Research on Performance Optimization of Electric Vehicle Based on Multi-objective Immune Algorithm

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Abstract. Aiming at the shortage of power and economy of a pure electric vehicle, the multi-objective immune algorithm is adopted to optimize the power index and the economy index with the maximum speed, 0 ~ 50 km/h and 50 ~ 80 km/h acceleration time and climbing slope as the power index and the endurance mileage as the economy index. In this paper, the main reducer ratio, the first gear ratio and the second gear ratio of the transmission are taken as variables, the dynamic and economic equations are taken as objective functions, and the multi-objective immune algorithm is used to obtain the three variables and other parameters satisfying the optimization of the function. Through the use of pure electric vehicle simulation software ADVISOR to input the optimized matching parameters, select 0~80km/h and NEDC working conditions, and set the climbing and acceleration parameters, the simulation results show that: the maximum speed is increased by 22%, the acceleration time is increased by 5.8%, 21.4%, the climbing slope is increased by 22%, and the endurance mileage is increased by 3.1%.

1. Introduction

In the research of electric vehicle, the range, acceleration time and speed have always restricted the development of electric vehicle. Through the optimization of transmission ratio of electric vehicle transmission system and the matching of driving motor and battery parameters, it has become the main solution to improve the power performance and economy[1-2].

Taking the transmission speed ratio of electric vehicle as the optimization parameter, Based on the dual goals of power performance and economy, the immune algorithm is chosen as the optimization algorithm. Secondly, due to the optimization of multi-objective algorithm, the constraint problem is inevitably involved. In this paper, the penalty function method is adopted to better complete the processing of the constraint and transform it into an unconstrained problem. Finally, the obtained optimization variables and matching parameters were input into the electric vehicle simulation software. The results show that all the indicators have been improved after optimization, and the problems of power performance and economy of electric vehicles have been well solved.

2. Analysis of EV vehicle parameters and design requirements

The vehicle parameters, power performance and economic index requirements of the electric vehicle studied in this paper are shown in Table 1.

| Parameter               | Numerical |
|-------------------------|-----------|
| Curb weight / (kg)      | 1180      |
| Top speed / (km/h)      | 100       |


3. Power system parameter matching

3.1 Matching of driving motor parameters

Based on the comprehensive parameters and selection requirements, a permanent magnet brushless motor with rated speed of $n_{\text{r}} = 2500\,\text{r/min}$ and peak speed of $n_{\text{max}} = 7500\,\text{r/min}$ is selected as the driving motor of the electric vehicle.

When the electric vehicle travels at the highest speed for more than 30 minutes, the driving motor power satisfied is taken as the reference value of the rated power, so the rated power is $P_e^{[2]}$. The input of the parameters $P_e$ is 32.45kW in Table 1. When the maximum slope of an electric vehicle passing the climbing ability test at a steady speed is $\alpha_{\max}$, the maximum output power is $P_c^{[3]}$. Put the parameters in $P_c$ is 27.35kW.

When the electric vehicle is in acceleration, since the speed and transmission ratio of the driving motor are unknown, this paper uses the empirical formula to solve the maximum output power of $P_a$. When the parameters in Table 1, $P_a$ is 35.24kW obtained. In the selection of the peak power of the motor $P_m$, $P_m \geq \{P_e, P_c, P_a\}$ should meet, so $P_m$ is 36kW.

In Literature [4], the maximum climbing slope of a vehicle is mainly determined by the total transmission ratio of the first gear, and the maximum speed is determined by the total transmission ratio of the second gear, the range of transmission ratio $q$ can be obtained as follows: 1~1.8.

As the design requirements in Table 1 are limited by the two-speed acceleration time, taking into relevant parameters, the transmission ratio of the reducer and the transmission ratio of gear 1 and gear 2 are 3.782, 2.531 and 1.327.

