

Drive Control Strategy Simulation Research of Plug-in Hybrid Electric Vehicle Based on Matlab/Simulink Platform

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Abstract

Aiming at the features of Plug-in Hybrid Electric Vehicles (PHEV) which can be charged through the network, the moving process of starting the engine was analyzed; the vehicle energy management strategy was formulated by combing of pure electric control strategy and economic model control strategy. Using genetic algorithm to optimize the upper and lower fluctuation limit values of state of charge (SOC) in charge sustain (CS) mode and engine optimal curve. The Simulation evaluation of PHEV energy consumption economy was conducted. The results indicate that control strategy keep the engine operation points within the peak efficiency region and reduce the energy consumption economy by 28.4%, 35.8%, 26.6 under New European Driving Cycle(NEDC), Urban Dynamometer Driving Schedule (UDDS) and Highway Fuel Economy Test (HWFET) cycle conditions, compared with prototype vehicle.

Keywords: *Plug-in Hybrid Electric Vehicle, control strategy, genetic algorithm, energy consumption economy*

1. Introduction

Plug-in hybrid electric vehicles (PHEVs) has the characteristics of charging by external power grid, it can be mainly driven by use of motor in a short distance that make full use of the low cost electricity and dramatically reduces the air pollution. PHEVs can be mainly driven through the engine when the distance is longer, which can maintain a long driving range as a HEVs. So PHEVs got attention of car companies, scientific research institutions and governments.

The control strategy is the key technology of PHEVs, which can be classified into rule-based control strategy, instantaneous optimization control strategy and global optimization-based control strategy [1]. Instantaneous optimization control strategy [2-3] and global optimization-based control strategy [4-6] can achieve better energy efficiency, but practicality is not strong due to the calculation time is longer. Rule-based control strategy is simple and intuitive, which can be widely used in the actual hybrid energy management system. The power control strategy is put forward [7], but the fuel economy is poor when traveled distance is longer. The opening of the accelerator pedal as switch mode parameters of control strategy is put forward [8], but not split the value of optimization.

In view of this, this paper aimed at the working characteristics of plug-in hybrid electric vehicle. First, the economic model control strategy is made based on analyzes the moving process of starting the engine. Second, the upper and lower limit value of the battery state of charge (SOC) for charge sustaining (CS) mode and the engine optimal curve are optimized by genetic algorithm. Finally, the energy economy of the PHEV is evaluated simulation.

2. Power System Configuration

The PHEVs power system structure studies in this paper as shown in Figure 1, which comprises engine, Integrated Starter/Generator (ISG), wet multi-plate clutch(C1), Continuously Variable Transmission(CVT),electric oil pump(EOP), battery pack and so on charger. The vehicle and power system parameters as listed in Table 1.

The vehicle control unit can control the combination and separation of wet multi-plate clutch, to realize the process of ISG motor starter engine and to switch working mode. It also can control electric pump operation to realize the establishment of the oil pressure of accumulator and CVT when the velocity is low. It may realize communicate with engine control unit, motor control unit, battery management system and CVT control unit through CAN bus, which monitor the running state of vehicle and complete control the speed and torque of motor and engine.

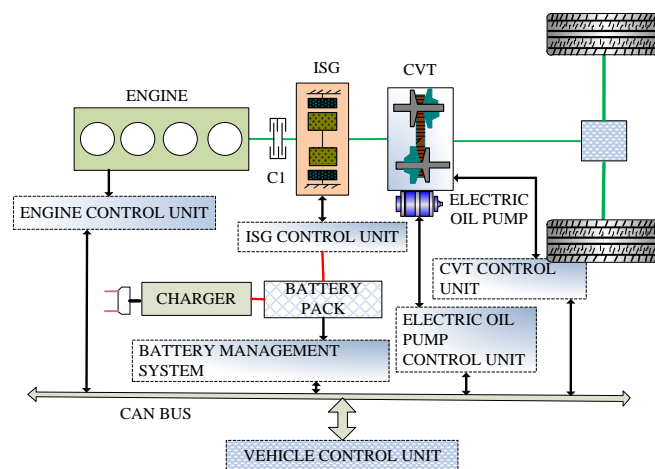


Figure 1. Drive Train Configuration of a PHEV

3. Energy Management Strategy

3.1 Process Analysis of Starting the Engine

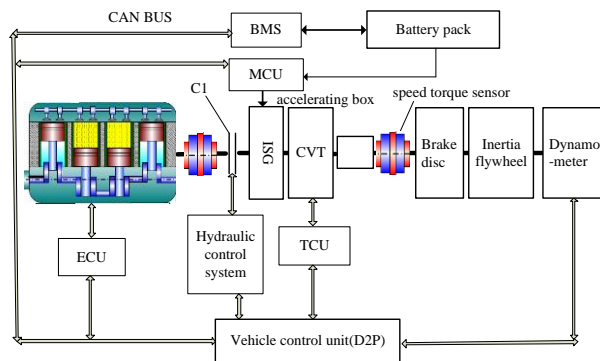
C1 consumes part of torque in the moving process of starting the engine. Ensure that power does not fall and disruptions when you start the engine, which request that motor torque can meet the demand of vehicle torque, but also has the backup torque of starting engine.

