Algorithmic and Simulated Based Transmission Ratio Optimization of A Two-Speed Electric Vehicle For Car-sharing

Jun Ma, Lei Wu, Zaiyan Gong, Yun Cao

School of Automotive Studies, Tongji University
lay.wulei@foxmail.com

Abstract. This paper proposes an approach to optimize the fuel economy of a two-speed electric vehicle (EV) in car sharing business through Genetic Algorithm and ADVISOR co-simulation. The ADVISOR simulation model built including dynamics, fuel cell, storage battery and motor. Under NEDC working condition, the two-speed gearboxmodeled, modeled and the optimal combination of transmission ration and main reduction ratio is found by genetic algorithm to improve fuel economy.

1. Introduction
Most electric vehicles sold on the market today eliminate the gearbox, and adopt a single-speed reducer with fixed speed ratio. Fuel cell vehicle model in ADVISOR also use single-speed reducer as default setting. The single-speed reducer is simple in structure but has higher performance requirement for driving motor. To reduce this requirement and improve the energy efficiency, the electric vehicle transmission system tends to develop be multi-speeds [1]. However, due to the better working curve of the motor than internal combustion engine, EV does not need multiple gear changes, a two-speed transmission is designed to improve fuel economy. This paper will use the genetic algorithm combined with ADVISOR simulation to optimize the design of the two-speed EV’s transmission ratio.

2. Fuel Cell Vehicle Selection
A0 class vehicle models are widely used in car-sharing business, thus the basic information of the simulated model is given in Table 1

| Table 1. Parameters of the simulated model |
|------------------------------------------|
| Size (length*width*height) (mm)          |
| Empty vehicle quality (kg)               |
| Loaded quality (kg)                     |
| Rotating mass conversion factor          |
| Front face area (m²)                     |
| Air drag coefficient C₁₀                 |
| Tire rolling radius (m)                  |
| Rolling drag coefficient                 |
| Main reducer ratio                       |
| Transmission efficiency                  |
| 3970*1680*1462                           |
| 1060                                     |
| 1460                                     |
| 1.09                                     |
| 1.90                                     |
| 0.28                                     |
| 0.281                                    |
| 0.01                                     |
| 6.7                                      |
| 0.92                                     |
Considering the dynamics requirements of car-sharing A0 EV model, the performance of the motor given in Table 2:

| Parameter                        | Value       |
|----------------------------------|-------------|
| Rated/maximum power (kW)         | 30/80       |
| Rated/maximum torque (N*m)       | 67/200      |
| Rated/maximum speed (r/min)      | 4000/8500   |
| Operating Voltage (V)            | 320         |

3. Advisor Simulation

3.1. Vehicle Dynamics Modeling

The driving force and resistances of the vehicle is existing during moving, where the driving force \( F_t \) is provided by the driving motor, and the driving resistances include rolling resistance \( F_r \), air resistance \( F_a \), slope resistance \( F_s \), acceleration resistance \( F_j \), thus the driving dynamics equation is:

\[
F_t = F_j + F_a + F_r + F_s
\]

Based on this dynamic equation, the iterative method can be used to find the acceleration of the whole vehicle, and then the vehicle speed can be obtained through integration, thus the dynamic model of the vehicle can be established as Figure 1

![Figure 1. Vehicle structure](image)

3.2. Battery Modelling

ADVISOR provides three different types of fuel cell models, power-efficiency model, polarized curve model, and GCTool external model. Power-efficiency model can be applied where fuel cell package characteristics are not concerned [2]. In this paper, only the relationship among fuel cell power, fuel consumption and emission is used in optimization, the specific operating characteristics of the fuel cell...
package are not concerned, so the power-efficiency model is selected. The model is showed in Figure 2.

![Fuel Cell Model](image)

**Figure 2. Fuel Cell Model**

Figure 2 shows that the fuel cell module includes fuel cell subsystem module, hydrogen consumption module and hydrogen emission module. The fuel cell subsystem module outputs power according to the power demand of the vehicle, and the hydrogen consumption and emission modules calculate the consumed hydrogen and the exhaust gas according to the output power.

The fuel cell applied in this paper has a power of 35KW, FC_ANL 50H2 type.

Besides fuel cell, to simulate the work of storage battery, ADVISOR RINT model is applied as storage battery, the Equivalent Circuit is showed as Figure 3, connect the external load and the internal resistance of the battery at same circuit.

