# Analysis of Dynamic System Operation Modes of Hybrid Electric Vehicle

Wu Qinglong, Yu Changhong, WangYan

(1. Global R&D Center, China FAW Corporation Limited, Changchun 130013)

【Cite this paper】WU Q L, YU C H, WANG Y. Analysis of Dynamic System Operation Modes of Hybrid Electric Vehicle [J]. Automotive Digest (Chinese), 2023(8): 42-47.

【Abstract】This paper analyzes the control strategies of dynamic system operation mode of hybrid electric vehicle. Based on factors such as vehicle torque demand, battery SOC, accelerator pedal and brake pedal, the switching conditions, control methods and assembly states between different modes are analyzed. The operation modes of the vehicle include pure electric start mode, 4WD start mode, engine start mode, idle charge mode, series drive mode, drive charge mode, parallel drive mode and energy recovery mode. The analysis of control strategies for these operation modes can be used to provide references for relevant engineering developers.

**Key words: Hybrid Electric Vehicle (HEV), Dynamic System, Operation mode, Control strategies**

# 混合动力汽车动力系统运行模式分析

伍庆龙　于长虹　王燕

(中国第一汽车股份有限公司研发总院,长春 130013)

【欢迎引用】伍庆龙, 于长虹, 王燕. 混合动力汽车动力系统运行模式分析(英)[J]. 汽车文摘, 2023(8): 42-47.

【摘要】对混合动力汽车动力系统的运行模式控制策略进行了分析,根据车辆扭矩需求、电池SOC、加速踏板和制动踏板输入因素,分析了车辆在不同模式之间的切换条件、控制方法和总成状态。车辆不同的运行模式包括纯电动驱动模式、四驱起步模式、发动机起机模式、怠速发电模式、串联驱动模式、行车发电模式、并联驱动模式和能量回收模式。通过对这些运行模式的控制策略分析,为相关工程开发人员提供借鉴和参考。

**关键词:混合动力汽车;动力系统;运行模式;控制策略**

**中图分类号:**U464.1　　**文献标识码:**A　　**DOI:** 10.19822/j.cnki.1671-6329.20220128

## Abbreviation

| | |
|---|---|
| BMS | Battery Management System |
| BSG | Belt-Driven Starter Generator |
| CAN | Controller Area Network |
| EMS | Engine Management System |
| HCU | Hybrid Control Unit |
| HEV | Hybrid Electric Vehicle |
| HV | High Voltage |
| MCU | Motor Control Unit |
| SOC | State Of Charge |
| TCU | Transmission Control Unit |

## 0 Introduction

The power sources of hybrid electric vehicle include engine and motor[1]. HV battery is used to provide electric energy for the motor, and the motor can not only drive the vehicle, but also adjust the operating point of the engine [2-3]. Based on control strategy, it can effectively reduce fuel consumption and emissions, and further improve the power performance and economy of the vehicle[4-5]. At present, the configuration schemes of hybrid electric vehicle system include series, parallel and series-parallel system[6]. Series hybrid vehicle has the advantages of simple struc-

ture and easy control, but it has the disadvantages of low efficiency and high cost[7]. Parallel hybrid vehicle has good fuel economy, but it requires high performance of engine and transmission, and the control strategy of parallel hybrid vehicle is more complex than that of series hybrid vehicle[8]. Series- parallel hybrid vehicle has the characteristics of both series and parallel, and it also has different operation modes and control methods[9-10].

This paper analyzes the hybrid dynamic system with dual motor configuration. The dual motor dynamic system can realize series function, parallel function and series-parallel function, and it can be developed different dynamic system operation modes. The dual motor hybrid dynamic system can effectively improve fuel economy and reduce emissions while enhancing the vehicle's power performance through effective and reasonable control methods. Based on the dual motor dynamic system, the structure and operation principles are described, and the control strategies are analyzed in this paper. These can be used to provide information references for relevant engineers.

