Analysis of Segment Parameters for Different Working Conditions on Mode Switching Control Strategy

Zhongyan Li$^{1,2}$ and Lin Yang$^1$*

$^1$ School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
$^2$ Jinlong United Automotive Industry (Suzhou) Co., Ltd. Suzhou, 215123, China

* E-mail: yanglin@sjtu.edu.cn

Abstract: Due to the requirements of global energy conservation and environmental protection, parallel hybrid electric buses have developed rapidly. The mode switching control strategy has great significance to the stability of the parallel hybrid electric bus. The principle of minimum value has achieved great development in the optimal control of the mode switching for parallel hybrid electric buses. Since the Hamilton function is a complex function of the control variable and the bus should traverse the entire control variable domain when searching for the optimal control variables. Therefore, the control strategy based on the principle of minimum value requires a large amount of computation time. Based on the principle of minimum value, this paper combines the mode switching control strategy with the identification and prediction of working conditions, and establishes a working condition segments library. The influence of segment parameters for different working conditions on mode switching control strategy is analyzed. The analysis results show that the prediction effect is better when the working condition segment size is 30s and the search range is specified as the actual trip time range, and the mileage range has little effect on SOC and fuel consumption.

1 Induction

With the increasing awareness of environmental protection and energy conservation in the world, the development of new energy vehicles has become an urgent need. Urban bus has the characteristics of large passenger capacity, frequent start and stop, low average speed and long working hours, resulting in high fuel consumption and high emissions [1]. The fuel saved by the application of new energy technology and the reduction of harmful gas emissions are higher than small cars. Parallel hybrid electric bus can combine the advantages of high specific energy, high specific power and zero motor emissions [2], low speed and high torque, and coordinate the energy distribution by optimizing the control strategy to make the engine and motor working in the high efficiency zone under different working conditions [3]. It meets the demand of frequent start and stop and high-power driving of city bus passengers. Therefore, parallel hybrid electric bus is the best choice for urban bus passengers to achieve low fuel consumption and low emissions [4]. However, maintaining the smoothness and continuity of the power output of the hybrid system and meeting the driver's demand for driving torque, higher requirements are placed on the parallel hybrid electric bus mode switching strategy.

The mode switching control strategy based on the principle of minimum value is to solve the optimal control problem of fuel economy of hybrid vehicles. It optimizes the fuel economy, emission
level and driving performance of the hybrid vehicle under the known cycle conditions, and uses the optimal control theory to obtain the energy distribution and mode switching of the hybrid system. The mode switching control strategy based on principle of minimum value is smaller than the mode switching control strategy based on the dynamic programming algorithm. Based on the minimum principle of Pontryagin, Serrao et al. [5] proposed an equivalent consumption minimization strategy for energy management of hybrid electric vehicles. When establishing the constraints of state variables, consider the state constraints in the whole time period into two cases: the state variables reach the boundary conditions and within the boundary conditions. On this basis, the Hamilton function is solved in sections. Since the result is obtained using a general formula for energy management problems in HEVs, it is effective for any powertrain structure. Lescot et al. [6] established an algorithm based on the equivalent fuel consumption minimization in consideration of the loss caused by low engine temperature, and increased the coolant temperature variable when constructing the Hamilton function. The strategy was tested offline under given driving cycle conditions, and the results showed a significant improvement in fuel economy, verifying the correlation between coolant temperature and fuel consumption.

The combination of HEV control strategy and the identification and prediction of working conditions has made some progress in recent years, but it is still in the basic stage. The paper [7] uses extreme learning machines to identify working states and fuzzy logic control algorithms to identify driving intentions. Then, an energy management strategy for plug-in hybrid electric vehicles based on driving intention and working condition identification is proposed. Jin Yan et al. [8] used the Markov model to predict the driving mode (parking, battery charging, engine operation, pure motor operation, engine and motor operation, and vehicle braking energy recovery), and then used the prediction information to improve the fuzzy logic control strategy.

