# Trade-off Design Method of Electric Car targeting to Chinese Consumers

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## Abstract

Developing electric vehicles (EVs) has been chosen as national strategy as solution to energy security and urban air pollution by China. China has invested much to develop electric vehicle technologies. For EVs' penetration, China government develop 'ten-city one thousand-EVs 'demonstration program in 25 cities from 2008. For mass penetration of EVs, there still exist many challenges, especially for electric car for private use. How to promote EVs application based on present electric powertrain technologies has become an urgent demand for China government.

Targeting to propose a kind of comprehensive trade-off method and to get the optimized powertrain parameters, such as battery capacity, in this paper, the simulation models were setup in Matlab/Simulink.

The energy consumption model was setup, and based on that model, electricity consumption efficiency of electric sedan under NEDC and China city passenger car driving cycle were analyzed and compared.

Based on energy consumption of a conventional reference car and a BEV, a comprehensive trade-off method for the average car user is proposed targeting to China market. The method takes into account the traction battery technology status and forecasting, vehicle daily kilometers travel, operating duty cycle, purchase price, fixed annual costs and operating costs, policy of EVs, etc.

By the analysis, it can be concluded that A-compact type BEV，the AER designed sweet region should be no more than 200km under weight constrain. With higher battery capacities the amortization time becomes significantly longer, but from the systematic view, it is the less economical. Based on above analysis, the most cost-benefit designed AER with 50km VKDT should be 80km from view of minimum TCO of life cycle. So the optimized installed battery capacity threshold based on China VKDT is highly recommended. And the subsidy policy for EV should be modified more reasonable.

*Keywords: electric cars, cost-benefit,all electric range, battery capacity, trade-off design*

# 1    Introduction

The issues of energy security and air pollution are becoming more and more seriously. The statistic data showed that the vehicle account for about 70% in the total urban GHG emission. The tailpipe emission is the main source of harmful PM2.5 in China.

In recent years, China automotive industry developed rapidly. The population of vehicle has increased sharply in past several years. From 2009, China has become the largest automotive production and sale country. In 2012, the vehicle sales reach to 19.30M.By the end of 2012[1], the vehicle population has reached to about 120M, corresponding to crude oil independence of 58%. Electric vehicles (EVs) are becoming of increasing interest in world with an intensified focus on energy security, urban air pollution, the climate change with CO2-emissions [2]. Since the 10th 5-year plan of developing energy saving and new energy vehicles, China has issued many policies to push the EVs development [3-5].



Figure1: automotive sales in China



Figure2: vehicle population and dependence on foreign crude oil of China

There are still many challenges for mass penetration of the electric vehicles for China, even though China has been forecasted as the largest EVs market in the world, especially in private application area.

# 2    External factors analysis

## 2.1    Vehicle daily traveled kilometers

Vehicle daily traveled kilometers (VKDT) is very important for electric sedan powertrain design and optimization. Many researching haven been done on the VKDT. In 2009,

Shanghai Transport Deportment had done survey on VKDT of Shanghai city taking more than 8000 samples. By the statistical data analysis, VKDT of Shanghai is shown as Figure 3. It can be seen that in China VKDT is not high, less than 40km accounting for 80% of total [6]. The daily travel range distribution [7-9] is  as following

$$F_s\left(s_j\right) = \int_0^{s_j} fs\left(s\right)ds = 1 - e^{-\lambda s_j} \quad (1)$$

Where $s_j$ is the range of daily traveled,km;

$F_s\left(s_j\right)$ is the distribution ratio function of different range.



Figure 3: VKDT of Shanghai city in China

## 2.2    Driving cycle

Operating cycle plays an important role in the powertrain parameters matching and optimization. At same time, the energy consumption and emission testing also are based on some duty cycle. At present, China takes NEDC, which is modal cycle, as passenger car (including electric car) testing duty cycle. CATARC was commissioned to develop China city passenger car duty cycle, which is named as China passenger car driving cycle (CPCDC), and it is transient cycle.