Power battery parameters are mainly selected from the following two aspects: the battery parameters are obtained from the peak power of the motor and the range of the vehicle. Literature [3] points out that the relationship between power battery parameters, peak power and endurance range. According to the relationship and the data in Table 1, it can be concluded that there are 68 groups and 116 groups.

Among them, the 0~80 km/h acceleration condition is used to explain the electric vehicle's dynamic performance after matching parameters, and the NEDC cycle condition is used to explain the economic performance of continuous driving range. Its main function is to analyze the power and economy of electric, fuel or hybrid electric vehicles. Figure 1 and Figure 1 show the dynamic performance representation after selecting operation conditions in ADVISOR, as shown in the figure below.

| Parameter                  | The numerical | Parameter                  | The numerical |
|----------------------------|---------------|----------------------------|---------------|
| Peak power /kw             | 36            | SOC allowable range        | 0.95~0.15     |
| Rated power /kw            | 25            | Monomer resistance /mΩ     | 2.3           |
| Peak speeds /r/min         | 7500          | The battery pack for several | 116          |
| Rated speed /r/min         | 2500          | Drive ratio of main reducer | 3.782        |
| The rated torque /N,m      | 134           | Transmission ratio of 1 gear | 2.531        |
The rated voltage /V 312
The rated voltage /V 3.2
Transmission ratio of 2 gear 1.327
Nominal capacity /Ah 45

4. Establishment of optimization model and algorithm

4.1 Power battery parameter matching

After the electric vehicle's driving motor power and battery parameters are determined, the parameter that determines the power performance and economy of electric vehicle is the transmission ratio of electric vehicle.

In this paper, the transmission ratio of the main reducer and the first and second gear ratio of the transmission are selected as optimization variables:

\[ X = [x_0, x_1, x_2] = [i_0, i_1, i_2]^T \]  (1)

In this paper, the optimization direction is dynamic performance and economy, so the objective function of dynamic performance and economy should be established. For electric vehicles with 0~80 km/h acceleration condition, the dynamic performance objective function is selected, and the dynamic performance objective component function \( f_{1i} \) is the maximum speed, \( f_{12} \) is 0~50 km/h acceleration time, \( f_{13} \) is 50~80 km/h acceleration time, and \( f_{14} \) is the maximum climbing slope:
The dynamic objective function can be obtained from the above dynamic objective component function as follows:

\[ f_1(x_1, x_2, x_3) = 0.25f_1 + 0.25f_2 + 0.25f_3 + 0.25f_4 \]  

In this paper, NEDC cycle conditions are selected as the economic performance of electric vehicles, and driving mileage is taken as an important index to measure the economic performance of electric vehicles.

At the time of circulating condition, the torque \( T_w(t) \) and speed of the driving motor \( n_w(t) \) are:

\[ T_w(t) = \left( mgf + \frac{C_D A u^2}{21.15} + \delta m \frac{du}{dt} \right) r, \quad n_w(t) = \frac{u}{0.377r} \]

In the cycle condition at time \( t \), the speed of the driving motor \( n_w(t) = n_a(i(t)), i(t) \) is the transmission ratio at time \( t \) in the cycle condition. Similarly, the torque of \( T_a(t) \) the driving motor at time \( t \) is:

\[ T_a(t) = \begin{cases} T_w(t) / i(t) \eta_r, & T_w(t) \geq 0 \\ \alpha T_w(t) / i(t) \eta_r, & T_w(t) < 0 \end{cases} \]

\( \alpha \) is the regeneration coefficient and \( \eta_r \) is the transmission efficiency. If \( T_w(t) \) greater than or equal to 0, it indicates that the motor output power drives the vehicle; if less than 0, it indicates that the motor is in the regenerative braking state.