![Equivalent Circuit](image)

**Figure 3. Equivalent Circuit**

### 3.3. Driving Motor Modelling

To simulate the permanent magnet synchronous motor used in the fuel cell vehicle, a driving motor module is built in ADVISOR based on motor working principles and motor control strategy. The motor’s actual output power and torque can be calculated through this model. The model structure showed in Figure 4.
Figure 4. Driving Motor Structure

This module is mainly composed of 3 sub-modules, power demand calculation module, actual output RPM & torque calculation module, and temperature affected calculation module.

3.4. Testing Condition
NEDC testing condition is applied to simulate the driving environment of car-sharing business. NEDC contains 4 urban and 1 suburban condition. And the detailed parameters are showed on Figure 5.

Figure 5. CYC_NEDC Parameters

4. Advisor Non-Gui Modelling
Autosize function in ADVISOR can calculate fuel cell power, storage battery power and driving motor power at specific vehicle performance requirements.
ADVISOR doesn’t provide tool for transmission ratio optimization, but this could be done through co-simulation with external optimization tool which runs independently of the GUI interface. As a result, the optimized design of gearbox transmission ratio can be done by using genetic algorithm combined with ADVISOR. The main instructions used in the ADVISOR Non-GUI modelling are followed:

\[
[error\_code,\text{resp}]=\text{adv\_no\_gui}(\text{action},\text{input})
\]

\%Open ADVISOR function, ‘action’ includes ‘initialize’, ‘modify’, ‘accel test’, ‘drive_cycle’

\%Input parameters to ADVISOR, variable ‘field’ and ‘subfield’ mean primary and subdomain, including ‘init.saved_veh_file’, ‘modify.param’, ‘modify.param’, ‘cycle.param’

\%Results returned including acceleration time ‘accel.times’, maximum speed ‘accel.max_speed’, Equivalent fuel consumption rate ‘cycle.mpgge’

5. Co-Simulation: Advisor & Genetic Algorithm
Genetic algorithm optimization is a global search method. Inspired by bio-simulation techniques, Professor Holland and his students created this adaptive optimization technique based on biological genetics and evolutionary theory [3] [4]. In 1993, Fonseca and Fleming proposed the MOGA multi-objective genetic algorithm, which penalized the individual population according to the shared fitness, solved the problem of niche calculation. It is widely used because of its easy implementation and high efficiency [5] [6] [7].

With strong practicability and robustness, today genetic algorithm has been well developed today. This paper used GATBX, a genetic algorithm toolbox developed by the University of Sheffield, UK, which has wide impact and fully functional.

5.1. Optimized Variable
This paper used a two-speed gearbox, so the main reduction ratio \(i_0\), first gear ratio \(i_1\), and second gear ratio \(i_2\) should be used as designed variables.

5.2. Objective Function
The main purpose of using genetic algorithm for gear ratio optimization is still to build a fuel cell vehicle model that is more suitable for car-sharing business. This paper uses dynamic and economical performances as optimized object.

The dynamic performance can be evaluated by the output maximum speed, economy performance can be evaluated by the output equivalent fuel consumption under the selected cycle conditions.

Using the weight coefficient method to convert the multi-objective function into a single objective function, we consider that car-sharing is currently weak in profitability, and the operating mileage of a car is long. Operating mileage has also become a new index for evaluating the energy consumption of new energy vehicles. In SAEJ1711 and SAEJ2841 standards, the Society of Automotive Engineers proposed using the operating mileage data to calculate the utilization factor, and based on the utilization factor to evaluate the average energy consumption of new energy vehicles under certain working conditions [8] [9]. Mathew Werber[10] found that the full life cycle cost of an electric vehicle would be lower only if the mileage was long and the price of gasoline was high.

So that fuel consumption should be minimized to lower cost structure, the weights assigned to the maximum speed and fuel consumption are 0.4 and 0.6 respectively. Flow of simulation algorithm as Figure 6:
NOTE: When designing the optimization target, the higher speed and lower fuel consumption is conflict, so a negative sign is required. The optimization range of the maximum speed is 130km/h~170km/h, and the optimized fuel consumption (hydrogen) range is 25L~50L, these two values need to be normalized.