Figure 4: characteristics of CPCDC

Figure 5: characteristics of CPCDC

Table 1: comparison between NEDC and CPCDC

|  | NEDC | CPCDC |
|---|---|---|
| Distance,km | 11.028 | 7.681 |
| Duration,s | 1180 | 1195 |
| Average Speed,km/h | 47.76 | 23.14 |
| Maximum Speed,km/h | 120 | 74 |
| Idle time ratio,% | 24.83 | 25.188 |
| Max a+,m/s2 | 1.0417 | 2.2942 |
| Max a-,m/s2 | 1.3889 | -2.5936 |

The driving cycle play important role on energy consumption ratio of electric car[10-13]. By simulation in Autonomie, the energy consumption under NEDC is 30% higher and under CPCDC is 40% higher than that of constant speed driving cycle (based on average speed).

# 3 Powertrain sizing

## 3.1 Basic parameters

The A class compact sedan is chosed as simulination model, and the parameters is shown as Table 2.

Table 2: the basic parameters of simulation electric sedan

| Parameters | Values |
|---|---|
| Glider mass,kg | 960 |
| Max speed,km/h | 120 |
| Accelerating time/s | 14 |
| $C_D$ | 0.4 |
| $A$,m | 2.1 |
| $f$ | 0.015 |

## 3.2 Electric motor sizing

The electric motor power has close relationship to duty cycle.

$$P_m = \frac{1}{\eta_T} \frac{1}{\eta_{M/G}} \left( \frac{1}{3600}\left( mgf\upsilon + mgi\upsilon + m\delta\upsilon\frac{d\upsilon}{dt}\right) + \frac{C_D A u^3}{76140}\right) \quad (2)$$

Where $P_m$ is traction motor output power,kw; $\eta_T$, $\eta_{M/G}$ $\eta_G$ are efficiency of transmission system and traction motor respectively; $m$ is the mass of vehicle,kg; $g$ is acceleration of gravity,m.s$^{-2}$; $C_D$ is drag coefficient; $A$ is frontal area, m$^2$; $f$ is rolling resistance coefficient; $\upsilon$ is vehicle velocity,km/h.

## 3.3 Traction battery sizing

Based on constant speed and duty cycle methods, the effective electricity consumption is

$$E_{eff} = \frac{1}{\eta_{EP}} \frac{1}{\eta_{M/G}} \frac{1}{\eta_T} \int_{t_0}^{t_i} P_u\left(t_i\right)dt + \int_{t_0}^{t_i} P_{aux}dt \quad (3)$$

$$E_{bat} = \frac{1}{\eta_{dis}} \frac{1}{SOC_w} E_{eff} \quad (4)$$

Where $E_{eff}$ is effective energy of traction battery,kWh; $\eta_{EP}$ is efficiency of power electronics; $\eta_{dis}$ is the efficiency of battery discharging; $SOC_w$ is the battery operating window of sate of charge, $SOC_w = SOC_{max} - SOC_{min}$, $SOC_{max}$ and $SOC_{min}$ are maximum and minimum state of Charging value respective; $P_u\left(t_i\right)$ is the vehicle driving power demand,kW; $P_{aux}$ is power of electric accessories,kW.

Most electric sedans were updated type which was converted from basic internal engine sedan in China. So the mass and volume limitation must be taken into consideration. The traction battery capacity can be determined by constant speed method and duty cycle method.

Table 3: energy type traction battery parameters in China

| items | LFP/C | LMO/C | NCM/C |
|---|---|---|---|
| specifc energy, Wh/kg | 70 | 80 | 100 |
| specific cost, Yuan/Wh | 3.5 | 3.8 | 4 |
| cycle life (100%DOD) | 700 | 650 | 630 |

### 3.3.1 Impact of electric accessories on range

The power consumed by electric accessories, such as air condition, light, audio system, heater, ventilation, have great important impact on electric range of electric car. The electric accessories power usally is from 500W to 2kW.



Figure 6: impact of electric accessories on range

### 3.3.2 Cycle life of battery

The cycle life of traction battery has great impact on TCO. By some researches, the cycle life of lithium traction battery has an index relationship with its depth of charging (DOD) [8]. Based on the data of battery companies in China, the equation is modified (See Figure 8).

$$L_{cyc} = A\chi^{B} \tag{7}$$



Figure 7: characteristics of cycle life

Where $L_{cyc}$ is traction battery cycle life; A, B are the constant coefficient of battery cycle life; $\chi$ is depth of discharge. A=800,B=1.47.

