Research on parameters matching and optimization method of power transmission system for electric logistics vehicle

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Abstract. As a main way of logistics transportation, electric logistics vehicle is beneficial to logistics industry and save energy. Parameters matching and optimization method of power transmission system for electric logistics vehicle is studied in this article. Data processing rules and principles are created for CHTC-LT working condition. Working condition and genetic algorithm are used for parameters matching and transmission ratio optimization of power transmission system. Driving range of electric logistics vehicle could be improved.

1. Introduction

With development of logistics industry, electric logistics vehicle market is growing rapidly. However, under the current global situation, energy shortages and environmental pollution problems are severe. Electric logistics vehicle is equipped with integrated power transmission systems and intelligent control systems, which make it have good working characteristics and high efficiency. Therefore, electric logistics vehicle is highly concerned by governments and enterprises, which becomes one of the inevitable trends in the development of logistics industry.

Parameters matching for power transmission system is the key method of electric logistics vehicle [1]. Some researches are based on vehicle dynamics [2], some are based on working condition. Working condition method was applied to electric vehicle design as early as 2002. NEDC working condition method is used to match power range of drive motor [3]. Genetic algorithm is used for transmission ratio optimization through operations such as selection, crossover, mutation, and recombination [4]. Genetic algorithm is used to determine optimal transmission ratio of single-speed and double-speed electric vehicle [5].

Actual road condition can be reflected by urban cycle test of working condition. Development of electric logistics vehicle is to meet requirements of point policy in next five years. Therefore, CHTC-LT working condition is one of the Truck Driving Condition proposed in 2020. Transmission ratio optimization method is also studied.
2. Parameters matching and optimization method of power transmission system

In order to increase driving range, parameters matching and optimization methods of power transmission system for electric logistics vehicle are studied. Firstly, CHTC-LT working condition method is proposed to match parameters of power system, including data processing for CHTC-LT working condition, parameters matching for drive motor and battery. Secondly, genetic algorithm is used to optimize transmission ratio. Vehicle model and co-simulation model for transmission ratio are created. Results of transmission ratio optimization are obtained.

2.1. Parameters matching of power transmission system by CHTC-LT working condition method

2.1.1. Data processing for CHTC-LT working condition

According to the definition of national standard, acceleration value is selected as the critical. Referring to NEDC working condition, data processing rules are formulated as follows:

1. If acceleration value is greater than or equal to 0.15 m/s², original acceleration value is retained;
2. If acceleration value is less than or equal to -0.15 m/s², original acceleration value is retained;
3. If acceleration value is greater than -0.15 m/s² and less than 0.15 m/s², acceleration is 0;

As the operating states data need to be determined, data processing principles are formulated as follows:

1. When speed is 0 and acceleration is 0, it is defined as stop state;
2. When acceleration is greater than 0 and speed continues to increase, it is defined as acceleration state;
3. When acceleration is less than 0 and speed continues to decrease, it is defined as deceleration state;
4. When acceleration is alternately set to 0 and speed fluctuates up and down at a certain value, it is defined as constant speed state;
5. Data should be assigned to later working condition after ensuring regularity of previous working condition;
6. When speed fluctuates and acceleration is 0, it is defined as constant speed state and the speed changes are ignored.

2.1.2. Parameters matching for drive motor

Power $P_{ds}$ of drive motor under constant speed $V_0$ is calculated according to formula (1).

$$P_{ds} = \left( mgV_d + \frac{cw \cdot A \cdot \rho \cdot \dot{V}_d}{21.25} \right) / 3600\eta$$

Power $P_{js}$ of drive motor under acceleration/deceleration $a_i$ is calculated according to formula (2).

$$P_{js} = \left( mgV_i + \frac{cw \cdot A \cdot \rho \cdot \dot{V}_i}{21.25 + \delta ma_i} \right) / 3600\eta$$

Thus, maximum drive motor power can be obtained by calculating drive motor power under each operation states under CHTC-LT drive condition.