## 1 Hybrid Electric Vehicle Dynamic System

### 1.1 Structural Scheme of Dynamic System

The dual motor dynamic system of hybrid electric vehicle in this paper is composed of engine, main motor, BSG motor, gearbox, clutch, HV battery, drive axle, main reducer, etc., as shown in Figure 1. The BSG motor is connected with the engine through the gear train belt, the crankshaft output shaft of the engine is connected with the clutch C2, and the clutch C2 is connected with the input shaft of the gearbox. The gearbox transmits dynamic power to the front wheels through the reducer and differential. The HV battery outputs electric energy to the main motor and BSG motor. The main motor transmits dynamic power to the rear wheels through the clutch C1 and transmission mechanism. The main motor can drive the vehicle alone, or jointly drive the vehicle with the engine, and can also recover energy from vehicle braking or coasting.

### 1.2 Dynamic System Operation Mode

HCU communicates with EMS, MCU1, MCU2, BMS and TCU through the CAN network. HCU receives the working status of each assembly of the dynamic system, and determines the dynamic system power and torque output through the control strategies according to the driver's accelerator pedal, brake pedal and gear shifter status. HCU receives the feedback information from the motor and HV battery, such as battery SOC, motor speed and torque, and then determines the dynamic system power and torque output through the control algorithm to realize the management and control of various operation modes.

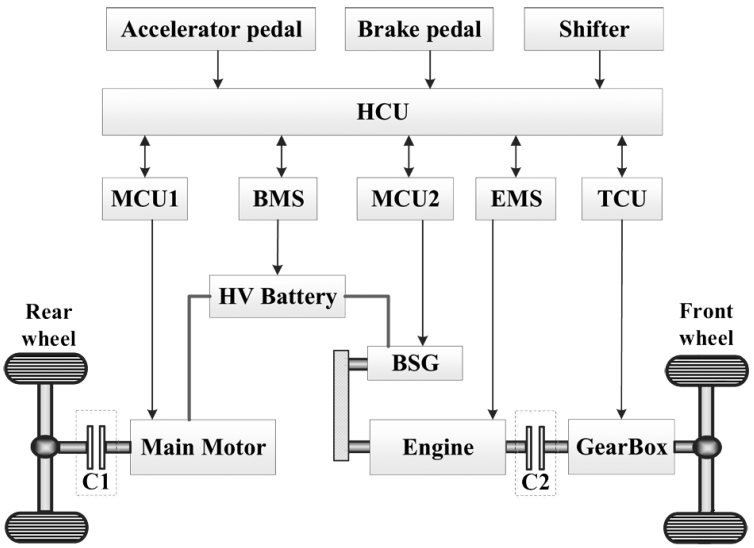


**Fig.1 The structure of hybrid dynamic system**

During the hybrid vehicle driving, the switching control between different operation modes of the dynamic system is realized through the cooperative control strategies of HCU. The operation modes include: pure electric start mode, 4WD start mode, engine start mode, idle charge mode, series drive mode, drive charge mode, par-

allel drive mode and energy recovery mode.

## 2 Pure Electric Start Mode

When all of the following conditions are met, the hybrid dynamic system drives the vehicle with the pure electric start mode.

(1) The vehicle speed is 0 km/h.

(2) The shifter position is in D or R gear.

(3) The engine is stop.

(4) The brake master cylinder pressure is more than the threshold value (for example, pressure > 0.3 MPa).

(5) The parking brake state is not activated.

(6) The HV battery SOC is more than the threshold value (for example, SOC value > 30%).

If the adhesion of the rear wheels of the vehicle is sufficient, and the driver releases the brake pedal and presses the accelerator, the dynamic system will drive the vehicle independently with the main motor.

In this mode, the status of each assembly is controlled as follows: The engine is stop, the main motor is driving, the BSG motor is in shutdown state, the C1 clutch is engaged, the C2 clutch is disengaged and the HV battery is in discharge status. The energy flow diagram of pure electric start mode is shown in Figure 2.