At present, the mode switching control strategy based on the principle of minimum value has achieved great results in the practical application of hybrid vehicles. However, the control strategy based on the minimum value principle requires a large amount of computation time, and it is actually difficult to implement real-time control. Therefore, it is possible to apply the minimum value control strategy based on the working condition recognition and prediction, thereby realizing real-time control, adapting to complex and varied driving conditions. The main arrangements of this paper are as follows. We constructed the working condition information remote acquisition system in Section 2 and working condition segments library in Section 3. Section 4 introduced the methods of identification and prediction for working condition and Section 5 revealed influence of segment parameters for working condition on mode switching control strategy. Finally, conclusions are drawn in Section 6.

2 Construction of working condition information remote acquisition system

2.1 Working condition information remote acquisition system platform architecture
The prediction of working condition is the basis of online optimization of mode switching control strategy, and the real-time road condition data is the basis of the research for working condition prediction algorithm. Therefore, we must first obtain the basic data of the actual road operation. To this end, this paper establishes working condition information remote acquisition system platform. The working condition information remote acquisition system platform is mainly composed of three parts: vehicle information remote collection terminal, wireless communication network and remote information center platform, which is shown as figure 1.
Figure 1. Schematic diagram of working condition information remote acquisition system platform.

2.2 Hardware construction of vehicle information remote acquisition terminal
The vehicle information remote acquisition terminal is designed by Freescale MC9S12 microcontroller. The vehicle information remote collection terminal takes analog input and switch input, and indicator light, LCD display and PWM module as output, and with SD card, EEPROM, POWER SUPPLY, GPRS port, GPS port, CAN module, RS232. Perform data interaction. Figure 2 shows the vehicle information remote acquisition terminal and the installation location of it.

Figure 2. the vehicle information remote acquisition terminal and the installation location of it

2.3 Software design of remote information center platform
The remote information center platform is integrated with C# and JavaScript under the Microsoft Visual Studio 2010 integrated development platform. The data storage of remote information center platform is stored in two ways. (1) The server system data (user management, vehicle terminal management, log file relationship management and other data) is stored in the Microsoft SQL Server 2008 database; (2) The data transmitted remotely from GPRS is stored in the text file in real time. On the Microsoft Visual Studio 2010 integrated development platform, real-time online tracking of the location of the vehicle can be achieved by calling the Baidu map application programming interface (API).

2.4 Data analysis of working condition information remote acquisition system
2.4.1 GPS information analysis. In the SD card, the standard form of each record is as follows:
sjtu000:2014-04-18 12:36:12 A,31.118608,N,121.287574,E,0.037;
18FFDC00:10 FF FF FF FF C1 FF FF; 0C000003:F0 FF FF FF FF FF FF; OCF00203:CC 00 00
CAN information analysis:

\[ R = Ra \times res + e \]  

(1)

Where, \( R \) is real data, \( Ra \) is raw data, \( res \) is resolution and \( e \) is offset.

As a result, the CAN speed and brake switch can be obtained and are more accurate than the GPS speed. The byte analysis is shown in Table 1, with the high byte first and the low byte last. Therefore, the CAN speed should be 1ACA (hexadecimal), converted to decimal after 6858, and brought into the analytical formula to get the CAN speed of 26.789 km/h.

**Table 1. Byte Analysis of CCVS**

| Byte 1 | Byte 2 | Byte 3 | Byte 4 | Byte 5 | Byte 6 | Byte 7 | Byte 8 |
|--------|--------|--------|--------|--------|--------|--------|--------|
| FF     | CA     | 1A     | 10     | 00     | 1E     | 1F     | FF     |

Take byte 4 as an example. The bit analysis is shown in Table 2. It should be noted that the order of the bits is different from the order of the bytes. The bytes are from small to large, and the bits are just the opposite. Therefore, the brake switch is 01, which is open.

