Parameter Design and Simulation Analysis of Power System in Plug-in hybrid vehicle

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Abstract. According to power system’s demands of plug-in hybrid vehicles, though design theory of hybrid vehicles, the parameters of motor, transmission system, engine-generator set and battery other subsystem are designed, and the model of power system is established and simulation analysis is performed using AVL-CRUISE software, simulation results show that all parameters designed can satisfy working demand under the NEDC, so design is very reasonable, which lays foundation for the plug-in hybrid vehicle’s development.

1. Introduction

Compared with ordinary hybrid vehicle, the plug-in hybrid vehicle can be charged at working, and also be charged using a outlet, it can running longer only by battery, particularly daily commute distance, plug-in hybrid vehicle can work in pure electrotpe. The internal combustion engine can provide additional power at the long distance travel, plug-in hybrid vehicle can use alternative fuel as full as possible, in the new energy vehicle it is with wide prospect. Contrasting the traditional engine vehicles, plug-in hybrid vehicle has engine-generator set, motor, power battery and many other systems, at early stage of plug-in hybrid vehicle, power, through the accurately designing parameters of power system, coordinating and matching subsystem performance, reliability and economy of plug-in hybrid vehicle can be greatly improved.

2. Performance parameters requirements OF Vehicle

Dynamic property of electric vehicles can be comparable with conventional vehicle, because of the constant development of the motor, battery, transmission and control technology. Combining electric vehicle’s performance characteristics, according to demand of vehicle performances, basic parameters and vehicle performance index of plug-in hybrid vehicle are shown in Table 1 and Table 2.

Table 1 Parameters of plug-in hybrid vehicle

| Name of parameters | Values     |
|--------------------|------------|
| Gross Mass         | 1580(kg)   |
| Kerb mass          | 1200(kg)   |
Wheel base
Frontal area
Centroid height
Drag coefficient
Rolling resistance coefficient
Static radius
Dynamic radius

| Performance demand               | Items                          | Index  |
|----------------------------------|-------------------------------|--------|
| Speed demand                     | Max-speed, 0~50km/h, 50~80km/h|        |
| Acceleration performance         |                               |        |
| Climbing slope performance       | Max-speed at 4% slop, Max-speed at 12% slop, Maximum gradeability |        |

3. Parameter design of dynamic system

3.1 Parameter design of motor

The maximum speed, acceleration and climbing of plug-in hybrid vehicle can be calculated through formula (1), formula (2) and formula (3).

\[
P_{e1} = \frac{1}{\eta_T} \left( \frac{mgfu_a}{3600} + \frac{C_D A u_a^3}{21.15 \times 3600} \right) \quad (1)
\]

\[
P_{e2} = \frac{1}{\eta_T} \left( \frac{mgfu_a}{3600} + \frac{C_D A u_a^3}{21.15} + \delta m u_a \frac{du}{dt} \right) \quad (2)
\]

\[
P_{e3} = \frac{1}{\eta_T} \left( mg \cos \alpha u_a + \frac{C_D A u_a^3}{21.15} + m g u_a \sin \alpha \right) \quad (3)
\]

In the formula, \( m \) is full-load quality, \( \eta_T \) is driveline efficiency, \( f \) is rolling resistance coefficient, \( C_D \) is air resistance coefficient, \( A \) is frontal area, \( u_a \) is the maximum speed, \( v \) is the speed, \( \alpha \) is climbing angle, \( \delta \) is moment of inertia conversion coefficient.

Table 3 Estimated value of peak power of motor

| Performance demand | Power of Motor |
|--------------------|----------------|
| Max-speed \( v_{max} \geq 120 \text{ km/h} \) | 20.88 kW |
Acceleration performance of 0~50km/h ≤ 7s 49.3 kW

Acceleration performance of 50~80km/h ≤ 8s 38.6 kW

Max steady speed at 4% slope ≥ 70 km/h 19.85 kW

Max steady speed at 12% slope ≥ 40 m/h 24.93 kW

Max steady speed at 20% slope ≥ 5 km/h 4.83 kW

The max power requirement which are estimated are shown in Table 3, though formula (1), formula (2) and formula (3).

To satisfy the power performance of plug-in hybrid vehicle, drive motor’s rated power must satisfy the needs of the max-speed, the peak power must satisfy the needs of acceleration performance. In Table 3, the rated power of motor is more than 20.88 kW, peak power is more than 49.3 kW, so the rated power should be taken as 25 kW, peak power of motor is taken as 50 kW.

Permanent magnet motor possesses the advantage of high power density and high efficiency, its working voltage is between 100V and 400V, maximum rotational speed is between 4000 and 10000r/min, the constant power factor is 2.25, so permanent magnet synchronous motor is adopted, the parameter of permanent magnet synchronous motor designed is shown in Table 4.

| Table 4 Motor’s Parameters |
|----------------------------|
| Parameter                  | Values       |
| Rated power                | 25 kW        |
| Overloading coefficient    | 2            |
| Motor voltage              | 324V         |
| Base speed                 | 3000rpm      |
| Peak torque                | 160Nm        |
| Peak speed                 | 8000rpm      |
| Peak power                 | 50 kW        |

3.2 Parameters calculation of engine-generator set

If with sufficient electric quantity, plug-in hybrid vehicle will switch off engine, preferentially uses electricity, when power battery’s electricity quantity declines to the certain extent, power battery can not continue to supply electrical, power provided by battery can not satisfy need of vehicle, the engine-generator set starts run for providing electricity power to satisfy need of vehicle.