In order to analyze the process of starting the engine, this paper set up a test platform. Test platform is composed of engine, ISG, CVT, accelerating box, brake disc, inertia flywheel, dynamometer, loading device, speed torque sensor, battery packs, data sampling and controlling system. The inertia flywheel simulates the moment of inertia of a vehicle. The loading device simulates moving resistance to load the dynamometer. D2P receives the signal of the ECU, MCU, BMS, TCU, EOP control unit through CAN bus, and sends control command to powertrain, as shown in Figure 2.

The process of starting the engine was tested and the result is shown in Figure 3, which can be seen that maximum compensation torque is 62- 64 Nm when the rotating speed is 800-2500 rpm. In this paper maximum compensation torque value is 65 Nm when considering the safety coefficient.

Table 1. Parameter Values of Power Train

	parameters	values
Vehicle	Weight m_0	1547 kg
	Windward area A	2.28 m ²
	Drag coefficient C_D	0.357
	Wheel radius r	0.289 m
	Rolling resistance coefficient f_r	0.0083
Engine	Maximum power $P_{e\max}$	93 kW
	Maximum torque $T_{e\max}$	160 N/m (3900rpm)
	Speed range n_e	800 ~ 6000 rpm
ISG	Maximum power P_m	32 kW
	Maximum torque $T_{e\max}$	113 N/m
Battery pack	Speed range n_m	0 ~ 6000 rpm
	Capacity Q_0	45 Ah
	Nominal voltage U_0	336 V
CVT	Ratio range i_{cvt}	0.422 ~ 2.432
	Final ratio i_0	5.297



(a) The principle diagram of the test bench



(b) The real product photo show of the test bench

Figure 2. Plug-in Hybrid Platform

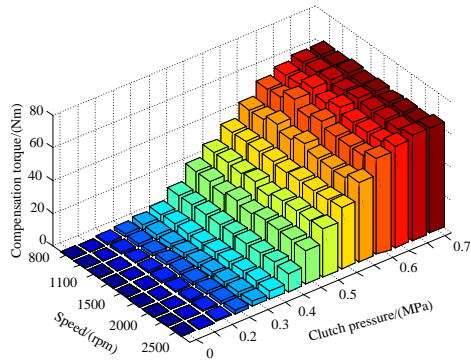


Figure 3. Compensation Torque

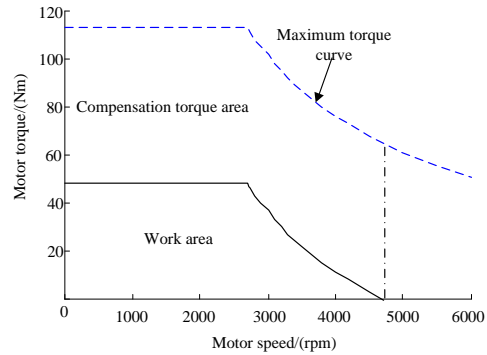


Figure 4. The Motor Working Curve

Combined with maximum torque curve of the motor can be seen, the motor can work area as shown in Figure 4.

3.2 Control Strategy

Can be seen from the Figure 4, the working range of the motor is small, which cannot satisfy the requirement of electric drive. To give full play to the advantages of the motor, this paper studies the PHEV installed electric switch power system, the mode of the vehicle can be divided into pure electric mode and economic operation mode. When the switch is activated by the driver, the system will work into pure electric mode, when the battery capacity is less than the set target, the system will automatically switch to the mode of economic operation.

Driving intention parsing

When the driver steps on the gas pedal, drive strength is calculated by vehicle control unit according to the accelerator pedal stroke, combined with torque provided by the motor and engine under different speed, it can be concluded that drive torque.

This paper use the linear pedal control strategy, the result is shown in Figure 5.

