The Design and Simulation of Plug-in Series Hybrid Electric Bus

LIANG FANG

ABSTRACT

With the development of the economy, the city traffic become heavier in China. The urban bus often stops but its speed is not very high. What’s more, the heavy consumption of fuel is causing serious pollution to the urban environment. In order to solve this problem, components parameters of series hybrid electric bus (SHEB) are designed and matched with the ADVISOR simulation software based on Matlab_simulink. Compared to the traditional bus, SHEB greatly improves fuel economy and reduce the emissions.

INTRODUCTION

The urban environment is increasingly being paid more and more attention. Citizens also call for higher requirements for the city traffic. The traditional vehicles bring great pressure to the environmental protection [1]. SHEB is especially suitable for frequent starting and low speed operation condition in the city. The engine can avoid the idle speed and low speed working condition, so as to improve the efficiency of the engine. Meanwhile SHEB can get electricity from electric network source and use the pure electric mode within a certain range to reduce the dependence of petroleum resources and the emissions [2]. ADVISOR is a simulation software developed by U.S. National Renewable Energy Laboratory, The application of this software in new energy vehicles greatly reduces the research period and cost.

STRUCTURE AND PARAMETERS OF SHEB

There are three connection types used in hybrid electric vehicle (HEV) including series HEV (SHEV), parallel HEV (PHEV), series/parallel HEV (SPHEV) [3]. The engine always works best in fuel economy or in the most efficient region in SHEV and its operation is not affected by the condition of the vehicle. The power source of series structure is only motor, which is similar to pure electric vehicle, and its control strategy is simpler. The power assemblies are electrical connections which is flexible and easy to arrange. In the center area of city SHEV structure can realize zero emission like the pure electric mode, and only when the power battery below the limit can the engine supply electricity to power battery. Because plug-in equipment is connected to the system from the outside electric network source, it will Improve fuel economy performance [4]. SHEB, as defined in this paper, is shown in Figure 1. The ISG motor in SHEB is more powerful than other structures and is more conducive to the recovery of braking energy. Since the motor has the natural characteristics of high

Liang Fang, Tianjin Vocational Institute, Tianjin, China
Figure 1. The structure of SHEB.

| TABLE I. THE PARAMETERS OF TRADITIONAL BUS. |
|--------------------------------------------|
| Parameter type                            | Value      |
| vehicle mass                              | 10000kg    |
| Length × width × height                    | 11600×2580×3000 |
| Tyre rolling radius                        | 0.52m      |
| Final ratio                                | 6.3        |
| Maximum gradeability                       | 20°        |
| Transmission efficiency                    | 0.9        |
| Drag coefficient                           | 0.62       |
| Maximum speed                              | 80km/h     |
| Rolling resistance coefficient             | 0.01       |

| TABLE II. THE PERFORMANCE OBJECTIVES OF SHEB. |
|----------------------------------------------|
| Performance Requirements | Value        |
| Maximum speed               | 80 km/h      |
| Maximum gradeability        | Not less than 20° |
| 0 ~ 50 km/h accelerate time | No more than 16 s |

Torque output during low speed operation, this characteristic can satisfy the acceleration function of the vehicle.

In this paper, a traditional bus is used as the prototype, and its structural parameters are shown in Table I, and the SHEB matching design is made on the premise of keeping the original car structure as far as possible. The target parameters of SHEB are shown in Table II.

PARAMETERS DESIGN OF SHEB

Engine Selection

Maximum engine power ($P_{emax}$) should meet the vehicle's highest speed ($V_m$) requirement. We can calculate $P_{emax}$ through the formula below. $f$ stands for rolling resistance coefficient; $C_d$ stands for drag coefficient; $m$ stands for vehicle mass; $\eta_t$ stands for transmission efficiency; $A$ stands for frontal area. $\eta_a$ stands for attachment consumption rate and take 0.15 in this paper. $g$ stands for gravity acceleration, 9.8 m/s$^2$. After calculation, $P_{emax}$=66.6kw. After a comprehensive analysis, a certain power of 70kw diesel engine is selected to match SHEB, which weighs 300kg. And its performance parameters have been entered into M file of ADVISOR.

$$P_{emax} = \frac{1}{3600\eta(1-\eta_a)} \left( mgf + \frac{C_d A v_m^2}{21.15} \right) v_m$$  (1)
Generator selection

The type of generator should be consistent with the engine work, and has high efficiency and power density. Its peak power meets formula (2). \( \eta_g \) means efficiency of generator, \( \eta_g \) takes 0.9. We calculate that \( P_{g_{\max}} = 63 \text{kw} \).

\[
P_{g_{\max}} = \eta_g P_{e_{\max}}
\] (2)

Motor Selection

The selection of the motor should be considered in three aspects: the maximum vehicle speed power demand, the climbing power demand and the acceleration power demand.

