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Parameter Matching Strategy of Electric Vehicle Based on Genetic Algorithm

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Storage battery's thin energy density has directly restricted the industrial development of electric vehicles, the pivotal parameters have been matching based on the theoretical analysis of circulating operation, and combined with genetic algorithm's superior ability, the peak power of motor and ratio of transmission have been optimized with the consideration of dynamic restriction. The results show that the optimized parameter can lead the automobile' driving mileage to increase 18.78% on the basic dynamic requirement of national standard.

1. Introduction

Electric vehicle refers to the motor-driven vehicle that can meet the requirements of the road safety regulations for automobile with the vehicle power supply as the driving force (Martin Noel and Khaled Soudkil (2014), Yezheng Fan (2015)). Compared with the traditional fuel vehicle, its drive system can improve the energy utilization rate, achieve zero emissions and maximizes the elimination of the impact of automobile exhaust on human living environment (Andrea Massaro and Ernesto Benini (2015), Minhhuy Le et al (2013)).
For the transmission system of electric vehicle, the motor and battery system are critical parts (George H.R. Costa and Fabiano Baldo (2015), Stratis Kanarachos and Andreas Kanarachos (2015)). The motor itself possesses excellent governor control characteristics. the kinetic energy of vehicles during the downhill or moderating process can be stored in the battery through the way of recovering the braking, so as to enhance the efficient use of energy (Wang Cuiping (2015), Gang Li et al (2013)). However, domestic studies now mostly focus on the model and parameter design of the motor itself, hoping to increase the market acceptance of electric vehicles (Nariman A. Khalil et al (2015), Hao-Chun Lua and Yao-Huei Huang (2015)).
However, the driving range becomes a major factor restricting the industrialization of the electric vehicles before the key breakthrough of storage battery technology (LI Yu et al (2015), Panwar M (2012)). This paper, on the strength of theoretical analysis, describes the basis for the parameter selection of important parts of transmission system, and optimizes the motor characteristic parameters and transmission ratio with the genetic algorithm, aimed at improving the driving mileage of electric vehicle on the basis of ensuring the automobile dynamic performance (Jiangyang Li and Zhenming Peng (2015), Song un and Chen Fuyan (2015)). At the end of the paper, the effectiveness of methods proposed is verified by means of simulation software, and the results show that the parameter matching strategy based on the genetic algorithm has significant theoretical meaning (Tingfang Zhang and Zhiquan Feng (2013), Chengfeng Jian et al (2015)).

2. Parameter matching of transmission components

The power transmission system of electric vehicle studied in this paper mainly includes the power storage battery, drive motor, transmission and control system, as shown in Figure 1.

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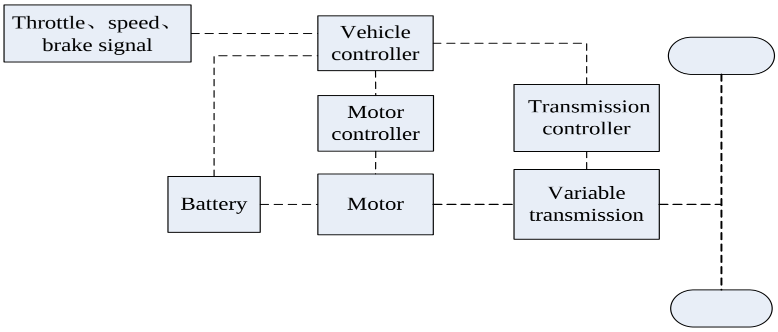


Figure 1: Transmission System Schematic Diagram

2.1 Parameter design requirements of electric vehicle

The parameter matching of transmission system of electric vehicle must be in accordance with national standards of People's Republic of China. For pure electric vehicles, the performance parameter includes the dynamic performance and economy of the vehicle. Therein, the parameter of dynamic performance is mainly reflected by the maximum speed, maximum gradability, and the acceleration time of 0-50 km/h and 50-80 km/h; and the economy can be verified through the driving mileage.