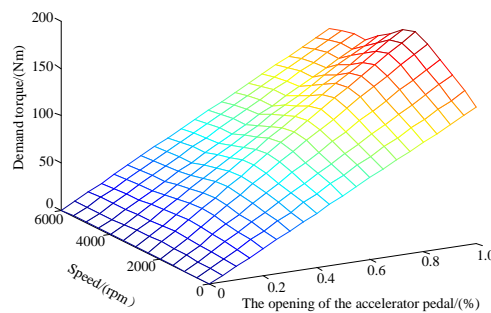


Figure 5. Linear Pedal Control Strategy

Pure electric mode control strategy

When the vehicle enters into pure electric mode, drive torque is the torque that motor can provide. At the same time, equipped with CVT of PHEV can adjust speed ratio, which make motor working point meet the needs of more working condition and make the vehicle reached the highest system efficiency.

This paper makes use of loop iteration optimization method to optimize speed ratio and the optimization results are shown in Figure 6.

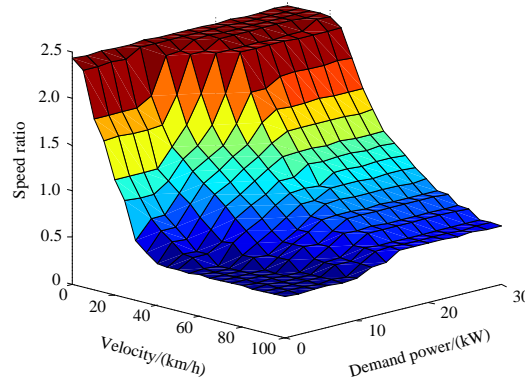


Figure 6. Speed Ratio of Pure Electric Mode

Economic model control strategy

Economic model control strategy mainly divided into charge depleting (CD) mode and charge sustaining (CS) mode two kinds of control strategy, depending on the battery SOC. Its core idea is to make the engine work in high efficient area. The division of work mode is mainly based on the characteristic curve of engine and motor, as shown in Figure7.

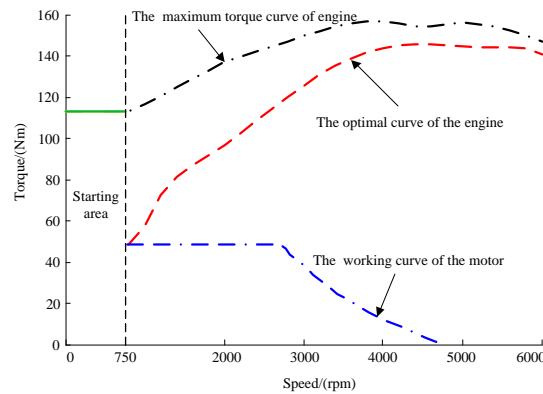


Figure 7. The Characteristic Curve of Engine and Motor

When the speed is less than 800rpm, belongs to the starting area of the vehicle. When the speed is more than 800rpm, belongs to the work mode of operation area. The vehicle driving mode mainly includes pure electric (PE) mode, engine drive alone (EDA) mode, united drive (UD) mode and the charging of driving (COD) mode. Four patterns of switching logic and torque distribution, as shown in Figure 8.

Where, SOC_{max} refers to the maximum battery SOC; SOC_{up} refers to the upper limit of CS mode; SOC_{down} refers to the lower limit of CS mode; T_{req} refers to the whole car demand torque;

T_e refers to the engine torque; $T_{e_{best}}$ refers to the best torque of engine; $T_{e_{max}}$ refers to the maximum of engine; T_m refers to the motor torque; T_{m_s} refers to the working torque of motor; N_m refers to the motor speed; N_j refers to the intersection point of speed between the optimal curve of engine and motor working curve; a and b represent the fluctuates up and down limit of the engine optimal curve.