Rated speed $n_d$ of drive motor is calculated by formula (3).

$$n_d = n_{d \text{max}} / \lambda$$

Rated torque $T_d$ and $T_{d\text{max}}$ are calculated by formula (4) and (5).

$$T_d = 9550P_d / n_d$$

$$T_{d\text{max}} = 9550P_{d\text{max}} / n_d$$

2.1.3. Parameters matching for battery

Battery capacity is calculated based on parameters obtained by CHTC-LT working condition method. Rated voltage of battery pack is determined. Number of battery cells is determined according to rated voltage and single battery voltage. In parking condition, power and battery capacity demand are 0. If deceleration condition is ignored, battery capacity calculation only needs to consider acceleration and constant speed condition.
Required energy $C_{ds}$ at constant speed condition is calculated by formula (6).

$$C_{ds} = P_{ds}t_{ds} / 3.6U$$

Required energy $C_{js}$ at constant speed condition is calculated by formula (7).

$$C_{js} = P_{js}t_{js} / 3.6U$$

Number of battery cells $N$ is calculated by formula (8).

$$N = U_p / U_c$$

Total required energy $W_C$ for CHTC-LT driving condition is calculated by formula (9).

$$W_C = W_{CT} T / 3600$$

Total required energy $W_T$ of battery is calculated by formula (10).

$$W_T = W_C \times 150 \text{km} / 15.88 \text{km}$$

According to formula (7)-(10), battery capacity $Q$ is finally obtained by formula (11).

$$Q = W_T / V_p$$

### 2.2. Transmission ratio optimization based on genetic algorithm

Genetic algorithm is used to optimize parameters of power transmission system in Figure 1.

Figure 1 Transmission ratio optimization method based on multi-island genetic algorithm

(1) Objectives and constraints

Driving range is regarded as objective function for transmission ratio optimization. Driving range is an economic indicator, so dynamic indicators such as maximum speed are selected as constraints.

(2) Range of variables

Under average speed of CHTC-LT working condition, maximum torque is obtained by formula (5). Lower limit of first gear transmission ratio is calculated according to maximum climbing ability. Upper limit of first gear transmission ratio is obtained by considering road condition. Lower limit of second gear transmission ratio is determined by maximum speed and torque-speed characteristics of drive motor. Upper limit of second gear transmission ratio is calculated by ability of drive motor to overcome rolling and air resistance at highest speed. Third gear transmission ratio is set to 4 based on experience.

### 3. Results of parameters matching and transmission ratio optimization

#### 3.1. Results of parameters matching for power system

#### 3.1.1. Results of data processing under CHTC-LT working condition

If it is specified that the maximum gradeability of electric logistics vehicle at average speed of CHTC-LT working condition is not less than 20%, according to data processing rules, parameters of urban working condition are obtained. Total time of CHTC-LT urban working condition is 309 s, which is occupied by parking, accelerating, decelerating, constant speed condition. Parking condition time is 87 s and accounts for 28%. Accelerating condition time is 65 s and accounts for 21%. Decelerating
condition time is 66 s and accounts for 21%. Constant speed condition time is 91 s and accounts for 29%. Parameters of suburban and high-speed working condition can be obtained by referring to urban working condition.

3.1.2. Results of data processing for drive motor

Power demand is obtained according to parameters matching method of drive motor. Power demand diagram of electric logistics vehicle under CHTC-LT working condition is drawn in Figure 2.

![Power demand diagram under CHTC-LT cycle working condition](image)

The maximum power value is 92 kW at 1400 s in CHTC-LT working condition. If acceleration time from 0 to 50 km/h is less than 7.5 s, power is calculated according to parameters matching method. Value of parameters are as follows: \( V_t \) is 50 km/h, \( a_t \) is 8 m/s\(^2\), \( P_{js} \) is calculated by formula (2) whose value is 100 kW, \( \lambda \) is 2, \( P_{ds} \) is calculated by formula (1) whose value is 50 kW, \( n_{Max} \) is 6000 r/min, \( n_d \) is calculated by formula (3) whose value is 3000 r/min, \( U \) is 380 V. Thus, parameters of permanent magnet synchronous motor are selected as follows: \( P_d \) is 50 kW, \( P_{dmax} \) is 100 kW, \( n_d \) is 3000 r/min, \( n_{dmax} \) is 6000 r/min.