Relevant structural parameters and performance requirements can be obtained by referring to GB/T 18386, as shown in Table 1:

Table 1: Main Technical Parameters of Electric Vehicle

	Parameter	Vehicle Characteristics
Parameter of dynamic performance	Maximum speed (km/h)	≥120
	Maximum gradability (%)	≥25
	0-50 km·h^{-1} acceleration time (s)	≤5
Parameters of economy	Driving mileage under working conditions (km)	≥100

2.2 Motor rated power matching

The operating characteristics of motor must meet following conditions: 1) ensure the load points in the vehicle's driving characteristics to drop in the high-efficient operation region as far as possible; 2) need to provide instant large torque at the starting, accelerating and other unsteady states of vehicles; 3) ensure the vehicle to maintain constant power output at high speed.

With the NEDC cyclic operation state as the research object, the power in the working conditions can be subdivided with 2 kW as the section interval, and the following formula can be obtained:

$$freq_i = \frac{N_i}{N_a}, \qquad i = 1,2,3 \cdots k \tag{1}$$

Where, k is the number of load power sections; freqi is the frequency of the i-th load power section in the entire state of cyclic operation; Ni is the sum of the frequency of various load power points appearing in the i-th load power section throughout the entire process; Na is the sum of the frequency of all load power points in the state of cyclic operation.

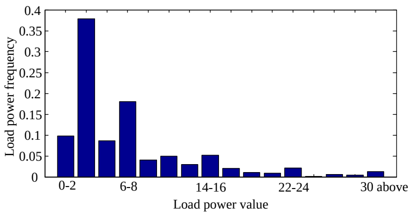


Figure 2: Load Distribution of NEDC Cyclic Operation State

Figure 2 shows that the power is mostly concentrated in the small and medium stage. Only from the viewpoint of economy, the motor rated power should be equivalent to the power (2 KW) with the highest frequency. And considering the requirements of stand-by power, the weighted sum of various power sections can be regarded as the rated power of the motor as follows:

$$P_e = \sum a_i Max(P_i) \tag{2}$$

Where ai=freqi; Pe is the motor rated power; Pi is the power of the i-th load power section; and ai is the weight of the i-th load power section.
The motor rated power calculated from the equation (2) is 11 kW. The 12 kW is selected as the motor rated power in order to meet the cyclic common speed requirements of the urban area and have some reserve power.

2.3 Parameter matching of battery pack

The total voltage of the battery pack is the series voltage value of several battery modules, decides the number of the battery modules. When matching, the voltage of battery pack should be able to ensure the rated working voltage of all electric equipment of the vehicle, but should not be too large. Then:

$$U_B = U_m + \frac{(P_m + \Delta P)R}{U_m} \tag{3}$$

Where, UB is the battery voltage, V; Um is the motor rated voltage, V; Pm is the peak power of motor, w; ΔP is the power of accessories which can take the value of 1.5 times the motor rated power of selected air-conditioner, w; and R is the internal resistance of battery, and here take the value of 0.18Ω.
On the basis of determining the voltage of battery pack (192V), the following equation can be obtained in order to meet the design requirements of driving mileage:

$$C = \frac{1000(E_{cyc} S / L + E_{ac})}{U_B} \tag{4}$$

Where, C is the battery capacity; E is the cyclic energy consumption of 100 kilometers of the vehicle, kwh; Ecyc is the energy consumption of the cyclic operation state, kwh; Eac is the accessories energy consumption of 100 kilometers of the vehicle, kwh; S is the required driving mileage, km; and L is the distance of the cyclic operation state, km.

3. Optional matching strategy of genetic algorithm

3.1 Optimizing process of genetic algorithm

When the combination is optimizing, the genetic algorithm has following general characteristics for the optimizing process of all physical models: that is, first select a set of feasible solutions, and calculate the fitness of the solutions according to the adaptive conditions set and make the selection in accordance with the survival of the fittest, and then make genetic manipulations similar to biological populations to the feasible solutions reserved; repeat above steps until the production of the optimal solution in the population.
Therein, the optimizing process of the genetic algorithm repeats the random search of population to obtain the optimal solution according to the genetic mechanism of the survival of the fittest until the termination of the cyclic condition. The whole process can be summarized as follows:
1) Initialization, including randomly generating meaningful populations and setting the maximum evolution algebra.
2) Individual evaluation, calculate the corresponding fitness of the individual in the population according to the responsive fitness function.
3) Select operation, select the individual with high fitness to inherit to the next generation based on the fitness evaluation of the individual in the population.
4) Crossover operation, crossover refers to replacing two parent feasible solutions to reorganize and generate new individuals according to a certain crossover probability.
5) Mutation operation, the variation means changing certain characteristic value of the individual in the population according to a certain probability.
6) The termination of conditional judgment, when the genetic algebra reaches the pre-set maximum evolution algebra, the optimizing process terminates, and the individual with the highest fitness during the evolution is taken as an optimal output.