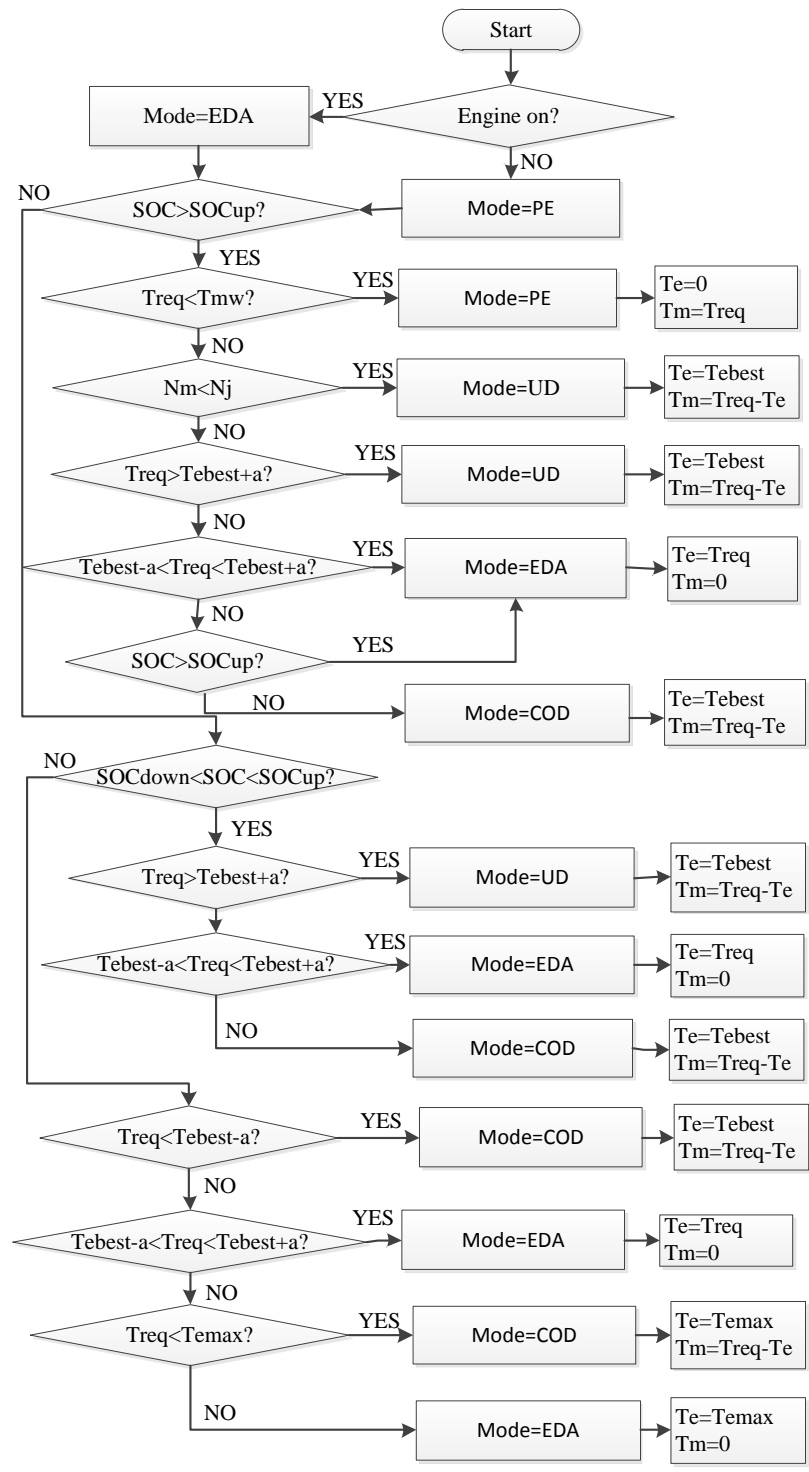


Figure 8. Economic Model Control Strategy

Figure 7 and Figure 8 shows that most parameters of the control strategy can be determined according to characteristic curve of the motor and the engine, but four parameters (SOC_{up} , SOC_{down} , a , b) could not be determined directly. This paper makes use of the genetic algorithm to optimize four parameters. Set the parameters as follows: the biggest evolution algebra is 80; the population size is 100; the number of elite is 10; the cross ratio of offspring is 0.4; the fitness function is formulated as follows:

$$\text{Minimize } Q_c(t) = \int_0^{t_f} (j_f Q_f(N_e, T_e) + j_e \frac{P_m(N_m, T_m)}{\eta_g \eta_m \eta_b}) dt \quad (1)$$

$$\text{Subject to } \begin{cases} SOC_{min} \leq SOC \leq SOC_{max} \\ T_{mmin} \leq T_m \leq T_{mmax} \\ T_{emin} \leq T_e \leq T_{emax} \\ 0 < N_m, N_e < 6000 \end{cases} \quad (2)$$

where Q_f refers to the consumption cost; t_f refers to the terminal time; j_f refers to the price of gasoline per liter; j_e refers to the price of per kilowatt hour; Q_f refers to the fuel consumption; P_m refers to the motor power, discharge is greater than zero, charging is less than zero; η_g refers to the charging efficiency of the grid; η_m refers to the motor efficiency; η_b refers to the charging and discharging efficiency of the battery; t refers to the time; the subscript min and max refer to the minimum and maximum respectively.

Take new European driving cycle (NEDC) as calculation conditions, at the same time in order to ensure the PHEV cover CD and CS mode, this paper repeats NEDC 40 times, the optimization results as shown in Figure 9.