### 3.4 Energy consumption efficiency analysis

Electricity economy (EE) is defined as total electricity from grid to drive electric sedan running 100 kilometers (equation 5,6).

$$EE = 100\frac{E_{grid}}{S} \tag{5}$$

$$S = \int_{t_0}^{t_i} u(t_i)dt \tag{6}$$

Where S is the vehicle traveled range,km; $E_{grid}$ is electricity from grid,kWh.

More than 90% electric cars are updated type and requiped from conventional internal engine cars. So the weight constrain by the glider must be met. The efficiency of energy consumption under weight constrain is shown as figure7.



Figure 8: Electricity consumption map of BEV under constrain

It can be seen that even with the best battery tecnology level, the reseasonable AER of compact electric sedan should be designed no more than 200km.

## 4   Life cycle cost-benefit analysis and optimization

Electric vehicle total cost of ownership(TCO) includes purchasing cost, electricity cost, battery changing cost, battery renting cost, maintenance cost, service cost, etc.

$$C_{TCO} = C_{pch} + C_{op} \tag{8}$$

$$C_{pch} = \begin{cases} Battery\ own: C_{BEV} \\ Battery\ lease: C_{Glider} + C_{Edrive} \end{cases} \tag{9}$$

$$C_{op} = \begin{cases} Battery\ own: C_{ele} + \dfrac{NS_{k}}{\sum_{i=1}^{n} S_{AER\_i} L_{cyc\_i}(DOD\%)} E_{bat}\delta_{bat} + C_{serv} \\ Battery\ lease: C_{ele\_1} + C_{bat}\left(\dfrac{r(1+r)^{N}}{(1+r)^{N}-1}\right) + C_{serv} \end{cases} \tag{10}$$

Where $C_{TCO}$ is the total cost of owership of electric car, $C_{pch}$ is the purchase cost, $C_{op}$ is operating cost, including energy cost, battery depreciation cost, maintainance cost, etc.Yuan; $\delta_{bat}$ is the specific cost of battery,Yuan/Wh; $C_{serv}$

is the cost of electric driving system servicing,Yuan; $C_{ele\_1}$ is leasing cost of battery; $C_{bat}$ is cost of battery pack,Yuan; $S_{AER\_i}$ is disgned all electric range of electric car,km; $C_{Glider}$ is glider cost,Yuan; $C_{ele}$ is the cost of electricity,Yuan; $L_{cyc\_i}(DOD\%)$ is the cycle life related function with battery depth of discharging; $N$ is the vechile service life,year; $r$ is discount rate,%.

Targeting to get minimum TCO, the constrained cost minimization function should be set up as following.

$$J = \min(C_{CTO}) \quad (11)$$

Subjected to $0 < S_{AER} \leq 200$;

$$5 < E_{bat} \leq 30$$

$$\max\ speed \geq \max(60, f(u_i));$$

$$VKDT \in \left[ f(s_i) \right];$$

$$\max\ acceleration \leq \max f'(u_i).$$

The optimization results can be seen in figure 9.



Figure 9: the optimization results of AER

From figure 9, we can see when the VKDT is 40km the designed AER should be 80km targeting to minimum TCO,corresponding to a no more than 15kWh battery installed capacity. The optimized AER and battery installed capacity have been listed in Table 4.

Table 4: the optimization results of AER and installed battery capacity

| VKDT,km | Optimization AER value,km | Installed battery capacity,kWh |
|---|---|---|
| 20 | 44 | 6.5 |
| 40 | 80 | 13.2 |
| 50 | 99 | 16.6 |
| 80 | 141 | 24.6 |

## 5  Conclusions

The battery capacity of a Battery Electric Vehicle (BEV) is decisive for the All Electric Range (AER) and crucial for the cost-effectiveness due to the limitation of present traction battery technology. The residents' daily traveled kilometers and vehicle driving cycle are the important factors for electric car economic design. For duty cycle matching, the installed battery capacity may be designed 30-40% higher than constant speed scenario.

By the TCO model, it can be concluded that based on the additional mass constrain, the AER designed sweet region should between 100-150km. The optimized battery capacity of 50km VKDT should be no more than 17kWh to meeting the more than 85% residents' daily travel demands.

And the subsidy policy for EV should be modified more perfect, such as the subsidy threthhod of BEV shoud modified from 15kWh to 8kWh.

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