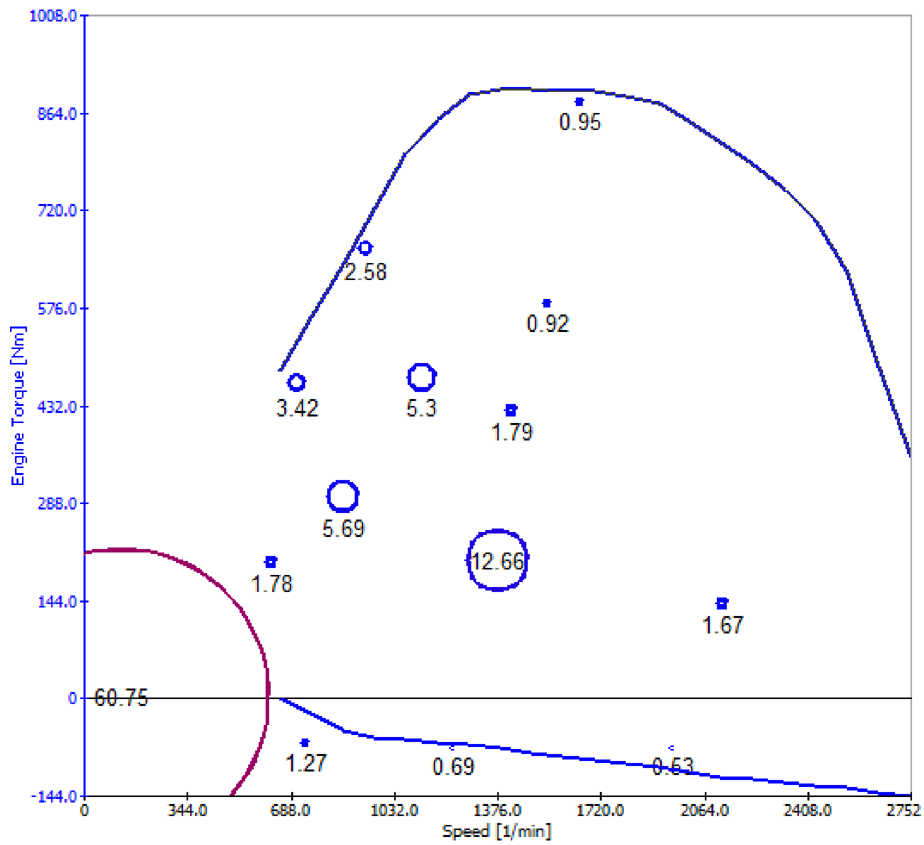

Figure 7. Inital soc is 40%

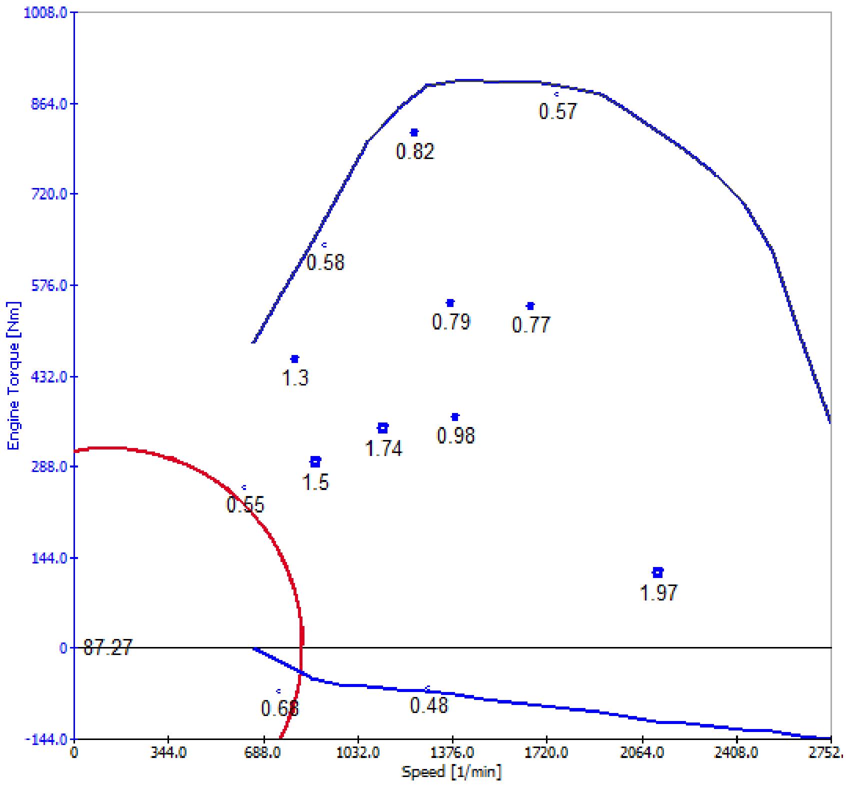

Figure 8. Inital soc is 80%.

4.2. Effect of Initial SOC on Engine Working Point

When the power battery state selects different initial values, the corresponding comprehensive fuel consumption will change. When the initial charge state of the battery is 40%, the power system will choose the pure electric mode first, so the engine fuel consumption is reduced in the whole simulation condition and the consumption of electricity will increase accordingly. When the initial charge state of the battery is 80%, the vehicle controller controls the engine to work on the optimal efficiency curve, so the engine working point is close to the engine's optimal efficiency curve.