5.3. Optimized Program

First modify the fuel cell, battery, motor and other related parameters in the customized fcbest_in model, then customize the .m file of a two-speed transmission, and set the shift strategy to shift at a certain speed (take 30km/h). Next, define the powertrain parameters

- `input.init.saved_veh_file='fcbest_in';`
- `[a1,b1]=adv_no_gui('initialize',input);` % Initialize the workspace and read related files
- `[fid,errmsg]=fopen('B:\MATLAB6p5p1\ADVISOR\ADVISOR2002\data\transmission\TX_2SPD.m', 'r+');` % Open TX_2SPD.m file
- `status=fseek(fid,1174,-1);` % Move the pointer to the position where the gear ratio is defined
- `fprintf(fid,'%6.2f',gbratio);` % Write new gear ratio
- `fclose(fid);` % Close TX_2SPD.m file
- `input.modify.param={'fd_ratio'};` % Write new main reduction ratio
- `[a2,b2]=adv_no_gui('modify',input);` % Modify the gear ratio and the main reduction ratio in the model

After defining the powertrain parameters, the simulation is performed, and the results of the maximum speed and the fuel consumption per 100 kilometers are read from the simulation.

- `input.accel.param={'max_speed_bool'};`
- `input.accel.value={1};` % Choose to calculate the maximum speed
- `[a4,b4]=adv_no_gui('accel_test',input);` % Run dynamic simulation
- `max_velocity(n)=b4.accel.max_speed;` % Read the simulated maximum speed
- `input.cycle.param={'name'};` % Load NEDC condition
- `[a5,b5]=adv_no_gui('drive_cycle',input);` % Test working condition
- `oil(n)=b5.cycle.mpge;` % Read fuel consumption per 100 kilometers

Next, define the relevant parameters of the genetic algorithm, set the genetic algebra maxgen=40, the initial population amount=40, the single code length code=20 (binary code), and the generation gap GAP=0.9. Next, we can use the existing functions of GATBX to perform iteration of the genetic algorithm.
6. Output and Analysis
The genetic algorithm program designed in this paper has a population size of 40 and iteratively 40 generations. The simulation results are stored in the ‘route’ matrix. It is a 40*8 matrix. The specific vector structure is:

Route(:,1) optimized target function value
Route(:,2) average target value
Route(:,3) maximum speed
Route(:,4) minimum fuel consumption
Route(:,5) second gear ratio
Route(:,6) first gear ratio
Route(:,7) main reduction ratio

The values for each generation are shown in the Table 3. The initial values vary greatly, the sampling is dense, the later values change little, and the sampling interval is large

| Gen | max speed (km/h) | Fuel (L/100km) | i2 | i1 | i0 |
|-----|------------------|----------------|----|----|----|
| 1   | 172.6027         | 55.72          | 3.2404 | 3.6122 | 2.8107 |
| 3   | 171.1555         | 47.329         | 0.51054 | 2.1867 | 2.9081 |
| 5   | 171.1555         | 47.327         | 0.73749 | 3.7752 | 2.1733 |
| 10  | 171.1555         | 47.32          | 2.2315 | 3.7451 | 1.3049 |
| 15  | 164.9969         | 44.949         | 2.4806 | 3.5207 | 2.8606 |
| 20  | 164.9969         | 44.95          | 0.36257 | 2.5726 | 2.0482 |
| 30  | 149.6405         | 41.629         | 3.7451 | 2.2315 | 1.3049 |
| 40  | 148.584          | 41.358         | 0.50201 | 1.203 | 3.2026 |

The optimized value and average value of each generation in the iterative process are shown in Figure 7. It can be seen from the figure that the optimal target value tends to be stable around 30th generation after experiencing a large variance in the early stage. The average target value fluctuates more during all generations due to genetic mutation existing in the genetic process.

![Figure 7. Target value convergence](image)

The maximum speed during the iteration process is shown in Figure 8. It has experienced a process of decreasing and finally rising suddenly. The final maximum speed is 148km/h.
The fuel consumption (hydrogen) showed in Figure 9, which is basically gradually reduced, eventually reaching a consumption of 41L per 100 kilometers.

Comparison between the optimized two-speed gearbox model with the original single-speed transmission system, is showed on Table 4.

|                | Single-speed | Two-speed |
|----------------|--------------|-----------|
| Maximum speed (km/h) | 157.8        | 148       |
| Hydrogen consumption (L/100km) | 66.1         | 41        |

7. Conclusion
In this paper, an approach for improving the performance of a fuel cell vehicle in car-sharing business by optimizing two-speed gearbox transmission ration is presented. Simulation on NEDC cycles are conducted to prove the impact of two-speed transmission system. Through obtained results, conclusions are drawn as follows:

1. The optimized two-speed electric vehicle can reduce 38% (41L/100km vs. 66.1L/100km) fuel consumption
2. The optimized two-speed electric vehicle’s dynamic performance only lowered 6.6% (148km/h vs. 157.8km/h)

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