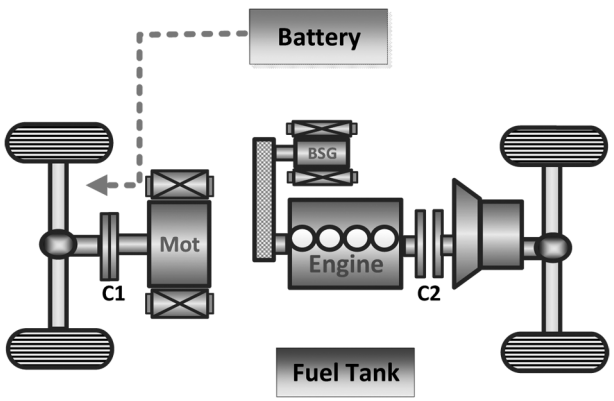


**Fig.2 Energy flow of pure electric start mode**

## 3 4WD Start Mode

When all of the following conditions are met, the hybrid dynamic system drives the vehicle with the 4WD start mode. (1) The vehicle speed is 0 km/h. (2) The shifter position is in D or R gear. (3) The brake master cylinder pressure is more than the threshold value (for example, pressure > 0.3 MPa). (4) The parking brake state is not activated. (5) The HV battery SOC is more than the threshold value (for example, *SOC* value > 30%). If the adhesion of the front and rear wheels is insufficient, and the driver releases the brake pedal and presses the accelerator, the powertrain uses the 4WD starting mode to drive the vehicle.

In this mode, the status of each assembly is controlled as follows: The engine is running, the main motor is driving, the BSG motor is following the engine rotation, the C1 clutch is engaged, the C2 clutch is engaged and the HV battery is in discharge status. The energy flow diagram of 4WD start mode is shown in Figure 3.

## 4 Engine Start Mode

When all of the following conditions are met, the hybrid dynamic system drives the vehicle with the engine start mode.

(1) The vehicle speed is 0 km/h.

(2) The shifter position is in P or N gear.

(3) The engine is stop.

(4) The BSG motor output power is more than engine starting power.

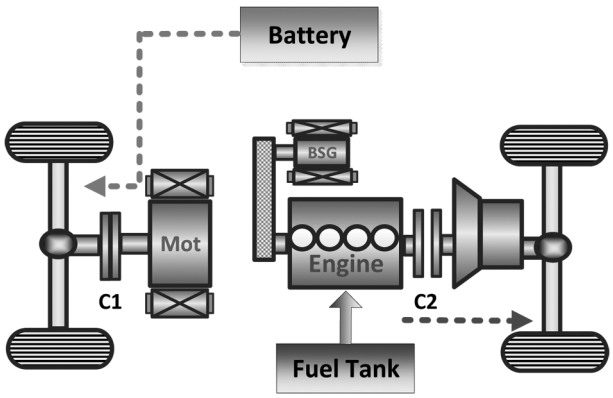


**Fig.3 Energy flow of 4WD start mode**

If the driver operates the shift lever to engage D or R, the HCU controls the BSG to drag the engine to the set speed, and then the EMS controls the engine injection and ignition. Then the engine speed is controlled to increase. When the engine speed reaches the target speed, the engine start-up is completed.

In this mode, the status of each assembly is controlled as follows: The engine is starting, the main motor is in shutdown state, the BSG motor is driving, the C1 clutch is disengaged, the C2 clutch is disengaged and the

HV battery is in discharge status. The energy flow diagram of engine start mode is shown in Figure 4.

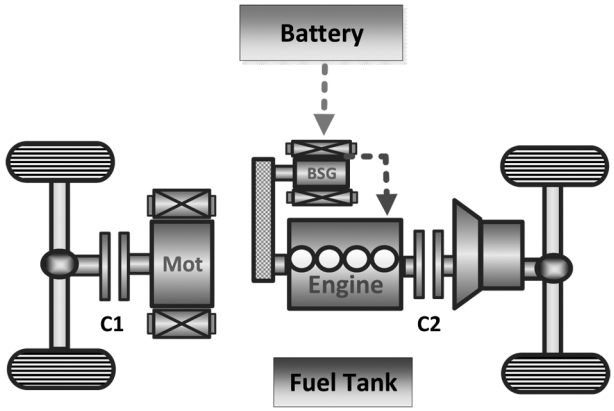


**Fig.4 Energy flow of engine start mode**

## 5 Idle Charge Mode

When all of the following conditions are met, the hybrid dynamic system drives the vehicle with the idle charge mode.