3.2 Parameter optimization of transmission system based on genetic algorithm

The parameter matching optimization design of the vehicle power transmission system is the non-linear complex optimization problem of combined variable [10].
Based on the foregoing ideas, we might take the design variable X as mixed variables composed by peak torque of motor, rated speed, maximum speed, the speed ratio of the first and second gear; and the constrain

conditions are bilateral constraints. Considering that the evaluation function is characterized by including multiple indexes, the dimensionless method shall be implemented when setting the objective function.
1) Objective function: $Min F(X)$

$$F(X)=a_1[\frac{(T_m-T_{m,\min})}{(T_{m,\max}-T_{m,\min})}]^2+a_2[\frac{(n_m-n_{m,\min})}{(n_{m,\max}-n_{m,\min})}]^2 +a_3[\frac{(Dist-Dist_{\min})}{(Dist_{\max}-Dist_{\min})}]^2+a_4[\frac{(i_1-i_{1,\min})}{(i_{1,\max}-i_{1,\min})}]^2 +a_5[\frac{(i_2-i_{2,\min})}{(i_{2,\max}-i_{2,\min})}]^2 \quad (5)$$

$$Dist=\sum_{i=1}^{n}[\frac{(T_i-T_N)-Min(T_i-T_N)}{Max(T_i-T_N)-Min(T_i-T_N)}]^2+ [\frac{(n_i-n_N)-Min(n_i-n_N)}{Max(n_i-n_N)-Min(n_i-n_N)}]^2 \quad (6)$$

Where, n is the number of load points in the state of cyclic operation.
2) The constraint condition $G(X)$ is:

$$\begin{cases} G(X)\ge 0 \\ G(X)=[g_1,g_2,g_3,g_4,g_5,g_6,g_7,g_8] \\ g_1=t_{1,ub}-t_1(X);g_2=t_1(X)-t_{1,lb} \\ g_3=i_{ub}-i_{\max}(X);g_4=i_{\max}(X)-i_{lb} \\ g_5=u_{\max}(X)-u_{lb};g_6=u_{ub}-u_{\max}(X) \end{cases} \quad (7)$$

3) The design variable X is:

$$X=(T_m,n_N,n_m,i_1,i_2)^T \quad X\in[A,B] \quad (8)$$

Where, $A=(100,900,3500,8,4)$; $B=(200,4000,10000,15,7)$. $T_{m,min}$ is the maximum torque of motor; $T_{N\,,\,max}$ is the rated torque; $N_{N,\,min}$ is the rated speed; $n_{m,min}$ is the highest speed of engine; $i_{1,min}$ is the speed ratio of the first gear; $i_{2,min}$ is the speed ratio of the second gear; $t_{1,lb}$ is the acceleration time of 0-50 km•h^{-1}; i_{lb} is the maximum gradability of the first gear; u_{lb} is the maximum speed.
During the optimization, the crossover probability and mutation probability of 0.75 and 0.02 are taken, and the computational accuracy of 0.002 is taken and the genetic algebra is set as 400. The fitness function of the population is:

$$f_t(\mathrm{x})=C/F(\mathrm{x})+\mathrm{r}\,k\cdot\mathrm{G(x)} \quad (9)$$

Where, rk is a penalty factor, and C is a positive number with the same order of magnitude to the denominator.
Parameter optimization of the power transmission system is carried out according to above condition, and the optimal solution is obtained when the genetic algebra is 6, as shown in Table 2:

Table 2: Optimization Parameters of Transmission System

	Indicator	Parameter value	X_{opt}
	Base speed of motor / r·min^{-1}	2500	2475
	Maximum torque/ N·m	138	132
	Maximum speed/ r·min^{-1}	6000	6020
Transmission	Speed ratio of the first gear	8.55	8.35
	Speed ratio of the second gear	3.84	3.65