3.1.3. Results of data processing for battery

CHTC-LT urban working condition parameters and battery capacity are calculated according to parameters matching method of battery. Total capacity of battery is obtained by calculating each battery capacity under urban, constant speed, acceleration condition whose value is 1 Aꞏh. Braking energy recovery is considered in deceleration condition. Energy recovery rate is set to 20%. Calculation results of battery capacity under urban deceleration condition is 0 Aꞏh. Thus, battery capacity under urban condition is 1 Aꞏh by summing up battery capacity under deceleration, constant speed and acceleration condition. Battery capacity under suburban and high-speed condition can be determined by referring to urban condition and whose calculation results are 8 Aꞏh and 10 Aꞏh respectively. Battery capacity diagram under CHTC-LT drive condition is drawn in Figure 3 based on calculation results.

Total capacity of battery is 18 Aꞏh in complete CHTC-LT cycle. If driving range is 150 km and ternary lithium battery is chosen as power source. \( U_p \) is 380 V and \( U_c \) is 3.6 V. \( N \) is calculated according to formula (8) and value is 106. \( V_s \) is 35 km/h, \( T \) is 1652 s, and \( W_{CHTC-LT} \) is calculated by formula (9) and value is 4 kWh. Mileage of complete CHTC-LT working condition is 16 km, the \( W_{Total} \) is calculated by formula (10) and value is 42 kWh. \( Q \) is calculated by formula (11) and value is 111 Aꞏh.
3.2. Simulation results of transmission ratio optimization

3.2.1. Vehicle model based on ADVIOSR
Vehicle parameters are set and script file of vehicle model is modified according to parameters matching results of power transmission system. Vehicle model is shown in Figure 4. CHTC-LT cycle working condition is introduced into vehicle working condition module. New sub-file of cycle working condition is built based on CHTC-LT cycle working condition. Sub-file is called back by vehicle model.

![Vehicle model](image)

Figure 4 Vehicle model

3.2.2. Co-simulation model
ADVISOR-Isight co-simulation model is established for transmission ratio optimization. Function modules include method module, vehicle model module, input and output module, and results module. Co-simulation model is shown in Figure 5.
3.2.3. Results of transmission ratio optimization
Parameters of genetic algorithm module are set as follows. The number of sub-islands is 2. Island individuals number under sub-islands is 10. Evolution generation is 10. Total evolution generation is the product of above three parameters. Total generation is 200. Inter-island migration rate is 1.0. Inter-island crossover rate and mutation rate are both 0.01. Initial values of first, second, third gears before optimization are 9.6, 7.2, 4 respectively. Variable range is set in transmission ratio optimization module. Upper and lower limits of first gear are 9 and 15. Upper and lower limits of second gear are 4 and 7.5. Equivalent fuel consumption is selected as target value of optimization results module. Optimization process is shown in Figure 6 and 7.

The Optimal value is obtained in the 99th generation after optimization. The first, second, third gear ratio are 14.8, 6.08, 4 respectively. Transmission ratios before and after optimization are input into vehicle model. Driving range before and after optimization are 120 km and 126 km under CHTC-LT cycle working condition, which is increased by 5%. Driving range before and after optimization are 83 km and 89 km under constant speed working condition, which is increased by 6%.

4. Conclusions
Parameters matching and optimization method of power transmission system for electric logistics vehicle is studied. Data processing method of CHTC-LT working condition is proposed. Working condition method is adopted to match power transmission system. Transmission ratio optimization method is proposed based on the results of parameters matching for power system. The driving range of electric logistics vehicle could be improved.
Acknowledgments
This article is supported by Key Projects of Jilin Province Science and Method Development Plan. (20180201060GX).

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