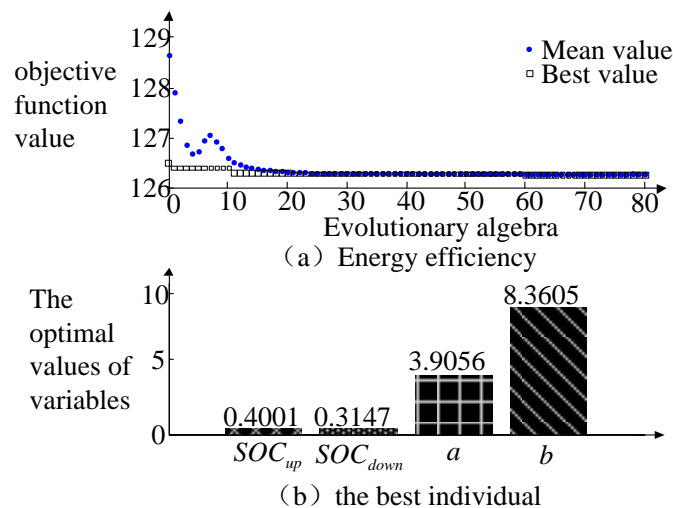


Figure 9. The Optimization Results of Genetic Algorithm

It can be seen as the population evolution, the best individual fitness function value decreases constantly, eventually converges to 126.28 China Yuan (CNY), corresponding to the optimal individual $(SOC_{up}, SOC_d, a, b) = (0.4001, 0.3147, 3.9605, 8.3605)$.

4. Simulation and Analysis

The vehicle model is built based on Matlab/Simulink simulation platform. The control strategy of this paper has carried on the simulation in NEDC, urban dynamometer driving schedule (UDDS) and highway fuel economy test (HWFET). The result is shown in Figure 11-12.

Figure 10 shows that the engine working points of the three driving cycles, which work along the best optimal curve.

Figure 11 shows the curves of the battery SOC in three driving cycles. You can see that the battery SOC value at the end of the range are not identical, but all follow CDCS mode, well meets the design requirements of the control strategy in this paper.

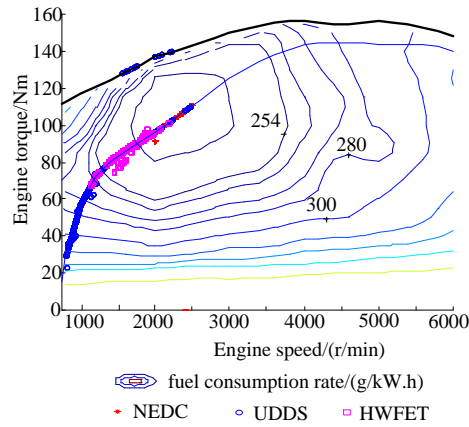


Figure 10. The Engine Working Points

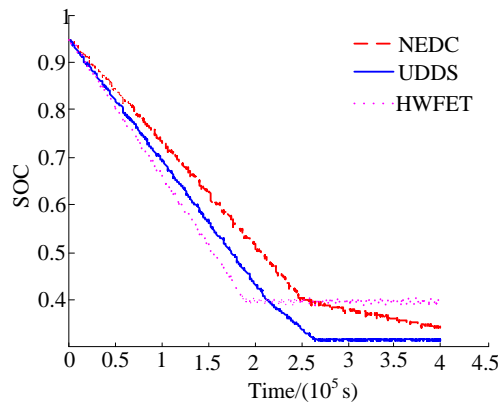


Figure 11. The Changing Curve of Battery SOC

In order to better evaluate the superiority of this control strategy, this paper calculate the hundred kilometers of the economy energy consumption compared with the traditional car, the results are shown in Table 2. As can be seen in the NEDC, UDDS and HWFET driving cycles, the PHEV using the strategy of this paper compared with the traditional car was reduced by 28.4%, 35.8% and 26.6% respectively.

Table 2. The Economy Energy Consumption

Driving cycles	Traditional car	PHEV	Improved
NEDC	48.2 CNY	34.5 CNY	28.4%
UDDS	46.7 CNY	29.9 CNY	35.8%
HWFET	54.5 CNY	40.0 CNY	26.6%

5. Summary

Economic model control strategy is put forward. The engine and motor torque can be achieved for the reasonable distribution under different conditions. The engine working points are operating in the best economic efficiency curve and the high efficiency area.

PHEV adopt economic model control strategy can make hundred kilometers consume economic costs in the NEDC UDDS HWFET three loop conditions, was reduced respectively 28.4%, 35.8% ,26.6% than conventional cars.

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