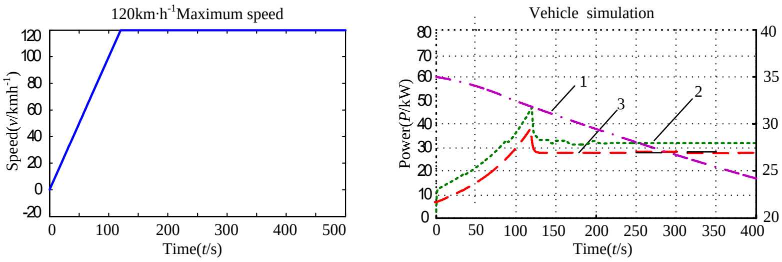
4. Analysis of simulation results

Based on MATLB software, the simulation results of maximum speed and maximum gradability is obtained by directly invoking nested motor module, battery module, transmission and the vehicle dynamic model and importing data of road conditions, as shown in Figure 3 as follows:
Figure 3(a) shows that when the optimized vehicle transmission system in this paper operates at a higher speed (120km·h-1), the SOC (State of Charge) value of the system linearly decreases to 23% from the initial 35%, which is in line with the setting of basic control strategies. It corresponds to the curve 2, that is, corresponding battery output power remains unchanged after increasing to a certain extent, in order to

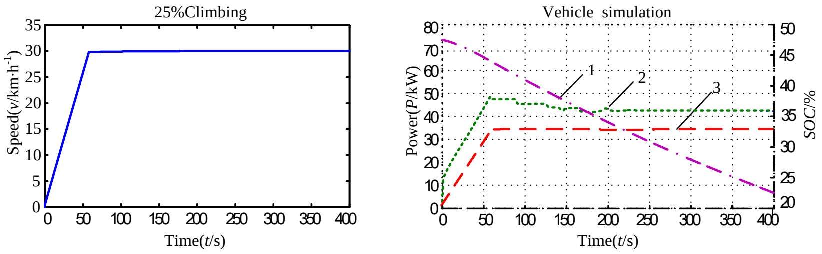
maintain the uniform working of the vehicle; and what the curve 3 shows just indicates that the output power of battery cannot be absolutely transmitted to the driving system. For example at 300s, the value of the former is 33 KW, but the power of driving system is only 28 KW, and the transmission efficiency is 85%.

In Figure 3(b), the SOC value decreases to 23% from the initial 75%, where the demand for charging electric vehicle should be satisfied as far as possible, in order to avoid the damage to the battery life due to the too low SOC value. The basic driving power of the output power and drive motor of battery are basically the same to Figure 3(a), and are 43 KW and 37 KW respectively, which satisfies the conversion efficiency of less than 100%.

The simulation results show that the vehicle can reach a predetermined target vehicle speed, indicating that the maximum power of the battery can well satisfy various demands of limiting conditions; the output power fluctuation of the battery is steady, that is, there is no excessive surplus power, justifying the reasonability and efficiency of the optimal matching strategy.



(a) Simulation of Maximum Speed



(b) Simulation of climbing

Figure 3: Simulation Results: 1. SOC of Battery Pack, 2. Output Power of Battery Pack, 3. Motor Output Power

5. Conclusions

1) The matching for the rated power of drive motor is carried out according to the distribution of load power of electric vehicle's given state of cyclic conditions; considering both the economy and power performance of the vehicle in limiting conditions, the optimization design of the motor peak power, speed, speed ratio of transmission system and other parameters is implemented in a wide range with the dynamic performance as the constraint condition and the genetic optimal algorithm as the means, in order to reduce the entire vehicle mass.

2) The features and processes of genetic algorithm are introduced briefly, and the parameter matching design of power transmission system is boiled down to the nonlinear programming class, and the problem is solved; through the simulation of matched parameter of transmission system in MATLAB/Simulink, the driving mileage of vehicle of 118.78km is obtained (greater than the national standard of 100), indicating that the optimization algorithm can well satisfy the design requirements of lengthening the operating range.

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