**Table 2. Bit analysis of CCVS**

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 0     | 0     | 0     | 1     | 0     | 0     | 0     | 0     |

3 Construction of working condition segments library

Vehicle working conditions can be described as the time-speed curve of the vehicle’s driving regular pattern [9]. It is applied to vehicle emission, fuel economy, power and other tests, reflecting the economic and emission indicators of the vehicle under real conditions [10]. In order to accurately predict the future working conditions of the bus, it is necessary to divide the collected road spectrum information into different segments and extract the information of each segment to form a working condition segments library.

3.1 Division of working condition segments

In the study, we divided the original road spectrum information (v-t curve) into a window with a fixed time (such as 30 seconds) to form a working condition segment. The specific method is as follows:

1. Divide the entire road spectrum into starting and stopping segments of variable size;
2. For each start-stop segment, divide it from the starting point by 30s, and if the remaining part is less than 30s, fill it with 0. Of course, the time interval can be arbitrarily adjusted, the impact of which will be discussed below.

3.2 Extraction of feature parameters

There are several speed-time points in the working condition segments library, and each working condition segment has its own different kinematic characteristics. To describe and evaluate a working condition segment, it is necessary to select appropriate kinematic feature parameters, which can describe the working condition segment as comprehensively as possible according to its operating state and form a mathematical model based on kinematic segments. In the description of the working condition segment, the characteristic parameters generally considered are: total distance, average speed (including idle speed), average acceleration, average speed of the vehicle during operation (excluding idle speed), maximum speed, standard deviation of speed, maximum acceleration, maximum deceleration, standard deviation of acceleration, ratio of parking time, ratio of speed section, etc. The characteristic parameters used in this paper are mainly divided into the following two categories:

1. Parameters reflecting road traffic conditions: total distance, parking time ratio, acceleration, and deceleration time. Road traffic conditions can be divided into three categories: smooth, general, and
congested. The greater the proportion of parking time, the less the total distance traveled by the car in the same period of time, and the more congested the road.

(2) Parameters reflecting the driver's style: maximum value of speed, acceleration, deceleration, average value and standard deviation. Driver style can be divided into stable, normal and aggressive. The larger the standard deviation of each parameter above, the more aggressive the driving style.

4 Working condition identification and prediction
This study identifies the working conditions from the following two aspects:

(1) The time and distance of the start of the segment are similar. When identifying the working conditions, the two factors of the time and the distance at which the segment starts can be considered, and the working condition fragment library is initially screened. In this way, on the one hand, the calculation amount of the subsequent processing can be reduced, the recognition speed can be accelerated, and on the other hand, the accuracy of the recognition can be improved for the characteristics of the segment.

(2) The similarity of fragments. Assuming that $A$ is a characteristic parameter vector during driving and $B$ is a characteristic parameter vector of a segment in the fragment library, the similarity between $A$ and $B$ is:

$$
\varepsilon = \frac{|\vec{A} - \vec{B}|}{|\vec{A}|} \tag{2}
$$

In the segments library, each segment is represented by $s(k)$ ($k = 1, 2, 3, ..., n$), which are substantially continuous on the time axis. If the similarity $\varepsilon$ of the segments $s(i)$ and $s(j)$ satisfies certain conditions ($\varepsilon < \varepsilon_0$), then the two segments are considered to be similar, and the similar logarithm of the segment is $a$; if the segment $s(i+1)$ and $s(j+1)$ also satisfies the above conditions, and it is considered that $s(i)$ and $s(j)$ are consecutively similar, and the continuous similar logarithm of the segment is $b$. After finding a segment similar to the actual working condition in the segments library, the immediately adjacent segment of the segment is used as a result of the prediction of the working condition, and is applied to the control strategy.

Using the minimum value control strategy described above, we conducted a preliminary assessment of the forecasting effect and selected several representative graphs to display the following.