Maximum speed power demand\( (P_1) \):

\[
P_1 = \frac{1}{3600 \eta_g} \left( m g f + \frac{C_p A v_c^2}{21.15} \right) v_m = 56.6 \text{KW}
\] (3)

Climbing power demand\( (P_2) \):

\[
P_2 = \frac{1}{3600 \eta_g} \left( m g f \cos \alpha_m + m g \sin \alpha_m + \frac{C_p A u_c^2}{21.15} \right) u_b
\] (4)

\( u_b \) stands for climbing at a constant speed and its value is 10km/h. \( \alpha_m \) means Maximum gradeability and \( \alpha_m = 20^\circ \). It is calculated that \( P_2 = 106 \text{kw} \).

acceleration power demand\( (P_3) \):

\[
P_3 = \frac{1}{3600 \eta_g} \left( \delta m u_c^2 + \frac{m g f u_c t_1}{2 \sqrt{t_1}} + \frac{C_p A u_c^2 t_1}{21.15 \times 2.5} \right)
\] (5)

In the formula (5), \( u_1 = 50 \text{km/h}; t_1 = 16 \text{s}; \delta = 1.04 \). We gained \( P_3 = 107.4 \text{kw} \).

The peak power\( (P_j) \) of the motor should be taken as the maximum of the three, and This paper selects three ac asynchronous motors and \( P_j \) is set as 110kw. The rated power\( (P_k) \) meets the formula: \( P_k = P_j/\lambda \). \( \lambda \) is the motor overload factor, and \( \lambda \) is equal to 2. The value of \( P_k \) is 55kw. In addition, the rated voltage of hybrid bus motor is approximately 300V~600V, and its maximum torque is 300Nm and the rated torque is 150Nm.

POWER BATTERY PARAMETERS MATCH

Two types of Power battery assembly can usually be used in the design: "first parallel then series", "first series then parallel"[5]. In order to prolong the service life of battery, improve reliability and reduce the probability of failure, this paper chooses "first parallel then series "type. The number of batteries should meet the following formula. \( P_{\text{mmmax}} \) means the output power of the Power battery at the lowest value of SOC. \( \text{E}_{\text{bat}} \) means single cell voltage and 12V is chosen. The battery internal resistance is \( R_{\text{bat}} \). 0.02Ω. \( \eta_{mc} \) means motor efficiency, 0.9. Based on the calculation above, 50Ah cell capacity is selected and the cell number is set as 50.
\[ n = \frac{P_{\text{max}}}{4E_2/(9R_{\text{rat}})} \eta_{m}(1-\eta_c) \quad (6) \]

**Selection of Transmission**

The maximum transmission (\(i_{hi}\)) ratio and minimum transmission ratio (\(i_{lo}\)) should satisfy the following formula (7) and formula (8) when SHEB is working normally. \(n_{mc\text{max}}\) means Maximum speed of motor and \(n_{mc\text{max}}=10000\text{r/min}\. \\
\[ i_{lo} \leq \frac{0.377r \cdot n_{mc\text{max}}}{i_0 \cdot v_{\text{max}}} \quad (7) \]

\[ i_{hi} \geq \frac{G(f \cos \alpha_{\text{max}} + \sin \alpha_{\text{max}})r}{T_{tg_{\text{max}}}i_0\eta_t} \quad (8) \]

The parameter values mentioned above are substituted into the formula, and it can be calculated that \(i_{lo} \leq 3.9, i_{hi} \geq 10.5\). The ratio of adjacent gear of transmission should not be greater than 1.7~1.8, so the transmission ratio of four gears is adopted and the transmission ratio is 11, 6.2, 3.7, 2.4.

**SHEB CONTROL STRATEGY**

SHEV's control strategy mainly includes thermostat and power follower [6]. In order to have the optimal performance of the whole power system, the integrated control strategy combining two control strategies is adopted. The control strategy is shown in Figure 2. The key parameters in the M file are modified as follows:

\[ \text{cs\_hi\_soc}=0.8; \text{cs\_lo\_soc}=0.4; \]
\[ \text{cs\_min\_pwr}=\text{fc\_map\_spd}\cdot\text{fc\_map\_trq}\cdot.45; \]
\[ \text{cs\_max\_pwr}=\text{fc\_map\_spd}\cdot\text{fc\_max\_trq}\cdot.65; \]

![Figure 2. Integrated control strategy model.](image-url)
### TABLE III. PERFORMANCE OF SHEB COMPARED WITH TRADITIONAL BUS.

| Acceleration time (s) | Type of vehicle in the test | SHEB | Traditional bus |
|-----------------------|----------------------------|------|-----------------|
| 0-20km/h             |                            | 3    | 4               |
| 0-50km/h             |                            | 7.1  | 8               |
| maximum speed (km/h) |                            | 89.4 | 85              |
| maximum gradeability |                            | 16.6%| 20%             |
| Fuel consumption of CYC_UDDS (L/100km) | | 31   | 36              |

### CONCLUSION

At last, we input the above SHEB parameters into ADVISOR and modify the M file and set the GUI interface parameters, for example: the cycle condition selects CYC_UDDS recurring condition, the number of cycles is 3, and the initial value of SOC is 0.8. The performance simulation results are shown in Figure 3 and Table III.

The results show that compared with the traditional bus, although SHEB has decreased the ability to climb the slope, the acceleration performance and the maximum speed have been improved, which can fully meet the operation of urban traffic. And SHEB's fuel economy performance has improved considerably compared with traditional bus.

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