(1) The vehicle speed is 0 km/h.

(2) The shifter position is in P or N gear.

(3) The engine is running.

(4) The BSG motor output power is more than engine starting power.

(5) The HV battery SOC is less than the threshold value (for example, *SOC* value <30%).

HCU controls the engine to maintain a target generating speed by sending a signal to the EMS. The BSG motor is in the generating state, and the generating power meets the HV battery charging demand and accessory power demand.

In this mode, the status of each assembly is controlled as follows: The engine is in generation state, the main motor is in shutdown state, the BSG motor is generating, the C1 clutch is disengaged, the C2 clutch is disengaged and the HV battery is in charge status. The energy flow diagram of engine start mode is shown in Figure 5.

## 6 Series Drive Mode

When all of the following conditions are met, the hybrid dynamic system drives the vehicle with the series drive mode.

(1) The vehicle speed is less than the threshold value (for example, speed value <120 km/h).

(2) The shifter position is in D or R gear.

(3) The accelerator pedal is pressed.

(4) The engine is running.

(5) The HV battery SOC is less than the threshold value (for example, *SOC* value <30%). If the HV battery power is insufficient, the front wheel adhesion coefficient of the vehicle is insufficient, and the rear wheel adhesion coefficient is sufficient, the dynamic system drives the vehicle in series mode.

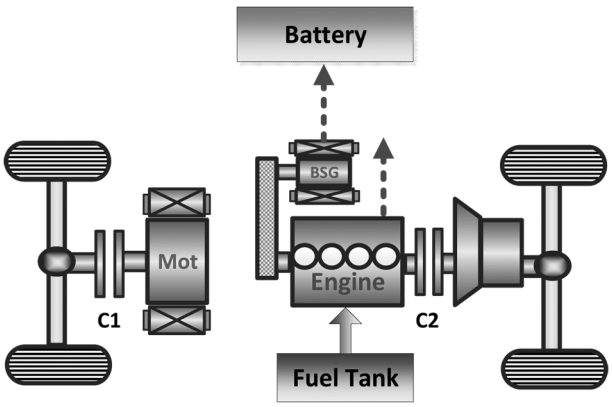


**Fig.5 Energy flow of idle charge mode**

In this mode, the status of each assembly is controlled as follows: The engine is in generation state, the main motor is driving, the BSG motor is generating, the C1 clutch is engaged, the C2 clutch is disengaged and the HV battery is in discharge status. The energy flow diagram of series drive mode is shown in Figure 6.

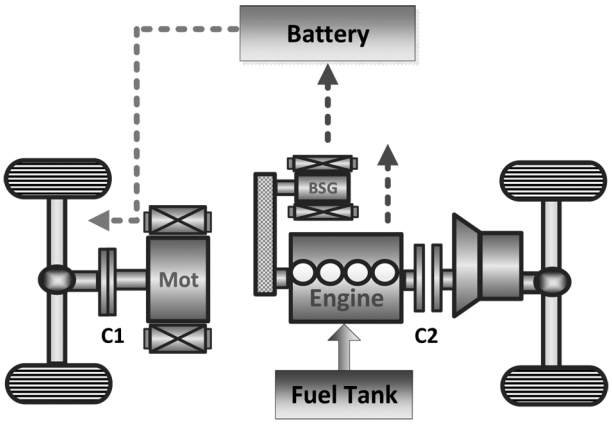


**Fig.6 Energy flow of series drive mode**

## 7 Drive Charge Mode

When all of the following conditions are met, the hybrid dynamic system drives the vehicle with the drive charge mode.

(1) The vehicle speed is more than the threshold val-

ue (for example, speed value > 120 km/h).

(2) The accelerator pedal is pressed.

(3) The shifter position is in D or R gear.