In order to ensure battery’s safety, reduce the discharge or charge times of battery, on design, generator begins working, also it can meet the demand of peak power when the charge quantity of battery is less 40%. Engine-generator set designed does not only satisfy need of the peak power, but also satisfy engine-generator running located at efficient district. Based on the analysis and matching work areas, parameters of engine-generator set calculated are shown in Table 5.

| Table 5 Parameters calculated of engine-generator set |
|------------------------------------------------------|
| Engine                                               |
| Max rotational speed                                 | 6000rpm |
| Generator                                           |
| Max rotational speed                                 | 6000rpm |
Max torque / 115Nm  Voltage  324
Max power  62kW  Max power  50 kW
Displacement  1.5L  Peak torque  160Nm
Max speed  4500rpm

### 3.3 Parameters design of power battery

The pure electricity endurance distance has great influence to application performance of plug-in hybrid vehicle, pure electricity endurance distance is distance of driving when battery is charged fully, does not rely on engine recharging. Battery’s rated capacity should be counted by formula 4.

\[
W_0 = \frac{P_S}{0.7v_n}. \tag{4}
\]

In formula 4, \(W_0\) is total battery’s rated energy, \(P_S\) is motor power when velocity is \(v\), \(S\) is driving distance when velocity is \(v\). \(Q\) is Rated capacity, \(Q\) should meets formula 5.

\[
Q = \frac{W_0}{U_B}. \tag{5}
\]

In formula 5, \(Q\) is battery’s rated capacity, \(U_B\) is voltage.

The plug-in hybrid is demanded driving 90km and the velocity is 40km/h using pure electric in design, according to the formula 4, battery capacity is 10.39kwh. According to formula 5, the battery rated capacity is taken as 32.07Ah.

### 3.4 Design of Transmission System

According to the requirement, speed ratio needs to meet need of maximum grade-ability, and it ensures the desired max-speed. Transmission ratio must satisfy the formula 6 and formula 7.

\[
i_0 \geq \frac{mg(f \cos \alpha_{max} + \sin \alpha_{max})r}{T_{max}\eta_i}. \tag{6}
\]

\[
i_0 \leq \frac{0.377n_{max}r}{v_{max}}. \tag{7}
\]

In formula, \(i_0\) is transmission’s speed ratio, \(r\) is the rolling radius of wheel, \(T_{max}\) is motor’s peak torque, \(n_{max}\) is maximum evolution speed of motor., the \(i_0\) is chosen as 7.05 in design.

### 4. Simulation Analysis

![Figure 1. Under condition on NEDC](image-url)
Figure 2. Running curve of motor

Figure 3. Running curve of engine

Figure 4. Battery’s working curve

Table 6 Simulation result of power performance

| Performance demands       | Items            | Simulation results | Reference scope |
|---------------------------|------------------|--------------------|-----------------|
| Speed demand              | Max-speed        | 128 km/h           | ≥120 km/h       |
| Acceleration performance  | 0~50km/h         | 6.6s               | ≤7s             |
|                           | 50~80km/h        | 5.82s              | ≤8s             |
| Climbing clop performance | Maxi-speed at 4% slop | 128 km/h           | ≥70 km/h        |
| Parameter                  | Value 1          | Value 2          |
|---------------------------|------------------|------------------|
| Max-speed at 12% slope     | 83 km/h          | ≥40 km/h         |
| Max gradeability          | 23.8%            | ≥20%             |

In order to prove the feasibility of the design, power system of plug-in hybrid vehicle is simulated in AVL-CRUISE software, the simulation results are shown in Figure 1, Figure 2, Figure 3 and Figure 4 under condition of NEDC.

From Figure 1, Figure 2, Figure 3 to Figure 4, it can be seen, total distance is 10.93 km under condition of NEDC, and duration time is up to 1179.8 s, max-speed is up to 120.5 km/h, max acceleration is 1.46 m/s², max deceleration is -0.953 m/s². The motor works between 2000 rpm and 7500 rpm at the most time, in the beginning the SOC of battery is 60%, from beginning to 1100 seconds, the SOC is approaching 43%, the engine-generator set starts running automatically, providing power for motor to maintain normal driving of plug-in hybrid vehicle, meanwhile charging for battery. From Table 6, It can be seen that the max-speed of plug-in hybrid vehicle is 128 km/h, acceleration time of the plug-in hybrid vehicle is 6.6 s from 0 to 50 km/h, acceleration time the plug-in hybrid vehicle is 5.82 s from 50 to 80 km/h, maximum grade-ability is up to 23.8%, and power parameters designed satisfy design demand.

5. Conclusion

On the basis of index of plug-in hybrid vehicle, through calculation, the parameters of drive motor, parameters of engine-generator set, parameters of battery, parameters of transmission system and other systems are designed, the model of plug-in hybrid vehicle is built in AVL-CRUISE software, though simulation, power performance under NEDC condition is obtained. Simulation result shows that the plug-in hybrid vehicle designed can satisfy running requirements under NEDC condition, while max-speed, climbing slope performance, acceleration performance satisfy design demands, all parameters designed of motor, engine-generator set, drive battery, transmission and other systems are reasonable, that lay the foundations for development and progress of plug-in hybrid.

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