The output and input power of the battery can be obtained through the formula, \( P_{out}(t) \), \( P_{in}(t) \) are:

\[ P_{out}(t) = \frac{T_m(t)n_w(t)}{9550\eta_{dis}(t)} \eta_e(t), \quad P_{in}(t) = \frac{T_m(t)n_w(t)\eta_{dis}(t)\eta_e(t)}{9550} \]

It can be concluded that the battery power at \( t \) \( P(t) \) is:

\[ P(t) = \begin{cases} P_{out}(t) / \eta_{dis}, & T_m(t) \geq 0 \\ P_{in}(t) \eta_{dis}, & T_m(t) < 0 \end{cases} \]
\( \eta_{\text{dis}}, \ \eta_{\text{in}} \) are the discharge and charging efficiency. According to the above formula, the energy required under NEDC cycle condition is:

\[
W_{\text{NEDC}} = \frac{1}{3600} \int_0^{1180} P(t) \, dt
\]

Therefore, the economic performance function of electric vehicles with continuous driving range as the objective function is established as follows:

\[
f_2 \left( x_0, x_1, x_2 \right) = \frac{76140W_{\text{NEDC}} \left( i_0, i_1, i_2 \right)}{21.15}
\]

In conclusion, the optimization objective function considering both dynamic performance and economy can be concluded as follows:

\[
f \left( x_0, x_1, x_2 \right) = 0.5f_1 \left( x_0, x_1, x_2 \right) + 0.5f_2 \left( x_0, x_1, x_2 \right)
\]

Under the optimization of the transmission ratio of electric vehicles, the following constraint equations are included, which processed as follows\(^5\):

\[
g_1(x), \ g_2(x), \ g_3(x), \ g_4(x), \ g_5(x), \ g_6(x), \ g_7(x).
\]

4.2 Optimization Algorithm

In this paper, based on the multi-objective function, the immune algorithm is chosen as the algorithm to solve the multi-objective function. Firstly, the optimal antibodies in the evolutionary population were obtained by using the algorithm as the first batch of antigens, and the redundant antigens were removed by clustering elimination method. The first antigens then assist in accelerating the evolution of the current antibody population, while ensuring that the first antigens do not participate in the evolution of the current antibody population. Next, by simulating the response of antibody and antigen in the principle of immune response, the antibody group is evolved based on immune operator. Finally, the antibody group obtained after evolution is the optimal solution of the multi-objective function. Its algorithm flow chart is shown in Figure 3.

![Algorithm flow chart](image)

4.3 Optimization results and comparison

After programming the algorithm, the optimal parameter solution obtained is input into ADVISOR software, and the indicators shown in Figure 5, Figure 4 and Figure 5 can be obtained.
After the optimization of multi-objective immune algorithm, the performance of electric vehicles has significantly improved in terms of power performance and driving range, as shown in Table 3.

| parameter                | Before    | After    | Rate /% |
|--------------------------|-----------|----------|---------|
| Transmission ratio       | 3.782     | 2.531, 1.327 | 4.286, 1.231 |
| Maximum speed km/h       | 100.3     | 122.7    | +22     |
| 0~50km/h /s              | 5.1       | 4.8      | -5.8    |
| 50~80km/h /s             | 7         | 5.5      | -21.4   |
| Maximum climb /%         | 20.4      | 25.8     | +27     |
| Limited distance /km     | 131.2     | 135.3    | +3      |

On the one hand, due to the increase of rotating speed, the intersection point of the driving force and the driving resistance of the car changes, thus increasing the maximum speed of the car. On the other hand, the improvement of driving range comes from the overall matching of motor efficiency and transmission ratio, which makes the driving range of the vehicle extend to a certain extent under the same NEDC cycle condition.

5. Conclusion
To sum up, through the analysis of the optimized transmission ratio, motor speed and efficiency, the reasons for the improvement of various indicators are obtained, and the optimal vehicle performance can be achieved under the matching parameters. For the improvement of electric vehicle's power performance and economy, the multi-objective immune algorithm presented in this paper improves the vehicle performance and achieves the optimization effect.

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