(4) The HV battery SOC is in a certain range (for example, 20 % < *SOC* value <30%).

(5) The HV battery power can not support the driving demand but can meet the power demand of electric accessory equipment.

If the front wheel adhesion coefficient of the vehicle is sufficient, and the engine is in the efficient working area, HCU shall control the dynamic system to drive the vehicle with engine running. At the same time, according to the energy management strategy of hybrid vehicle dynamic system, when the HV battery SOC is low, HCU shall control the BSG motor to generate electricity.

In this mode, the status of each assembly is controlled as follows: The engine is running, the main motor is in shutdown state, the BSG motor is generating, the C1 clutch is disengaged, the C2 clutch is engaged and the HV battery is in charge status. The energy flow diagram of drive charge mode is shown in Figure 7.

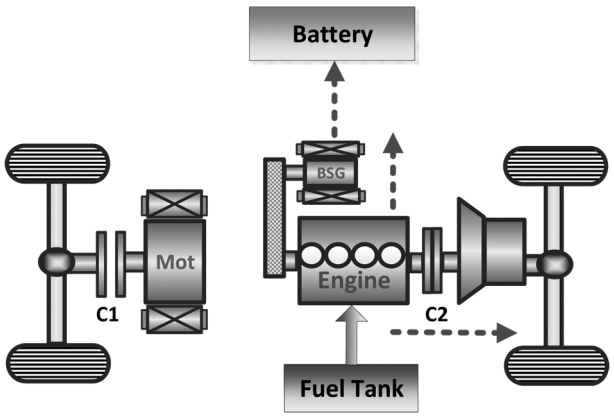


**Fig.7 Energy flow of drive charge mode**

## 8 Parallel Drive Mode

The hybrid dynamic system drives the vehicle with parallel drive mode if all of the following conditions are met.

(1) The vehicle speed is more than the threshold value (for example, speed value > 100 km/h).

(2) The accelerator pedal is pressed.

(3) The shifter position is in D or R gear.

(4) The HV battery SOC is more than the threshold value (for example, *SOC* value > 30%).

When the single axle drive adhesion coefficient of the vehicle is insufficient or the total driving torque demand of the vehicle is more than the peak output torque of the main motor, the engine will drive the vehicle together with the main motor. The dynamic system of the hybrid electric vehicle runs in parallel drive mode and drives the vehicle by triggering the 4WD function.

In this mode, the status of each assembly is controlled as follows: The engine is running, the main motor is driving, the BSG motor is driving, the C1 clutch is engaged, the C2 clutch is engaged and the HV battery is in discharge status. The energy flow diagram of parallel mode is shown in Figure 8.

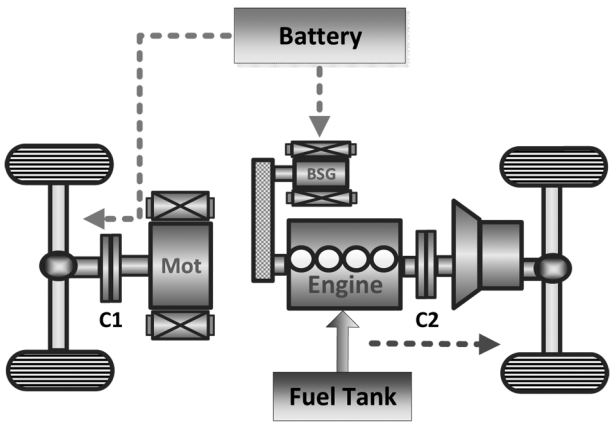


**Fig.8 Energy flow of parallel drive mode**

## 9 Energy Recovery Mode

The hybrid dynamic system drives the vehicle with energy recovery mode if all of the following conditions are met.

(1) The vehicle is the process of braking or coasting.

(2) The vehicle speed is between 15 km/h and 120 km/h.

(3) The shifter position is in D or R gear.

(4) The brake pedal is pressed.

(5) The HV battery SOC is less than the threshold value (for example, *SOC* value < 90%).