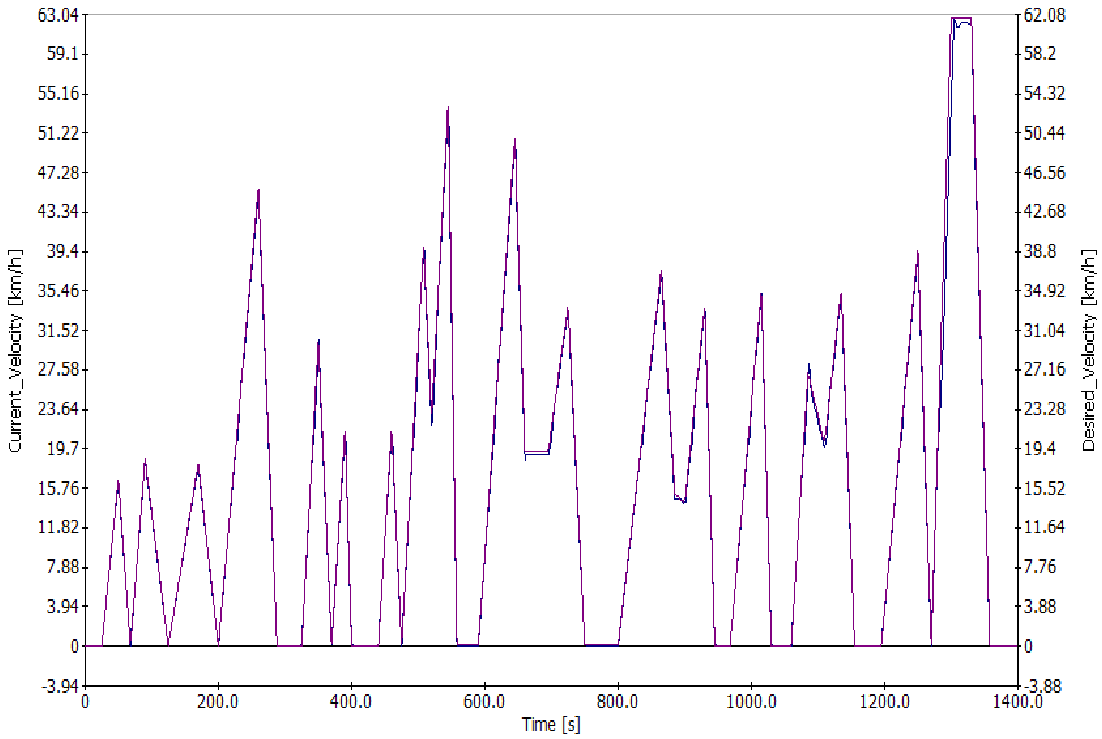

Figure 9. Target speed and current speed.

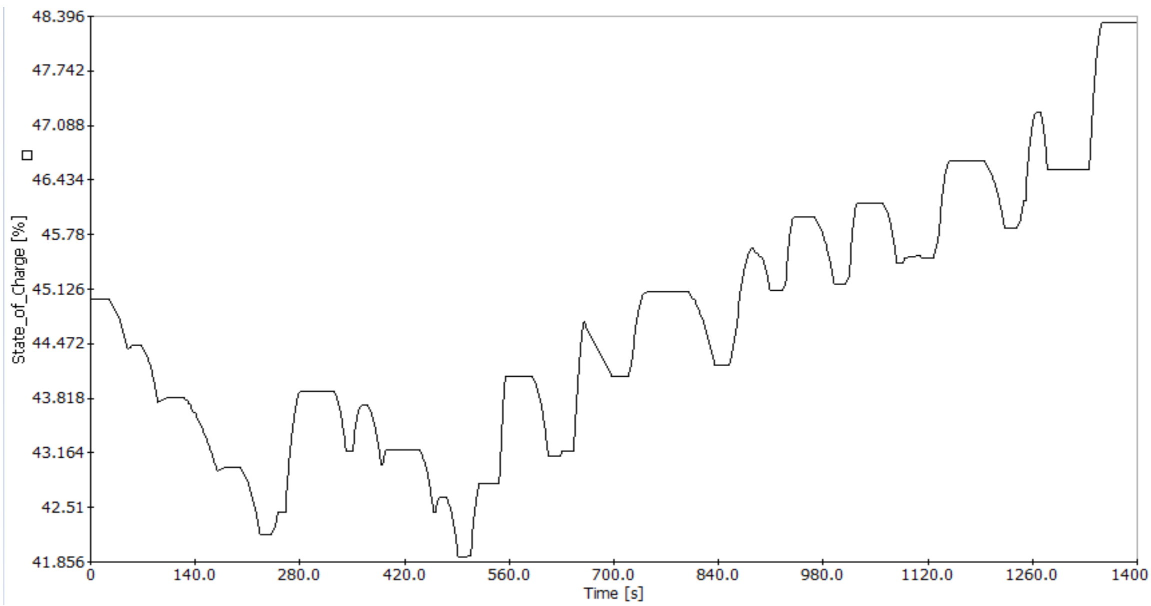

Figure 10. SOC curve changes with time.

4.3. Analysis of the Speed Following and SOC Balance

As shown in Figure 9.In the whole simulation process, the current speed is in good agreement with the target speed, which indicates that the hybrid electric vehicle is simulated with the standard condition of CCBC. In the process of charging and discharging, the high efficiency area of the power battery is generally located at between 40%~60% [12], The SOC balance is mainly to ensure that the power battery should not change too much during the process of simulation. From the Figure 10, the dynamic battery SOC changes from the initial 45% to the end of 48.3%, and the SOC balance is kept within 5%, so the control strategy is designed reasonably.

5. Conclusion

The control strategy based on speed and SOC planning is designed in this paper. The simulation analysis shows that the fuel economy of the whole vehicle is better when the initial value of SOC is 45%~55%, and the fuel economy is less than 3% under different simulation conditions, and the balance of SOC is within 5%, which validates the effectiveness of the control strategy.

Acknowledgement

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