In the figure 3, red represents the actual trip and blue represents the predicted trip. It can be seen that, except for a small number of samples, the SOC change of the predicted trip can basically keep up with the actual trip. Although there is a certain gap in fuel consumption, this gap does not take into account the impact of different power consumption of the power battery. On the whole, the prediction of working conditions is better and further research can be carried out.

5. Influence of segment parameters for working condition on mode switching control strategy
Using 26 actual trips and predicted trips as test samples, the minimum value control strategy is used to discuss the segment parameters for working condition on mode switching control strategy.

5.1 Segment size
The previous segments library was created with a segment size of 30 s. If the segment size is changed, the effect of the road prediction will change, as shown in Figure 4. Summarize the above figure and get Table 3. Based on the difference between SOC and fuel consumption, it can be considered that when the size of the fragment library is 30s, the prediction effect is better, which is closer to the actual trip.
Figure 3. SOC changes and fuel consumption of several different trips (g)

Figure 4. Effect of different segment sizes on SOC and fuel consumption

Table 3. Effects of different fragment sizes on SOC and fuel consumption

| Items             | 10s     | 20s     | 30s     | 40s     | 50s     |
|-------------------|---------|---------|---------|---------|---------|
| SOC gap           | 0.0573  | 0.0544  | 0.0387  | 0.0332  | 0.0390  |
| Fuel consumption gap (g) | 457.4416 | 242.3682 | 142.2815 | 181.4822 | 207.8156 |
5.2 Mileage range
First consider the impact of the mileage range on the effectiveness of the control strategy, as shown in Figure 5.

Figure 5. Effect of different mileage ranges on SOC and fuel consumption

Summarize the above figure and get Table 4. Based on the difference between SOC and fuel consumption, it is found that the mileage range has little effect on SOC and fuel consumption, but in order to reduce the search volume, a certain mileage range can still be selected in the control strategy.

| Items               | ±50m  | ±100m | ±200m | ±300m |
|---------------------|-------|-------|-------|-------|
| SOC gap             | 0.0393| 0.0398| 0.0399| 0.0387|
| Fuel consumption gap (g) | 145.1385 | 132.8567 | 157.1636 | 142.2815 |

5.3 Time range
As with the mileage range, the time range is also an influencing factor related to the search time of the segments library. The statistical results are shown in Table 5. The comprehensive SOC and fuel consumption gap are found to be different from the mileage range. The time range has a certain impact on the SOC and fuel consumption. When the search range is specified as the actual trip time range, the prediction effect is better.

| Items               | Trip time | ±0.5h | ±1h  | Unlimited |
|---------------------|-----------|-------|------|-----------|
| SOC gap             | 0.0387    | 0.0429| 0.0398| 0.0445    |
| Fuel consumption gap (g) | 142.2815  | 172.5578 | 156.9499 | 186.6931 |

6. Conclusion
Parallel hybrid electric bus mode switching control strategy directly affects the driving quality of parallel hybrid electric bus. In order to study the influence of segment parameters for different
working conditions on mode switching control strategy, based on the principle of minimum value, this paper combines the mode switching control strategy with the identification and prediction of working conditions, and gets the working condition segments library. Then, we propose the identification and prediction methods of working conditions. Finally, the influence of segment parameters for different working conditions on the mode switching control strategy is obtained. The main conclusions of this paper are as follows:

1) Using the time and distance similarity at the beginning of the segment and the similarity of the segments to identify the condition. The ratio of fuel consumption to actual fuel consumption, SOC change and fuel consumption rate are compared. The results show that the predicted SOC change of the trip can basically keep up with the actual trip, and the prediction of the working condition is better.

2) By comparing 26 actual trips and predicted trips, the effects of segment size, mileage range and time range on the condition prediction of the mode switching control strategy based on the principle of minimum value are analyzed. When the size is 30s and the search range is specified as the actual trip time range, the prediction effect is better, and the mileage range has little effect on the SOC and fuel consumption.

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