According to the braking energy recovery strategy, the recovered torque and mechanical braking torque are distributed. The braking energy of the main motor meets the braking energy recovery demand. HCU controls the hybrid electric vehicle dynamic system to operate in the energy recovery mode.

In this mode, the status of each assembly is controlled as follows: The engine is in shutdown state, the main motor is generating, the BSG motor is in shutdown

state, the C1 clutch is engaged, the C2 clutch is disengaged and the HV battery is in charge status. The energy flow diagram of recovery mode is shown in Figure 9.

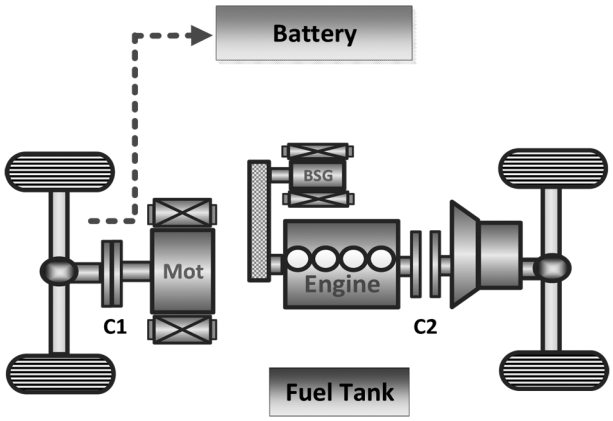


**Fig.9 Energy flow of energy recovery mode**

## 10 Summary

The dynamic system and the control strategies of the hybrid electric vehicle are analyzed and researched in this paper, and the different operation modes are described in detail. The dual motor dynamic system is a hybrid energy-saving technology that can effectively improve power performance and reduce energy consumption of the vehicle.

Based on the configuration characteristics of the hybrid dynamic system, since there are multiple power sources of the hybrid dynamic system, it is necessary to control multiple power sources to play their respective roles under different driving demand conditions. By coordinating the control of the engine、the main motor, the BSG motor and the HV battery, the hybrid dynamic system can meet the driver´s needs and improve the power, economy and drivability of the vehicle. The technical analysis described in this paper can provide some references for correlative engineering research and development.

**References**

[1] TAGHAVIPOUR A, AZAD N L, MCPHEE J. Design and evaluation of a predictive powertrain control system for a plug-in hybrid electric vehicle to improve the fuel economy and the emissions[J]. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2015, 229 (5): 624-640.

[2] PANDAY A, BANSAL H O. A Review of Optimal Energy Management Strategies for Hybrid Electric Vehicle[J]. International Journal of Vehicular Technology, 2014, (11):1-19.

[3] YAN F J, WANG J M, HUANG K S. Hybrid Electric Vehicle Model Predictive Control Torque-Split Strategy Incorporating Engine Transient Characteristics[J]. IEEE Transactions on Vehicular Technology, 2012, 61(6): 2458 - 2467.

[4] WU Q L. Function Analysis of Remote Control Drive for New Energy Vehicle[J]. Automotive Digest (Chinese), 2020 (1): 24-27.

[5] WU Q L, ZHANG T Q, YANG F, etc. Vehicle energy management method, device and system, vehicle and storage medium: CN112060974A [P]. 2020-12-11.

[6] WU Q L, YANG F. Research on Information Display of Hybrid Electric Vehicle Power System[J]. Automotive Digest (Chinese), 2019(5): 54-57.

[7] MASHADI B, EMADI S A M. Dual-mode power-split transmission for hybrid electric vehicles[J]. IEEE Transactions on Vehicular Technology, 2010.

[8] WU Q L. Light hybrid vehicle torque distribution control method, storage medium and vehicle: CN110834621B[P]. 2021-03-02.

[9] WU Q L. Method for calculating driver torque demand of light hybrid power system, storage medium and vehicle: CN110606073B [P]. 2021-02-09.

[10] WU Q L. Research on Power Management and Diagnosis Strategies of Hybrid Electric Vehicle [J]. Automotive Digest (Chinese), 2019(7): 38-41.